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Understanding the Cleaning Performance of High Pressure Sprays at Long Stand-off Distances

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Abstract
This paper is concerned with the efficient cleaning of the interior of large tanks used for storing substances such as tooth-paste, hand creams and other consumer products. It is describes a systematic experiment which characterises the cleaning rates of a number of solid cone pressure jet atomizers with respect to impact force, mass flux and droplet size at stand-off distances up to 5m. Water pressures up to 80bar are used with water flow rates up to 40litres/min. Tests are carried out using both static sprays and also rotating sprays, with a static target. The factors determining cleaning performance of the nozzles at various pressures and distances when removing viscous substances from a target plate were evaluated.

Introduction

High pressure aqueous sprays are used in various cleaning applications throughout industry [1]. In the pursuit of reducing energy costs, water wastage, and the downtime in production during cleaning, it is desirable that the atomizer is optimised for the cleaning application. Furthermore optimisation leads to less water usage and minimises the need to dispose of contaminated water. The relatively little work on cleaning methods and efficiency has concentrated on the atomizer being close to the object that is being cleaned; however there are cases within industry where efficient cleaning performance needs to be achieved at stand-off distances of 5m or more, e.g. cleaning large storage tanks. Systematic experiments have been designed by the authors using both static sprays ("static cleaning") and rotating sprays ("transient cleaning"), were the objectives include;

1. Relate cleaning rates to the impact conditions of the sprays, as measured by a range of techniques
2. Relate the impact conditions to the atomizer design and the position of the atomizer (and rotation rate when applicable.
3. Quantify cleaning efficiencies for different test conditions, where cleaning efficiency is based on the mass of water required to clean a given mass of soil.
4. To thus derive atomizer designs that maximise cleaning efficiency for given soil type, stand-off distance etc.

Because of the many parameters that are involved in the cleaning process we can give here only an overview of the experiments and also reasons of commercial confidentiality prevent detailed description of aspects of the work.

Apparatus and Procedures

As shown in Fig 1, the atomizer could be positioned up to 5m from the target plate. This plate held either a 125mm diameter aluminium alloy disk, for static tests, or a 500mm (high) x 125mm (wide) rectangular plate, for transient tests. These plates were covered by the soil to a uniform thickness before each test. The cleaning process was measured by (a) weighing and photographing the soil plate at intervals, (b) high speed video.

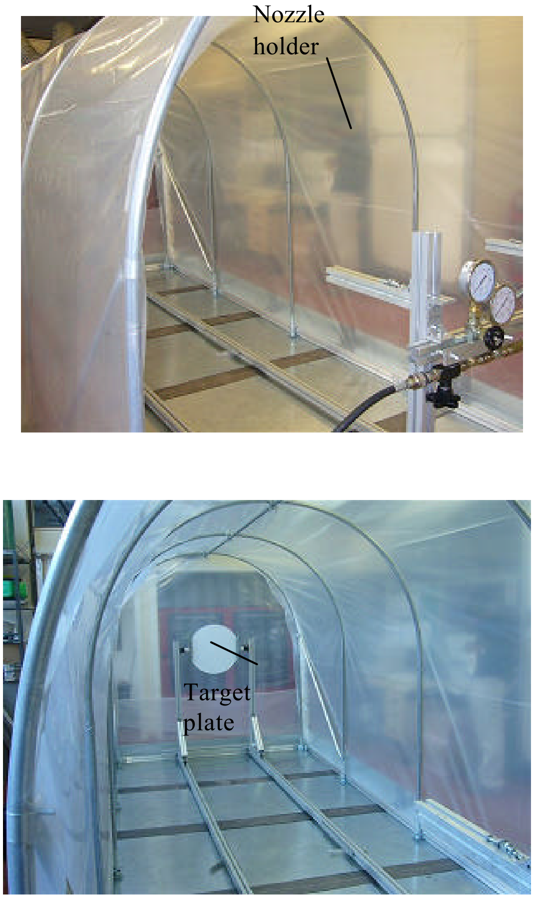


Figure 1: Views of poly-tunnel containing test target and spraying equipment.

The spray was characterised at the different impact distances used, 2.5m, 3.75m and 5.0m, by the following;

1. Mass flux was measured using a Patternator collection arrangement (Fig 2a).
2. The distribution of impact force across the spray was measured by a transducer connected to a 15mm impact disk (Fig 2b).
3. The sizes and shapes of droplets were measured from sequences of images obtained using a Redlake (Motionpro-HS1) high speed video with a K-Type "long distance microscope" macro lens system and at 20000 fps.

