Fine Sprays for Coating and Decontamination in the Healthcare Environments

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Abstract

A spray unit has been developed for the purpose of coating and decontamination within healthcare environments. The unit provides uniform spray coverage onto a given surface, in absence of streaking patternations.

This investigation used four exemplary surfaces; steel, acrylic, glass and laminated wood that have been sprayed separately using a novel Spill-Return Atomiser (SRA)© with a simulated MRSA disinfectant liquid. This paper reports the findings that were obtained in uniformly coating and decontaminating these surfaces. All tests were conducted using the optimum spray input conditions for the atomiser: pressure, flow rate, distance and time that were required for uniform coating various surfaces without the occurrence of streaking.

Introduction

Surfaces within the healthcare environment contribute to the transmission of epidemiologically important microbes such as Methicillin Resistant Staphylococcus Aureus (MRSA), Vancomycin-Resistant Enterococcus (VRE), Clostridium difficile, and viruses (ie, norovirus, rotavirus, and rhinovirus) thereby causing Hospital Acquired Infections (HAIs); the fact that personnel may contaminate their gloves (or hands in the absence of gloves) by touching such surfaces suggests that contaminated surfaces may serve as a reservoir or source of MRSA and VRE in hospitals.

The effective use of disinfectants on surfaces, therefore, within the health care environment constitutes an important factor in preventing HAIs [1-5]. For surface disinfection processes in hospitals the open bucket and closed bucket systems are commonly used, these systems involves the use of wipers to deliver the disinfectant agents to the target surface. Wipers (cotton rags, cellulose- based wipers) however, have proven to be inefficient in the delivery of disinfectant agents as they are incompatible with some disinfectant agents or have a high possibility of contaminating the disinfectant solution or other surfaces they come in contact with.

Spray devices are also used such as ultrasonic system [4]. Sprays provide an efficient and effective delivery system for liquids as bulk liquid can be broken down into fine droplets and distributed evenly across the target surface without prior or post contamination of the disinfectant liquid. However, an efficient spray unit is that which can deliver disinfectant in form of a uniform coating across the target surface, without forming any streaking pattern or puddle of disinfectant due to excessively large droplets, thereby causing waste.

A mobile fine spray unit, utilising a novel spill return atomiser has been developed for the purpose of disinfection within healthcare environments. The developed system [3], produces droplet sizes $15\mu m < D_{32} < 25\mu m$ for flow rates as low as 0.1 l/min with liquid supply pressure of up to 12MPa. This is achieved by providing an effective and efficient delivery system for specified disinfectant agents. Furthermore, the unit is able to spray uniformly onto any given surface, providing „mist-like coverage. Any streaking patterns, caused by excessively large droplets, left 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 ongoing 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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Apparatus and Procedures

The test rig shown in Figure 1, reported previously [5] comprises of a basic four-wheeled trolley onto which a portable 10 litre tank, Spill-return Atomiser (SRA) and a spill return pipe which bleeds liquid from the rear of the atomiser back into the tank for recirculation, a pressure gauge where the operating pressure of the setup is controlled, 2m aluminium pillar and high pressure water pump are mounted. The Spill-return Atomiser is attached to the pillar and high pressure hydraulic pipes are connected from the pump to the atomiser for the delivery of liquid from the pump to the atomiser.

Water was used as a simulated disinfection liquid solution as it has similar physical properties as most solutions likely to be used in practice. Water was sprayed into a laser beam (Malvern Mastersizer-X) for spray characterisation and the data was recorded for subsequent analysis as reported previously [3].

Series of tests were also carried to ascertain the coating performance of the SRA on different surfaces. Typical surfaces found in the healthcare environment were used as the test surfaces; they are polished laminated plywood, glass and brushed stainless steel as commonly found in bedside cabinets, windows and medical equipments.

The apparatus setup within the simulated hospital chamber [5] used for coating performance test is shown in Figure 2. The apparatus includes the test rig described in Figure 1 and the SRA including an absorbent material (i.e. sponge) and a high-intensity lighting system for image analysis. A tray and a sponge was used in measuring the liquid collection prior to the coating test by spraying on it, at the required time intervals, and then subsequently weighed and recorded.

