Fine spray behaviour upon impaction of varied material surfaces

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Fine Spray Behaviour upon Impaction of Varied Material Surfaces

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Abstract

A mobile fine spray unit, utilising a spill-return atomiser has been developed for the purpose of decontamination within healthcare environments. The unit must be able to spray uniformly onto any given surface, providing 'mist like' coverage. Any streaking patterns on the surface during or after spray application would jeopardise the efficiency of delivering the decontaminant. Thus it is pertinent to understand the behaviour of droplets impacting on various surfaces, and particularly the conditions that cause streaking.

Within this investigation four sample surfaces; steel, acrylic, glass and laminated wood have been sprayed separately using the spill return device with a substitute MRSA disinfectant liquid. Through experimentation the optimum spray input conditions for the atomiser: distance, time and pressure required to uniformly coat various surfaces without the occurrence of streaking have been obtained.

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Introduction

Hospital Acquires Infections (HAI's) are a major problem for worldwide. Inefficient cleanliness and hygiene practice has lead to a steep rise in infection rates, with subsequent increases in HAI associated illnesses and fatalities. MRSA (Methicillin Resistant Staphylococcus Aureus) has become synonymous with these problems as the appearance of organisms resistant to antibiotics has, in some cases lead to patient mortality. Other similar infections includes VRSA (Vancomycin Resistant Staphylococcus Aureus) and Clostridium Difficile. A mobile fine spray system has been developed [1-2], producing droplet sizes 15μm<D_{32}<25μm. This is achieved by providing an effective and efficient delivery system for specified disinfectant agents, which have been proven to kill infection-causing organisms. These disinfectants function by coming into contact with the organisms present on a surface, and remaining in contact for a certain length of time (typically minutes) so as to kill any harmful organism present. The efficiency of the disinfection process depends mostly upon the correct application of disinfection solution in providing maximum surface coverage, without any streaking. It is therefore important to gain a comprehensive understanding of the behaviour of droplets impacting on various surfaces and the occurrence of streaking.

The Spray Research Group cooperated with relevant industries, led by HSS Ltd, UK [3] in collaboration with a major international company [3] in developing a portable surface coating disinfection system, which uses a high-pressure, spill-return atomiser [4]. The main aim of this investigation is to utilise the spill-return atomiser, which can produce similar spray patterns and surface coverage to the existing ultrasonic system. Furthermore, despite the requirement of a mains power supply, neither compressed air canisters nor a pressurised liquid reservoir would be required. Thus the system will be more cost effective and it is as efficient as an ultrasonic system.

Previous experiments [5] with the existing Hughes Ultrasonic Atomiser (HUSA) system showed that it successfully coated surfaces (walls, furniture etc.) using flow rates of the order of 0.1 l/min and drop sizes with SMD<20 microns. Excessive flow rates or larger drop sizes could result in disproportionate localised surface wetting and poor coverage. If flow rates are too low, coating times will be excessive and the finer droplets may not penetrate to the required surface. An investigation of high-pressure swirl atomisers, with spill-return features, has shown that they are capable of producing both similar flow rates and drop sizes to ultrasonic atomisers at a supply pressure to the order of 10MPa [6]. Without a spill return facility flow rates can be high, whilst its addition reduces flow rate with minimum effect on drop sizes. Moreover, the 'spilled-off' liquid is not wasted as it is returned to the liquid reservoir.

This paper provides the results of a number of spray performance tests which were carried out using the spill-return atomiser and focuses particularly upon the findings of the liquid streaking behaviour and how different surface materials will affect the streaking process.

Apparatus and Procedures

Figure 1 shows the test apparatus which comprised of a spill-return atomiser, which was described in detail in the previous publications [1-2 and 6], fixed to a vertical aluminium pillar, which was in turn fastened to a portable trolley. An unpressurised liquid reservoir tank was mounted onto the trolley, together with a high-pressure pump, manufactured by the Interpump Group, capable of producing up to 150bar, at a flow rate of 8 l/min. A pressure gauge, distribution block and high-pressure hydraulic piping were used for the delivery of the liquid from the pump to the atomiser. Water was used as a simulated disinfection solution as it has similar physical properties to most solutions likely to be used.

A more detailed description of the spill-return atomiser, used throughout this investigation, and its performance characteristics is featured in previous publications [1-2 and 4] and shown schematically Figure 2.The actual geometry used was selected to give relatively small spray cone angles (<40°) and thus achieve efficient penetration.