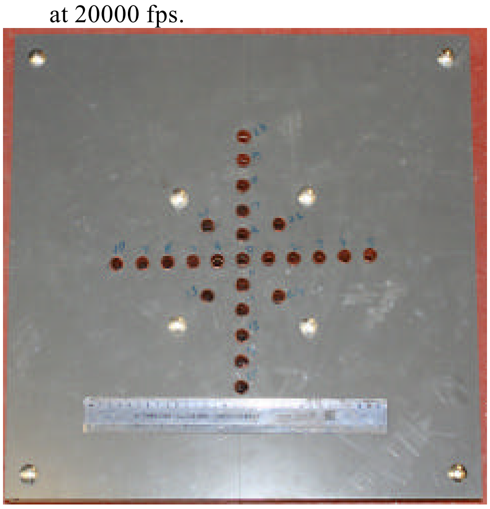


Figure 2a: Patternator.

Figure 2b: Impact probe.

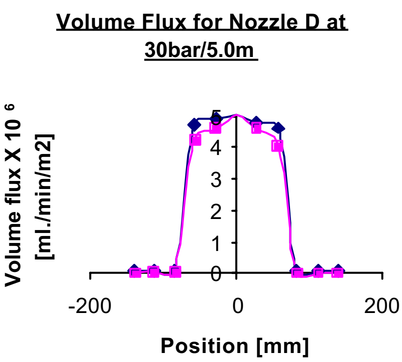
For the transient tests the atomizer was rotated at a controllable speed up to 12rpm, with the spray scanned in the vertically upwards direction across the target. Particular care was required to ensure that the soil on the plate was not splashed with water before or after the scanning event.

Results

Figure 3 is an example of the appearance of the target during static cleaning trials. For "difficult" viscous soils the main cleaning mechanism was a shearing process due to the impacted water jet which produced a wall jet flowing outward, plus splashing. For lower impact and dilute sprays (unsuitable for efficient cleaning) a washing process with dissolving of soil occurred so that cleaning then occurred in patches across the target, rather than via a gradually growing cleaned area.

Figure 4 shows examples of the volume flux and impact force measurements for two atomizers; 7 different atomizers, that had different exit orifices and internal flow characteristics, were used.

Figure 3: Example of paste coated target before and 1 second after spray impact



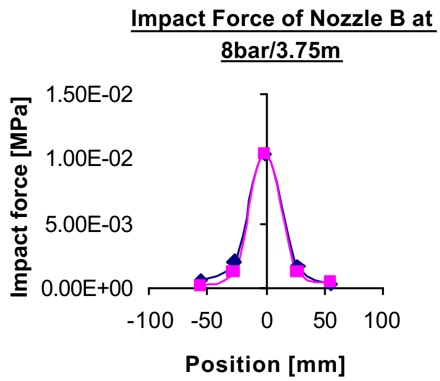


Figure 4: Examples of volume flux and impact force distributions.

Figures 5 and 6 show examples of the cleaned area and mass of soil removed versus time. Generally both of these parameters vary approximately linearly, note that 100g and 12000 mm^2 represent a completely cleaned target. Figure 7 shows example video frames. For this case most droplets are near-spherical, however some cases showed a poorly atomized spray core with elongated droplets. It was decided to attempt to correlate the static cleaning rates with impact conditions by choosing the cleaned mass and area at 3s and tabulating these values with peak volume flux at impact, peak impact force, drop diameter and mean drop velocity. Table 1 shows examples from this data set.

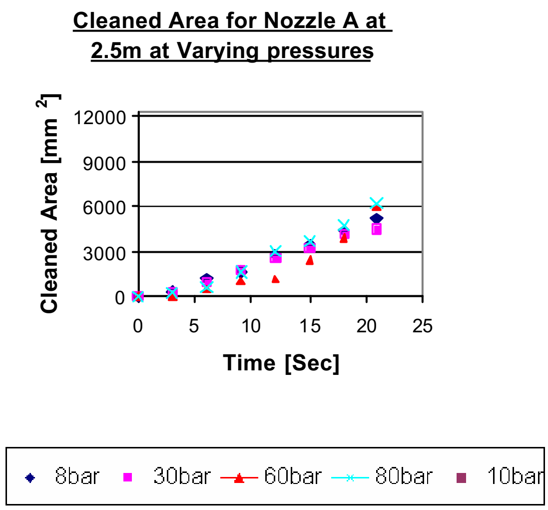


Figure 5: Examples of cleaned area versus time data, static cleaning.

