Spray Characterisation of Glycerine_Water Mixture, Using Spill-Return Atomiser (SRA)

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Abstract

The risk of exposure to hazardous materials, in many industrial environments and in everyday life due to the possibility of terrorist attacks, is widely recognised. It is therefore necessary to have robust decontamination equipment to limit the effects of hazardous materials and in turn protect human life and assets. This can be done by the application of neutralisation (coverage) and rinsing techniques to the hazardous materials. The overall aim of this investigation was to characterise the spray of the glycerine_water mixture and obtain their operating range of viscosities when using a spill-return atomiser in decontamination processes. The atomiser must provide similar spray characteristics when compared with the sprays which were produced by using water. A novel miniature spill-return atomiser was capable of producing fine drop sizes of less than 21 microns at high pressure (<120 bar) and low flow rates (<0.5 l/min). Different glycerine and water mixtures were prepared and tested. The percentage of glycerine to water were used was between 25% - 75%.

This paper highlights the results and analysis of the performance tests which were carried out in characterisation of the spray mixtures. The effect of pressures and flow rates of the mixtures on the droplet sizes compared with that of pure water are also shown together with the corresponding viscosities of the glycerine_water mixtures at various room temperatures.

Introduction

Chemical, Biological, and Radiological or Nuclear (CBRN) materials can be classed into four main types of hazards: contact, inhalation, injection and ingestion. The risk of exposure to these hazardous materials, particularly in case of terrorist attacks, is widely acknowledged. It is therefore pertinent to have robust decontamination equipment to minimize the effects of hazardous materials by the utilisation of neutralisation (coverage) and rinsing techniques to the hazardous materials [1].

In practice the Treatment (Neutralising) stage requires deposition of agents on the body and the aim here is to use fine sprays at low flow rates (rather than the high flow rate showers currently used in this stage). The use of fine sprays should result in the need for smaller volumes of water (or water mixtures), which is particularly important because the sprayed water must be subsequently collected and treated. The authors considered options for making fine sprays at low flow rates (e.g. < 0.2 l/min). Specially manufactured miniature high pressure swirl atomizers were developed [3, 4] producing narrow angle sprays (<40°). It is noted that although the atomizers produced *hollow cone* sprays near the exit orifice, rapid diffusion due to the small drop sizes, gave *solid cone* sprays within several cm downstream. These atomizers incorporated *spill return* systems [2-5] so that spray flow rate could be controlled with little effect on drop size. Other potential advantages of this fine spray system over competitive decontamination showers [6] are: (1) the possibility for recycling water during treatment via filters (this is possible due to the relatively low flow rates compared with conventional systems), (2) the low impact momentum of individual droplets in the spray, so any injuries (like fresh cuts, grazes, etc) would not be affected by the fine sprays, (3) the possibility of retrofitting existing shelters with the new technology, (4) ease of use in areas in which the access to water is restricted or limited (such as deserts, battlefields, etc).

The overall aim of this investigation was to obtain an operating range of viscosities for the atomiser that would give a similar performance compared to the spray obtained when using water. Glycerine was chosen as the test fluid and sprayed using the Spill-Return Atomiser (SAR) which produced fine drop sizes of less than 21 microns. The viscosity of Glycerine is very dependent on temperature. At –40°C it is a viscous as some rocks, at 30°C it is about

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as viscous as heavy machine oil. This paper reports the results and analysis of the performance tests which were carried out in characterisation of the spray glycerine_water mixtures using the SRA.

Apparatus and Experimental Procedure

Fig.1 shows the test apparatus which comprised of a spill-return atomiser providing fine sprays, and attached to an aluminum pillar that was fixed to a portable trolley. An unpressurised liquid reservoir tank was mounted on the trolley together with a high pressure pump capable of producing up to 125bar, at a flow rate of 8 l/min. A pressure gauge, distribution block, and a high pressure hydraulic pipe were used for delivery of the liquid from the pump to the atomiser. The apparatus also comprised of a spill-return pipe that returns the glycerine/water mixture from the spill orifice to the tank. As the viscosity is dependant upon the temperature of the fluid, the temperature of the supply reservoir following each test was recorded. Spray that was sampled was 150mm downstream from exit of the atomiser as shown in Fig. 2.

