Fine Spray for Disinfection Purposes within Healthcare Environments

J. A. Stewart*, G. G. Nasr and M. Burby
Spray Research Group (SRG)
Institute of Materials Research (IMR)
School of Computing, Science and Engineering (CSE)
University of Salford
Salford, Manchester M5 4WT, England

Abstract

A mobile fine spray unit, with 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 the spray system. Thus it is pertinent to understand the behaviour of droplets impacting on various surfaces, and particularly the occurrence of streaking.

Four sample surfaces (300mm x 300mm), (i.e. steel, acrylic, glass and laminated wood) will be sprayed separately using the spill return device and the substitute MRSA disinfectant liquid. This will provide information on the level of surface wetness using photographic images. The tests are to be conducted at steady conditions of room temperature, atmospheric pressure and relative humidity. Test results from similar work, which involved the use of an ultrasonic atomiser will be used as a benchmark and comparisons will be made.

In each test the atomiser will be placed at two chosen distances (300mm and 700mm) relative to each corresponding surface. The surface will then be sprayed until the first signs of streaking are detected.

The purpose of this investigation is to obtain information relating to the optimum combinations of spray input conditions (i.e. distance(s), time(s) and pressure(s)) required to uniformly 'mist' spray coat the surface(s) without the occurrence of streaking.

Introduction

Background

It has become a well known fact that Hospital Acquires Infections (HAI's) are a major problem for both the UK's National Health Service (NHS) and other health services 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 have also begun to appear in recent times, such as VRSA (Vancomycin Resistant Staphylococcus Aureus) and Clostridium Difficile. Costs associated with extra treatment and extended hospital stays for patients acquiring an infection during their hospitalisation are said to be significant, not to mention the human and social effects.

A mobile fine spray system has been developed [1-2], producing droplet sizes $15\mu m<D_{32}<25\mu m$, which is able to tackle HAI-related problems by providing a clean environment for both patients and hospital staff. 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 kills any harmful organism present. Any streaking of the disinfectant solution immediately after application would seriously jeopardise the efficiency of the disinfection process. Therefore, it is important to understand the behaviour of droplets impacting on various surfaces, and particularly the occurrence of streaking.

Overall Objectives

The spray Research Group in collaboration with a major international company [3] has developed a portable surface coating disinfection system, which uses "Sonicore" 052H ultrasonic gas atomisers. Further work has recently been carried out into the development of a mobile spray disinfection system which uses a high-pressure, spill return atomiser [1, 2]. The main aim of this investigation is to utilise the spill return atomiser which can produce similar spray patterns and surface coverage than 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 and also the system will be more cost effective and it is as efficient as an ultrasonic system.

* Corresponding Author: j.a.stewart@pgr.salford.ac.uk

A number of spray performance tests were carried out using the spill return atomiser, however this paper focuses particularly upon the findings of the streaking behaviour and how different surface materials will affect the streaking process. The results were also compared to the data obtained using ultrasonic system [4].

Reasons for Using Spill-Return Atomisers (SRA)

Previous experiments [4] 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 of the order 10MPa. 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.

Experimental Apparatus and Procedures

Figure 1 shows the test apparatus which comprised of a spill return atomiser [2] 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 and is 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 as most solutions likely to be used.

A more detailed description of the spill-return atomiser and its performance characteristics is featured in a separate publication [2]. Figure 2 shows a schematic diagram of the spill return atomiser used throughout this work. The actual geometry used was selected to give relatively small spray angles (<40^{o}) and thus achieve efficient penetration. The apparatus also comprised of a spill return pipe which is used to return the liquid from the spill orifice to the reservoir tank.

