**SAP #: 10013710**

# Measurements of Particle Size Distribution by Wet & Dry Laser Diffraction

**For:**

## USGS-NASA

**DFC BLDG 20 MS 964**
**Denver, CO 80225**

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**Dates of analysis: 5th July 2007**

**Summary**

**The techniques of wet and dry laser diffraction have been used to characterize the particle size distribution of Lunar Highlands Type simulant powder samples supplied by USGS-NASA. The methodologies, assumptions and derived particle size distribution are discussed within this report.**

# Contents

## 1. Objectives

The objective of this study was to provide size distribution information on Lunar Highlands Type simulant samples from USGS-NASA. Shape information is included in another report which shows measurements of the two samples with a dry imaging technique.

## 2. Background

Two samples were submitted by USGS-NASA for measurement with laser diffraction techniques provided by Malvern Instruments Inc. The samples were:

1 Lunar Highlands Type simulant, medium grain size, NU-LHT-1M, 121
2 Lunar Highlands Type simulant, medium grain size, NU-LHT-1M, 026

## 3. Materials (and form) and instrumentation

The two samples were both grey powders, with larger black specs. The samples were analyzed on laser diffraction (Malvern Mastersizer MS2000, s/n 34355-181, 5.4 version software) with wet analysis using the Hydro S dispersion unit (capacity 100-150 ml). Dry analysis was also performed using the Scirroco dry dispersion unit.
Instruments in the laboratory are performance verified with NIST-traceable standards on a monthly basis. The MS2000 has a particle size distribution range of 0.02 – 2000μm. See:

http://www.malvern.com/common/downloads/MRK501-02_LR.pdf

## 4. Method

### 4.1 Dry Laser Diffraction

The methodology followed the broad recommendations outlined in ISO13320-1, the international standard for laser diffraction. In particular, Section 6.2.3 (Dispersion) was followed closely. In both wet and dry method development the objective is to understand the effect of energy on the particulate system (distinguishing agglomerates from dispersed particles) in line with the needs of the measurement outcome (bulk or primary particle size).
In a dry measurement, to assess both dispersion and the extent of attrition (if applicable), the material is subjected to what is called a “pressure-size titration” where the effect of increasing controlled energy input is examined (See Section 6.2.3.2 ISO 13320-1). Controlling the ΔP across the venturi regulates this energy input. Shear processes by acceleration will (in theory) separate any agglomerates into primary particles. Increased energy can cause attrition of friable samples especially those that are organic or of high aspect ratio. For large samples then another consideration is that of carrying the particles through the measurement zone in the air stream and high flow rates are normally used for this.
Bulk samples of the material were scoop sampled and placed into the vibratory hopper of the Scirocco dry dispersion unit and consecutive repeat measurements undertaken in order to assess the reproducibility of measurement which is a function of the homogeneity of the material (or otherwise). The mass flow was adjusted until a stable

and correct particle concentration was achieved at 4-bar and then left constant for the remainder of the experiments. Measurements were taken at 4-bar, 3-bar, 2-bar,1-bar and 0.5-bar disperser pressure. For setting of the correct and accurate working pressure, a wet or other reference measurement should be undertaken and the results of the dispersed material compared in both cases. The particle size distributions results will be the same if the material is in the same state of dispersion (likely to be full) and the correct optical properties used (especially in the wet measurement where the RRI is lower and can tend to unity depending on the sample).

4.2 Wet Laser Diffraction

In the case of wet dispersion, energy is imparted to the system using sonication. Similar to disperser pressure in a dry measurement, sonication can disperse any agglomerates to the primary particle size of the material. Aggregates are generally 'hard' and not dispersible under any standard measurement conditions. Excessive energy for fragile and/or friable samples may cause attrition, but this is unusual and is easily seen in the size-energy plot.

Water was used as the dispersant. Each sample was prewetted with a small amount of water and then added to the Hydro S dispersion unit. The samples were measured before, during and after a brief period of sonication.

More information on wet and dry dispersion is given in the attached application notes.

## 5. Assumptions

For a light scattering experiment the optical properties of the material are essential for accuracy (ISO13320-1 Appendix A) for material less than 40λ (~ 25μm for a He-Ne laser at 0.6328μm) in size.

Laser diffraction instruments collect (stable) raw data in the form of an Intensity-Angle plot and it is this information (with the corresponding assumptions) that is converted to particle size distribution data. Thus the only objective of the measurement is to collect stable data suitable for deconvolution. Particle size is measured indirectly and the nature of the assumptions made is vital. Hence ancillary evidence is usually vital in confirming one result with respect to another.

The relative refractive index (RRI) is always higher in a dry measurement than in the corresponding wet one ($RI_{air}$ ~ 1, $RI_{H20}$ ~ 1.33, $RI_{particle}$ ~ 1.5, for example) and thus the optical properties are somewhat more robust in a dry measurement especially if the material is reasonably large. For a wet measurement, especially for small material (d < 10μm or so) then the RI values need determining either by measurement or via a reference text (e.g. CRC Handbook).

In this case, an RI value was estimated from the provided composition of the samples. This estimated value was 1.75. An absorption index of 0.1 was used for all samples since it gave the best fit to the data. It also was reasonable given the colored nature of the samples.

It is important to explore the robustness of the derived measurement to small, systematic and sensible (the "3S's") changes to the RI parameters. Changes to these parameters can only be explored for a fully dispersed system, as it is quite obvious that agglomerate

optical properties (especially with respect to the imaginary component of the RI) will be different to those of a single primary particle.
The RI used for air was 1.000 and for water was 1.33 (CRC Handbook & Malvern Dispersant information within the software).

