Ph No: 0135 - 2524317, 4318
Fax 0135 - 2748041
Email: pns@iirs.gov.in

# GOVERNMENT OF INDIA
# DEPARTMENT OF SPACE
# INDIAN INSTITUTE OF REMOTE SENSING
# IIRS
# DEHRADUN
## PURCHASE & STORES

Date : 19/02/2015

## INVITATION TO TENDER

**Our Ref No :** GIER **2014-000428-01**

**M/s** 000000

**Tender Due:** 15:00 **Hrs IST on** 05/03/2015

**Dear Sirs,**

Please submit your sealed quotation , in the Tender Form enclosed here along with the descriptive catalogues / pamphlets /literature ,superscribed with Our Ref.No. and Due Date for the supply of the following items as per the terms & conditions mentioned in Annexure( Form No: )

| S.No. | Description of Items with Specifications | Unit | Quantity |
|---|---|---|---|
| 1 | Fabrication of Rainfall Simulator with accessories, Conceptualizing, Design and Production of Rainfall Simulator (Details in Annexure-I) | NOS. | 1 |

**DELIVERY AT:** IIRS

**MODE OF DESPATCH** DOOR DLVRY

**DUTY EXEMPTIONS**

**SPECIAL INSTRUCTIONS** NIL

**SPECIFIC TERMS**

V.V. NARAYANAN KUTTY
PURS. & STORES OFFICER
For and on behalf of the President of India
The Purchaser

OK

**GENERAL TERMS & CONDITIONS:**

1. Material should be delivered & installed at IIRS.
2. Payment will be made within 30 days from date of receipt of supply and acceptance of the material for orders value upto Rs. 2.0 lakhs. For order value above 2.0 lakhs, 90% payment within 30 days and 10% against Bank Guarantee for the warranty period.
3. We cannot furnish Form C/D. Please indicate the applicable percentage of Trade tax / VAT in your quotation, if applicable. Otherwise the quoted rate will be considered as inclusive of all taxes.
4. Clearly mention the Make/Brand of the item in your quotation. Please enclosed the Authorization Certificate from the principal of the quoted Make/Model along with the quotation.
5. Also clearly mention the exact delivery period and validity of your offer shall be min. 60 days.
6. Supplier should have experience in making and fabrication of one such type of equipment and installation (Attach Certificate)

**Annexure-I**

**General Criteria for Rainfall Simulator**

1. Simulator should have stationary Nozzles (Pressure Nozzle System).
2. Drop Size distribution should be near that of natural rainstorms.
3. Drop impact velocity near those of natural raindrops.
4. Rainfall Intensity should be in the range of 15 to 250 mm/hr.
5. Drop characteristics & intensity of application should be fairly uniform over the study area.
6. Raindrop application should be continuous throughout the study area.
7. Angle of impact should not be greatly different from vertical for most drops.
8. The simulator should have the capability of applying same simulated rainstorm repeatedly.
9. It should be portable for movement from one research site to another.
10. It should be light weighted enough that 2 people can move it.
11. It must be easy and quick to setup in the variable size fields.
12. It should be fabricated with easily available components.
13. The frame should be metallic and stiff enough to avoid sagging due to water load and pressure.
14. The material used should be corrosion free.

**Draft Design is in Fig. 1.**

**Specific Requirements:**

1. Rainfall Simulator should have Spray nozzles to simulate rain, assembly supported by metallic frame on upper end.
2. It should be adjustable in width and length with the variable study plot size. Width of the simulator should be in the range of 3 to 10 m.
3. Length should be adjustable in the range of 5 to 15 m.
4. The simulator should have tilting and adjustable facility (Adjustable nozzle height). The height can vary from 2 to 5 m.
5. Each nozzle should be fitted with control valve and pressure gauge excluding main control valve and pressure gauge near the pump outlet.
6. Flow meter at the pump outlet to measure the outflow discharge from pump.
7. Connecting pipes should be of best quality (wear and tear free, corrosion free) sufficient length to accommodate with the variable simulator frame size.
8. The connection pipes should be fitted so as to avoid any kind of sagging or pressure loss during conveyance.

**Specific Nozzle Requirements:**

The nozzle should be of material suitable for resisting abrasion, erosion and corrosion.

