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Comparison of cleaning of toothpaste from surfaces and pilot scale pipework

Pamela A. Cole[a,b], *Konstantia Asteriadou*[a], *Phillip T. Robbins*[a], *Eddie G. Owen*[b], *Gary A. Montague*[c], *Peter J. Fryer*[a,*]

[a] *Department of Chemical Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK*
[b] *GlaxoSmithKline, UK*
[c] *School of Chemical Engineering and Advanced Materials, University of Newcastle, Newcastle upon Tyne, NE1 7RU,UK*

ABSTRACT

Experiments have been conducted to study the cleaning of toothpaste at two length scales. Laboratory scale cleaning studies have been conducted on fouled coupons in a horizontal flow cell. At pilot scale, the cleaning of fully fouled pipes has been studied and monitored by temperature, conductivity and turbidity probes. Removal from the pipe occurs in two steps: *core removal*, leaving a thin wall layer that is then removed by *thin film removal* that takes the majority of the cleaning time. At both scales, cleaning time is influenced by temperature and velocity of the cleaning fluid. The pipe length range studied, 0.3–2 m, does not appear to have a significant impact on cleaning time. Cleaning time correlates well with (shear stress)$^{-1}$. A dimensionless cleaning time is defined and a correlation between cleaning time and Reynolds number developed.

Keywords: Cleaning; Toothpaste; CIP; Hygiene; Flow effects; Fouling

1. Introduction

Within a manufacturing environment many equipment types are used to produce a product, including tanks, pumps, valves and pipework. Any surface which material contacts during its production will have to be cleaned to an appropriately safe and hygienic standard to enable the use of the equipment for further production. Cleaning In Place (CIP) is the process typically used to clean the inside of process plant. Process plant cleaning is a time and resource consuming action within a manufacturing operation, significantly contributing to the environmental footprint of the plant (Eide et al., 2003). Efforts to minimise the use of time, water, CIP chemicals and energy can improve both the efficiency of a plant and its environmental impact. If the cleaning process were understood it would be possible to increase its efficiency to use the least time, water and/or energy and have confidence that the plant is clean. Conventionally CIP systems do not use any feedback control, and cleaning times are set to fixed values. van Asselt et al. (2002) discuss CIP inefficiencies due to insufficient monitoring and study dairy cleaning process with conductivity, turbidity, flow and temperature and off-line product analysis methods.

A fundamental understanding of cleaning mechanisms and of the interactions between the fouling deposit, the cleaning fluid and the surface is important. Fryer and Asteriadou (2009) proposed a relationship between the soil or foulant to be cleaned and the type of cleaning required. They classified the systems most difficult to clean as follows:

- *Type 1*: *highly viscous or viscoelastic fluids* which remain on the surface and can be removed by action of water alone.
- *Type 2*: *biofilms*—these differ from the other two categories by requiring the cleaning process to kill all the adhered organisms.
- *Type 3*: *solid deposits* formed by components of the process fluid as a result of one or more of the fouling mechanisms, and that require cleaning chemicals for efficient deposit removal.

* *Corresponding author*. Tel.: +44 121 414 5451; fax: +44 121 414 5324.
E-mail address: p.j.fryer@bham.ac.uk (P.J. Fryer).
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Nomenclature

c_f	friction factor
d	diameter (m)
Q	flowrate ($m^3\,s^{-1}$)
Re	cleaning fluid Reynolds number
t	time (s)
t_r	mean residence time (s)
t_c	cleaning time (s)
u	fluid velocity ($m\,s^{-1}$)
V	volume of fluid (m^3)

Greek letters

τ_w	wall shear stress (Pa)
θ	dimensionless time (tu/d)
θ_c	dimensionless cleaning time ($t_c u/d$)
ρ	fluid density ($kg\,m^{-3}$)
μ	water viscosity ($kg\,m^{-1}\,s^{-1}$)

In this work, toothpaste is studied as an example of a Type 1 soil. This material was chosen as an example of a viscous semi-solid product which is relevant to many manufacturing industries. It is known that this deposit can be removed by fluid flow alone.

At the start of the cleaning process, the plant is full of toothpaste which has to be removed, i.e. the pipework has to be emptied. This is in contrast to the case where fouling deposit forms a thin film on the surface of the process plant formed by deposition of a reacted or precipitated component, such as proteins and minerals from milk (Fryer et al., 2006; Changani et al., 1997). Many experimental cleaning studies have been conducted at the laboratory scale by Tuladhar et al. (2002), Gillham et al. (1999, 2000) and Liu et al. (2007) amongst others. Cleaning of process equipment in a manufacturing plant must however occur at a plant metre-scale using fluid velocities in excess of $1\,m\,s^{-1}$, for example the velocities used by Friis and Jensen (2002) to examine the EHEDG guidelines in experiments on T-pieces. It is important to study the cleaning of realistic size plant items. As discussed by Akhtar et al. (2010) many experiments on cleaning use low flow rates and are difficult to scale-up. Some work has been done at pilot or full scale such as that by Lelièvre et al. (2002a,b) who used a 46 mm ID pipe system to study the removal of bacteria. Wiklund et al. (2010) and Henningsson et al. (2007) studied the removal of various food fluids by water and other liquids, and showed that it is possible to use ultrasonics to follow the transition.