The Atomiser

The Spill-return Atomiser (SRA) as shown in Figure 3 [6] has been designed for the purpose of disinfection in healthcare environments. It consists of a long swirl chamber which is the distinctive feature which differentiates it from other SRA's that are utilised for example in gas turbines. The swirl chamber refers to the distance between the tangential inlets and the exit orifice as shown Figure 3(b). The SRA is a simplex swirl atomiser where the liquid is injected tangentially at high pressure into a swirl chamber via small orifices. As high pressure liquid (≤12MPa) is fed into the atomise's swirl chamber via the high pressure hydraulic pipe, the liquid divides into two jets. One jet is discharged to the outside at high speed and atomised, producing conical sprays and the other jet is spilled via low pressure pipe to the liquid reservoir.

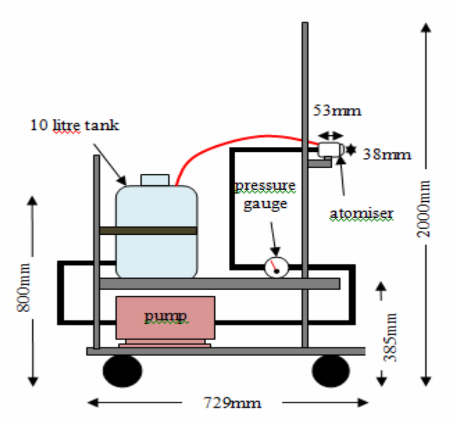

Figure 1. The test apparatus

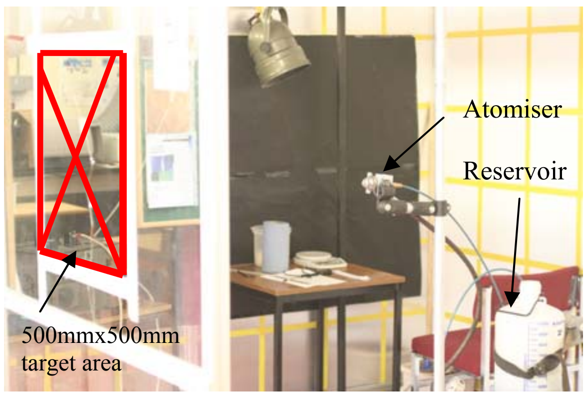

Figure 2. The apparatus set up within the test chamber

Coating Performance and Analysis

The assessment of coating performance involved the analysis of the amount (weight) of liquid deposited by the SRA upon various surfaces from a range of distances and angles. By adding a specialist dye to the liquid in the reservoir of the test rig, drops became more visible to both the human eye and the camera lens, therefore upon the image analysis, droplet sizes and formations could be easily identified. The dye used in this case was 'hydra-aqua' which is a specialist blue water dye. This particular dye was chosen as it did not affect the viscosity of the liquid, which would in turn affect the drop size and various other spray characteristics. Each test in this particular series of trials, utilised an exit orifice diameter of 0.3mm, a spill diameter of 0.5mm, swirl chamber length-diameter ratio (L/D) of 6:1and a delivery pressure of 9MPa. Six different downstream locations were used in this study; 0.8, 1, 1.2, 1.4, 1.6 and 1.8m. At each distance five angles of application were used; 0 (front-on), 20^o, 40^o, 60^o

and 80°. The application angle here is defined as the angle relative to the atomizer axial position. In addition to the five stationary angles of application a sweeping (side-to-side) method of application was used at each of the six pre-determined distances. Although a sweeping method of application is difficult to replicate manually during tests, each right-to-left and left-to-right sweep took approximately 1 second.

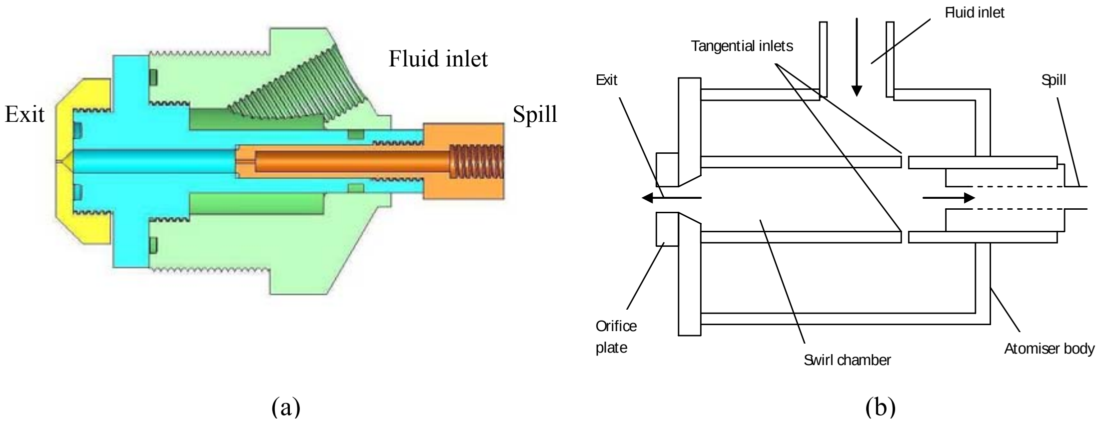

Figure 3. SRA (a) general assembly and (b) schematically showing the location of swirl chamber and the tangential inlets

