Effect of Swirl Chamber on Uniform Spray Coating of surfaces using Spill-Return Atomiser (SRA)

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Abstract

The atomisation of liquid disinfectants is an efficient means of delivering disinfectant agents within the healthcare environment; a Spill-Return Swirl Atomiser (SRA) with a long swirl chamber was designed for this purpose. The control of spray characteristics and the determination of the coating performance of the SRA on various surfaces are essential to achieve the desired efficiency in the disinfection procedure.

This paper provide the results of the investigation that were carried out on the effect of swirl chamber length on spray characteristics with respect to drop size, flow rate, cone angle and penetration distance, as well as the coating performance of the atomiser on sample surfaces that are commonly found within the healthcare environment. Swirl chamber length to diameter ratio of 0.36mm, 2.5mm, 5.5mm and 6mm were tested at supply liquid pressure of up to 12 MPa 120bar. Water, at room temperature, was used as the atomising disinfectant liquid.

Drop size and spray cone angle were shown to vary with an increase in swirl chamber length to diameter ratio while flow rate and penetration distance demonstrated to consistently increase. The atomiser also showed different coating performances on different surfaces at different spraying cone angles and distances. The optimisation of swirl chamber size is crucial in production of fine droplet sizes (i.e. SMD ≤ 20µm), including long penetration, low flow rate (≤ 0.1l/min) and wide spray cone angle which are also necessary for uniform coating in disinfecting corresponding surfaces.

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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. Therefore, the effective use of disinfectants on surfaces within the health care environment constitutes an important factor in preventing HAIs [1-3]. 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.

Disinfectanted surfaces using spraying devices provide an efficient and effective delivery system for liquids as bulk liquid that are 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 must 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.

A potable fine spray unit, utilising a novel Spill-Return Atomiser (SRA) [4-5] has been developed for the purpose of disinfection within healthcare environments. The unit must be able to spray uniformly on to 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. The quality of atomisation is largely dependent on the length of the swirl chamber. Thus it is pertinent to understand the effect of swirl chamber length upon drop size when using spill-return atomisers.

This paper reports the results of the investigation that were carried out on the effect of swirl chamber length on spray characteristics with respect to drop size, flow rate, cone angle and penetration distance, including the coating performance of the atomiser on sample surfaces that are commonly found within the healthcare environment, such as varnished plywood, glass, steel and plastic.

Apparatus and Procedures

The test rig as shown in Figure 1, reported previously [6] 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 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.

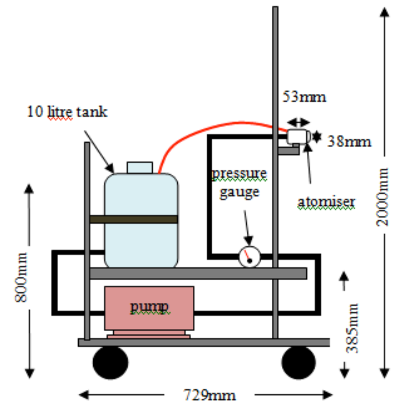


Figure 1. The test apparatus

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

Series of tests were 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 [6] used for coating performance test is shown in Figure 2. The apparatus includes the test rig described in Figure 1 and the Spill-Return Swirl Atomiser including a beaker for liquid collection measurement, an 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 and previously reported in [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 SR's. The swirl chamber refers to the distance between the tangential inlets and the exit orifice as shown Figure 3(b). The spill-return atomiser 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 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.