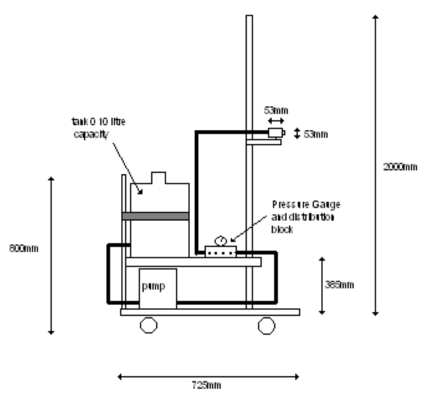

Figure 1 Schematic arrangement of the test apparatus

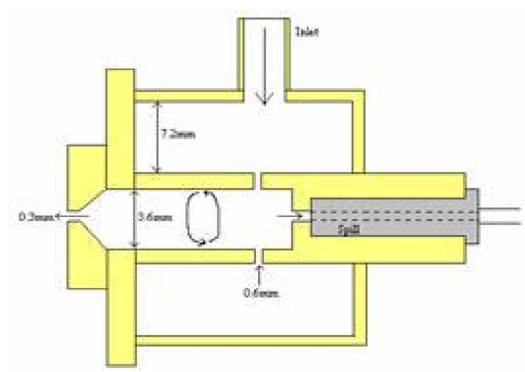

Figure 2 Schematic diagram of the spill return atomiser, showing two tangential inlets.

All tests were conducted within a simulated hospital environment, referred to here as the 'test chamber' (Dimensions*:* Length=3.7m, Width=2.5m, Height= 2.6m). For each test the most efficient pressure, orifice plate and spill diameter combinations chosen (pressure: 90bar, spill: 0.3mm, exit orifice diameter: 0.5mm). The coating tests were performed in test chamber that could be controlled 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 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 before impacting upon the desired surface.

The setup of each test involved positioning the atomiser directly in front of a 300mmx300mm square plate of a range of materials (acrylic, plywood, glass, brushed steel). A centreline was marked out at distances downstream from the tip of the atomiser. A stopwatch was used to record the spray duration.

The four specimen materials were specifically chosen as they are all commonly found within healthcare environments. Initially the atomiser was placed 300mm from the target plate and a stop watch was used to record the time between the initiation of the spray and when the first signs of streaking were observed on the plate. This process was repeated several times for each material at both 300mm and 700mm from the target plate. During commercial operation the fluid supplied will be a solution of decontamination agent, *Sterichelle*, and water. The recommended concentration for this solution is 65 parts water to 1 part Sterichelle. At these small concentrations it was sufficient for only water to be used in the testing of the atomiser for coating performance. The flow rates for the atomiser at the two water pressures tested up to 90 bar and calculated by collecting the water from the atomiser at the aforementioned conditions over a chosen period of 1 minute. This was carried out using plastic tubing over the atomiser, which collected all of the spray on its interior walls and led the water to a container. The fluid was then weighed and a flow rate obtained.

Images of the coatings produced by the atomizer at the various spray coatings were captured with the use of an EOS 350D Cannon digital camera. A Canon compact macro lens EF 50mm 1:2.5 extension was used with the camera. Each image captured, was set to a picture definition of 2496 x 1664 pixels and the pictures were taken 140mm from the material surface. Six images of the coated surfaces were taken for each condition, and a selection of these imagesare shown in Fig. 4. For images b-f a view-finder was used, with marking in increments of 5mm. The captured images provided qualitative information on the streaking process by analysing close up views of each of the coated surface. The plate was dried thoroughly between each test so as to eliminate the chance of any remaining surface moisture affecting future tests. The corresponding results were then processed and compared to the available data which were previously obtained from the HSS ultrasonic atomiser system [4].