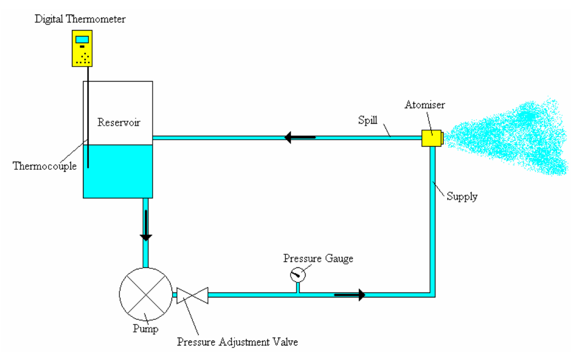

Figure 1. Schematic set up of the apparatus

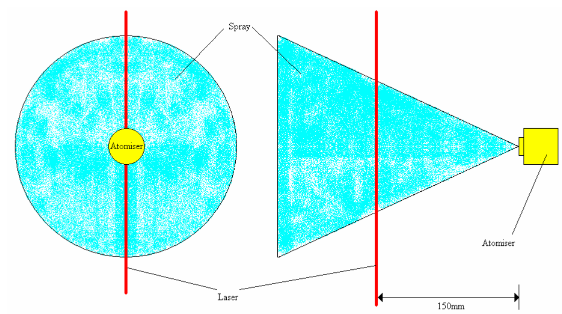

Figure 2. Schematic arrangement for charaterisation of sprays using Malvern Mastersizer-X

The viscosity of the solution in the reservoir was altered by altering the ratio of glycerine to water. An increase in the percentage of glycerine led to an increase in viscosity of the solution. A number of solutions were used and the percentage glycerine of each of these are: 0% glycerine solution, 25% glycerine solution, 33% glycerine solution, 55% glycerine solution, 56% glycerine solution, 57% glycerine solution, 58% glycerine solution, 60% glycerine solution, 65% glycerine solution, 75% glycerine solution. Each of the solution was tested using 90bar (95bar in one case) to allow a comparison of the droplet sizes to be drawn with water at the same pressure (of 90bar). The flow rate tests were carried out by collecting the atomised spray mixture in a plastic bag secured over the atomiser by an elastic band. The fluid from the spill was collected in a beaker that was weighed prior to the experiment to obtain an empty weight. The plastic bag containing the atomised glycerine solution was weighed and the weight recorded, the beaker containing the spilled glycerine solution was also recorded. The density of the solution was obtained by siphoning off a sample of solution from the reservoir and measuring the mass of solution (100ml in most cases). The weight of the measuring cylinder was measured prior to the experiment to allow the weight of glycerine solution to be calculated. The density was then used to convert the flow rate from grams per minutes ($gmin^{-1}$) into litres per minute ($lmin^{-1}$).

Discussion of the Results

General observations during testing

It was noted that the temperature of the spray that exited the atomiser orifice increased as the viscosity and the pressure increased. The temperature of the spray were thus measured for each test that were performed. It may be prudent to perform additional testing if organic solutions are to be used in the mass decontamination system under development as some organic solution can contain enzymes that would be killed should the temperature of the solution rise too high. During the initial tests, a solution of 100% glycerine was used and it was evident that no spray was produced. However, the glycerine was simply forced out the atomiser orifice in form of a liquid. This indicates that the atomiser is not capable of successfully creating a spray using 100% glycerine at 90bar (the test was thus not performed at 125 bar).

Results and Analysis

It can be seen from Fig.3 that as the glycerine content increases, drop sizes increases. This trend is as expected since the increase in the viscosity of the liquid mixture is directly related to an increase in the glycerine content of the total solution. Each of the points shown in Fig. 3 represents the related test run. Figure 4 also shows the effects of pressure on SMD for different percentage of glycerine solution. As can be seen, as the droplet size increases the glycerine content of the solution increases. Moreover, as pressure increases the droplet size, as expected, decreases.

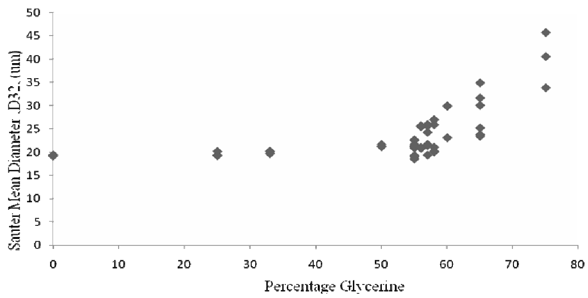

Figure 3. Variation of SMD with percentage of glycerine solution

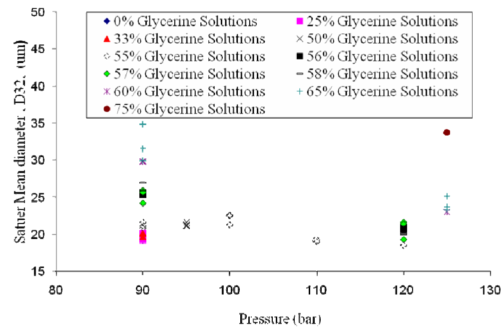

Figure 4. Variation of SMD with pressure for different glycerine Solutions (%)