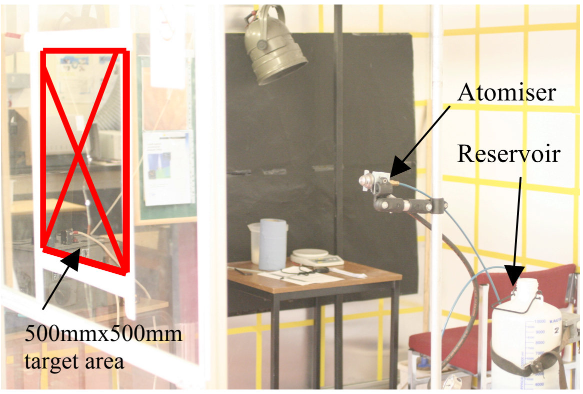
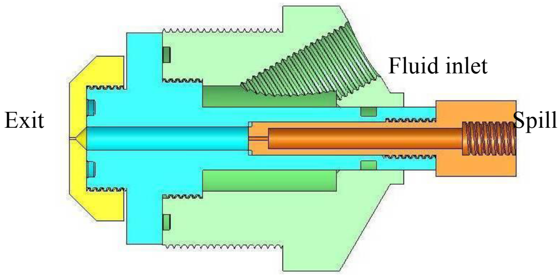
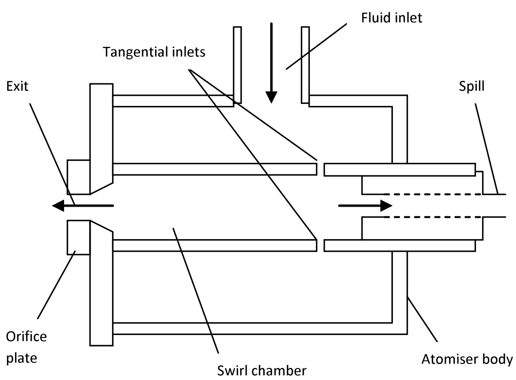


Figure 2. The apparatus set up within the test chamber



(a)



(b)

Figure 3. Spill return atomiser shown as (a) general assembly and (b) Schematic diagram showing the location of Swirl Chamber and the Tangential inlets

To gain a full understanding of how the swirl chamber affects spray characteristics and the surface coating, particularly in health environments. By performing various tests with a range of swirl chamber lengths with different diameters, spray characteristics can be analysed to examine what effect, if any, the swirl chamber has upon the fine spray production. In this case, the three spray characteristics which were analysed were drop size (SMD, D_{32}), cone angle, flow rate and penetration distance. The SRA used specifically for the swirl chamber series of tests (Figure 3) was specially designed to house the inserts/plugs, whilst having the capacity to accommodate an additional plate/section of atomiser body, as shown schematically in Figure 4.

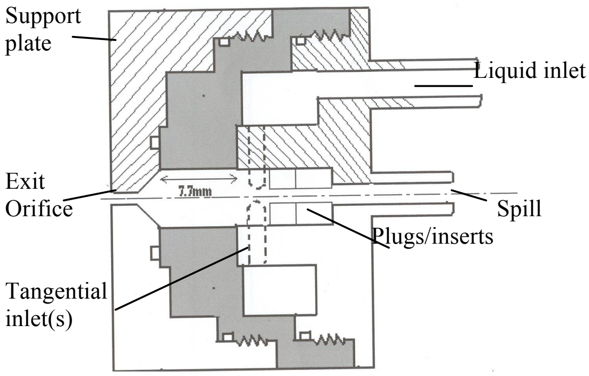
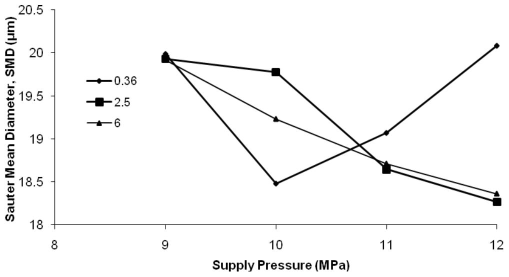


Figure 4. Schematic diagram of the SRA using the location of various inserts/plugs to test the effect of Swirl Chamber on coating performance