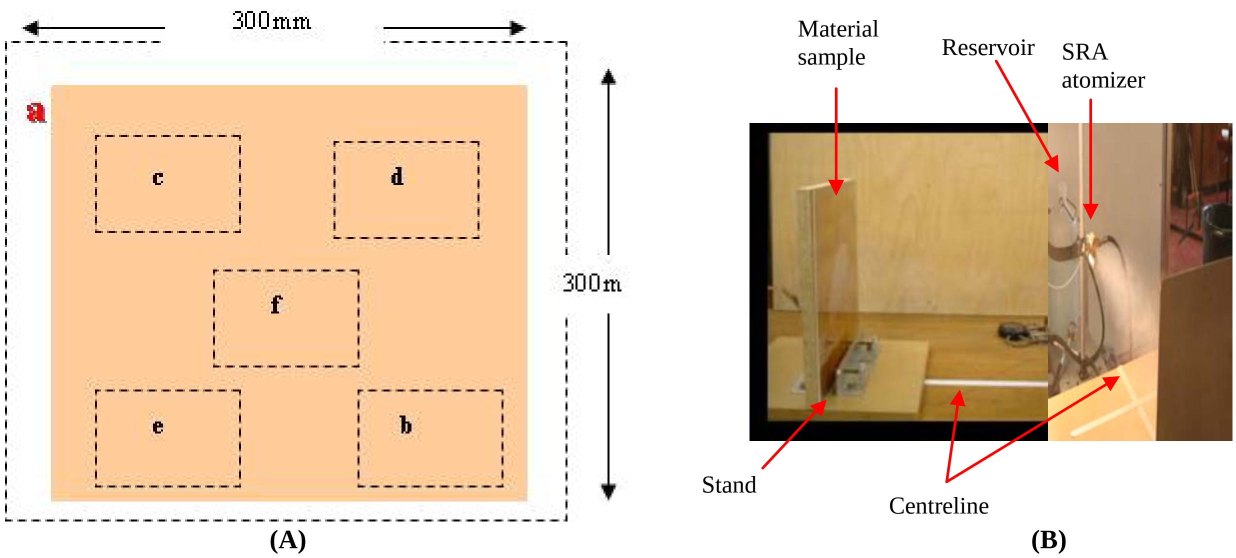

Figure 3 Illustration of lettered plate sections (A) and the target plate together with the functioning SRA (B)

Results and Discussion

The test results were divided into four distinct sections in accordance with the four target plate materials used (acrylic, plywood, glass, brushed steel). As previously mentioned, tests were conducted using a range of distances (300 and 700mm) 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” shape at impaction, giving a relatively uniform spray patternation within the central impact zone. All tests used a flow rate of 0.245 l/min and a supply pressure of 90bar.

Streaking and Over Wetting

“Streaking” occurs when a large droplet is deposited upon the surface of a material with sufficient mass to cause the drop under the influence of gravity to overcome the friction coefficient of the material and then move down the wall of the surface. In doing so the drop interacts with other droplets produced by the spray and gains in both mass and momentum, thus creating a streakline, as typified in Fig. 4. The requirement is to keep the number of streaklines to a minimum, to prevent wetting of the floor and "over wetting" the surface of the material.

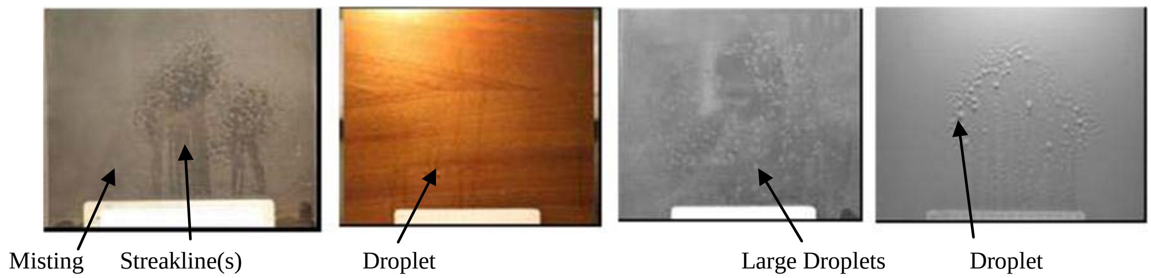

Figure 4 Typical streak lines on all four test surfaces (acrylic, plywood, glass and brushed steel).