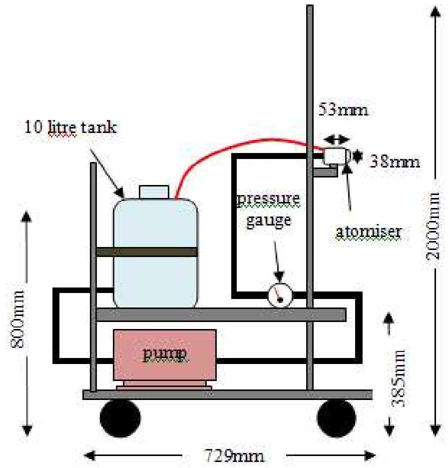


Figure 1 Schematic arrangement of the test apparatus

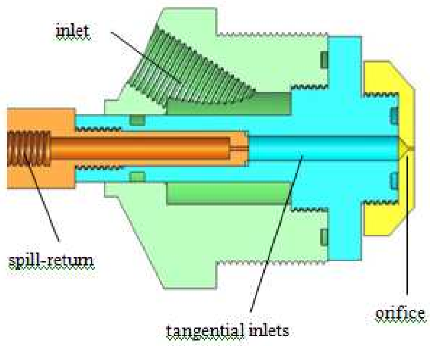


Figure 2 Schematic diagram of the spill return atomiser, showing two tangential inlets.

A simulated hospital environment, referred here the 'test chamber' was used to carry out all related tests. The room had the following dimensions: Length=3.7m, Width=2.5m, Height= 2.6m. The test chamber was maintained at a constant temperature throughout testing, as any variation in ambient temperature has been found to affect the rate of evaporation of spray droplets impacting upon the desired surface.

For each test the most efficient pressure, orifice plate and spill diameter combinations were chosen (pressure: 9MPa, flow rate: 0.245 l/min, spill diameter: 0.3mm, exit orifice diameter: 0.5mm). The coating tests were performed in a controlled test chamber to simulate the desired temperature and humidity experienced on a normal day. The temperature, pressure and humidity were recoded for each period of testing, using a dedicated handheld probe.

The setup and the detailed procedure were provided previously [5-6] in which each test involved positioning the atomiser directly in front of a 300mmx300mm square plate, as shown in Figure 3, for a range of materials (acrylic, wood laminate, glass, brushed steel). A centerline was marked out at distances downstream from the tip of the atomiser. Initially the atomiser was placed 300mm from the target plate and the time between the initiation of the spray and when the first signs of streaking were observed on the plate. This process was repeated for each material at 100mm intervals between 300-800mm from the target plate. Water was used as a simulated disinfection liquid solution as it has similar physical properties as most solutions likely to be used. The flow rates were measured by collection weighing techniques. Images of the coatings produced by the atomiser at the various spray coatings were captured with the use of an EOS 350D Cannon digital camera with macro lens [5]. The captured images provided qualitative information on the streaking process by analysing close up views of each of the coated surfaces. The plate was dried thoroughly between each test so as to eliminate the chance of any remaining surface moisture affecting future tests. The results were then processed and compared to determine the effects of each sample surface upon the streaking process.

Results and Discussion

The test results were divided into four distinct sections in accordance with the four target plate materials used (acrylic, varnished plywood, glass, brushed steel) for a range of distances from the atomiser exit orthogonal to the chosen surface. Because of the fine nature of the spray and the relatively narrow initial angles, the sprays were of the "solid cone" formation at impaction, giving a relatively uniform spray patternation within the central impact zone.

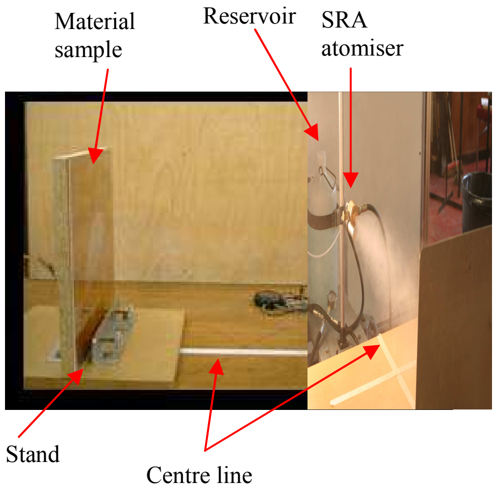


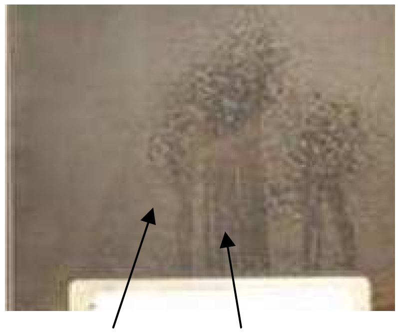
Figure 3 Image of the target plate together with the functioning SRA

