



Elucidating enzyme-based cleaning of protein soils (gelatine and egg yolk) using a scanning fluid dynamic gauge

Patrick W. Gordon^a, Anju D.M. Brooker^b, Y.M. John Chew^c, Nathalie Letzelter^b, David W. York^b, D. Ian Wilson^{a,*}

^a Department of Chemical Engineering and Biotechnology, University of Cambridge, New Museums Site, Pembroke Street, Cambridge, CB2 3RA, UK

^b Procter & Gamble Technical Centres Ltd., Whitley Road, Longbenton, Newcastle-upon-Tyne, NE12 9TS, UK

^c Department of Chemical Engineering, University of Bath, Claverton Down, Bath, BA2 7AY, UK

ABSTRACT

The enzyme-based cleaning of two model protein soils was investigated using a scanning fluid dynamic gauge (sFDG). The sFDG device allows data to be collected from more than one sample or location during a single experiment and therefore makes a range of comparative studies feasible. The sFDG was modified to allow the forces imposed on the surface to be controlled during a test. Gelatine films on stainless steel swelled in the presence of alkali at 20 °C but were not removed. Enzymes from a commercial dishwasher product interrupted swelling when the mean water volume fraction of the film reached ~0.9 and promoted removal. The enzyme effectiveness decreased over time. Egg yolk deposits (spray dried on mica) were studied in a protease/buffer solution at 40 °C. The deposits swelled on contact with alkali, and removal started after ~40 min. Some flow over the deposit was required to achieve complete cleaning, but the time taken to clean exhibited a weak dependence on the shear stress imposed by the flow for shear stresses above 10 Pa. The cleaning behaviour was strongly influenced by the nature of the deposit. Baking the deposit at 150 °C reduced the rate and extent of swelling as well as the rate of removal, and could result in the formation of a residual film that exhibited yield stress characteristics.

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1. Introduction

The growth or removal of soft-solid layers on process surfaces immersed in liquids is of interest to many industrial sectors, where the layer may be a biofilm, a polymer coating, or a fouling layer. These materials can pose measurement challenges as they are often heterogeneous, deform on contact, and collapse when removed from the liquid environment. Tuladhar et al. (2000) reviewed the techniques available to study such materials and noted that many required knowledge of the layer material's properties and so did not yield a direct measurement. Those techniques which do allow direct measurement often carry limitations, such as laser sheets (Mendret et al., 2007) where the liquid must be transparent, or magnetic resonance imaging (MRI, Creber et al., 2010) where

the system must be free from materials that interfere with the magnetic field. Both require specialist apparatus and expert operators. Tuladhar (2001) developed fluid dynamic gauging (FDG) as an alternative, relatively cheap, non-contact measurement technique which can be used to track the thickness of such layers *in situ* and in real time.

Fig. 1(a) illustrates the key concepts behind the FDG technique. Flow behaviour is exploited to locate the layer surface: it is a non-contact technique, requiring that the surface is locally flat and stiff over the time and scale of the measurement. A small conical nozzle of throat diameter d_t is positioned close to the surface. A pressure difference, imposed between the bulk liquid and the nozzle discharge, draws liquid into this nozzle. Fig. 1(b) shows that the flow rate through the nozzle, m_f , is very sensitive to the clearance between the nozzle and the surface,

* Corresponding author. Tel.: +44 01223 334791; fax: +44 01223 334796.

E-mail address: diw11@cheng.cam.ac.uk (D.I. Wilson).

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Nomenclature

Latin

A	area of boundary cross-section, mm ²
C_f	fanning friction factor, –
d_t	nozzle diameter, mm
d_{tube}	siphon tube diameter, mm
g	acceleration due to gravity, m s ⁻²
h	nozzle-layer separation, mm
h_o	nozzle-substrate separation, mm
H	siphon pressure head, m
k	constant, s ⁻ⁿ
L_e	siphon tube effective length, m
m_f	mass flow rate into the nozzle, g s ⁻¹
m_g	mass of gelatine, g
m_w	mass of water absorbed, g
n	constant, –
p	pressure, Pa
Δp	pressure change, Pa
r	radius, mm
t	time, s
v	fluid velocity, m s ⁻¹
x	Cartesian coordinate (horizontal), mm
y	Cartesian coordinate (horizontal), mm
z	Cartesian coordinate (vertical), mm

Greek

δ	layer thickness, mm
δ_f	fluid film thickness, mm
μ	fluid viscosity, Pa s
ρ	fluid density, kg m ⁻³
τ_w	wall shear stress, Pa

Subscripts

1, 2, ...	boundaries between flow regions
i	inside edge of the nozzle
o	outside edge of the nozzle

Abbreviations

AFM	atomic force microscope
CFD	computational fluid dynamics
FDG	fluid dynamic gauging
MRI	magnetic resonance imaging
RO	reverse osmosis
sFDG	scanning fluid dynamic gauging

h , when $h/d_t < 0.25$. If the location of the nozzle relative to the substrate, h_o , is known, the thickness of the deposit layer, δ , may be obtained by difference ($\delta = h_o - h$). FDG measurements are typically made with the nozzle located at $0.1 < h/d_t < 0.2$.