Acrylic

Figures 5 and 6 show the comparative operating envelope of both the spill return and ultrasonic atomisers, at a distance of 300mm from the target surface. The operating conditions which the atomisers have to be operated at, in order to prevent streaking and to deliver good fluid coverage for the different materials. These figures have been obtained by interpolating and extrapolating the present data together with additional spraying tests to define when streaking occurs. The band (between the shaded areas or two green lines) of operating conditions in each Figure shows the approximate range of pressures and time combinations that give near 100% coverage without streaks forming. Although the ultrasonic atomiser has a larger operating envelope, both systems are able to work efficiently within the ideal application time of between 0.5-2 seconds [1]. However, with the increase in distance between atomiser and target, the operating envelope increases in size and time frame for both the spill return and ultrasonic atomisers. This is due to the fact that droplet sizes usually decrease the further they get from the atomiser orifice. As a result, a build-up of droplets in a localised area takes much longer to take place, minimising the occurrence of streaking or over wetting. Moreover, the smaller droplet size also brings a more even surface coverage, resulting in a decrease in insufficient coverage. In the case of the spill return atomiser the operating envelope is 0.79-1.36 seconds at 300mm and 1.55-2.3 seconds at 700mm. The ultrasonic atomiser's operating parameters are 1.01-1.99 seconds at 300mm and 1-2.99 seconds at 700mm.

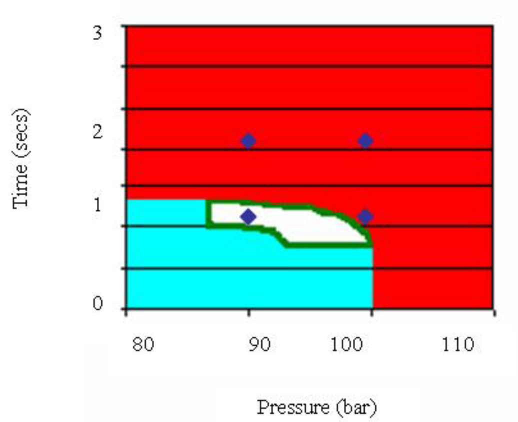

Figure 5 Ideal coating condition using SRA: acrylic - 300mm Downstream.

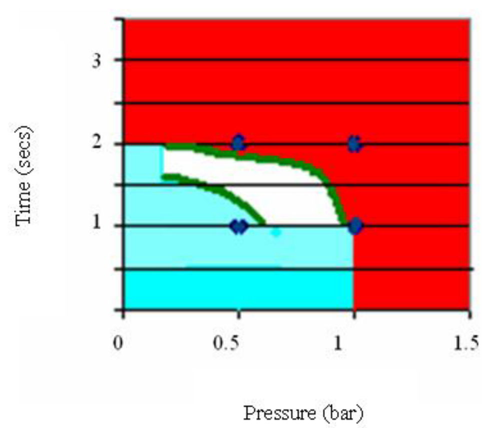

Figure 6 Ideal coating condition using Ultrasonic atomiser: acrylic - 300mm Downstream.

The spray duration and distance from the surface of the sample has to be varied in accordance to the material that is being coated in order to prevent streaking. One of the reasons for this is due to the friction coefficient (surface roughness) of the material. Materials with low friction coefficients, for example glass are more prone to streaking as there is not sufficient friction to prevent the droplet from moving down the surface and interacting with other droplets, thus causing streaking. In addition the *"friction"* that acts against streaking is influenced by the surface tension of the liquid for the surface being sprayed. This surface tension can be greatly influenced by the cleanliness of the surface and factors as polish on the surface (all of these tests were conducted with carefully cleaned surfaces). The result of this is that the atomiser has to be operated within a tighter performance band with regard to water pressure and duration of spray for materials with low skin friction coefficients.