## 6. Results

### 6.1 Dry Laser Diffraction

The pressure-titration plot for Lunar Highlands Type Simulant sample 121 is shown below.

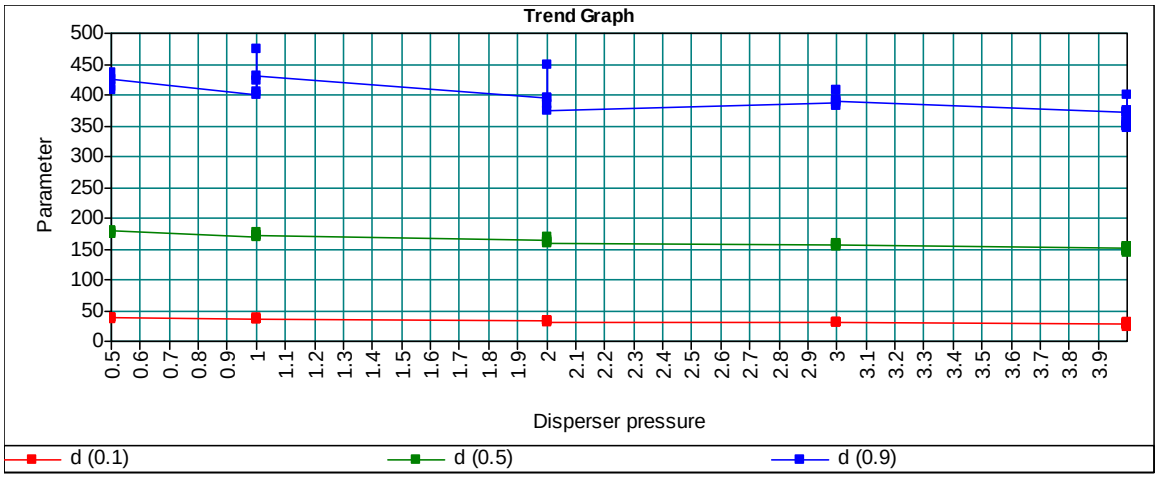


**Figure 6-1 Pressure size titration plot for 121 showing the d(0.1), d(0.5) and d(0.9).**

There is some change in the particle size distribution with varying disperser pressure. The variability in each set of measurements is a result of the variability within the sample itself. Given the broad range of particle sizes in this samples, some variation, such as that shown above, is expected.

Figure 6-2 shows a particle size distribution for 121 measured at 4-Bar.

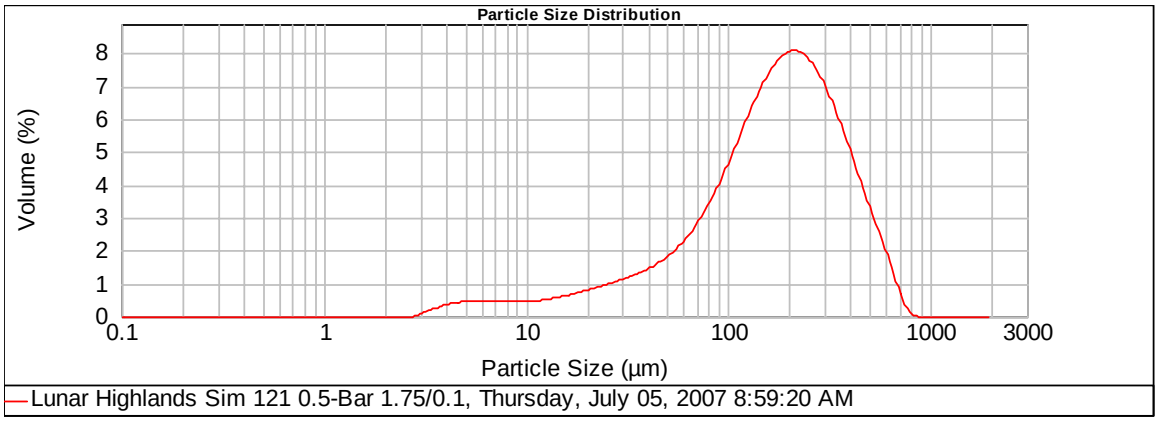


**Figure 6-2 Size distribution plot for 121 measured at 4-Bar.**

The 026 sample showed similar behavior when subjected to a pressure-size titration. A

representative particle size distribution for 026 measured at 4-bar is shown below.