1. Full Jet Spray Nozzle (Full Cone) (preferably of Spraying Systems Co.)
2. Nozzle Inlet Conn. Female NPT
3. Capacity of nozzle to simulate rainfall should be in the range of 20 mm/hr to 250 mm/hr ( 20 lit/min to 200 lit/ min).
4. Drop size distribution should be uniform for the entire study plot area.
5. Size of drops generated by nozzle should be nearly same as of natural rainstorms.
6. Nozzle attachment fixtures should be like that so as to accommodate another type of nozzle also.
7. Spray Angle should not be less that 85 degrees.
8. Maximum PSI 10

**Specific Pump Requirements:**

Technical Specifications

Depth: 3 to 15 metres
Capacity : Max. 200 lit per min
Power Rating Single Phase : 0.37 to 1.1 kW (0.5 to 1.5 HP)

1. No moving parts inside the well, hence easy to service
2. Designed to prevent overloading and motor burning out
3. Models incorporated with IP-44 protection and class 'B' insulation
4. Dynamically balanced rotating parts ensure minimum vibrations
5. Replaceable wear and tear parts and hence longer life
6. CED coated wetted components for long life and rust free operations
7. More hygienic operations for drinking water
8. Fitted with shielded ball bearing – no lubrication required through life cycle
9. Should have suction lift self-priming.

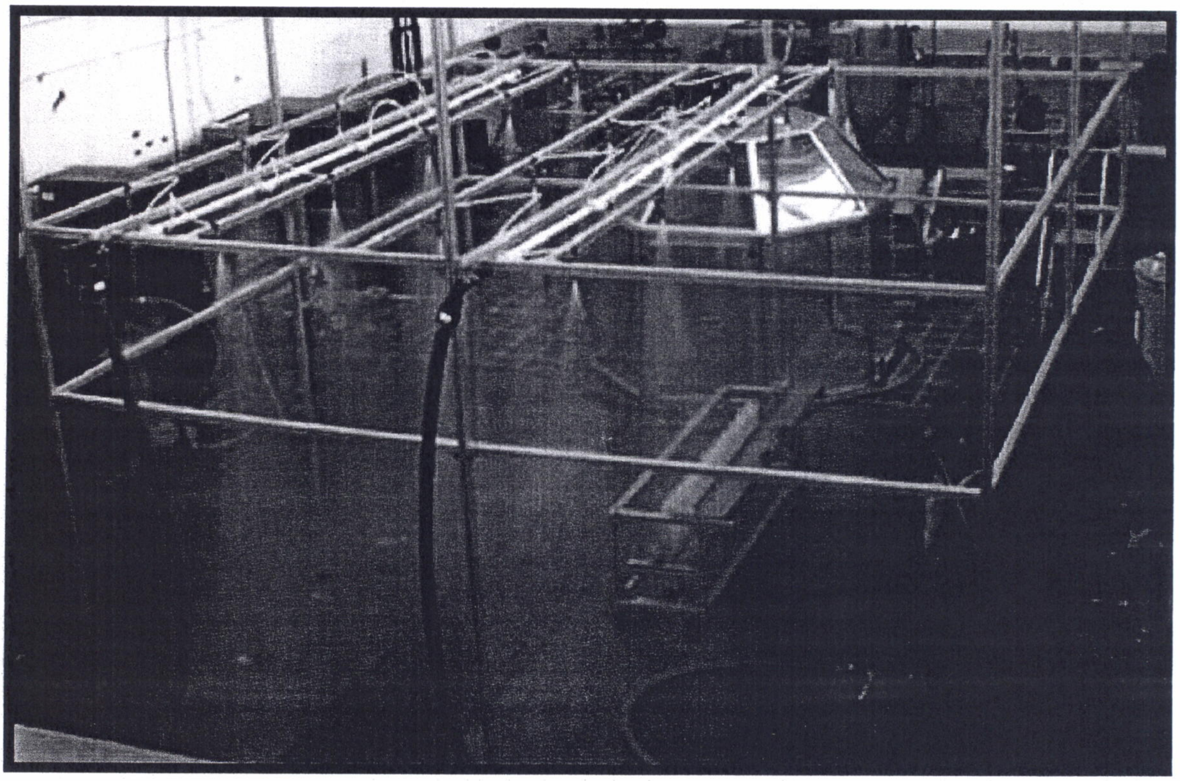

**Figure 1.** Rain simulator

→ Supplier can refere the research paper attached.

Spray Analysis
and Research Services

P.O. Box 7900, Wheaton, IL 60189-7900 USA Tel: 630-665-5201 Fax: 630-260-7593 www.sprayconsultants.com

# Multiscale Design of Rain Simulator

K. Knasiak*, R. J. Schick and W. Kalata
Spray Analysis and Research Services
Spraying Systems Co.
Wheaton, IL 60189-7900 USA.

**Abstract**

The United States Army is interested in building a rain test simulator. It must be able to simulate rain rates ranging from 1.07 - 14 mm/min. Furthermore, the drop size shall be in the range of 500 - 4500 µm. The simulator has to be designed to support two types of tests, rain resistance (top spraying) and water integrity (side spraying). The top spraying rain simulator was build and tested for the drop size and rain fall distribution with variable spray heights and rain rates. For each rain rate separate spray nozzle was chosen. The measured drop size fell within the desired size range. The measured rain fall distributions were the most uniform at the highest nozzle heights.