Streaking and Over Wetting

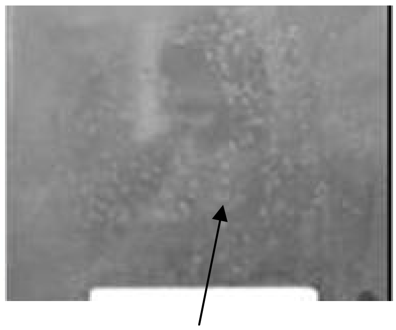
There is currently no previous work in the public domain with regards to surface coating, particularly in "Streaking" and "Over Wetting" which is directly relevant to the present application. The best example of streaking can be seen when a domestic showerhead is used to spray within a bathroom. Large droplets from the showerhead are deposited on the surface of tiled wall, cubicle or bath. When the droplet is above a certain size, and its gravitational force is sufficient enough to overcome the frictional force between the droplet and the surface, it begins to move down the wall creating a streak. This problem is worsened when the drop begins to move down the wall surface, interacting with other droplets produced by the incoming spray showerhead, which gains in both mass and momentum, thus creating a streakline, as typified in Fig.4. The occurrence of streaklines will depend on the frictional coefficient of the surface (rougher surfaces have higher coefficients) and also the size of the droplets deposited on the surface. With this in mind, and considering the practicalities of operation of the fine spray unit, utilising spill-return atomiser, streaks are clearly undesirable. Streaking often results in droplets collecting on the floor which become a potential slip hazard and therefore require removal. Moreover, when streaking occurs the natural cycle of coating and evaporation from the surface is disrupted. Dry trail marks left behind the streak show a lack of uniform coverage of the disinfectant produced by the mist, which would evaporate from the surface naturally. It could be impractical to alter the surface of every item in every hospital to increase its coefficient of friction. It is therefore important to analyse the characteristics and behavior of the spray upon impaction for coating various surfaces. Factors which contribute to the uniform surface coverage include downstream distance from the exit orifice of the atomiser to the target surface, supply pressure, required spray duration, and flow rate.

As Figures 5-8 illustrate, the ideal coating conditions are relatively similar for all four sample materials. In the case of all four sample surfaces, the time at which streaking first occurs increases with distance. This is because as distance increases, droplet sizes decreases, making over-wetting and streaking a far lengthier process, as smaller droplets are unable to overcome the surface tension. This consequently minimises the occurrence of streaking. In the cases of shorter distances, a combination of the higher velocity droplets, which exceeds the surface tension and the gravitational force together with the random deflection of droplets could cause streaking or over wetting of certain areas. The surface roughness (friction coefficient) that resists the occurrence of streaking is influenced by the surface tension of the liquid surface being sprayed. This surface tension can be greatly influenced by the cleanliness of the surface. All surfaces were thus thoroughly cleaned and/or polished prior to conducting each test. It was therefore necessary to operate the system with a 'close' setup in terms of water supply pressure and required spray duration.

Acrylic



Glass



Brushed Steel

Laminated Wood

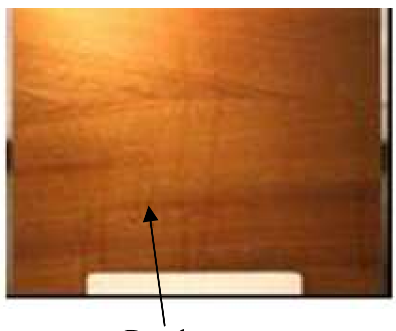


Figure 4 Typical streaklines on all four test surfaces

The *acrylic* sample surface had the smallest overall operating envelope and shortest average streaking times, over an extensive range of application distances, as illustrated by Figure 5. This is because the flat, smooth nature of the surfaces lends itself to uniform spray coverage and with low surface tension which decreases the chance of streaking. The streaking envelope of the acrylic surface ranged from 0.77s at 300mm to 2.30s at 800mm.

The *glass* overall operating envelope is also shown in Figure 6 over a range of application distances. This is unsurprising as, like the acrylic surface, its smooth nature gives it relatively nominal surface tension. The streaking envelope of the glass sample surface ranged from 0.64s at 300mm to 2.37s at 800mm.