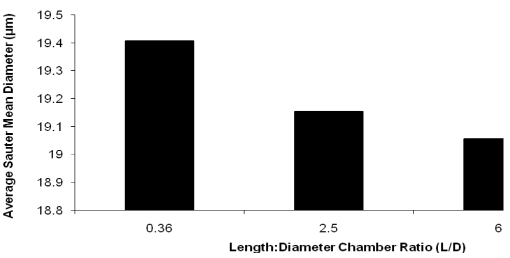
The swirl chamber length-diameter ratio of the atomiser featured in all the tests in this investigation was 6 (21.6mm) [6] at supply pressure of 9MPa and spray flow rate of greater than 245 ml/min (at the total flow rate of 1045 ml/min). Swirl chamber lengths are expressed as length-diameter ratios with swirl chamber diameter of 3.6mm, with the three swirl chamber lengths tested being 1.3mm, 9mm and, including, 21.6mm with ratio of 0.36, 2.5 and 6 respectively. The swirl chamber length was altered by adding small inserts/plugs (See also Figure 4) to a specially designed SRA to shorten the chamber length. Inserts ranged in size from 2.5 - 4mm.

Results and Discussion

As Figure 5 illustrates, swirl chamber length has a variable effect upon drop size, penetration, cone angle and spray flow rate. The smallest swirl chamber diameter-length ratio (0.36:1) does produce the largest drop size (SMD≥ 19μm) at the chosen ideal operating configuration of 0.3mm orifice diameter, 0.5mm spill diameter and 9MPa, as also shown in Figure 5(b). It is evident that the swirl chamber does have an effect upon drop size, albeit a relatively small one. The data confirms well with those reported by Yule and Widger [7] with no spill return pressure swirl atomizer. The diameter-length ratio which produces the lowest average drop size over all four pressures tested, and at the ideal supply pressure of 9MPa is 6:1. Therefore it can be surmised that it is not just the inclusion of the swirl chamber, but also the exact length of the swirl chamber which must be considered in order to achieve the smallest possible drop size (SMD≤19μm). Figure 6 also shows the variation of spray flow rate at various diameter-length ratio.



(a)



(b)

Figure 5. Variation of drop size, SMD, at a range of supply pressures (a) and length/diameter ratio (b)

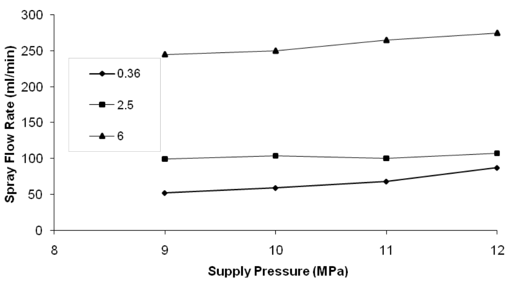


Figure 6. Effect of swirl chamber length upon spray flow rate

Figure 7 shows the effect of swirl chamber length on penetration distance. The penetration distance can be defined as the distance from the exit of the orifice of the atomizer to the target surface. In this case the penetration distance will be measured in a horizontal straight line from the centre of the atomiser exit orifice. The penetration distance is important in the application process because if this distance is exceeded, the application process will not be performed efficiently and effective disinfection will not occur as the target surface will not be covered in a uniform fashion.

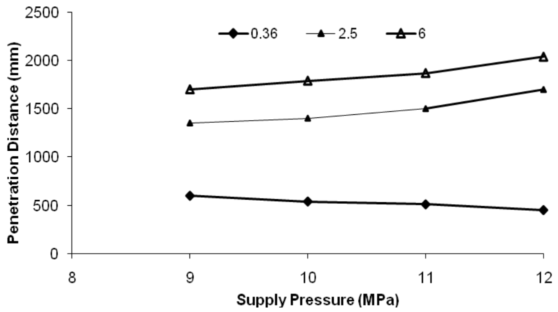


Figure7. Effect of swirl chamber length on penetration distance at a range of supply pressures