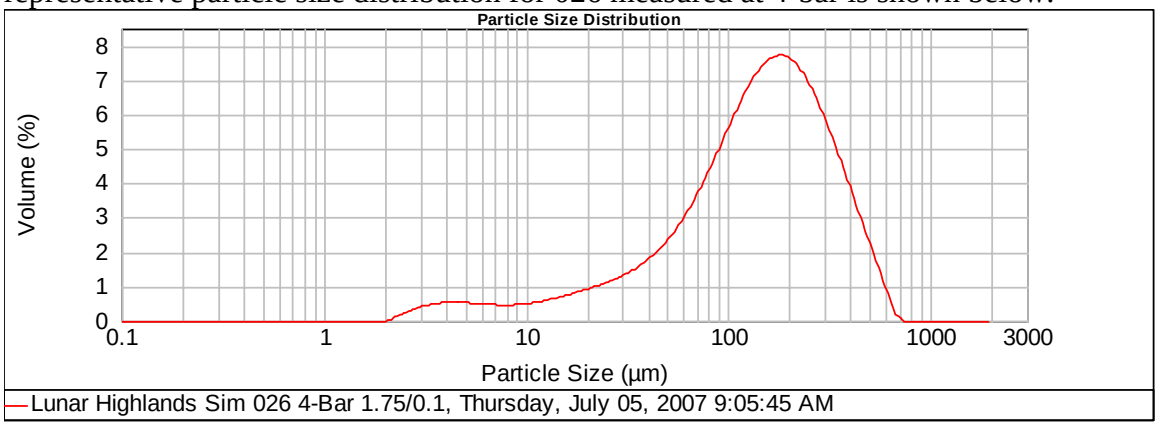


**Figure 6-3 Particle size distribution for 026 measured at 4-Bar.**

Reproducibility of measurements can be assessed by exporting data to Excel. Tables 6-1 and 6-2 show reproducibility for measurements of both samples at 4-Bar disperser pressure.

| Record number | Sample Name | d (0.1) | d (0.5) | d (0.9) |
|---|---|---|---|---|
| 63 | Lunar Highlands Sim 121 4-Bar 1.75/0.1 | 29.147 | 150.811 | 360.15 |
| 64 | Lunar Highlands Sim 121 4-Bar 1.75/0.1 | 26.423 | 147.801 | 348.761 |
| 65 | Lunar Highlands Sim 121 4-Bar 1.75/0.1 | 28.288 | 148.629 | 351.391 |
| 66 | Lunar Highlands Sim 121 4-Bar 1.75/0.1 | 27.579 | 146.383 | 349.211 |
| 67 | Lunar Highlands Sim 121 4-Bar 1.75/0.1 | 27.394 | 146.231 | 355.267 |
| | | | | |
| | Mean | 27.77 | 147.97 | 352.96 |
| | SD | 1.02 | 1.88 | 4.77 |
| | RSD | 3.67 | 1.27 | 1.35 |

**Table 6-1 Reproducibility for 121 at 4-Bar.**

| Record number | Sample Name | d (0.1) | d (0.5) | d (0.9) |
|---|---|---|---|---|
| | | | | |
| 101 | Lunar Highlands Sim 026 4-Bar 1.75/0.1 | 29.153 | 149.46 | 353.415 |
| 102 | Lunar Highlands Sim 026 4-Bar 1.75/0.1 | 28.507 | 146.63 | 357.525 |
| 103 | Lunar Highlands Sim 026 4-Bar 1.75/0.1 | 28.502 | 148.277 | 375.18 |
| 104 | Lunar Highlands Sim 026 4-Bar 1.75/0.1 | 28.566 | 148.174 | 370.407 |
| | | | | |
| | Mean | 28.68 | 148.14 | 364.13 |
| | SD | 0.32 | 1.16 | 10.33 |
| | RSD | 1.10 | 0.78 | 2.84 |

**Table 6-2 Reproducibility for 026 at 4-Bar.**

All reproducibility of results is acceptable to ISO 13320-1 and is a reflection of the homogeneity of the sample, rather than of instrument variability.

6.2 Wet Laser Diffraction

The D10, D50 and D90 before, during and after sonication for 121 appear in Figure 6-4.

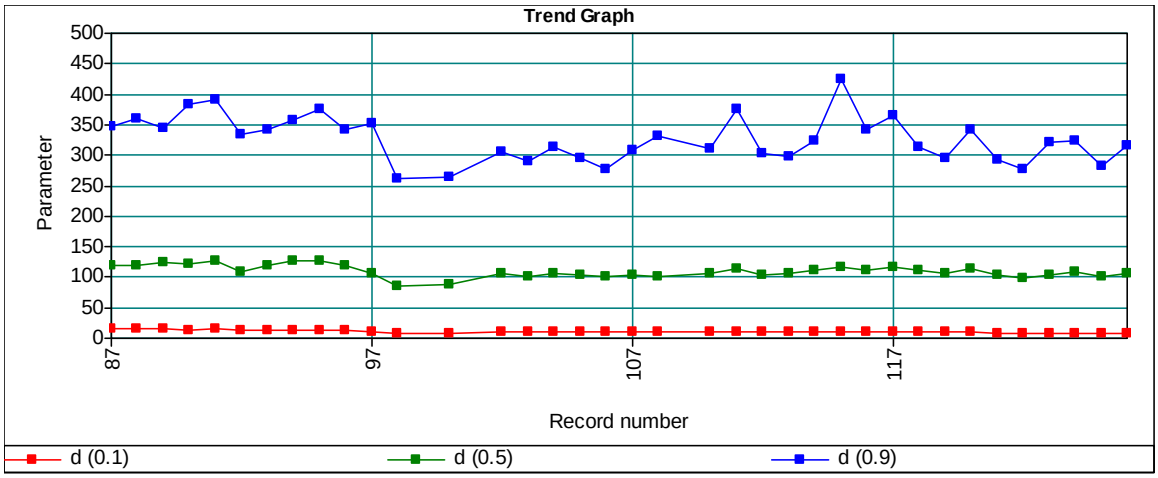


**Figure 6-4 Results before (records 87-96), during (97-102) and after (98-126) sonication for 121.**

Fluctuation in the d(0.9) occur both before and after sonication. These fluctuations are likely a result number fluctuations in the system. Sample 026 shows a similar response to sonication.

