INVESTIGATION OF FABRIC CLEANING USING FLUID DYNAMIC GAUGING

Effects of Fine Bubbles

M. Thongpiam[1], T. Lertuamporn[1], P. Saikhwan[1], Y.M.J. Chew[2,3]

[1] Department of Chemical Engineering, Thammasat University, Thailand
[2] Department of Chemical Engineering, University of Bath, UK
[3] Centre for Advanced Separations Engineering (CASE), University of Bath, UK

Introduction

Clothes washing in the food industry and domestic setting is regarded as a common chore and is commonly carried out by hand or electrical appliances. The cleaning process is far from optimum and consumes large amount of energy, water and chemicals.

Commercial clothes washing powders and liquids are often formulated to contain enzymes. Such formulations can (Muir *et al.*, 2013):

- Improve washes performance so that they can be carried out at lower temperatures
- Increase the amount of surfactant attaching to a stain or soil
- Reduce the surfactant load both in the wash, and also in the effluent

Nevertheless, most clothes washing studies are often performed in-house by manufacturers of cleaning formulation such that data is protected and rarely available in the public domain.

This research describes the application of the technique of fluid dynamic gauging (FDG) to fabric cleaning with the aim to develop a systematic, affordable and versatile lab-based protocol to investigate and quantify the performance of cleaning formulations at varying conditions. Here, the model food stain was prepared by staining dyed coconut milk on plain-weave cotton fabrics. The efficacy of two bio-detergents and the effect of soaking at 20 and 30ºC were investigated and analysed. The extent of cleanliness of the fabric was characterised using gravimetric and optical methods. Studies on using fine bubbles (diameter ~20-50 μm) as a pre-treatment step to enhance cleaning was also conducted at 20 and 30ºC.

Experimental Methods

Each sample on the stained fabric (Fig. 1) was prepared by spreading 1 mL of dyed coconut milk (75% coconut extract, 25% water, polysorbate 60, carboxymethylcellulose and sodium metabisulphite) onto a plain-weave cotton fabric maintained at 60°C. Coconut milk was always applied to the middle of a ring (diameter 25.4 ± 1 mm) placed over the fabric and was left to spread evenly for 20 minutes. Four coconut milk stains were prepared at the same time on each fabric sample.

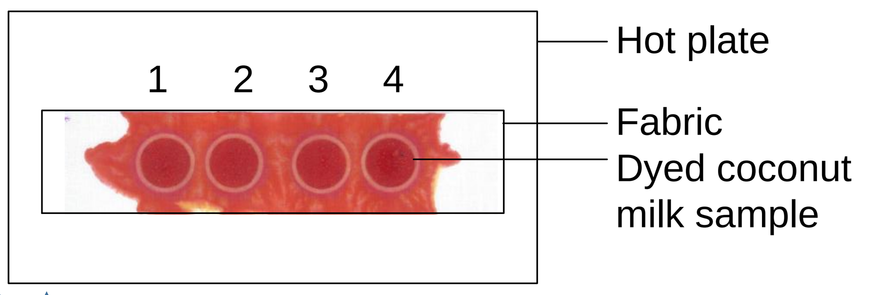


Fig. 1: Four coconut milk stains prepared on a fabric heated to 60ºC.

Detergent	T (°C)	pH
A	20	10.20
	30	10.23
B	20	7.50
	30	7.83

Table 1: Cleaning conditions used in this study.

