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# Cleaning of thick films using liquid jets

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**Abstract**

Cleaning of process plants is important to ensure product purity and safety. Cleaning is however expensive with respect to energy, waste and time. It is important to be able to minimise losses from cleaning, by maximising product recovery and reducing waste. Viscous food and personal care products can form thick layers on process surfaces. Cleaning of a surface by a water jet has been studied here. Two modes of cleaning are identified experimentally; for thin films, cleaning is by formation of a crater that expands with time, whilst for thick films a 'blister' forms in which water spreads underneath the deposit. The blister eventually cleans, but over a much longer timescale than for the thinner film. The cleaned area after 10 seconds is comparable in size to the blister area after less than half a second of cleaning. This behaviour has implications for the cleaning of real systems.


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*Keywords:* Cleaning; Impinging jet; Thick Film; Waste Minimisation

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## 1. Introduction.

Cleaning process equipment to remove fouled material from the surface of a process plant is essential in any food business. Ineffective cleaning can lead to reduced product quality, cross contamination of products, and even growth of microorganisms in the system. Cleaning-in-place (CIP), is used ubiquitously to clean the process equipment without the requirement to dismantle it [1]. CIP is an automated cleaning process designed to deliver consistent cleaning conditions, after each cleaning cycle. To ensure cleaning adheres to hygienic standards, CIP protocols are often over engineered, with longer cycles, higher temperature cleaning fluids, and higher flow rates than necessary. This wastes water, energy and time; which increases both the economic and environmental impact of production [2]. Often in multiuse plants the major water and product losses necessitated by cleaning and changeover are the major process losses; food and home and personal care (HPC) products are often fluids of complex rheology that are difficult to remove without a lot of water. Many foods are starch based, and form solid layers with significant yield stress on cooling. Increasing energy efficiency and minimising waste requires better understanding of cleaning [3,4].

Process plants consist of a combination of pipework and process vessels. Previous work has investigated the removal of complex fluids from pipework, and found that cleaning time is a function of the yield stress of the material being removed [5,6]. Spray devices are commonly used to clean industrial product mixing, or holding vessels. These range from simple stationary spray balls, to complex rotating spray devices [7]. The devices act as an impinging jet, where both the pressure force and shear stress of the jet fluid facilitates cleaning. The wetting and drainage of the cleaning fluid also removes deposit through separate mechanisms. Studying cleaning by impinging jets gives insight to the most suitable spray device, and its optimal operating conditions.

Wilson et al [8] developed a model describing the change in the cleaning radius with time for a thin film (from microns to ca. 2 mm) of material product removed by adhesive failure between deposit and surface. The model assumes a uniform deposit thickness, and the rheological properties of the deposit are unchanged during the cleaning process. Growth of the cleaned radius, $r_c$, is shown as function of time, t. The time at which cleaning front is first seen, is defined as $t_i$, and c is a constant determined by liquid properties ($c = 10\pi^2\rho\mu/3$). In this model a kinetic parameter, k', was described, but not investigated. The variation in cleaned radius with time is a function of the mass flow, m, in the jet:

$$r_c \approx \sqrt[5]{\frac{3k'}{\pi c} m^3 (t - t_i)^{\frac{1}{5}}} = K\Delta t^{0.2} \tag{1}$$

Glover et al. [9] developed the model of [7] investigating K as a function of deposit thickness and deposit type. The cleaning of thin films from surfaces has thus been well studied. There is less work reported on the behaviour of thick films. The aims of this work are (i) to study the removal of relatively thick films from surfaces, mimicking the common industrial problem of such films being left over at the end of a tank drainage step, and (ii) to identify similarities and differences between those films and the thin layers that have been modelled.

**Nomenclature**

| | |
|---|---|
| c: constant determined by liquid properties | t: time |
| k': kinetic parameter | $t_i$: time at which the cleaning front is first seen |
| K: lumped parameter | CIP: Cleaning-in-place |
| m: mass flow | HPC: home and personal care |
| $r_c$: cleaned radius | |

## 2. Experimental method.

A series of experiments have been carried out to study cleaning of thick films of viscous fluid / soft solid materials. Water was supplied through a nozzle at a controlled flowrate onto a flat stainless-steel plate angled at 15 - 30° to the horizontal (to allow water to drain from the surface). The jet length of 40 - 60 mm ensured a coherent jet impacted the material, as defined by Middleman [10]. The flat plate was covered with a uniform layer of material – a number of