The particle size distributions for both samples before and after sonication are shown in Figure 6-5 and 6-6.

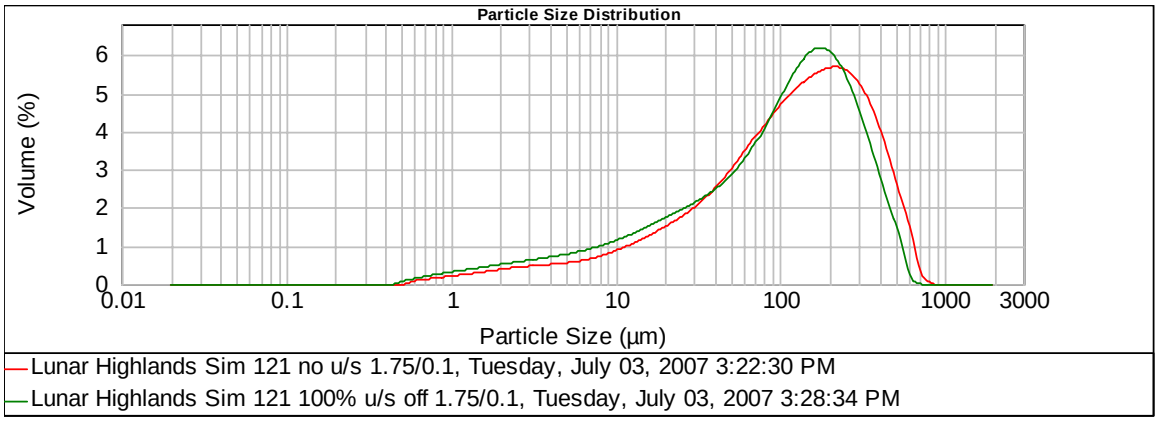


**Figure 6-5 Particle size distribution plots for 121 before (red) and after (green) sonication.**

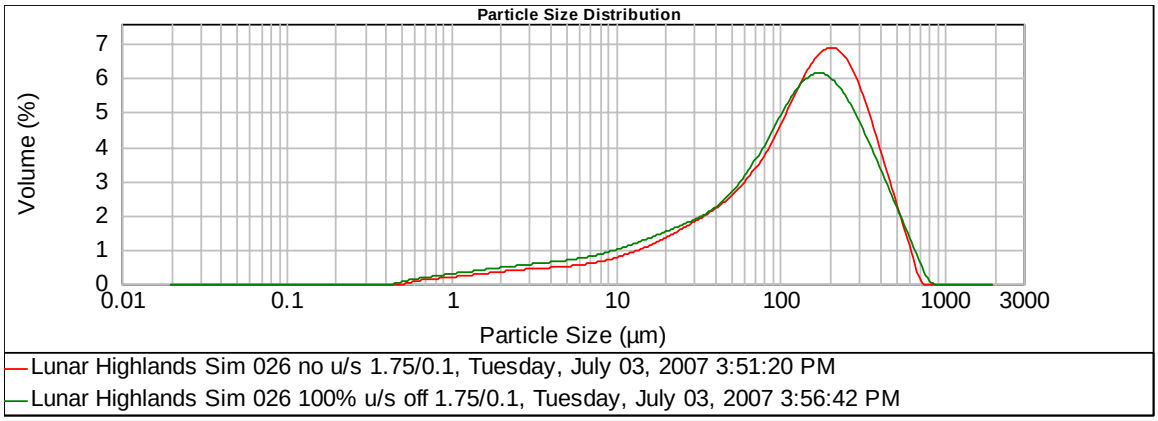


**Figure 6-7 Particle size distribution for 026 before (red) and after (green) sonication.**

Repeat measurements can be exported to Excel for easy statistical calculations. Tables 6-3 and 6-4 show the repeatability for each sample after sonication.

| Record number | Sample Name | d (0.1) | d (0.5) | d (0.9) |
|---|---|---|---|---|
| 87 | Lunar Highlands Sim 121 no u/s 1.75/0.1 | 14.491 | 119.782 | 346.061 |
| 88 | Lunar Highlands Sim 121 no u/s 1.75/0.1 | 14.336 | 120.048 | 359.425 |
| 89 | Lunar Highlands Sim 121 no u/s 1.75/0.1 | 14.771 | 124.625 | 344.839 |
| 90 | Lunar Highlands Sim 121 no u/s 1.75/0.1 | 13.9 | 122.77 | 383.655 |
| | | | | |
| | | | | |
| | Mean | 14.37 | 121.81 | 358.50 |
| | SD | 0.36 | 2.31 | 18.03 |
| | RSD | 2.53 | 1.90 | 5.03 |

**Table 6-2 Repeatability of measurements for 121 before sonication.**

| Record number | Sample Name | d (0.1) | d (0.5) | d (0.9) |
|---|---|---|---|---|
| | | | | |
| 130 | Lunar Highlands Sim 026 no u/s 1.75/0.1 | 16.631 | 139.607 | 396.655 |
| 131 | Lunar Highlands Sim 026 no u/s 1.75/0.1 | 15.297 | 137.633 | 385.234 |
| 132 | Lunar Highlands Sim 026 no u/s 1.75/0.1 | 16.238 | 138.715 | 366.565 |
| 133 | Lunar Highlands Sim 026 no u/s 1.75/0.1 | 16.429 | 136.383 | 387.025 |
| | | | | |
| | Mean | 16.15 | 138.08 | 383.87 |
| | SD | 0.59 | 1.39 | 12.58 |
| | RSD | 3.65 | 1.01 | 3.28 |

**Table 6-3 Repeatability of measurements for 026 before sonication.**

It should be noted that, in a wet measurement, the same particles are being analyzed over multiple measurements because they repeatedly circulate past the detector. This means that the statistics over repeat measurements indicate the repeatability of the measurement and how the same aliquot of material behaves over time. In a dry measurement, a different set of particles is analyzed each time, meaning that statistics over measurements are an indicator of reproducibility instead of repeatability and give an indication of the homogeneity (or otherwise) of the material.