*Corresponding author

*ILASS Americas, 20th Annual Conference on Liquid Atomization and Spray Systems, Chicago, IL, May 2007*

**Introduction**

The United States Army at Aberdeen Test Center is interested in building a rain test simulator. This simulator shall conform to the United States Department of Defense (DOD) MIL-STD-810F.Method 506.4 standard [1] and related North Atlantic Treaty Organization's specifications. Specifically, it must be able to simulate rain rates ranging from 1.07 - 14 mm/min for which the rain conditions are shown in Table 1. Furthermore, the drop size shall be in the range of 500 μm - 4500 μm. In addition, consideration needs to be given to ensure that changing the simulation rates is easy and that the entire simulator is as lightweight and flexible as possible.

The flow rate will be determined based on the amount of liquid needed for each rain intensity test level. The pressure required achieve this flow will be depend on several factors which include drop size, spray angle, and coverage. The pressure ranges will be determined by analyzing the effect of pressure on drop size, spray angle and coverage in this application.

*Spray Coverage*

Within each spray pattern type there are many nozzles providing different spray angles, resulting in narrower or wider spray pattern coverage. While the tabulated spray angles are helpful from the standpoint of comparing relative spray coverage of different nozzles,

| *Rain Condition* | *Rain Fall Rate* | *Flow Rates* |
|---|---|---|
| Extreme | 14 mm/min (33.1 in/hr) | 7310 l/min (1930 GPM) |
| High | 8 mm/min (18.9 in/hr) | 4160 l/min (1100 GPM) |
| Steady-state ("medium") | 1.7 mm/min (4.0 in/hr) | 890 l/min (235 GPM) |
| Steady-state ("low") | 1.07 mm/min (2.5 in/hr) | 568 l/min (150 GPM) |

**Table 1.** The total flow rate required for each simulation mode over a 22.9×22.9 $m^2$ area.

the spray angle should not be extended geometrically if accurate spray coverage information is required.

The spray at distances does not maintain the theoretical spray angle coverage farther away from the orifice. Based on this information, the actual coverage for a single nozzle will have to be determined experimentally at the application conditions. The coverage for multiple nozzles will also be determined experimentally. Ideally, the nozzle with the largest spray angle will be chosen, however such a selection may be compromised by the drop size and velocity requirements. This problem can generally be addressed by a narrow spray angle at the expense of adding more nozzles in order to obtain the coverage.

To facilitate the rain test simulator, it is required to be installed in a building with a floor area of 30.5×45.7 $m^2$ (100×150 $ft^2$). The simulator has to be designed to support two types of tests, rain resistance (top spraying) and water integrity (side spraying). The general requirement for the rain resistance system is a 22.9×22.9 $m^2$ (75×75 $ft^2$) spray grid composed of 4 retractable grids at a maximum spray height of 12.2 m (40 ft). The requirement also calls for independent control of each grid. The general requirement for the water integrity system is a 22.9×6.1 $m^2$ (75×20 $ft^2$) modular spray grid with a maximum spray distance of 6.1 m (20 ft). The spray support structure is required to provide support to all of the water plumbing which would feed the nozzles in both the rain resistance and water integrity systems.

**Theory**

***Flow Relations in Spray Nozzles***

The nozzle flow rate is directly related to nozzle pressure and is computed as shown in Equation (1). $Q_1$ and $P_1$ are the rated flow and the rated pressure and $Q_2$ and $P_2$ are the required flow and pressure. The "n" exponent' will vary based on nozzle type, with a typical range of 0.44 – 0.5 [2].

$$\frac{Q_1}{Q_2} = \left(\frac{P_1}{P_2}\right)^n \quad (1)$$

***Drop Size and Velocity***

Drop Size is greatly affected by nozzle type, flow rate and pressure. Generally, at the same operating conditions (i.e. flow and pressure), the drop size in each spray pattern is largest to smallest in the following order: Full Cone, Flat Spray and Hollow Cone. An increase in flow rate at a constant pressure increases the drop size. An increase in pressure or an increase in spray angle reduces the drop size.

The most common measures of drop size are volume median diameter (VMD, $D_{V0.5}$), Sauter mean diameter (SMD, $D_{32}$), $D_{V0.1}$, $D_{V0.9}$. These were included in this work. VMD is a value where 50% of the total volume or mass of liquid sprayed is made up of drops with diameters smaller or equal to this value. SMD is the ratio of the total volume of all the drops to the total surface area of all the drops. $D_{V0.1}$ and $D_{V0.9}$ are values where 10 and 90% respectively of the total volume or mass of liquid sprayed is made up of drops with diameters smaller or equal to this value. To get an indication of uniformity of drop size distribution, a parameter known as Relative Span Factor (RSF) can be computed from Equation (2). Additionally, average velocity and volume flux of the spray drops can be obtained [2-5].

$$RSF = \frac{D_{V0.9} - D_{V0.1}}{D_{V0.5}} \qquad (2)$$

***Nozzle Construction Materials***

The nozzles should be constructed of a material suitable for resisting abrasion, corrosion and erosion. Abrasion is the erosion resulting from the cutting or scarring action by suspended solid particles, which are harder than the nozzle surfaces. To minimize abrasion or attrition problems, harder materials such as stainless steel, hardened stainless steel, tungsten carbide, and other carbides should be considered.