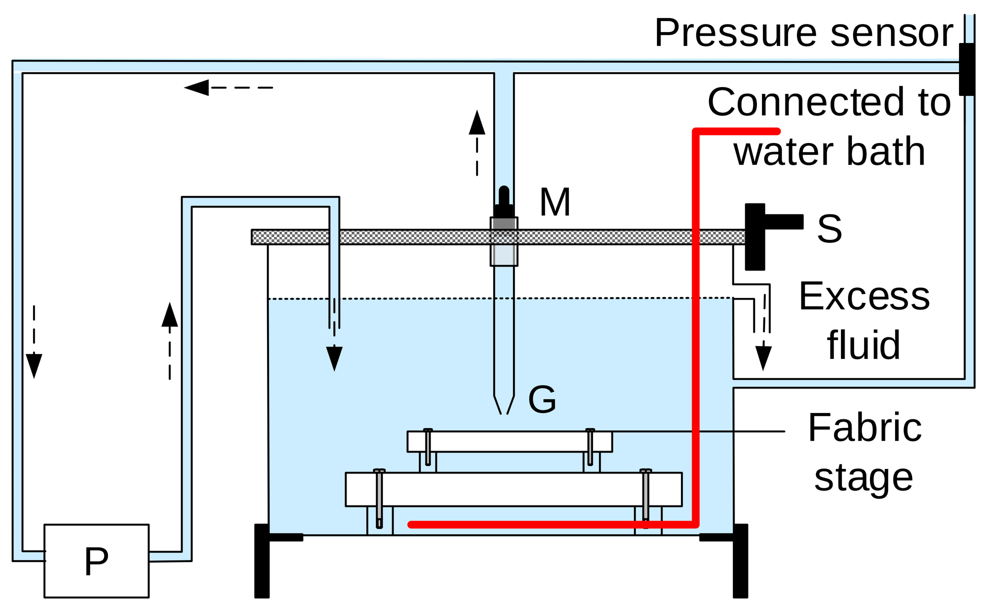


Fig. 2: Schematic of fluid dynamic gauging: G-FDG nozzle, M-Micrometer, P-Pump, S-Traversing screw, arrows show direction of flow of cleaning formulation. The red line indicates the heating coil.

Fig. 2 shows the experimental setup used in this study. Fluid dynamic gauging (FDG) is a non-contact proximity technique used to measure the thickness and strength of deposits formed on surfaces (Chew *et al.*, 2004). The technique works by inducing a constant flow of fluid into the FDG nozzle (G). Previous work has shown that the fluid shear stresses imposed by the suction flow on the deposit were significant when the gap between the nozzle and layer is small, tending to remove the deposit from the surface. The shear stress imposed by the gauging liquid could be estimated using Eq. 1 (Peck *et al.*, 2015):

$$\tau = \frac{3 m_g \mu}{\rho \pi h^2}\frac{1}{R} \quad \text{Eq. 1}$$

where m_g - suction flow rate controlled by the pump (P, Fig. 2), μ – liquid dynamic viscosity, ρ – liquid density, h – gap between the gauge and sample and R – radius of FDG nozzle.

Prior to each cleaning test, the stained fabric sample was soaked in the formulation for 10 minutes at preset temperatures. Cleaning studies were conducted using detergents A (15-30%: Anionic Surfactants, 5-15%: Nonionic Surfactants Soap, <5%: Enzymes, Perfume, Phosphonates, Polycarboxylates, Butylphenyl Methylpropional, Citronellol, Geraniol) and B (15-30%: Anionic Surfactants, 5-15%: Non-Ionic Surfactants, Soap, <5%: Optical Brighteners, Perfume, Phosphonates, Polycarboxylates), both formulated to 0.375 wt% i.e. typical in a washing machine cycle. Table 1 summarised the pH values of the formulation at 20 and 30°C. Temperature of cleaning liquid was controlled using a heating coil connected to a water bath (Fig. 2). During cleaning tests, no shear stress was applied to sample 1 (Fig. 1), so that this sample would only show the effect of soaking. A traversing screw (S, Fig. 2) was used to locate the gauge nozzle approximately in the middle of each stain. A range of shear stresses (by varying m_g or h) were applied to samples 2-4 in an increasing trend. Overall removal was analysed in terms of average mass loss per fabric whereas removal on each stain was analysed using image (Image J) and colour analysis (Optical spectrometer, Shimadzu, uv-1601).

Reference

Chew J.Y.M., Paterson W.R. and Wilson D.I. (2004). Fluid dynamic gauging for measuring the strength of soft deposits. *Journal of Food Engineering*, **65**(2):175-187.

Muir, A. C., McKeown, P., Li, Y., Kobine, J. J. and Bird, M. R. (2013). The removal of food fat based soils during the washing of fabrics. *Chemical Engineering Research & Design*, **91**(9), pp. 1602-1613.

Peck, O. P. W., Chew, Y. M. J., Bird, M. R., and Bolhuis, A., (2015). Application of fluid dynamic gauging in the characterization and removal of biofouling deposits. *Heat Transfer Engineering*, **36**(7-8), pp. 685-694.