Plywood

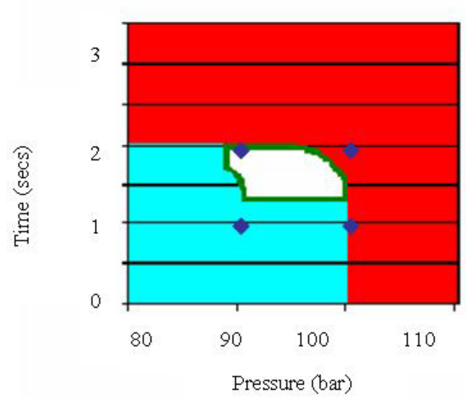

Figure 7 Ideal coating condition using SRA: plywood - 700mm downstream.

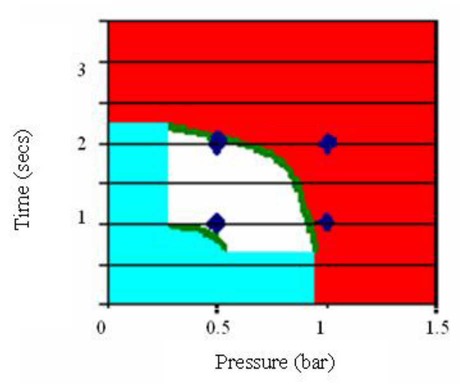

Figure 8 Ideal coating condition using Ultrasonic atomiser: plywood - 700mm downstream.

Results show that both systems, on the plywood surface, are capable of working efficiently within the ideal application time. Figures 7 and 8 show the comparative operating envelope of both the spill return and ultrasonic atomisers, at a distance of 700mm from the target surface. In the case of the spill return atomiser the operating envelope is 0.71-1.62 seconds at 300mm and 1.39-2.01 seconds at 700mm. The ultrasonic atomiser's operating parameters are 1.00-1.99 seconds at 300mm and 0.75-2.28 seconds at 700mm.

Glass

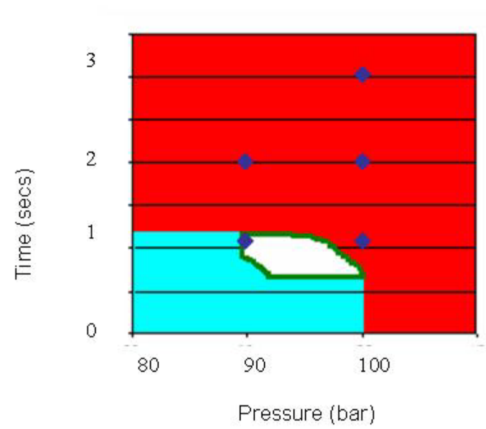

Figure 9 Ideal coating condition using SRA: glass - 300mm downstream.

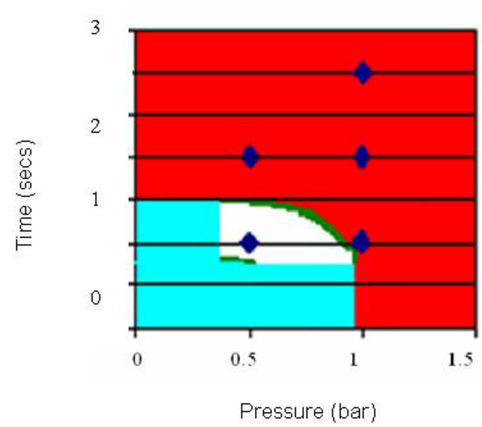

Figure 10 Ideal coating condition using Ultrasonic atomiser: glass - 300mm downstream.

Figures 9 and 10 typified the comparative results of both systems which were obtained at 700mm downstream from the glass plate. Like the results taken using the previous surfaces. At 700mm distance from the glass plate for the spill return atomiser the operating envelope found to be between 0.69-1.20 seconds at 300mm and 1.36-1.77 seconds at 700mm. The ultrasonic atomiser's operating parameters are between 0.79-1.48 seconds at 300mm and 0.81-1.74 seconds at 700mm. Of all the four materials tested, glass had the shortest overall envelope of operation.