Figure 7 clearly illustrates that there is a clear correlation between swirl chamber length and penetration distance. Penetration distance increases with chamber length. An application distance of less than 1.2m (1200mm) is ineffective on all three test surfaces, even when using a sweeping method of application, due to the presence of streaking and/or over-wetting. Therefore the smallest swirl chamber size (0.36:1), which effectively removes the presence of the swirl chamber altogether, is unsuitable for disinfection as over the range of tested pressures, the penetration distance reached a maximum of 980mm. All other swirl chamber length-diameter ratios (2.5:1, and 6:1) are suitable for disinfection as the minimum distance at which streaking or over-wetting occurred on any of the three test surfaces was less than 1400mm. Although at 2.5:1 ratio the spray cone angle increases to $60^{0.}$ Out of the three suitable chamber lengths, the 6:1 chamber would be most suitable as it produces the lowest spray flow rate (≥245ml/min), whilst having only a minute effect upon drop size at the chosen operating pressure of 9MPa (see also Figure 5 and 6). At the desired application distance of 1800mm the 6:1 length-diameter chamber ratio would indeed produce uniform coverage on all three test surfaces.

Figure 8 features a graph showing the effect of swirl chamber length on spray cone angle. Cone angle is an important feature of the application process as it affects all other spray characteristics such as drop size, penetration distance and spray flow rate. Cone angle also affects the coverage area produced by the spray.

The ideal cone angle must provide effective uniform coverage at the selected application distance of 1600-1800mm. Therefore cone angle and subsequent penetration distance produced at the chosen operating pressure of 9MPa (90bar) must be able to provide efficient uniform coverage at the selected application distance. Most existing high pressure swirl atomisers produce a cone angle of 40-90^{o} at a supply pressure of approximately 9MPa (90bar). Moreover the ultrasonic atomiser being used as a benchmark for which to compare SRA data to produces cone angles of approximately 50-180°. Therefore as the SRA produces similar cone angles at the same range of supply pressures, it is clearly capable of providing adequate coating for the disinfection process.

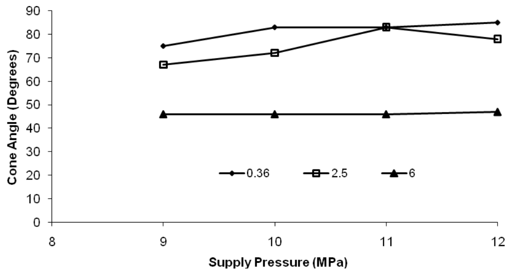


Figure 8. The effect of swirl chamber length on spray cone angle

Figure 8 shows that the presence of a swirl chamber has a large effect upon the cone angle of the spray. As illustrated in Figure 8, the lack of a swirl chamber (0.36 length-diameter ratio) produces a resultant cone angle of 75-85^0 over the range of pressures utilised. In contrast, the addition of a swirl chamber reduces cone angle to between 45-80° over the range of test pressures. By increasing the cone angle, the coverage/coating process can be completed in a shorter amount of time. Furthermore, at the required application distance at which to achieve the most efficient coating (1400-1800mm), only the 2.5 and 6 swirl chamber length-diameter ratio's are suitable. The 0.36 chamber (no swirl chamber) is not capable of providing the required uniform coverage, without streaking of the disinfectant, as the cone angle and subsequent penetration distance produced far fall short of the required distance at all tested pressures. This also reveals the efficacy of the swirl chamber in the coating and cleaning applications. Moreover, as can be seen in Figure 5-8, the main effects of increasing chamber length are to increase penetration and spray flow rate, and reduce cone angle. This better penetration, without adversely affecting drop size, is useful for the spray coating and cleaning applications.

Out of the three suitable chamber lengths, the 6:1 chamber would be most suitable as it produces both a suitable cone angle and the lowest spray flow rate (245ml/min), whilst having only a small effect upon drop size at the chosen operating pressure of 90bar (see also Figure 7 and 8). At the desired application distance of 1400-1800mm, the 6:1 length-diameter chamber ratio would indeed produce uniform coverage on all three test surfaces. When considering the pertinent characteristics of the sprays (SMD, spray flow rate, penetration distance and cone angle) the most suitable tested swirl chamber length for efficient and effective performance should have a length-diameter ratio of 6:1.