## 7. Discussion

An overplot of sample 121 measured dry at 4-bar and wet before sonication is shown in Figures 7-1.

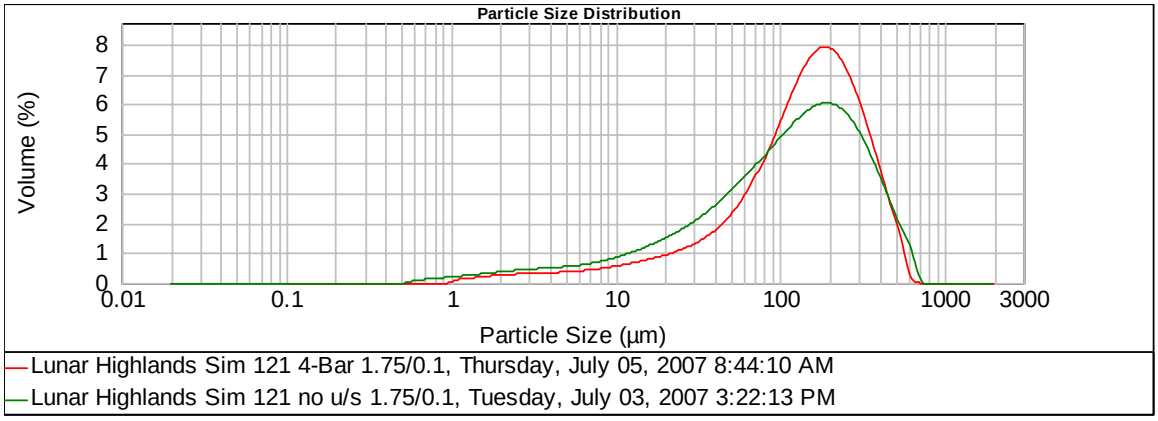


**Figure 7-1 Overplot of measurements for 121 measured dry (red) at 4-bar and wet (green) before sonication.**

The overall shape and range of the particle size results are similar when the wet and dry are compared. Wet measurement gives a somewhat broader distribution than dry measurement. Given the broad size range of this sample and possible reaction of the sample with water, the difference in results for the two measurement conditions is within expectations. 026 shows a similar wet/dry comparison.

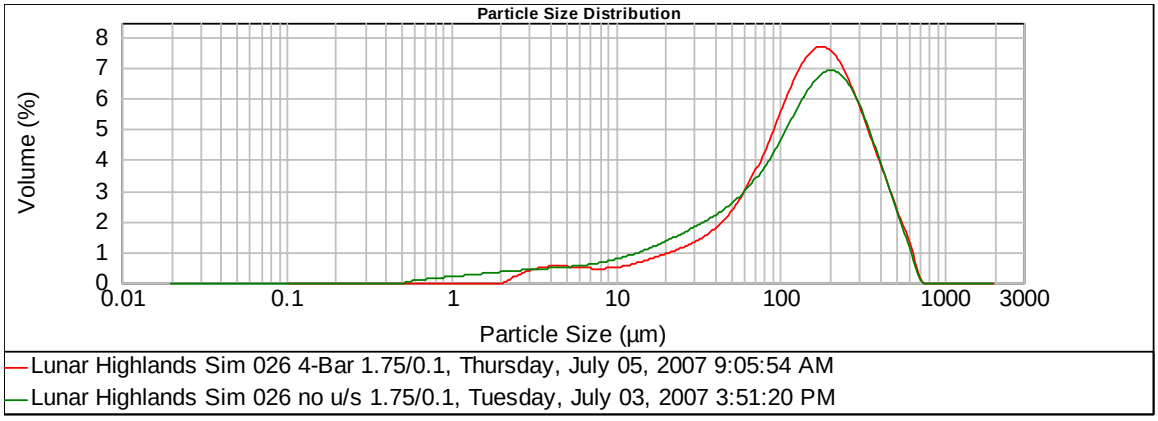


**Figure 7-2 Overplot of measurements for 026 measured dry (red) at 4-bar and wet (green) before sonication.**

Figure 7-3 shows an overlay of 121 and 026 measured dry at 4-bar disperser pressure.