One observation that was made was that the atomiser gave a smaller spray angle (less that 40 degrees) when the glycerine content increased to about 56%. Increasing the pressure redeemed the spray angle and decreased the droplet sizes. When a glycerine content of 60% was used with a supply pressure of 125bar, the droplet diameters were 23.06µm. The overall aim of this investigation was also to be able to compare the droplet diameters obtained when using an aqueous glycerine solution with those obtained when using water [2]. Using the droplet size of 19.27µm for pure water, at pressure of 90 bar, as a benchmark, it was thus possible to construct Increasing the pressure further to 120bar gives the droplet size of 18.5µm giving a reduction of 3.90 % compared to water.

Table 1 to obtain an allowable tolerance for subsequent analysis. Note that 'Zero' represent that 100% pure water was used with no glycerine. It should be noted that each test was repeated three times which provided confidence in the consistency of the obtained data. The droplet size for a glycerine content of 55% at a pressure of 90bar, for example, was averaged out as 21.20µm, which is 9.91% larger than the droplet size for water. This is within the 10% variance band, as described and shown previously in Table 1, which can thus be acceptable. An increase in pressure to 100bar gives a larger droplet size. However when the pressure is increased to 110bar, the droplet size reduces to an average of 19.09µm (a reduction of 0.93% compared to that obtained using water). Increasing the pressure further to 120bar gives the droplet size of 18.5µm giving a reduction of 3.90 % compared to water.

Table 1 Allowable percentage variance

SMD Percentage Variance (%)	SMD (µm)	
	Lower Limit	Upper Limit
0	19.27	19.27
5	18.31	20.23
10	17.34	21.10

Table 2 shows the test numbers that gave the droplet sizes that are within the values outlined earlier in the Increasing the pressure further to 120bar gives the droplet size of 18.5µm giving a reduction of 3.90 % compared to water.

Table 1. The values of SMD given in Cell-I in Table 2 are thus within the 5% band and are within 10% band in Cell-II. As can be seen in Table 2 for 55% glycerine solution at 90bar the corresponding droplet sizes fell within the 10% band and when the pressure was raised to 110bar and 120bar, the size of the droplets fell into the 5% band. This indicates that for a pressure of 90bar, the highest viscosity that can be used corresponds to a 55% glycerine

solution at 14.0°C. The use of 56% did not give a droplet size within the 10% limit compared to the drop size obtained by using water at 90bar. All the tests that fell within 5% occurred at high pressures (with the lowest pressure of 110bar). However using a higher pressure of 120bar allows the use of a 58% glycerine solution at 13.4°C.

Table 2 Tabulated results of SMD for different glycerine solution (%), supply pressures and temperatures

Test Number	Percentage Weight of Glycerine (%)	Supply Pressure (bar)	Temperature (°C)	SMD (μm)	Measured Viscosity (CP)	
1031	55	120	13.9	18.5	10.8	
1033	55	110	13.9	18.96	10.8	
1002	0[1]	90	17.3	19.15	1.15	
1004	25	90	16.1	19.22	2.54	
1032	55	110	13.8	19.22	10.8	
1005	25	90	16.2	19.28	2.15	
1043	57	120	13.7	19.32	14.1	**Cell-I**
1001	**0[1]**	90	17.3	19.33	1.1	
1003	**0[1]**	90	17.4	19.33	1.01	
1008	33	90	18.1	19.63	4.36	
1037	58	120	13.5	19.99	10.8	
1009	33	90	18.3	20.11	4.36	
1006	25	90	16.2	20.12	2.15	
1039	58	120	13.4	20.16	10.8	
1007	33	90	18.0	20.17	4.33	
1049	56	120	12.8	20.75	10.7	
1025	**55**	**90**	**14.0**	20.86	10.9	
1051	56	120	12.9	20.95	10.7	**Cell-II**
1050	56	120	12.8	20.96	10.7	
1038	58	120	13.5	21.02	10.8	
1010	50	95	15.8	21.13	7.51	
1027	**55**	**90**	**14.0**	21.13	10.9	