Corrosion is the destruction of nozzle surfaces caused by a chemical attack by the solution on the nozzle material surfaces. The usual measures for limiting the corrosion of nozzle surfaces include selecting materials which are compatible with the chemical being used. This is generally a function of the liquid identity, liquid temperature, and percent concentration of the corrosive agent.

Erosion is the destruction of material surfaces by abrasion, attrition, chemical corrosion, or a combination of these factors. It is caused by liquid flows with or without solid particles. Harder materials, reduced liquid velocity, and added corrosion inhibiters to the sprayed liquid can slow down the erosion rate of nozzle surfaces.

**Methods**

***Nozzle Solutions***

For all rain rate (RR) simulations, FullJet® nozzles produced by Spraying Systems Co. (Wheaton, Illinois, USA) were chosen. These nozzles are full cone nozzles available in narrow, standard and wide spray angle configurations. For lower rain rates targeted for 0.42, 0.85, 1.3 and 1.7 mm/min (1, 2, 3 and 4 in/hr) wide angle spray nozzles were used with coarse nozzle distribution. For higher rain rates targeted for 3.4, 5.1, 7.6, and 14 mm/min (8, 12, 18 and 33 in/hr) the narrow angle spray nozzles were used with fine nozzle distribution.

***Rain Simulator***

To validate the nozzle performance, a rain simulator shown in Figure 1 was constructed. 18 nozzles were placed on top of the apparatus with spatial distributions shown in Figures 2 and 3. The coverage area was approximately 4.1×5 $m^2$ (13.5×16.5 $ft^2$). To measure the distribution of simulated rain fall, a patternator or a cart with 24 collection tubes placed side by side in a straight line was used. Each tube had 2400 ml volume capacity with 8 cm internal diameter. The patternator had a collection height of 0.8 m. This means that the spray height is the difference of nozzle height and patternator height.

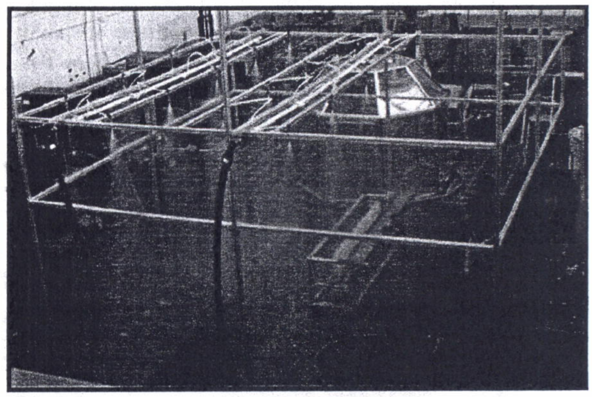

**Figure 1.** Rain simulator

***Lower Rain Rate Tests***

For the lower rain rates (0.42, 0.85, 1.3 and 1.7 mm/min), the spray setup had 4 nozzles active. These nozzles were positioned in such way, that each active nozzle was located in the center of an hexagonal cell formed by inactive nozzles. The cart with patternator tubes was positioned on the centerline between two nozzles. The patternator had an origin set on the right-hand side (see Figure 2). The measurements were performed at one nozzle height of 6.1 m (20 ft). During each test, in addition to collected volumes, the pressure, flow rates and collection time were measured.

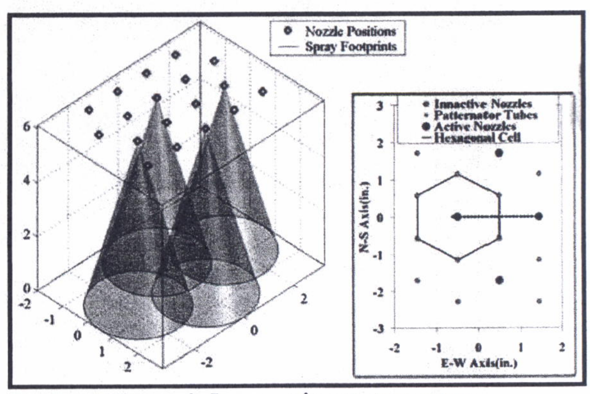


**Figure 2.** Lower rain rate test set up.

***Higher Rain Rate Tests***

For the higher rain rates (3.4, 5.1, 7.6, and 14 mm/min), the spray setup had all nozzles active. The cart with patternator tubes was positioned at numerous locations with the approximate coverage surface of 2×4 $m^2$ as shown in Figure 3. The rain simulation measurements were performed at three different nozzle heights: 3, 4.6 and 6.1 m (10, 15 and 20 ft). During each test, in addition to collected volumes, the pressure, flow rates and collection time were measured.