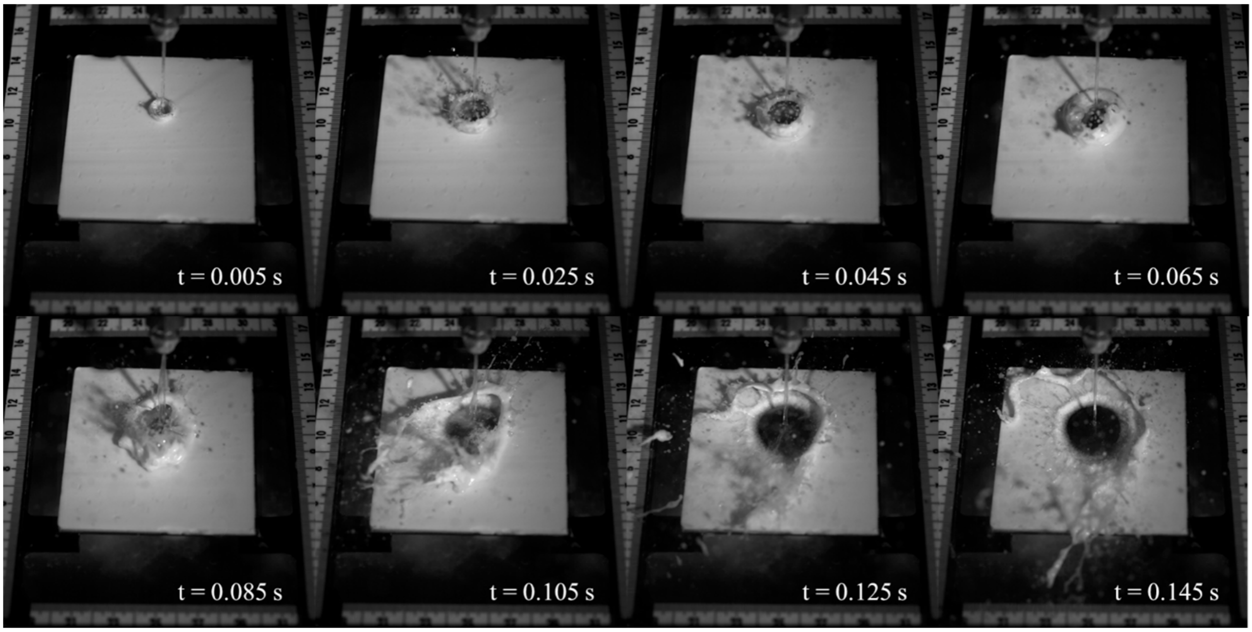


Fig. 1. Jet cleaning of a 2 mm thick deposit on a 10 cm wide plate, showing (i) in the first 0.1 s, displacement of material to form a crater, (ii) after ca. 0.125 s, a clear circular region of clean surface that then increases in diameter as a function of time.