At each of the chosen application distances and angles, the atomiser was aimed at the centre of a clearly marked $0.25m^2$ target area, as shown previously in Figure 2. Target area dimensions were limited by the test chamber. The atomiser was set inline with centre of the target area in all tests, at a height of 1.2m.

Three target surfaces (laminated plywood, brushed steel and glass) were used in order to assess the coating quantity and performance of the SRA across a range of surfaces commonly found within healthcare environments (glass – windows, laminated plywood – bedside cabinets, stainless steel, medical apparatus). An operating pressure of 9MPa was used in all tests as preliminary testing showed that this was the optimum pressure for a range of performance characteristics, such as flow rate and drop size. An application period of 5 seconds was chosen for each test as this was stated as the maximum application time used within the NHS for the application of disinfection fluid [6]. Before each individual test, a $0.25m^2$ piece of sponge was placed inside a specially constructed steel housing tray, which was then subsequently weighed using a set of digital scales, the weight being accurately recorded. Once the SRA had completed its operation period of 5 seconds [6], using a standard stopwatch, the tray containing the sponge was carefully weighed again and recorded. The difference in the weight indicated the amount of the liquid which should be deposited on the target surfaces when sprayed. Thus, by subtracting the original 'dry' weight of the sponge and tray from the secondary reading recorded by weighing the tray and sponge with the addition of the liquid deposited on the target test surface area, the amount of liquid deposited onto a $0.25m^2$ target surface area of each material (laminated plywood, brushed steel and glass) could be estimated. In order to ensure that the sponge used in each individual test procedure was dry, so as to avoid the production of anomalous data, several pieces of sponge, each measuring $0.25m^2$, were used in a rotation system in order to complete this particular series of tests. Each piece of sponge was left to dry for a minimum period of two hours, before being used again in any test.

Results and Discussion

Through the processing of data obtained from the streaking trials [5], a comparison of the acrylic and glass surface showed that the use of the latter was more appropriate to consider for testing coating. Furthermore, the surface texture of both were similarly smooth, thus resulting in the choice to continue the testing of glass alone to accompany the other previously used test materials; laminated plywood and brushed steel. Figures 4-5 show the effect of application distance and angle upon the quantity of liquid deposited upon the $0.25m^2$ target areas on each of the three test surface materials (laminated plywood, brushed steel and glass). A sweeping method of application at all test distances (800-1800mm) in order to assess the comparative coating quantity performance of sweeping and fixed/stationary atomiser application positions.

Figure 4 shows that, of the distances tested, the distance at which the most liquid is uniformly deposited, without the onset of streaking using the laminated plywood test surface was 1400mm. It was also noted that at all fixed application angles, streaking occurred up to and including an application distance of 1000mm. However, none of the application distances tested when employing a sweeping method of application resulted in streaking of the liquid deposited on the target surface.

Figure 5 shows that, of the distances tested, the distance at which the most liquid is uniformly deposited, without the onset of streaking using the brushed steel test surface was also 1400mm. It was also noted that at all fixed application angles, streaking occurred up to and including an application distance of 1200mm. However, only the application distances of 800 and 1000mm when employing a sweeping method of application resulted in streaking of the liquid deposited on the target surface.