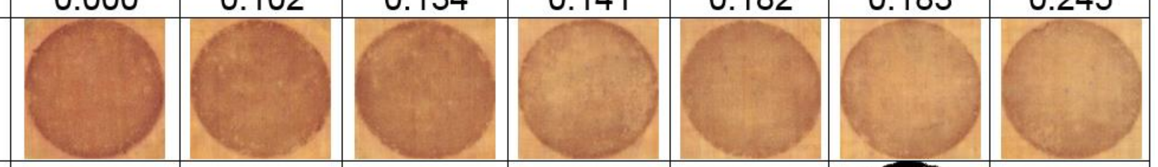
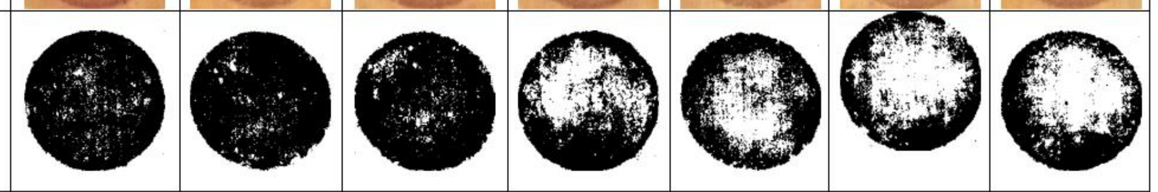
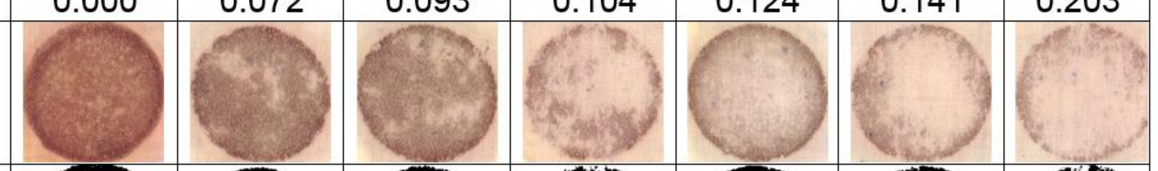
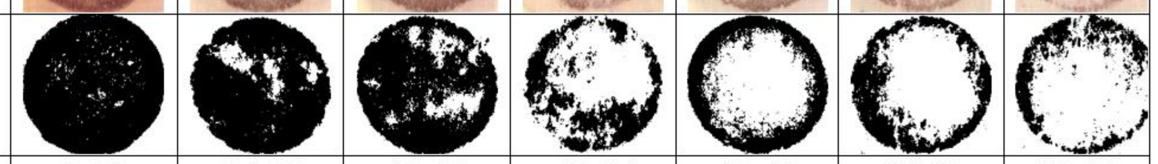
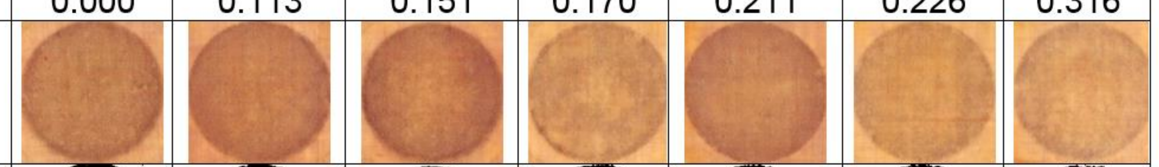
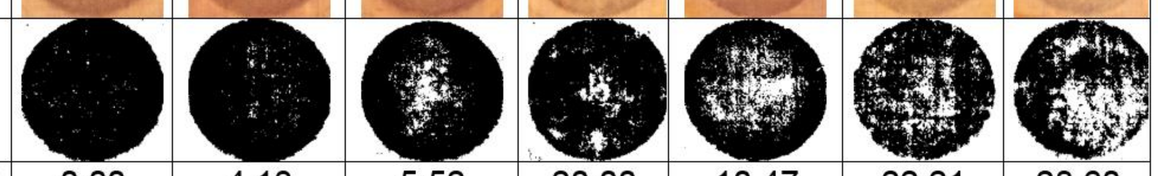
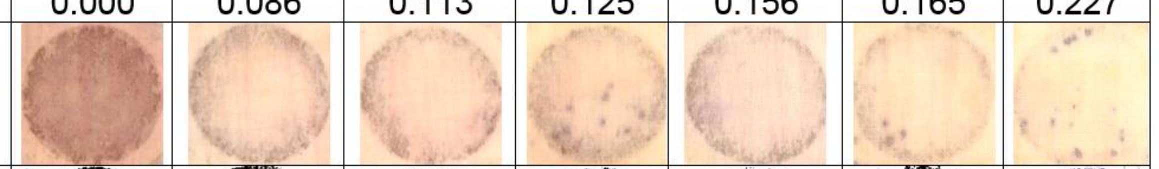
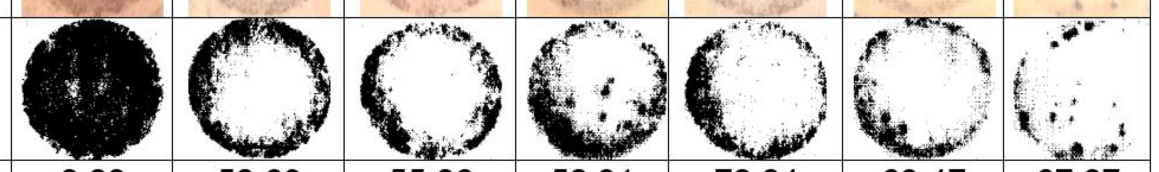
Acknowledgements

Funding from the University of Bath and Thammasat University is gratefully acknowledged. Training and technical advice on the use of FDG and colorimeter from Ms Jo Douglas (Department of Chemical Engineering, Bath) is also acknowledged.