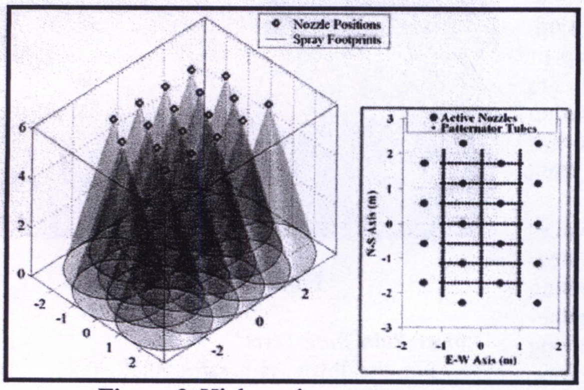


**Figure 3.** Higher rain rate test set up.

***Drop Size Measurements***

A two-dimensional Artium Technologies Phase Doppler Inferometer (PDI) 200MD instrument (shown in Figure 4) was used to make drop size and velocity measurements, as shown in Figure 4.

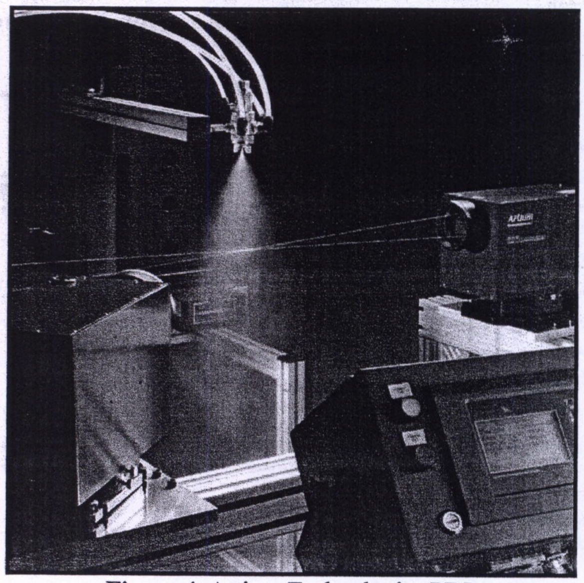

**Figure 4.** Artium Technologies PDI

The solid state laser systems (green 532 nm and red 660 nm) used in the PDI-200 MD are Class 3B lasers and provide about 50-60 mW of power per beam. This is an intense enough laser power to help offset dense spray effects.

The transmitter and receiver were mounted on a rail assembly with rotary plates; a 40° forward scatter collection angle was used. For this particular test, the choice of lenses was 2000 mm for the transmitter and 2000 mm for the receiver unit. This resulted in a size range with a size of about 27.9 µm – 3351.7 µm. This optical setup was used to ensure capturing the full range of droplet sizes while maintaining good measurement resolution. The particular range used for these given tests was determined by a preliminary run where the $D_{V0.5}$ and the overall droplet distribution could be examined. This appeared adequate to collect the entire droplet size range produced by the nozzles. For each test point, a total of 25,000 samples were used. The principals of drop size measurement techniques and use of the PDI were previously published by various authors [6-12].

**Results**

***Lower Rain Rates***

The 0.42-1.7 ml/min rain rates were measured to verify that they met the drop size requirements. For a single nozzle height of 6.1 m and different rain rates, different capacities of wide angle full cone nozzles were used. Figure 5 shows the distribution of collected liquid for each lower rain rate case which were collected between two active nozzles as shown in Figure 2.

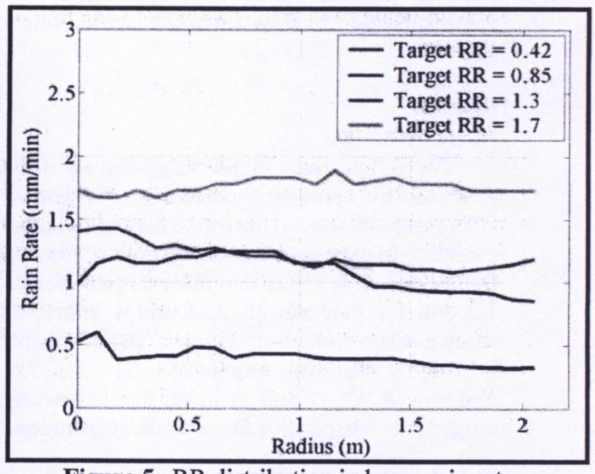


**Figure 5.** RR distribution in lower rain rates.

Figure 5 shows relatively even distributions of liquid collected by a patternator. In order to quantify the variability of the collected liquid, the ratio of the standard deviation to the average, known as the coefficient of variance (CV), was computed. The statistical summary of all cases is provided in Table 2.