The *brushed steel* sample surface has the largest overall operating envelope as illustrated by Figure 7. This is because the uneven nature of the surface gives it relatively high surface tension. This thus causes the concentration of the droplets for long period of time before gaining sufficient mass to overcome the friction coefficient of the material, thereby causing streaking. The streaking envelope of the steel surface ranged from 0.51s at 300mm to 2.61s at 800mm, giving it the widest range of readings of all the four sample materials tested.

The *varnished laminated wood* operating envelope over an extensive range of application distances is illustrated in Figure 8. Despite its relatively smooth varnished surface texture, the wooden surface did contain small indentations. This could increase the surface tension which results in the build-up of the droplets remaining on the wooden varnished surface for long time and eventually overcoming the friction coefficient and causing streaking. The overall operating envelope is shown in Figure 8 is smaller than that of the brushed steel surface, thus *even small imperfections on a surface will affect the processes of both streaking and coating*. The streaking envelope of the wooden surface ranged from 0.61s at 300mm to 2.55s at 800mm.

Legend

Streaking and over-wetting

Insufficient coverage

Operating envelope

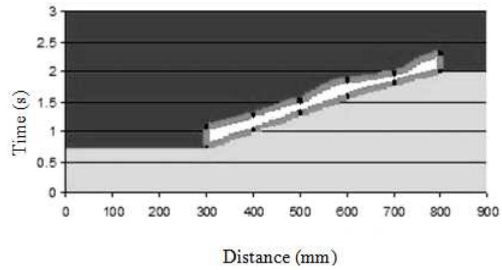


Figure 5 Ideal coating envelope for acrylic surface

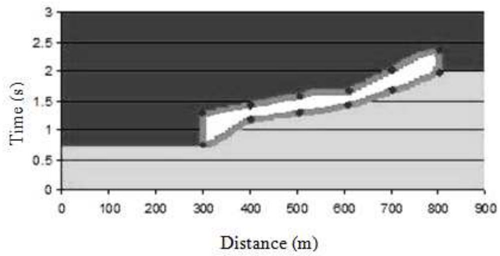


Figure 6 Ideal coating envelope for glass surface

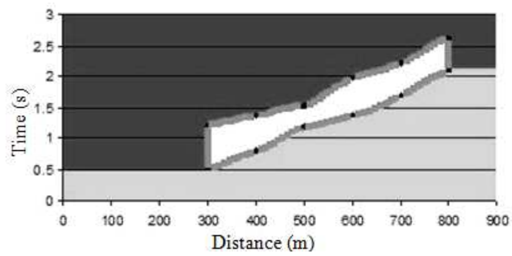


Figure 7 Ideal coating envelope for brushed steel surface

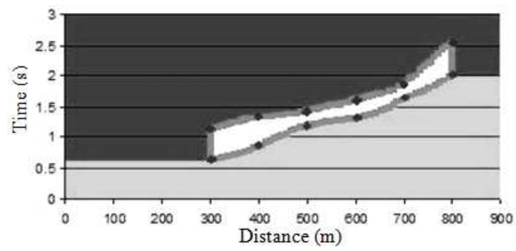


Figure 8 Ideal coating envelope for laminated wood surface

Figures 9-12 show iso-contour plots of '*time at which streaking first occurs'* at different pressures and application distances for all four sample surfaces. Figures 9–12 reiterate Figures 5–8 in that they show that the time at which streaking first occurs increases with distance and generally decreases as pressure increases.

The iso-contour plots of the two flattest surfaces, acrylic and glass are shown in Figure 9 and 10 which display a clear correlation between the increase of supply pressure, application distance and time amassed prior to streaking. The increase in pressure causes the droplet sizes to decrease, thereby reducing streaking time. This also results in the production of fine sprays, providing relatively uniform coverage. Figures 9 and 10 also illustrate that the time amassed prior to the detection of streaking varies most between the distances of 300-600mm. Thus these distances should be avoided during application due to the unpredictable outcome in the form of streaking and inefficient disinfection.

Figures 11 and 12 each display the iso-contour plots for brushed steel and laminated wood, showing the correlation between supply pressure, application distance and time amassed prior to streaking. Due to the relatively uneven surface and comparatively high surface tension several peaks and troughs are evident within the contours shown, indicating the presence of uneven coverage of both surfaces.

An increase in pressure requires an increased flow rate, which is detrimental to the 'high pressure, low flow rate' and it is unique selling point (USP) of the SRA. It has been proven that the results obtained for the lower pressures of 90-120 bar are suitable for efficient disinfection, therefore this pressure range will be recommended to potential clients.