Results and Discussions

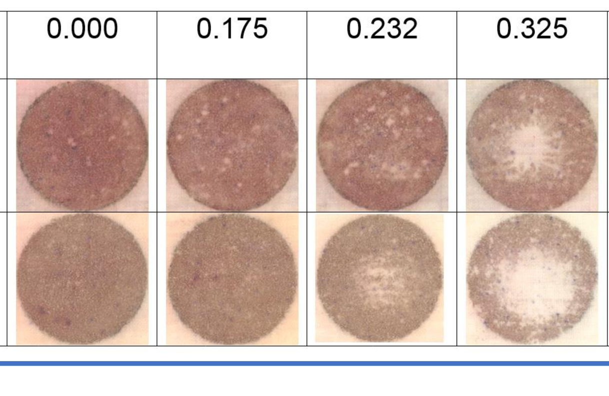
Table 2 summarises the main cleaning results. By just soaking, there was only marginal difference between detergents A and B at 20 and 30°C. However, under fluid shear detergent A caused more removal than B at 20°C. The reverse was observed at 30°C.

Table 2: Extent of removal observed with varying shear rates (Results from colour analysis and Image J are reported as lightness removal and ImageJ removal respectively).

Detergent A (pH 10.20) at 20°C							
Shear stress (Pa)	0.000	0.102	0.134	0.141	0.182	0.183	0.245
Scanner							
ImageJ							
Lightness removal (%)	0.00	1.58	4.59	19.39	24.91	16.39	25.74
ImageJ removal (%)	0.00	1.22	1.46	31.71	27.68	34.39	40.49
Weight removal (%)	36.21 ± 10 (average)						
Detergent A (pH 10.33) at 30°C							
Shear stress (Pa)	0.000	0.072	0.093	0.104	0.124	0.141	0.203
Scanner							
ImageJ							
Lightness removal (%)	0.00	14.96	18.40	46.54	48.40	54.53	52.99
ImageJ removal (%)	0.00	15.41	19.29	60.62	56.28	61.53	72.37
Weight removal (%)	71.64 ± 10 (average)						
Detergent B (pH 7.50) at 20°C							
Shear stress (Pa)	0.000	0.113	0.151	0.170	0.211	0.226	0.316
Scanner							
ImageJ							
Lightness removal (%)	0.00	4.13	5.52	20.00	10.47	22.21	28.60
ImageJ removal (%)	0.00	0.45	10.11	9.20	20.34	22.39	34.55
Weight removal (%)	39.87 ± 10 (average)						
Detergent (B) pH 7.83 at 30°C							
Shear stress (Pa)	0.000	0.086	0.113	0.125	0.156	0.165	0.227
Scanner							
ImageJ							
Lightness removal (%)	0.00	52.69	55.06	52.31	72.24	63.47	67.07
ImageJ removal (%)	0.00	57.91	70.10	63.44	72.24	78.39	90.83
Weight removal (%)	67.09 ± 10 (average)						

Effect of Fine Bubbles

Fig. 3: Stain removal observed using Detergent A at 20°C with and without 10 minutes fine bubbles pre-treatment

Shear stress (Pa)	0.000	0.175	0.232	0.325	% Weight removal
No fine bubbles					72.00 (average)
With fine bubbles					95.24 (average)

Preliminary studies using fine bubbles as a pre-treatment step prior to detergency action was conducted at 20 and 30°C. It was found that soaking the stained fabric in fine bubbles (diameter ~20-50 μm) prior to cleaning test could enhance removal under fluid shear. Further experiments using fine bubbles are currently underway.

Conclusions

- Successfully developed a systematic and affordable lab-based protocol to study fabric cleaning.
- Removal of stains was caused by suction flow in FDG and cleanliness was characterised using gravimetric, colorimeter and ImageJ analysis.
- Preliminary studies using fine bubbles shows promising results and opens up new possibilities for enhance cleaning.