The drop size data shown in Table 3 indicates that all lower rain rate simulated data fell within the required drop size ranges. The $D_{V0.1}$ ranged from 260 to 500 µm, $D_{V0.9}$ ranged from 1580-1900 µm, and $D_{V0.5}$ varying at range 530-1450 µm. RSF varied from 1 to 2.5. SMD varied from 480 to 1000 µm.

***Higher Rain Rates***

The 3.4-14 ml/min rain rates were measured to verify that they met the drop size requirements. For each spray height different capacities of narrow angle full cone nozzles were used. Figure 6 shows the distribution of the collected liquid for each case. The top portion of Figure 6 shows each case's measurement data (in red dots) and their corresponding meshed surface that was computed with a 2D Hermite interpolation algorithm. The bottom portion of Figure 6 shows the uneven structures (bumps) in each case, providing general performance features of each case.

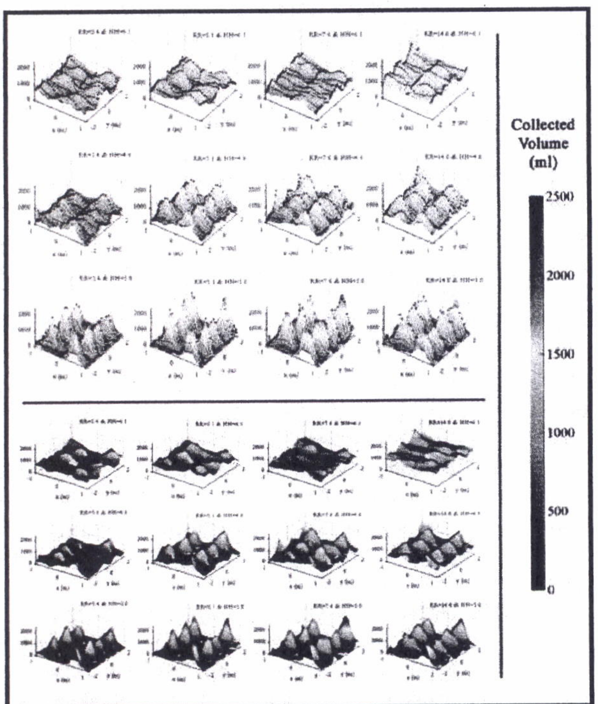


**Figure 6.** ***Top:*** Collected volume spatial distributions for different rain rates (RR) and nozzle heights (NH). Red dots indicate measured data. Mesh indicates 2D interpolated data. ***Bottom:*** Surface plot of 2D interpolated volume spatial distributions.

Figure 6 clearly indicates that cases at 3.4 m nozzle height have the largest variance and at 6.1 m nozzle height, the variance was the lowest. The variance corresponded to the nozzle positions. The significant volume peaks that are most distinctive at 3.4 m spray height were approximately at the nozzle positions. The statistical summary of Table 2 confirms the graphical results shown in Figures 6, where the CV is the highest at 3.4 m nozzle height and it is the lowest at 6.1 m. Generally, at each nozzle height, CV decreased as the desired rain rate increased. Figure 7 graphically indicates the changes in CV.

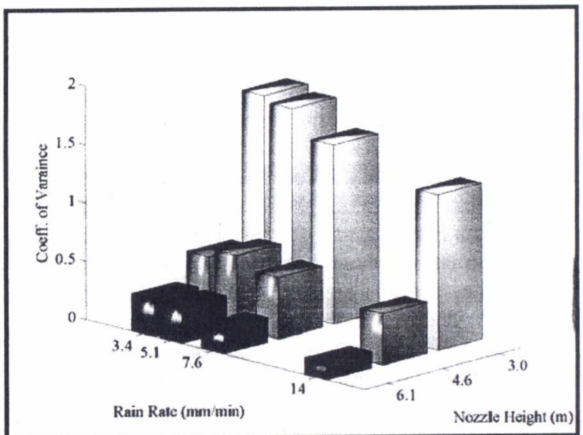


**Figure 7.** Coefficient of variance of rain rate data for higher rain rates at multiple nozzle heights.

The drop size data shown in Table 3 indicates that all higher rain rate simulated data fell in required drop size. All had about the same $D_{V0.1}$ at range of 250-290 µm, the same $D_{V0.9}$ at range 3050-3180 µm, but $D_{V0.5}$ varying at range of 640-1100 µm. RSF varied from 2.6 to 4.6 µm. SMD varied from 530 to 650 µm.