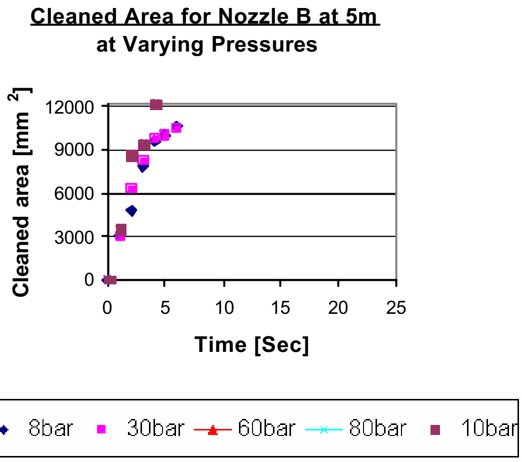


Figure 5: Examples of cleaned area versus time data, static cleaning.

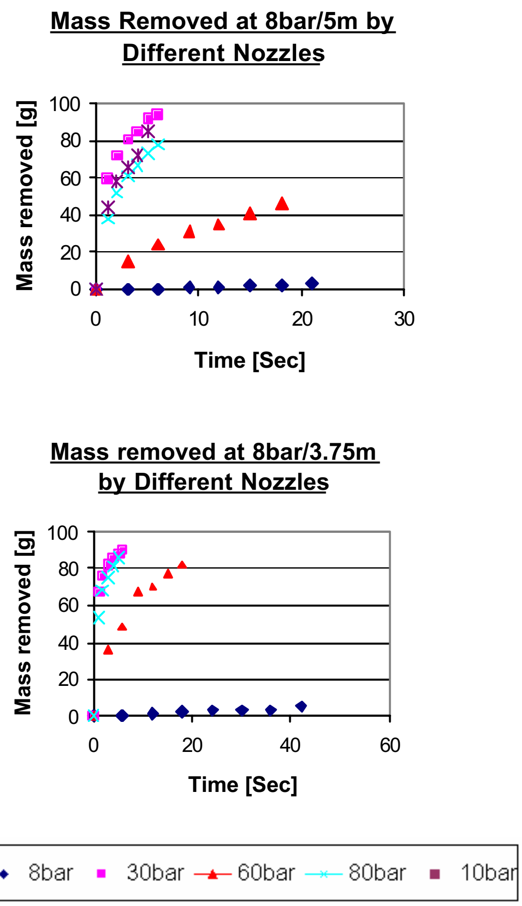


Figure 6: Examples of mass of soil removal versus time.

Table 2 shows a selection of the best cleaning efficiencies measured at 3 distances downstream. Attempts at correlating cleaning rates with impact conditions were made and Figure 8 shows that a good correlation was obtained when plotting the cleaning rate versus the product of peak impact force and peak mass flow rate. The gradient of the correlation (from this log/log plot) is very close to 0.5. It is noted that all of the results shown here are for one type of soil with the same soil thickness in all cases (4mm) and also with horizontal sprays and a vertical target. Other tests showed that cleaning rate increases for a horizontal spray when it is impacted on an inclined target. Also a vertically downward spray impacting on a horizontal target cleaned more rapidly.

The transient cleaning trials used a large number of combinations of atomizer types, supply pressures, distances and rotation rates. In general the impacting spray was resident at any point on the target for no more than 1s so that the later times in the static cleaning trials could not be directly related to the transient tests. Figures 9 and 10 show the soiled plate after 1, 2 and 3 scans using different nozzles. It can be seen that careful matching of nozzle and operating conditions to the soil type and reach, can give more rapid and more efficient transient cleaning.

Calculations of the cleaning efficiency for the transient cases showed that values several times higher than for static cleaning could be achieved. There are thus differences in the mechanisms of static and transient cleaning.