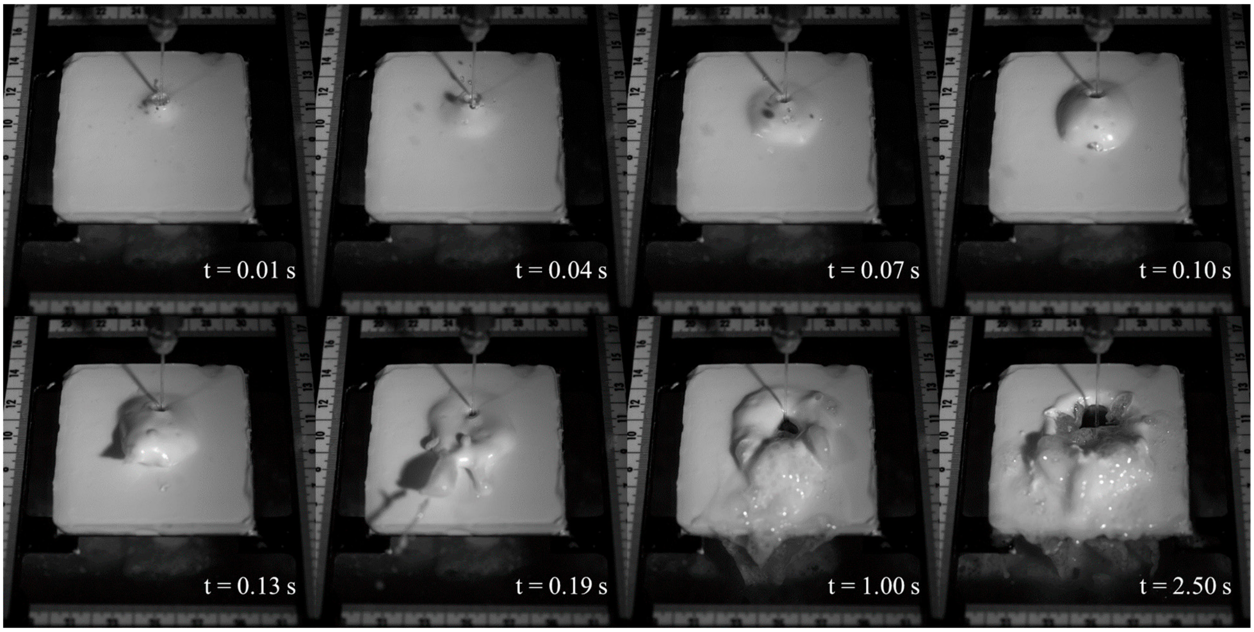


Fig. 2. Jet cleaning of a 8 mm thick deposit on a 10 cm wide plate, showing (i) in the first 0.1 s, displacement of material to form a blister containing the water flow, (ii) up until 2.5 s, the area recorded as clean is very small, as the blistered area breaks slightly to allow water to escape rather than becoming clean.

fast moving consumer goods products were used, as well as transparent carbopol 940 (0.2 wt. %) in water solutions. The yield stress of the materials of Figures 1 – 4 was measured as 48 $N/m^2$ and of the material of Figure 5 was 4 $N/m^2$. The data was analysed by (i) filming the process with a variety of high-speed cameras, and (ii) recording the cleaned area as a function of time, by using image analysis where possible and manually from the images if not. Details of the experimental methods are given in [11].

## 3. Effect of deposit thickness.

A large number of experiments have been carried out to quantify the cleaning process. Here we report only on the effect of the thickness of the deposit being removed. Figures 1 and 2 shows two series of runs, for films of 2 mm thickness and 8 mm thickness respectively, for the same jet flowrate of 1590 ml/min, a mass flowrate of 0.0266 kg/s. The data shows two significantly different mechanisms:

- At the lower deposit thickness, the flow follows the type of behaviour described by [7]; a cleaned area forms under the jet and spreads out; cleaning is largely by adhesive failure of the deposit at the metal surface.
- At the highest thickness, however, a completely different pattern is identified; water is absorbed into the deposit, creating a 'blister' under which water is stored for a period of time. This blister eventually ruptures, but this process takes a considerable length of time.

Figure 3 illustrates this as it shows a close up of the test area for an 8 mm thick layer; the 'clean' area is very small (highlighted in Figure 3(i)) whilst the disturbed layer (under which water has penetrated) is much larger, as shown by Figure 3(ii). The deposit has been separated from the surface, but it is still adhering to the rest of the deposit. Eventually the blister fails by cohesive failure of deposit-deposit bonds, leaving a cleaned region; in Figure 3(iii), the area cleaned after a minute is seen.