This work forms part of a large collaborative project in which a consortium of universities and industries have studied cleaning. The project has aimed to generate reliable cleaning data for a range of materials of industrial interest, and to compare cleaning at laboratory and pilot scale with industrially interesting flow velocities and at a pilot scale. This paper describes the removal of toothpaste from (i) coupons positioned in a horizontal duct of 0.025 m equivalent diameter and (ii) 47.7 mm ID pipes of lengths 0.3–2 m. A range of temperatures (20–70 °C) and flow rates have been studied at the coupon (0.25–0.5 $m\,s^{-1}$) and pilot scale (1.0–2.9 $m\,s^{-1}$). The relationship between experiments at different scales has been studied.

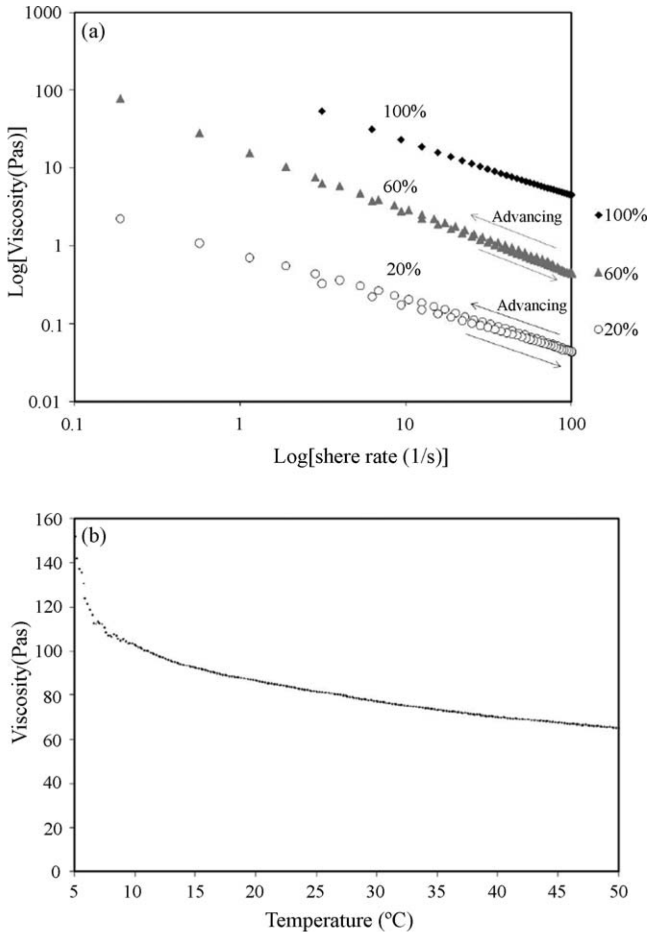

Fig. 1 – Rheological data of toothpaste: (a) data from shear stress sweeps undertaken between 15 and 0 s^{-1}, held at 0 s^{-1} and returned from 0 to 15 s^{-1} shear rate at a variety of toothpaste dilutions with water at 30 °C. Some hysteresis is evident in the 60 and 20% dilutions. The toothpaste has a Herschel–Bulkley behaviour having an apparent yield stress and being shear thinning. (b) Temperature ramp when the shear rate is held at 4 s^{-1}, and the temperature ramped from 5 to 50 °C.

2. Materials and methods

2.1. Material rheology

Toothpaste was supplied by GSK (Brentford, UK). Fig. 1(a) shows the rheology of the material obtained on a TA AR100 rheometer (TA Instruments). A series of shear rate sweeps were undertaken between 0 and 15 s^{-1}, with a peak hold step at 15 s^{-1} for 1 min and a return sweep from 15 to 0 s^{-1} to test the properties of the Type 1 (Fryer and Asteriadou, 2009) soil, for a variety of toothpaste dilutions with water. The undiluted toothpaste exhibits Herschel–Bulkley behaviour with an apparent yield stress of 92 Pa s (based on a model fit) and is shear thinning. The hysteresis of the deposit was tested; there is a negligible amount of permanent deformation for both undiluted product and 60% product in distilled water; however some evidence of hysteresis is seen at 20% product in water. The change in the apparent viscosity of the material with dilution is clear since at 20% toothpaste, the material is two orders of magnitude less viscous than the undiluted material. Fig. 1(b) displays a temperature sweep of the material, performed across the range of temperatures used for the