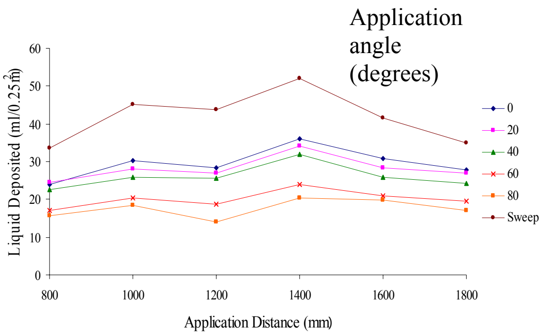

Figure 4. Effect of application distance and angle upon liquid quantity (ml) deposited on $0.25m^2$ laminated plywood test surface (supply pressure - 9MPa)

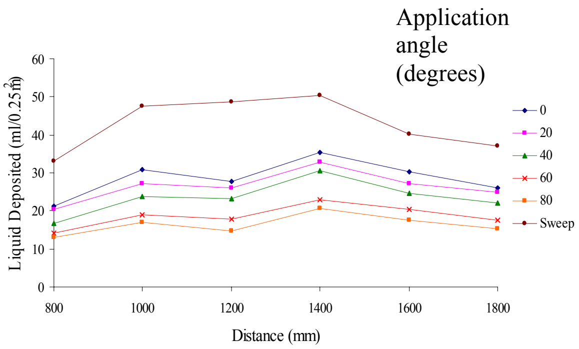

Figure 5. Effect of application distance and angle upon liquid quantity deposited on $0.25m^2$ brushed steel test surface (supply pressure - 9MPa)

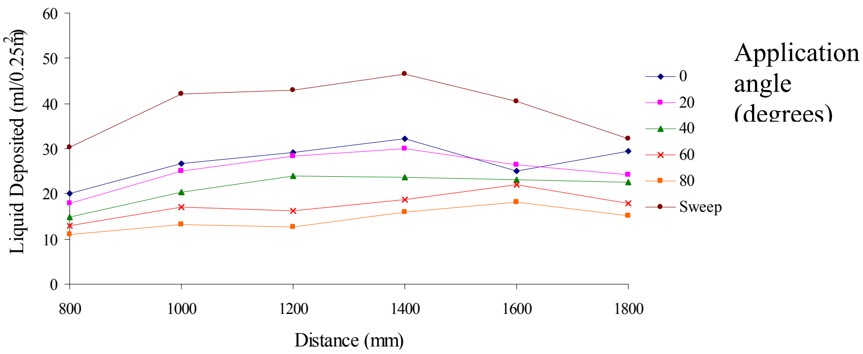

Figure 6. Effect of application distance and angle upon liquid quantity deposited on $0.25m^2$ glass test surface (supply pressure - 9MPa)

Figure 6 shows that, of the distances tested, the distance at which the most liquid is uniformly deposited, without the onset of streaking using the glass test surface was 1400mm. It was also noted that at all fixed application angles, streaking occurred up to and including an application distance of 1200mm. Furthermore, at the application distance of 1400mm, it was found that streaking occurred once the application angle exceeded 20^o. However, only the application distances of 800 and 1000mm when employing a sweeping method of application resulted in streaking of the liquid deposited on the target surface.

Figures 4-6 all display several trends relating to the relationship between atomiser application distance and angle. For example, a significantly larger amount of liquid was uniformly deposited on all three test surfaces when employing a sweeping method of application as opposed to a fixed/stationary atomiser application position. Thus, the most efficient method of application of the disinfectant in practice would be a sweeping motion.

Figures 4-6 have also demonstrated that as the angle of the atomiser in relation to the target surface is increased, the amount of liquid subsequently deposited on the target surface is decreased. The optimum application distance for both fixed and sweeping atomiser application methods was 1400mm. At this distance, the highest amount of uniformly deposited liquid was collected from each of the three test surfaces (laminated plywood, brushed steel and glass) and streaking was not detected in any case. Of the three materials tested, the laminated plywood and brushed steel surfaces lent themselves most to the application of liquid in a uniform fashion using the SRA as they both produced very similar results in terms of liquid deposition at all application distances and angles used in this series of tests (see also Figure 4 and 5). The reason for the comparatively high liquid deposition on both the laminated plywood and brushed steel surfaces in relation to the glass surface is thought to be a result of higher surface tension, caused by small imperfections on each material. Higher surface tension in this case means that droplets must be of a greater size or carry greater momentum in order to overcome the surface tension and subsequently either deflects off the surface or cause streaking. As the relatively smooth glass surface had little or no imperfections it therefore has less surface tension.

Among the three materials tested, the laminated plywood and brushed steel surfaces lent themselves most to the application of liquid in a uniform fashion using the SRA as they both produced very similar results in terms of relatively small impacted drop sizes at all application distances and angles used in this series of tests, as typified in Figure 7 and 8. Figure 9 also shows the application distance of <1400mm, at which the onset of streaking occurred using the brushed steel test surface. As in the case of the laminated plywood test surface, it was noted that at all fixed application angles (0-90^o), streaking occurred up at the application distance of <1400mm. Nevertheless, none of the application distances tested, when employing a sweeping method as opposed to a fixed/stationary atomizer position, resulted in streaking of the liquid deposited on the target surface. Of the three material surfaces tested, the brushed steel surface produced the smallest overall impacted droplet size over the range of application distances, angles and methods featured in this series of tests. The laminated plywood surface did also produced very similar results.