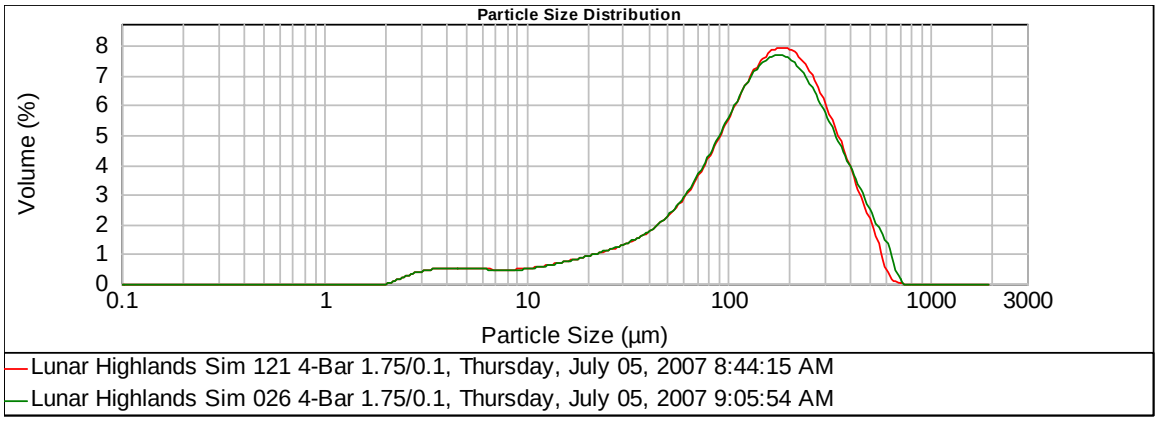


**Figure 7-3 Particle size distributions for 121 (red) and 026 (green) measured dry at 4-bar.**

The size distributions for the two samples are quite close as can be seen above and in the table below.

| Sample Name | d(0.1) | d(0.5) | d(0.9) |
|---|---|---|---|
| | | | |
| Lunar Highlands Sim 121 Avg | 27.7662 | 147.971 | 352.956 |
| Lunar Highlands Sim 026 Avg | 28.682 | 148.1353 | 364.1318 |

**Table 7-1 Average d(0.1), d(0.5) and d(0.9) values for 121 and 026 measured dry at 4-bar.**

## 8. Conclusions

The particle size distributions of the two samples are quickly and easily measured dry using the Mastersizer 2000.Wet measurements were also obtained successfully. Sampling of the material is important due to the broad range of particle sizes present in these samples.

Attached: Dry method development application note
Wet method development application note
Basic Principles of Particle Size Analysis

References: ISO 13320-1:1999 Particle Size Analysis – Laser Diffraction. Available from http://www.iso.ch with a credit card payment.
www.luxpop.com
Cho J.; Park J. *J. of Vacuum Science & Technology A.* 2007, **18**, 2, 329-333.
MgO Refractive Index. Harrick Optical Materials. www.harricksci.com.

Mae Gackstetter
Malvern Instruments Inc
5th July 2007

MASTERSIZER 2000

# Result Analysis Report

**Sample Name:**
Lunar Highlands Sim 121 4-Bar 1.75/0.1

**SOP Name:**

**Measured:**
Thursday, July 05, 2007 8:44:15 AM

**Sample Source & type:**

**Measured by:**
cmujat

**Analysed:**
Thursday, July 05, 2007 11:16:53 AM

**Sample bulk lot ref:**

**Result Source:**
Edited

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**Particle Name:**
1.75/0.1

**Accessory Name:**
Scirocco 2000

**Analysis model:**
General purpose

**Sensitivity:**
Normal

**Particle RI:**
1.750

**Absorption:**
0.1

**Size range:**
0.020 to 2000.000 um

**Obscuration:**
2.03 %

**Dispersant Name:**

**Dispersant RI:**
1.000

**Weighted Residual:**
0.785 %

**Result Emulation:**
Off

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**Concentration:**
0.0032 %Vol

**Span :**
2.174

**Uniformity:**
0.658

**Result units:**
Volume

**Specific Surface Area:**
0.121 m²/g

**Surface Weighted Mean D[3,2]:**
49.552 um

**Vol. Weighted Mean D[4,3]:**
172.914 um

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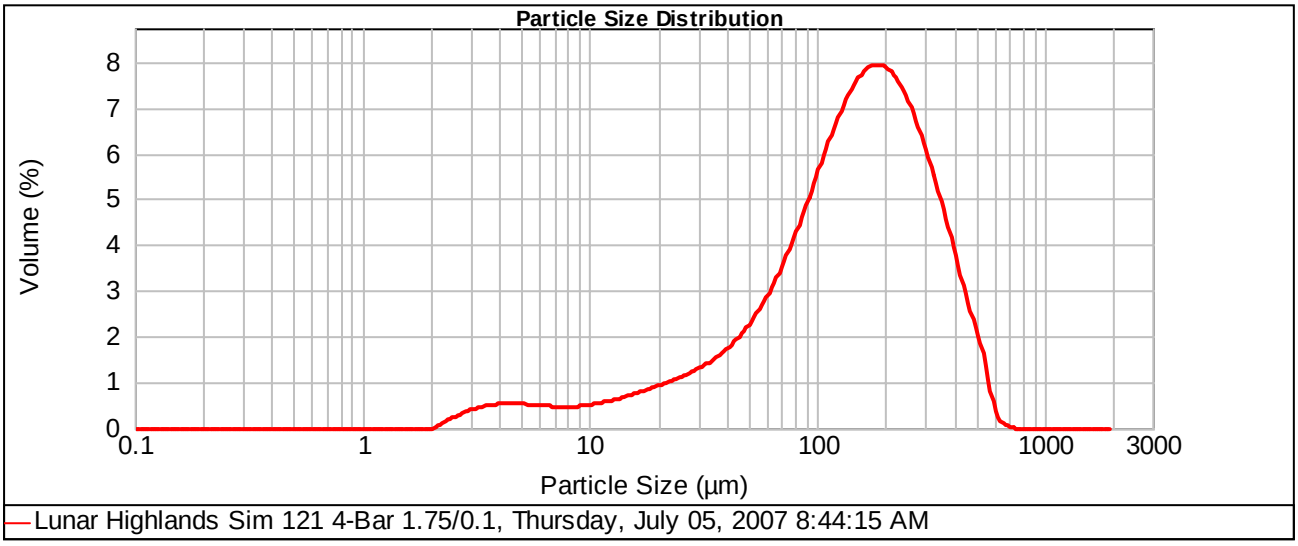
**d(0.1):** 28.288 um **d(0.5):** 148.629 um **d(0.9):** 351.391 um




| Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.010 | 0.00 | 0.105 | 0.00 | 1.096 | 0.00 | 11.482 | 0.54 | 120.226 | 6.28 | 1258.925 | 0.00 |
| 0.011 | 0.00 | 0.120 | 0.00 | 1.259 | 0.00 | 13.183 | 0.61 | 138.038 | 6.81 | 1445.440 | 0.00 |
| 0.013 | 0.00 | 0.138 | 0.00 | 1.445 | 0.00 | 15.136 | 0.70 | 158.489 | 7.11 | 1659.587 | 0.00 |
| 0.015 | 0.00 | 0.158 | 0.00 | 1.660 | 0.00 | 17.378 | 0.79 | 181.970 | 7.14 | 1905.461 | 0.00 |
| 0.017 | 0.00 | 0.182 | 0.00 | 1.905 | 0.00 | 19.953 | 0.88 | 208.930 | 6.88 | 2187.762 | 0.00 |
| 0.020 | 0.00 | 0.209 | 0.00 | 2.188 | 0.15 | 22.909 | 0.99 | 239.883 | 6.35 | 2511.886 | 0.00 |
| 0.023 | 0.00 | 0.240 | 0.00 | 2.512 | 0.27 | 26.303 | 1.11 | 275.423 | 5.61 | 2884.032 | 0.00 |
| 0.026 | 0.00 | 0.275 | 0.00 | 2.884 | 0.39 | 30.200 | 1.25 | 316.228 | 4.71 | 3311.311 | 0.00 |
| 0.030 | 0.00 | 0.316 | 0.00 | 3.311 | 0.45 | 34.674 | 1.44 | 363.078 | 3.74 | 3801.894 | 0.00 |
| 0.035 | 0.00 | 0.363 | 0.00 | 3.802 | 0.48 | 39.811 | 1.67 | 416.869 | 2.72 | 4365.158 | 0.00 |
| 0.040 | 0.00 | 0.417 | 0.00 | 4.365 | 0.49 | 45.709 | 1.97 | 478.630 | 1.83 | 5011.872 | 0.00 |
| 0.046 | 0.00 | 0.479 | 0.00 | 5.012 | 0.47 | 52.481 | 2.36 | 549.541 | 0.60 | 5754.399 | 0.00 |
| 0.052 | 0.00 | 0.550 | 0.00 | 5.754 | 0.45 | 60.256 | 2.85 | 630.957 | 0.07 | 6606.934 | 0.00 |
| 0.060 | 0.00 | 0.631 | 0.00 | 6.607 | 0.43 | 69.183 | 3.44 | 724.436 | 0.00 | 7585.776 | 0.00 |
| 0.069 | 0.00 | 0.724 | 0.00 | 7.586 | 0.42 | 79.433 | 4.12 | 831.764 | 0.00 | 8709.636 | 0.00 |
| 0.079 | 0.00 | 0.832 | 0.00 | 8.710 | 0.44 | 91.201 | 4.86 | 954.993 | 0.00 | 10000.000 | |
| 0.091 | 0.00 | 0.955 | 0.00 | 10.000 | 0.48 | 104.713 | 5.61 | 1096.478 | 0.00 | | |
| 0.105 | 0.00 | 1.096 | 0.00 | 11.482 | | 120.226 | | 1258.925 | | | |

**Operator notes:**

MASTERSIZER 2000

# Result Analysis Report

**Sample Name:**
Lunar Highlands Sim 026 4-Bar 1.75/0.1

**SOP Name:**

**Measured:**
Thursday, July 05, 2007 9:05:45 AM

**Sample Source & type:**

**Measured by:**
cmujat

**Analysed:**
Thursday, July 05, 2007 11:27:29 AM

**Sample bulk lot ref:**

**Result Source:**
Edited

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**Particle Name:**
1.75/0.1

**Accessory Name:**
Scirocco 2000

**Analysis model:**
General purpose

**Sensitivity:**
Normal

**Particle RI:**
1.750

**Absorption:**
0.1

**Size range:**
0.020 to 2000.000 um

**Obscuration:**
2.11 %

**Dispersant Name:**

**Dispersant RI:**
1.000

**Weighted Residual:**
0.434 %

**Result Emulation:**
Off

---

**Concentration:**
0.0033 %Vol

**Span :**
2.244

**Uniformity:**
0.68

**Result units:**
Volume

**Specific Surface Area:**
0.121 m²/g

**Surface Weighted Mean D[3,2]:**
49.527 um

**Vol. Weighted Mean D[4,3]:**
173.821 um

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**d(0.1):** 28.507 um **d(0.5):** 146.630 um **d(0.9):** 357.525 um