If the nozzle approaches the deposit too closely, and the deposit is sufficiently weak, the stress induced by the gauging flow can disturb the deposit. This effect can be exploited by combining FDG with computational fluid dynamics (CFD) simulations (Chew et al., 2004), enabling the technique to be used as a surface strength probe. Where removal of the deposit is of a steady, cohesive nature, knowledge of the shear stress imposed by the gauging flow enables determination of the cleaning rate under those conditions. Alternatively, where deposits are removed following adhesive failure at the substrate surface, the technique can be used to test substrate modification or coating.

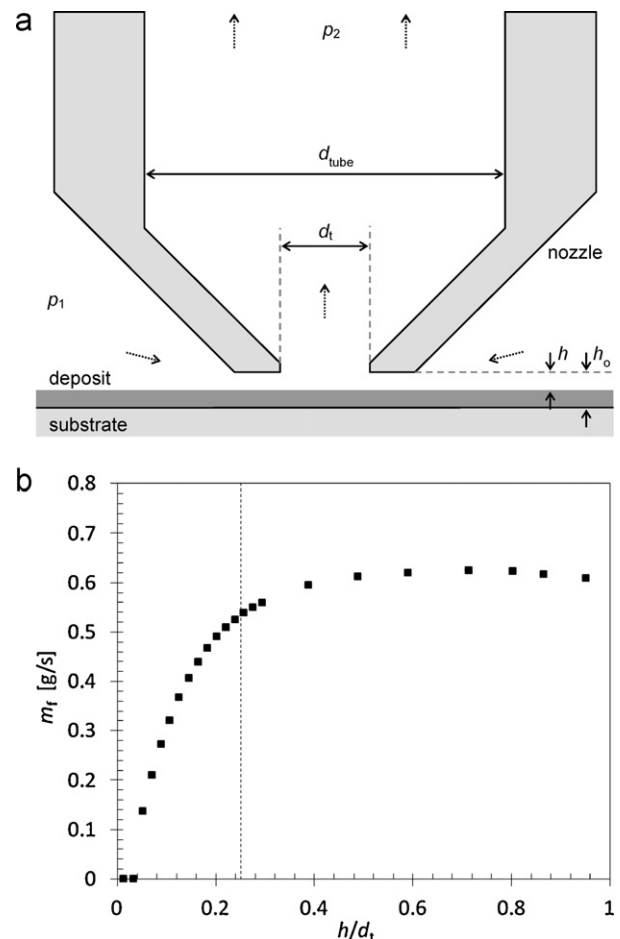


Fig. 1 – (a) Schematic of a FDG nozzle, where h is the clearance between the nozzle and the deposit. Dashed arrows indicate the liquid flow path. (b) Example of a m_f vs. h/d_t calibration profile. The pressure driving force through the gauge, $\Delta p_{12}(=p_1 - p_2)$, in this case was 1000 Pa. The gauge is operated within the range $0 < h/d_t < 0.25$, the upper limit of which is marked by the vertical dashed line.

Until recently FDG devices made measurements at a single location on the substrate. This paper employs a version of FDG with scanning capability, which can be moved across a surface, and multiple deposit thickness or strength measurements made (Gordon et al., 2010a). Several locations on the surface can therefore be monitored, increasing the amount and usefulness of data which can be obtained from a single test. Alternatively, the substrate can be patterned so that different sample treatments/histories can be challenged in a single experiment with the same liquid environment, eliminating variation between tests. The device is computer controlled and can be programmed to sample in a raster pattern to develop a topographical image of the substrate or layer, in a manner analogous to an atomic force microscope (AFM).

The scanning FDG (sFDG) functionality is demonstrated here in studies of the enzyme-based cleaning of two protein soils, namely gelatine and egg yolk. Enzyme-based cleaning is widely used in cleaning domestic and industrial food deposits (e.g., Boyce et al., 2010), but the precise mechanisms by which enzymes effect cleaning of complex soils is relatively poorly understood. Gelatine is used here as a model protein layer although it has several commercial applications. Previous studies such as that by Yang et al. (1997) focused on the equilibrium extent of swelling, while Gordon et al.

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