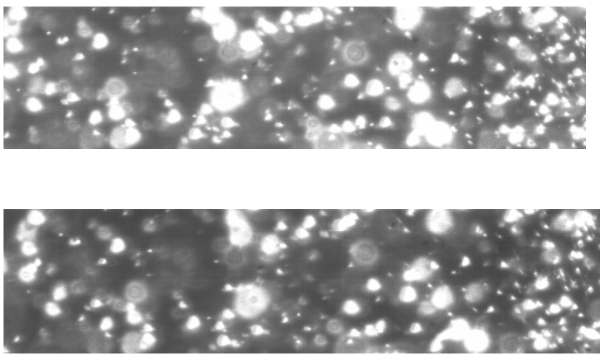


Figure 7: Examples of video frames at 50microsec interval, largest images 1mm approximately

Spraying Code	Test Number (cleaning)	Wt TPaste removed in 3sec (g)	Area cleaned in 3sec (mm2)	Peak volume flux (L/min/m2)	Peak Impact (Pa)	Largest drop diameter (microns)	Velocity of largest drop (m/s)	Spray half-width (mm)	Comment on cleaning
TP8,2.5A	7	5	303	831	856	155	15.5	45	Small hole grows linearly in area
TP8,3.75A	36	0	0	350	89	109	5.1	90	Negligible visible except at plate edge
TP8,3.75B	58	82	9500	5064	10414	705	9.3	90	Rapidly growing hole,
TP8,5A	37	0	0	104	14	108	5.1	90	Negligible visible
TP8,5B	55	81.4	5300	5064	8025	1024	11.3	120	As above
TP30,2.5A	6	25	50	786	855	39	19	80	Clear hole occurs only after 3sec
TP30,3.75A	9	5	0	266	62	34	10	160	Negligible visible except at plate edge
TP10,3.75B	71	80	10450		10800	750	12.1		
TP30,5A	38	1.0	0	247	14	32	9.9	60	
TP10,5B	72	82	10450		10414	630	10.7		
TP60,2.5A	1,2,4	5	70	909	790	17	16.1	70	Central hole just started forming at 3s
TP60,3.75A	11	7	0	220	140	18	10.8	200+ (irregular profile)	
TP60,5A	8	2	0	119	9.5	18	4.5	230	
TP80,2.5A	3,5	15	94	935	111	14.5	7.6	75	Central hole growing rapidly after 3sec
TP80,3.75A	40	4	0	230	114	14.3	6.2	250+ (flat profile)	
TP80,5A	39	3	0	140	9.5	14.0	5.7	170+ (irregular	

Table 1 : Example of tabulated data for static cleaning

DISTANCE M	ATOM-IZER	Pressure Bar	Cleaning Rate g/s	Cleaning efficiency, 100x g(soil)/g(water)	RANK
2.5	C	9.5	15.5	15.5	**1**
2.5	A	30	8.3	8.3	**2**
2.5	D	9.5	23.5	6.1	**3**
3.75	C	9.5	11.7	11.7	**1**
3.75	D	9.5	25.0	6.5	**2**
3.75	C	30	8.7	5.2	**3**
5.0	D	9.5	20.3	5.3	**1**
5.0	C	30	8.7	5.0	**2**
5.0	C	9.5	5.0	5.0	**3**

Table 2 Examples of measured static cleaning efficiencies

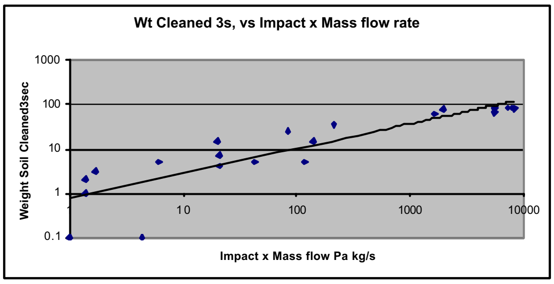


Figure 8: Correlation of cleaning rate with impact conditions

Figure 9: Nozzle B at 5m, 8bar, 38litres/min, 3.4rpm 3 scans.

Conclusion

Static spray cleaning, over a period of 3s, with horizontal sprays and with different orientation of the target plate, show that there are significant increases in the rate of cleaning achieved by increasing the product of impact force and mass flux. In addition, a vertically downward spray impacting on a horizontal target cleaned more rapidly.

Cleaning efficiencies in the static tests were much lower than those achieved in the rotating spray cases. It thus appears that there are differences in the mechanism of static and transient cleaning.

Figure 10: Nozzle E at 5m, 11.2bar, 38litres/min, 3.4rpm 3 scans.

Reference

Nasr, GG, Yule, AJ and Bendig L Industrial Sprays and Atomization, Springer Verlag, July 2002.