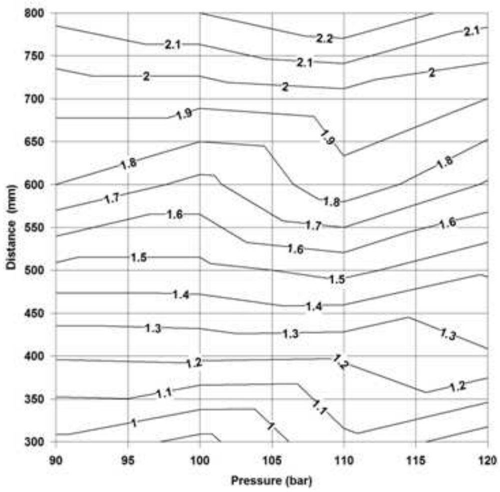


Figure 9 Streaking time contours for acrylic surface

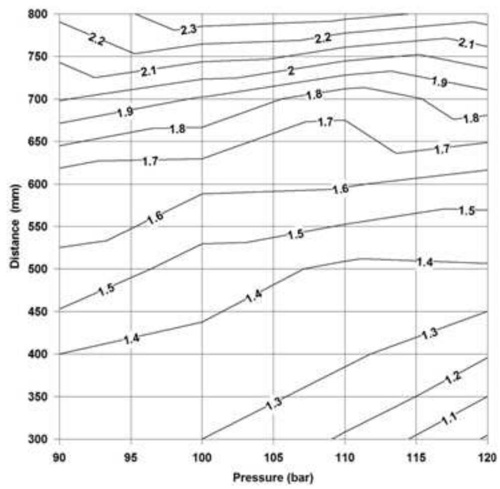


Figure 10 Streaking time contours for glass surface

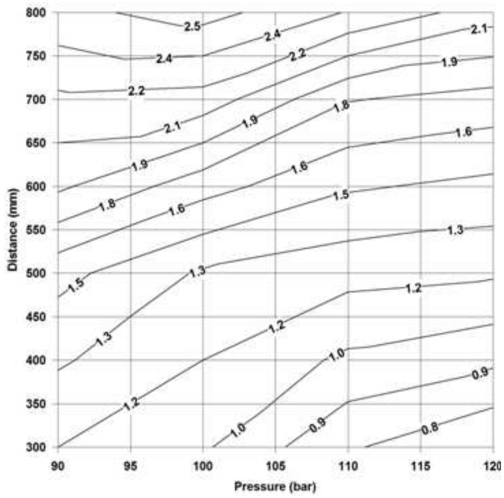


Figure 11 Streaking time contours for brushed steel surface

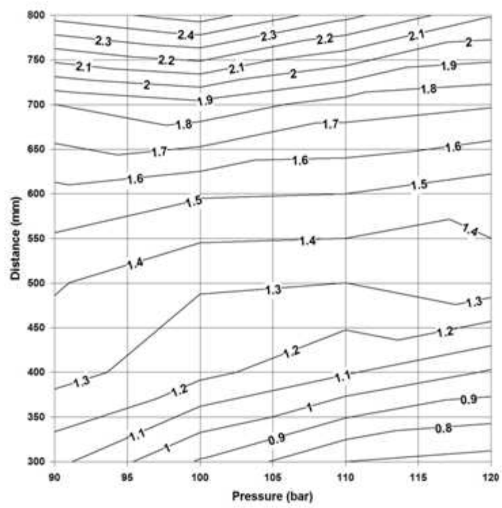


Figure 12 Streaking time contours for laminated wood surface

Conclusions and Future Work

The investigation has found that the utilisation of fine sprays (15µm<D_{32}<25µm) at high liquid pressure (<120bar) and low flow rates (<0.3 l/min) is indeed suitable for surface disinfection in healthcare applications (i.e. MRSA and VRSA prevention). At a distance of approximately 800mm between atomiser and target surface, using a spill diameter of 0.3mm, a nozzle orifice diameter of 0.5mm and a pressure of 120<bar, the most efficient and cost-effective coating can be achieved. Although results varied slightly between surface types, it has been demonstrated that the spill return atomiser can provide proficient cleaning on all surfaces commonly found within healthcare environments. Streaking as illustrated in the tests is a function of spray duration, distance, water supply pressure and material properties. There are however other factors that could be investigated that would also affect streaking, such as room temperature, material surface temperature and humidity. Furthermore if the disinfectant additive changes the surface tension of the liquid, this could affect drop size, streaking and ideal coating conditions.

Future work includes the development of a prototype system together with clinical trials within actual healthcare environments (i.e. hospitals).

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