**Discussion**

In order to satisfy the conditions posed by the rain characteristics, full cone type nozzles that provided reasonable volume coverage throughout its spray area were chosen. Since the sprayed volume distribution of such nozzle is Gaussian in nature, overlapping the sprays needed to be taken in to account, particularly for the lower rain rates (0.42-1.7 ml/min) where not all nozzles were activated as shown in Figure 2. Also, the higher rain rates (3.4-14 ml/min) spray overlap was significant and was affected by all neighboring nozzles. The flow rate and pressure ratings that were used were based on overall coverage rather than for a single nozzle. For the lower rain rates, the flow rate calculation was approached differently. It was calculated based on the circular area computed from the radius defined by the distance between active nozzle and any of six neighboring inactive nozzles (see Figure 2). The usual approach for spray overlap in such cases is targeted to 1/3 of spray diameter. This means that the volume that is sprayed outside the cell area has to be accounted for. Since there would be 6 neighboring active nozzles around the cell, it is assumed that their combined overlap volume that falls into the cell is approximately the same as that cell's overspray volume. Spray coverages produced by the selected wide angle nozzles used for the lower rain rains produced result nearly equivalent to those that were calculated using the 1/3 overlap approximation. It can be concluded based on the results shown in Figure 5 and Table 2 that this assumption in lower rain rates provides reasonable rain fall distributions.

Simulating nature has always been challenging, especially physical phenomena such as natural precipitation. Significant differences can be noted in the droplet formation of rain as compared to spray nozzle atomization. Rain is created by condensation of moist air into small droplets that then agglomerate into larger drops and fall to earth. Drops generated by spray nozzles are created by forcing fluid at elevated pressures through small openings with various geometrical configurations forcing the fluid into sheets, ligaments and then drops [5,13]. One may argue that the lower end drop size range (500 - 4500 μm) posed by DOD standard [1] was not completely satisfied because the smallest $D_{V0.1}$ ranged from 250 to 500 μm. This means that 10% of the total volume measured had droplets smaller than 500 μm. While this is true, the majority of liquid volume from the sprays is overwhelmingly within required drop size range. With 85% to 90% of sprayed volume within the required drop size range, the experimental results can be considered as valid. Additionally, the rain simulator produced rain fall distributions that were reasonably even and therefore the majority of natural rain phenomenon was reproduced.

**Conclusions**

Beginning from the drop size ($10^{-4} - 10^{-3}$ m scales) and ending up on dimensions of the test apparatus ($10^{1}$ m scales), the design parameters of the rain simulator were satisfied. In all cases drop size ranged from 250 μm (smallest $D_{V0.1}$) to 3200 μm (highest $D_{V0.9}$) and satisfied the project's drop size requirements. Rain fall distributions were relatively even at all rain rates ranging form 0.42 to 14 mm/min at 6.1 m nozzle height. The design consisted of consistent spacing of narrow angle full cone nozzles at higher rain rates and required all nozzles to be active. In lower rain rates the wide angle full cone nozzles were used. These nozzles were spaced in such a pattern, where active nozzles were in the center of hexagonal cells formed by the inactive nozzles.

| | |
|---|---|
| *2D* | Two Dimensional |
| *CV* | Coefficient of Variance |
| *DOD* | Department of Defense |
| *NH* | Nozzle Height |
| *PDI* | Phase Doppler Interferometer |
| *RR* | Rain Rate |
| *SMD* | Sauter Mean Diameter |
| *VMD* | Volume Median Diameter |
| *RSF* | Relative Span Factor |

**References**

1. MIL-STD-810F.Method 506.4, "Test Method Standard for Environmental Engineering Considerations and Laboratory Tests", United States Department of Defense.
2. Engineer's Guide to Spray Technology, Spraying Systems Co., 2000.
3. ASTM E 1296, "Terminology Relating to Liquid Particle Statistics", ASTM International.
4. ASTM E 1620, "Terminology Relating to Liquid Particles and Atomization", ASTM International.
5. Schick, R.J., Spray Analysis and Research Services, Spray Technology Reference Guide: Understanding Drop Size, Spraying Systems Co., 2006
6. Bachalo, W.D., "A Method for Measuring the Size and Velocity of Spheres by Dual Beam Light Scatter Interferometry", Applied Optics, Vol. 19, No. 3, February 1, 1980.
7. Bachalo, W.D. and Houser, M.J., "Phase Doppler Spray Analyzer for Simultaneous Measurements of Drop Size and Velocity Distributions", Optical Engineering, Volume 23, Number 5, September-October, 1984.
8. Bachalo, W.D. and Houser, M.J., "Spray Drop Size and Velocity Measurements Using the Phase Doppler Particle Analyzer", Proceedings of the International Conference on Liquid Atomization and Spray Systems (Third International), July, 1985.
9. Sankar, S.V. and Bachalo, W.D., "Response Characteristics of the Phase Doppler Particle Analyzer for Sizing Spherical Particles Larger Than the Light Wavelength", Applied Optics, April 20th, 1991, Volume 30, #12.
10. Bachalo, W.D., "Experimental Methods in Multiphase Flows", International Journal on Multiphase Flow, Vol. 20, Suppl. pp. 261-295, 1994
11. Strakey, P., Talley, D. G., Sankar, S.V. and Bachalo, W.D. "Phase-Doppler Interferometry with Probe-to-Droplet Size Ratios Less Than Unity. Trajectory Errors I.", Applied Optics, Vol. 39, No. 22, August 2000.
12. Strakey, P., Talley, D. G., Sankar, S.V. and Bachalo, W.D., "Phase-Doppler Interferometry with Probe-to-Droplet Size Ratios Less Than Unity. Application of the Technique II.", Applied Optics, Vol. 39, No. 22, August 2000.
13. A. H. Lefebvre, Atomization and Sprays, Hemisphere, New York, 1989.