Results confirm that the spill-return atomiser is capable of atomising up to 55% glycerine solution at 90bar to obtain a SMD within 10% that of pure water (0% glycerine solution) and 33% at 90bar to obtain a SMD within 5% that of pure water. Increasing the supply pressure to 120bar allows the use of 58% glycerine solution with a SMD of within 5% (for two series of the tests and 10% for a further series of the tests). The effect of the pressure on the SMD can also be seen in Fig. 5, for 56% solution, the droplet size increases with a decreasing pressure. Figure 5 has 6 points plotted at two different pressures (90 bars and 120bar); however some of these points overlap due to the closeness of the droplets.

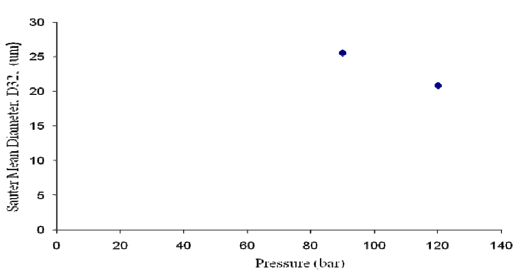

Figure 5. Effect of pressure on SMD for 56% solution

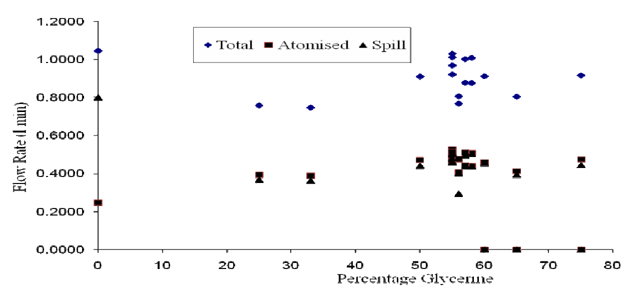

Figure 6. Variation of flow rates with different glycerine solutions (%)

1 Pure water with no glycerinee

The three category of flow rates (spilled, atomised (or spray) and total) for each of the percentage glycerine tests are shown in Fig. 6. The variation of the data points is clearly visible but the atomised flow rate appears to be higher than the flow rate for the spill. This differs from that of water as the spilled flow rate is approximately 3 times greater than the atomised flow rate. It can be noted that the total flow rate of the 25 and 33% glycerine solutions is lower than the flow rate of the others solutions. The flow rate increases when the pressure increases, as would be expected. The flow rate of spray, when using water at 90bar is 0.245 l/min and 0.800 l/min spilled. When using a 55% glycerine solution, the spray flow rate is 0.4628 l/min and 0.4580l/min spilled due to viscosity of the water-glycerine mixture. The spilled flow rate thus decreases with the increase in spray flow rate as the percentage of glycerine increases.

Plotting the flow rates of the different percentage of glycerine at 90bar onto a stacked column chart allows the comparison of the flow rates under similar conditions in terms of pressure as shown in Fig.7. The reduction in the total flow rate can be seen clearly in Fig.7. The effect of the glycerine does not appear to be high on the total flow rate except for increasing the spray flow rate and decreasing the spilled flow rate.

The effect of pressure on the flow rate can also be seen in Fig. 8. The atomised flow rate and the spilled flow rate increase as the pressure increases. Referring to Table 3, the percentage change of the atomised flow rate of increasing the pressure of 55% glycerine solution from 90bar to 120bar is 13.40%. It can be noted that the atomised flow rate increases at a greater rate than the spilled flow rate as the pressure increases. As the viscosity of the fluid increases, the boundary layer thickness would increase which would decrease the effective diameter of the atomiser orifice and the spill diameter. However the flow rate of the atomised fluid increases as glycerine is added to the solution in the reservoir.

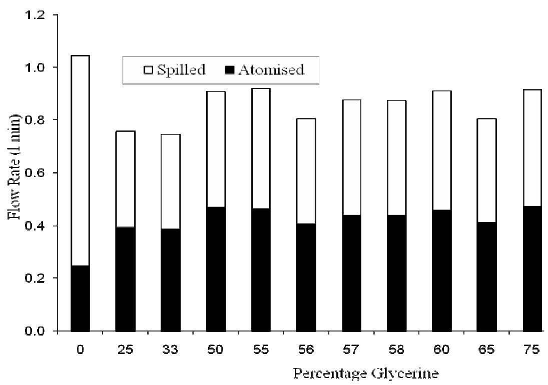

Figure 7 Variation of flow rates at 90bar supply pressures with different percentage of glycerine.