This is due to the fact that glass has the smoothest surface of all the materials tested, therefore surface tension is minimal and any droplets intends to run off its surface with little resistance.

Brushed Steel

Figures 11 and 12 also exemplified the comparative operating envelope of both the spill return and ultrasonic atomizers, at a distance of 700mm from the brushed steel target surface. Both systems are able to work efficiently within the desired 0.5-2 second window. Of all the four materials tested, brushed steel had the largest overall envelope of operation. This is due to the unevenness of the brushed steel plate surface compared with all the other surfaces which were tested. Surface tension is thus relatively high and droplets can remain on the steel surface for a longer period of time before gaining sufficient mass to overcome the friction coefficient of the material, thereby causing streaking. For the spill return atomiser's the operating envelope is 0.72-1.4 seconds at 300mm and 1.49-2.09 seconds at 700mm. The ultrasonic atomiser's operating parameters are between 0.97-2.48 seconds at 300mm and 0.76-3.39 seconds at 700mm.

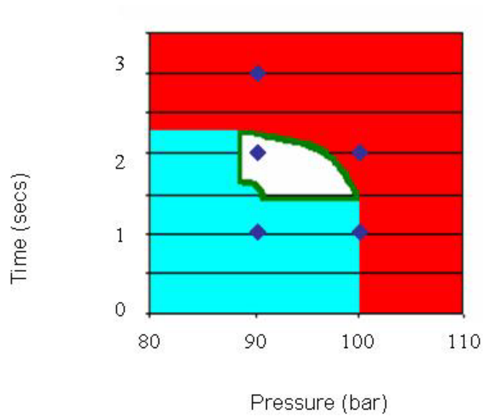

Figure 11 Ideal coating condition using SRA: brushed steel - 700mm downstream

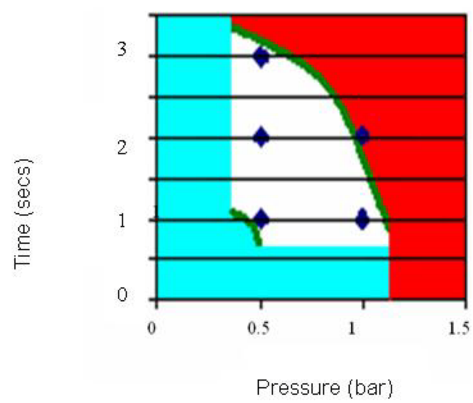

Figure 12 Ideal coating condition using Ultrasonic atomiser: brushed steel - 700mm downstream.

Conclusions and Future Work

The investigation has found that the utilization of fine sprays (15μm<D_{32}<25μm) at high liquid pressure (<110bar) and low flow rates (<0.3 l/min) is indeed suitable for surface disinfection in healthcare applications (i.e. MRSA, VRSA etc.). At a distance of approximately 700mm between atomiser and target surface, using a spill diameter of 0.3mm, a nozzle orifice diameter of 0.5mm and a pressure of 90bar, the most efficient 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). This analysis, along with other previous data will then be used to illustrate the fact that the spill return system offers comparable performance characteristics at a much lower price than the ultrasonic system.

References

1. Yule A.J. and Nasr G.G. , '*Spray Device'*, Patent No. GB0625687.9. 9th Dec. 2006.
2. Nasr G.G., Yule A.J., Lloyd S.E., 'The *Characterisation of the Spray from a New Design of a Spill Return Swirl Atomizer'*, ILASS-Europe 2007.
3. www.hughes-safety-showers.co.uk (accessed Sept. 2009).
4. Burby, M.L and Nasr, G.G. '*Spray characterisation and performance tests for an ultrasonic atomizer in the de contamination process'*, ICLASS, Kyoto, Japan, Aug.27-Sept.1, 2006.