# Tables

| *Desired RR (mm/min)* | *Nozzle Height (m)* | *Measured RR (based on collected volume)* | | | | |
|---|---|---|---|---|---|---|
| | | *Ave. RR (mm/min)* | *Min. RR (mm/min)* | *Max. RR (mm/min)* | *Std. RR (mm/min)* | *Coeff. of Variance* |
| 0.42 | 6.1 | 0.40 | 0.32 | 0.60 | 0.07 | 0.16 |
| 0.85 | 6.1 | 1.08 | 0.85 | 1.25 | 0.14 | 0.13 |
| 1.3 | 6.1 | 1.21 | 1.08 | 1.42 | 0.11 | 0.09 |
| 1.7 | 6.1 | 1.76 | 1.67 | 1.89 | 0.06 | 0.03 |
| 3.4 | 3.0 | 2.75 | 0.068 | 25.5 | 4.97 | 1.81 |
| | 4.6 | 3.59 | 0.80 | 11.0 | 1.97 | 0.55 |
| | 6.1 | 3.60 | 1.42 | 6.71 | 1.14 | 0.32 |
| 5.1 | 3.0 | 4.38 | 0.08 | 39.5 | 7.68 | 1.75 |
| | 4.6 | 5.23 | 1.25 | 17.7 | 3.24 | 0.62 |
| | 6.1 | 5.67 | 2.87 | 10.3 | 1.72 | 0.30 |
| 7.6 | 3.0 | 6.65 | 0.28 | 45.6 | 10.2 | 1.54 |
| | 4.6 | 8.23 | 2.65 | 23.6 | 4.31 | 0.52 |
| | 6.1 | 9.55 | 5.70 | 15.1 | 1.93 | 0.20 |
| 14 | 3.0 | 10.2 | 0.85 | 53.7 | 13.6 | 1.33 |
| | 4.6 | 13.6 | 5.17 | 32.4 | 5.98 | 0.44 |
| | 6.1 | 15.9 | 11.5 | 24.8 | 2.29 | 0.14 |

**Table 2.** Statistical summary of measured rain fall for all tests.

| *RR (mm/min)* | *Pressure (kPa)* | $D_{32}$ | $D_{V0.5}$ | $D_{V0.1}$ | $D_{V0.9}$ | *RSF* | $V_{avg}$ | $V_{rms}$ |
|---|---|---|---|---|---|---|---|---|
| | | *(μm)* | | | | | *(m/s)* | |
| 0.42 | 67.6 | 481 | 533 | 263 | 1579 | 2.5 | 1.25 | 0.77 |
| 0.85 | 51.7 | 638 | 734 | 361 | 1752 | 1.9 | 1.91 | 0.85 |
| 1.3 | 66.9 | 996 | 1450 | 498 | 1885 | 1.0 | 2.02 | 1.24 |
| 1.7 | 82.7 | 913 | 1370 | 450 | 1901 | 1.1 | 1.92 | 1.15 |
| 3.4 | 317 | 529 | 641 | 253 | 3181 | 4.6 | 3.33 | 0.76 |
| 5.1 | 290 | 647 | 1096 | 288 | 3140 | 2.6 | 3.97 | 0.92 |
| 7.6 | 241 | 616 | 933 | 290 | 3050 | 3.0 | 3.93 | 1.09 |
| 14 | 483 | 569 | 904 | 259 | 3145 | 3.2 | 5.57 | 1.06 |

**Table 3.** Drop size and velocity measurements for all tests at 6.1 m nozzle height.

Spray Analysis
and Research Services

P.O. Box 7900, Wheaton, IL 60189-7900 USA

Tel: 1.800.95.SPRAY Intl. Tel: 1.630.665.5000
Fax: 1.888.95.SPRAY Intl. Fax: 1.630.260.7593
www.SprayConsultants.com