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 9 and 10. Figure 11 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°), 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 12 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. 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°. 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 13 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.

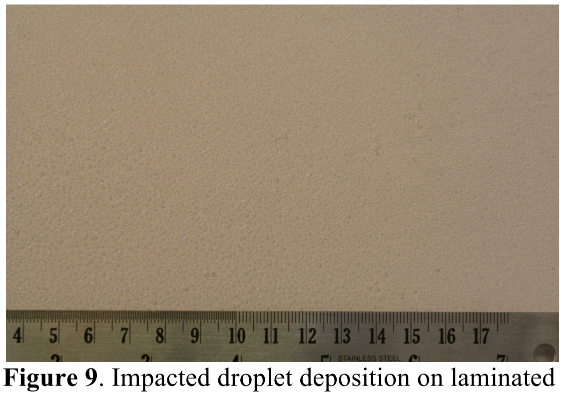


Figure 9. Impacted droplet deposition on laminated plywood test surface using an application angle of 0° and application distance of 1800mm (L/D=6)

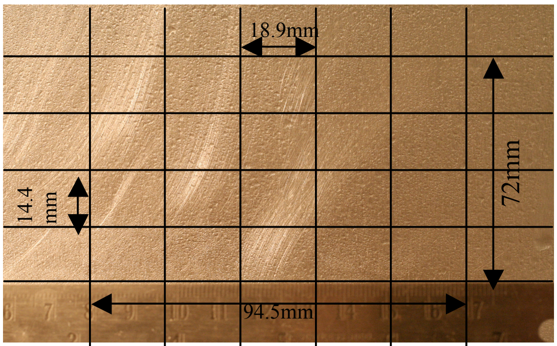


Figure 10. Impacted droplet deposition on brushed steel test surface using an application angle of 0^o and application distance of 1800mm (L/D=6)

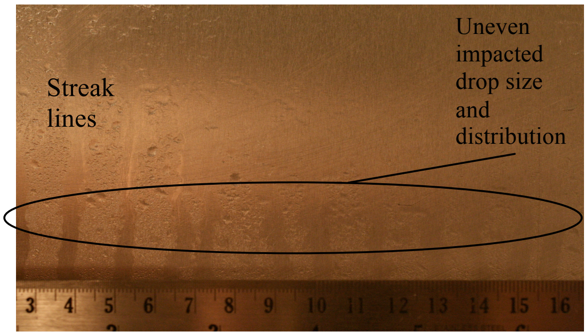


Figure 11. Impacted droplet deposition on brushed steel test ~~surface~~ using an application angle of 40^o and application distance of less than1400mm (L/D=6)

Figure 11. Impacted droplet deposition on glass test surface using an application angle of 0^o and application distance of 1800mm (L/D=6)

Figure 12. Impacted droplet deposition on glass test surface using sweeping action at the application distance of 1600mm (L/D=6)

Conclusion and future works

The investigation has found that the utilisation of fine sprays (15μm<D_{32}<25μm) at high liquid pressure (<12MPa) and low flow rates (<245ml/min) is indeed suitable for surface disinfection in healthcare applications.

The atomiser configuration used to obtain the smallest overall drop sizes utilised an exit orifice of 0.3mm, a spill orifice of 0.5mm and an operating pressure range of 9-12MPa. When considering all the spray characteristics (SMD, spray flow rate, penetration distance and cone angle) it was demonstrated that the most suitable tested swirl chamber length for efficient and effective performance has a length-diameter ratio of 6:1.

Future work may also 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). If these trials prove successful, the handheld disinfection system could be used as an accompaniment to the trolley-based disinfection system, making it ideal for disinfecting small, localised areas.

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