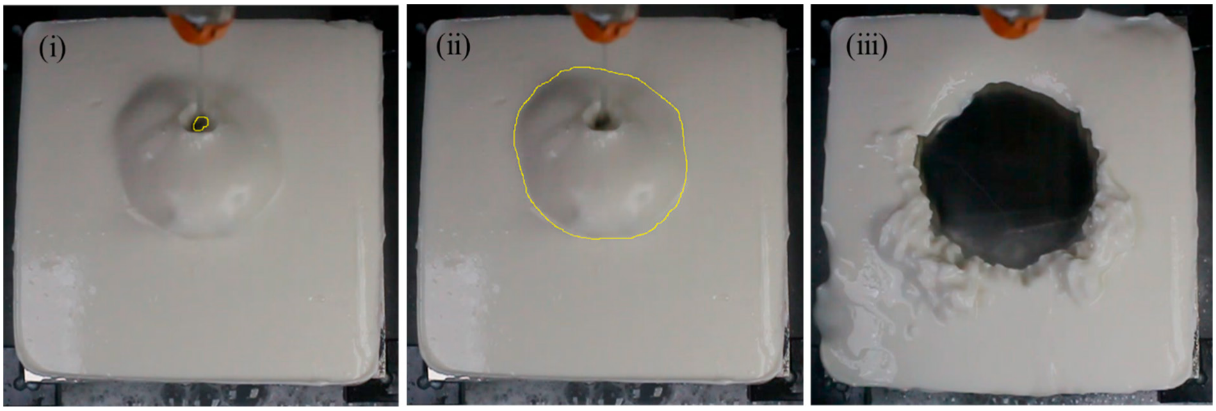


Fig. 3. Jet cleaning of a 8 mm thick deposit on a 10 cm wide plate, showing (i) in the left hand image, the 'clean' area – i.e. the region where the metal plate surface can be seen, (ii) in the center image, the approximate area where the surface of the deposit has been disturbed by water flowing beneath it, (iii) the final cleaned area after one minute of cleaning.

Figure 4 shows the areas of cleaned and disturbed surface as a function of time, extracted from images similar to Figure 3 – it can be seen in Figure 3 that these areas are difficult to define precisely, but it is clear that for a significant time the cleaned area (essentially only the region where the jet enters the blister, through which the steel surface can be seen) remains markedly constant and that the disturbed area increases over a period of about half a second. The block on the far right of Figure 4 shows the cleaned area after 10 s of cleaning, after the blister has burst. The magnitude of the cleaned area is similar to that of the disturbed region, suggesting that after ca. 0.5 s the effect of water is to break and remove the disturbed area, under which water flows, rather than to remove more material from the surface. This increases the water and energy required for cleaning.

The net effect of this on the cleaned area can be seen in Figure 5, which compares three experiments for the removal of 2 mm, 4 mm and 8 mm thick layers of material, cleaned by a common flow of 0.0266 kg/s. It can be seen that although for the 2 mm thick product the cleaned area increases immediately the jet contacts the surface, for the 4 mm and 8 mm thick deposits there is a significant lag of up to a second before there is visible area cleaned. Once the blister has burst, the subsequent cleaning rates are similar for the three thicknesses.

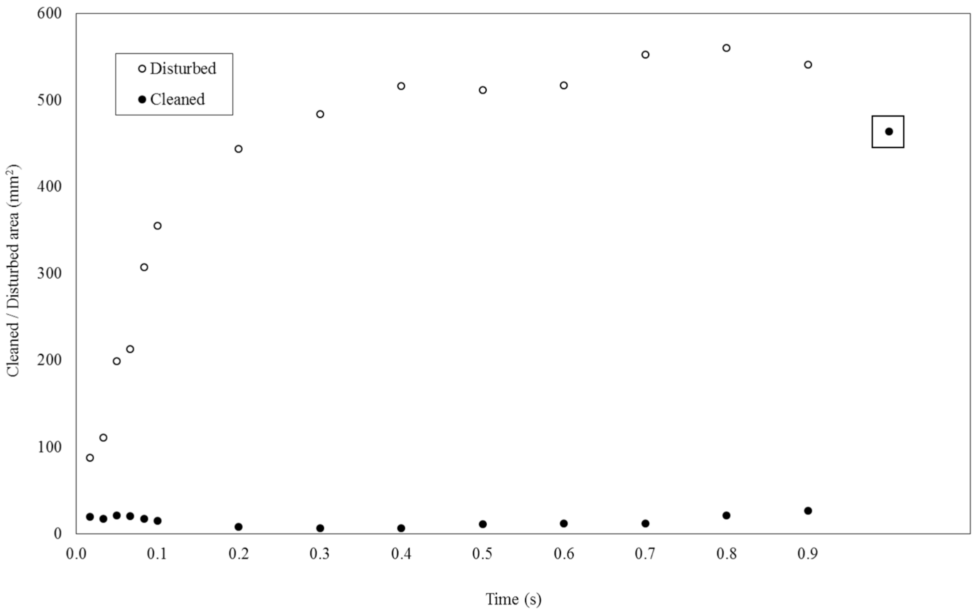


Fig. 4. Quantification of the cleaning of an 8 mm thick deposit, showing (i) the cleaned area, here defined as the amount of metal surface that can be seen, (ii) the disturbed surface area forming the blister, under which water has spread, and (iii) the point with the square around it, which is the cleaned area seen after 10 s of water flow. The cleaned area after 10 s is comparable to the area of the blister formed after 0.2 s.