Figure 10 shows a typical image of the uniformly coated glass. The distance at which the most liquid is uniformly deposited, without the onset of streaking using the glass test surface was found to be 1400mm.

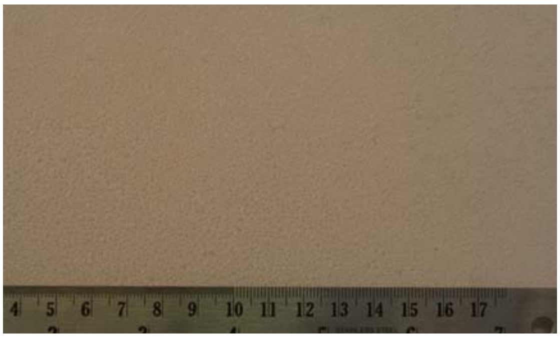

Figure 7. Impacted droplet deposition on laminated plywood test surface using an application angle of 0^o and application distance of 1800mm (L/D=6)

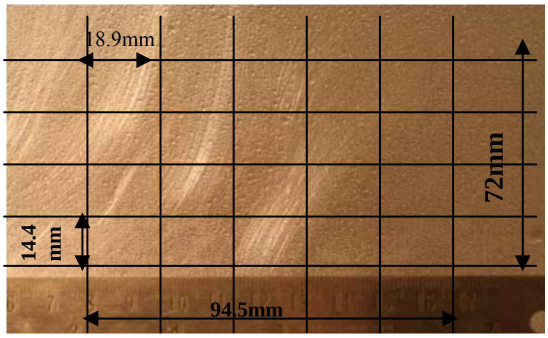

Figure 8. Impacted droplet deposition on brushed steel test surface using an application angle of 0^o and application distance of 1800mm (L/D=6)

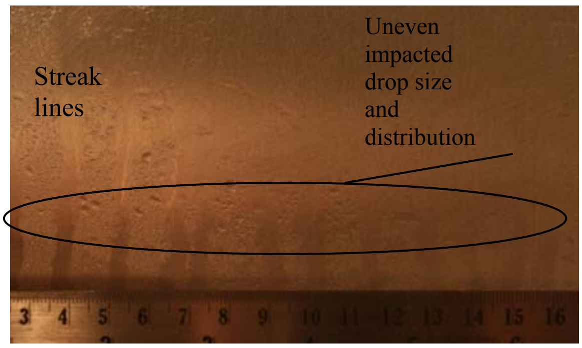

Figure 9. Impacted droplet deposition on brushed steel test surface using an application angle of 40^o and application distance of less than1400mm (L/D=6)

Figure 10. Impacted droplet deposition on glass test surface using an application angle of 0^o and application distance of 1800mm (L/D=6)

It was also noted that at all fixed application angles, streaking occurred up to and including an application distance of 1200mm. Furthermore, at the application distance of 1400mm, it was found that streaking occurred once the application angle exceeded 20^o. However, only the application distances of 800 and 1000mm when employing a sweeping method of application resulted in streaking of the liquid deposited on the target surface. Figure 11 shows a typified image of the uniformly coated glass surface at the application distance of 1600mm when a sweeping action was employed. Of the three material surfaces tested, the glass surface produced the largest overall impacted droplet size over the range of application distances, angles and methods featured in this series of tests. The reason for this is due to the comparatively low surface tension of the smooth glass test surface.

Figure 11. Impacted droplet deposition on glass test surface using sweeping action at the application distance of 1600mm (L/D=6)

Conclusion and future works

Although coating characteristics found to be varying for each surface type, 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, mainly, spray duration, distance, water supply pressure and material properties.

Future work will include the development of a handheld disinfection system together with subsequent clinical trials within actual healthcare environments (i.e. hospitals). The clinical trials will be used to examine the performance of the handheld disinfection system within its proposed environment(s).

Mathematical modeling will also be carried out, which could be used to predict the coating performance of a range of sprays. This mathematical mapping could further be used in the study of other spray coating applications, such as paint coating and combustion processes.

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