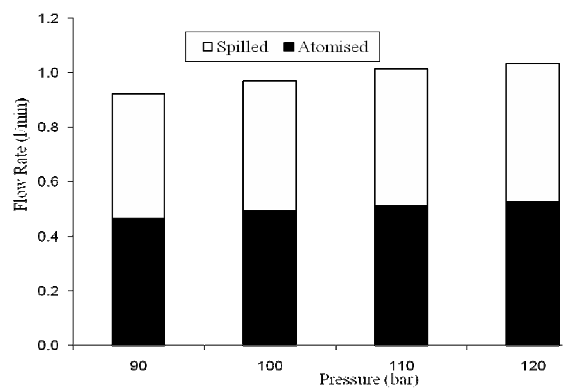

Figure 8. Variation of flow rates for 55% glycerine solution

Table 3 Percentage of difference of flow rates for 55% glycerine solution

Pressure (bar)	Flow Rate (l/min)			Percentage Increase compared to 90bar (%)			Percentage Increase compared to Water at 90bar (%)		
	Atomised	Spill	Supply	Atomised	Spill	Supply	Atomised	Spill	Supply
90	0.4628	0.4580	0.9208	0.0	0.0	0.0	88.9	42.7	11.9
100	0.4914	0.4771	0.9685	6.2	4.2	5.2	100.6	40.4	7.3
bb	0.5105	0.5010	1.0115	10.3	9.4	9.8	108.4	37.4	3.2
120	0.5248	0.5057	1.0305	13.4	10.4	11.9	114.2	36.8	1.4

Fig. 9 shows the variation of the viscosity of glycerine_water mixture at diffberent temperatures, using published data [7], compared with those which were estimated using the measured data shown in Table 2. As can be seen from Fig. 9, the highest viscosity (≈11CP) corresponds to a 55% glycerine solution abt 14.0°C and 90 bar which is in close agreement with the published data at the given temperature. This also provides a SMD of ≈ 21 µm and it is within 10% of the SMD (≈ 18 µm) of water at the same pressure.

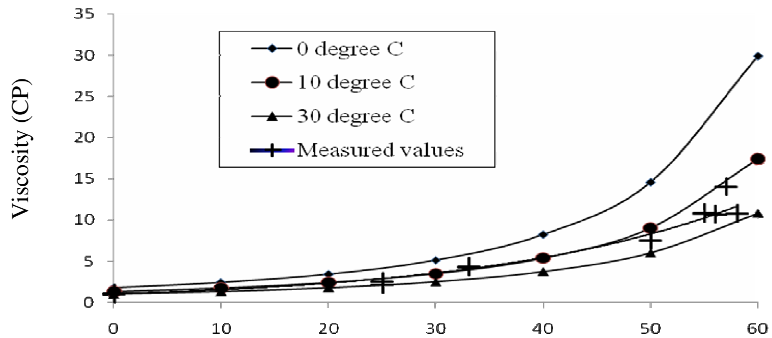

Figure 9 Comparison of published and measured viscosity with percentage of glycerine (%) solution

Conclusion

It was demonstrated that SRA, producing fine sprays at low flow rates, is robust and versatile enough to be use in the decontamination processes, using high viscous neturalising agents. Glycerine was chosen during the trials as an example, due to its high viscosity, and was mixed with water. The highest percentage of glycerine solution that can be used, at 90bar, is 55% with viscosity of the mixture of ≈11CP. The SMD obtained for the mixture is (≈ 21 µm) which is within 10% of the SMD of water (≈ 18 µm) at the same pressure. A percentage variance of the SMD of 5% does not allow the use of 90bar. However, by operating at 110 bar and 120 bar, it is possible to obtain the required SMD within 5% by using a 58% glycerine solution. Furthermore, it was found that increasing the glycerine content beyond this gave a SMD that was in excess of the 10% variance limit. Increasing the pressure to 110bar and 120bar can reduce the SMD at 55% glycerine solution. The atomised (spray) flow rate of 55% glycerine solution at 90bar is 0.4628l/min which is 88.9% higher than that of water at the same pressure. The total flow rate to the atomiser is 11.9% lower than that required when using 100% water.

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