## 4. Implications for cleaning and product recovery.

The aim of process cleaning is both product recovery and cleaning, i.e. first to remove as much product as possible that can be reused, and then to remove the remaining product as quickly as possible. The possibility of removing thick layers makes the process of cleaning more complex – removal will be difficult if thick layers form as water requires considerable time to disrupt and then remove the material, which will be diluted by the large amount of water used in the removal process. The products looked at here have a high yield stress, and thus represent the most difficult type of material to remove, but suggest that recovery of product will be difficult in this case. The amount of water used to remove the deposit is considerable; a cleaned area of 400 $mm^2$ is achieved after the flow of more than three times as much water for the thick deposit than for the thin deposit in Figure 5.

The types of solid product studied here show a yield stress and are thus more difficult to remove than less viscous products – they are however typical of difficult-to-remove materials such as starchy foods, and thicknesses that are found in the bottom and lower sides of process vessels after draining or pumping product out. A thick layer of such a material will be especially difficult to remove other than by large amounts of water. This suggests that jet cleaning systems should consider product rheology in more detail, to identify yield stresses, for example. This work has also only studied stationary jets, whilst in practice the jets are moving. The best jet speed for such films is not yet known – and is the subject of future work. However it may be that rapidly moving jets are not the best way of removing deposits where considerable water is needed to remove deposit of the type seen in Figure 2.

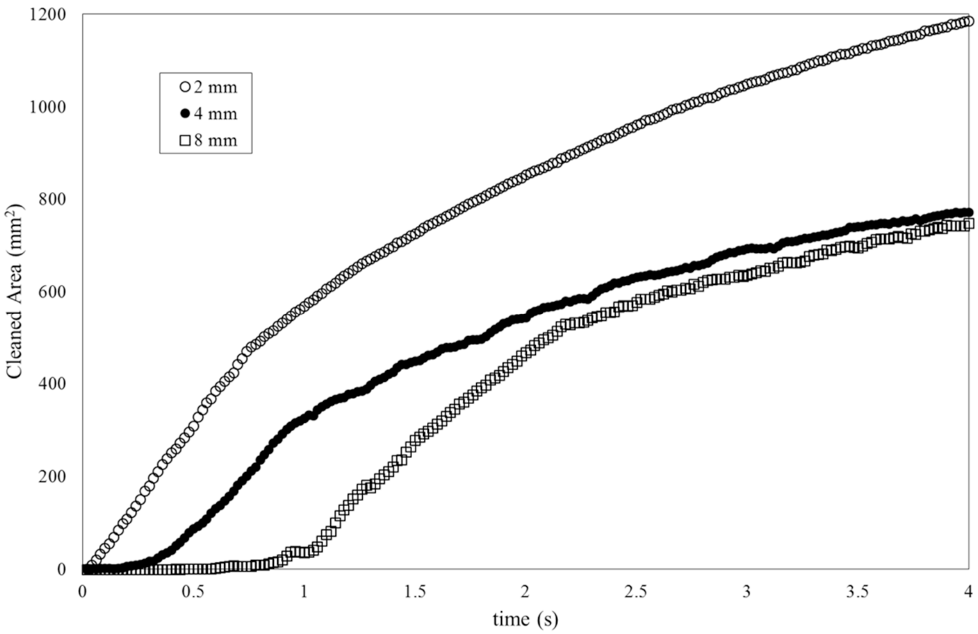


Fig. 5. The cleaned area as a function of time for three thicknesses of deposit (2 mm, 4 mm, 8 mm) quantifying the effects seen in Figures 1-3. For the 2 mm experiment, cleaning begins immediately, whilst for the 4 and 8 mm experiments, there is a lag phase during which there is no deposit removed, corresponding to the formation of the blister seen in Figure 2.

## 5. Conclusions.

Cleaning is a necessary process in food and HPC processing that adds significantly to the energy losses and waste generated by a process. The jet cleaning of surfaces has been studied for layers of yield stress fluids between 2 and 8 mm in thickness. At 2 mm the cleaning process is similar to that described in Wilson et al. [8]. At higher thicknesses, however, the mechanism is significantly different; water forms a blister under the deposit, which takes several seconds before it breaks open to give a clean surface. Such deposits are much more difficult to remove than thinner ones. Work is ongoing to characterise this behaviour in more detail and define the process in terms of engineering variables. Understanding cleaning better will lead to savings in both energy and waste from a process.

## Acknowledgements

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