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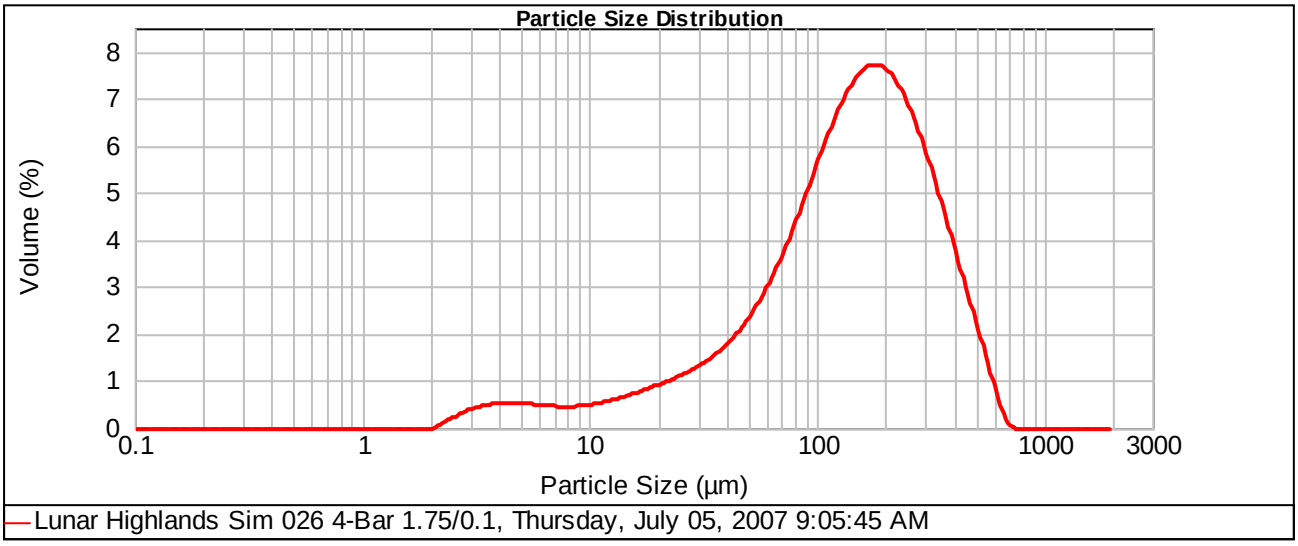


| Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.010 | 0.00 | 0.105 | 0.00 | 1.096 | 0.00 | 11.482 | 0.53 | 120.226 | 6.26 | 1258.925 | 0.00 |
| 0.011 | 0.00 | 0.120 | 0.00 | 1.259 | 0.00 | 13.183 | 0.61 | 138.038 | 6.71 | 1445.440 | 0.00 |
| 0.013 | 0.00 | 0.138 | 0.00 | 1.445 | 0.00 | 15.136 | 0.69 | 158.489 | 6.95 | 1659.587 | 0.00 |
| 0.015 | 0.00 | 0.158 | 0.00 | 1.660 | 0.00 | 17.378 | 0.78 | 181.970 | 6.93 | 1905.461 | 0.00 |
| 0.017 | 0.00 | 0.182 | 0.00 | 1.905 | 0.00 | 19.953 | 0.88 | 208.930 | 6.65 | 2187.762 | 0.00 |
| 0.020 | 0.00 | 0.209 | 0.00 | 2.188 | 0.15 | 22.909 | 0.99 | 239.883 | 6.12 | 2511.886 | 0.00 |
| 0.023 | 0.00 | 0.240 | 0.00 | 2.512 | 0.27 | 26.303 | 1.12 | 275.423 | 5.42 | 2884.032 | 0.00 |
| 0.026 | 0.00 | 0.275 | 0.00 | 2.884 | 0.39 | 30.200 | 1.28 | 316.228 | 4.58 | 3311.311 | 0.00 |
| 0.030 | 0.00 | 0.316 | 0.00 | 3.311 | 0.45 | 34.674 | 1.47 | 363.078 | 3.69 | 3801.894 | 0.00 |
| 0.035 | 0.00 | 0.363 | 0.00 | 3.802 | 0.48 | 39.811 | 1.73 | 416.869 | 2.79 | 4365.158 | 0.00 |
| 0.040 | 0.00 | 0.417 | 0.00 | 4.365 | 0.48 | 45.709 | 2.05 | 478.630 | 1.90 | 5011.872 | 0.00 |
| 0.046 | 0.00 | 0.479 | 0.00 | 5.012 | 0.47 | 52.481 | 2.46 | 549.541 | 0.98 | 5754.399 | 0.00 |
| 0.052 | 0.00 | 0.550 | 0.00 | 5.754 | 0.44 | 60.256 | 2.97 | 630.957 | 0.18 | 6606.934 | 0.00 |
| 0.060 | 0.00 | 0.631 | 0.00 | 6.607 | 0.42 | 69.183 | 3.57 | 724.436 | 0.00 | 7585.776 | 0.00 |
| 0.069 | 0.00 | 0.724 | 0.00 | 7.586 | 0.42 | 79.433 | 4.24 | 831.764 | 0.00 | 8709.636 | 0.00 |
| 0.079 | 0.00 | 0.832 | 0.00 | 8.710 | 0.43 | 91.201 | 4.95 | 954.993 | 0.00 | 10000.000 | |
| 0.091 | 0.00 | 0.955 | 0.00 | 10.000 | 0.47 | 104.713 | 5.65 | 1096.478 | 0.00 | | |
| 0.105 | 0.00 | 1.096 | 0.00 | 11.482 | | 120.226 | | 1258.925 | 0.00 | | |

**Operator notes:**

MASTERSIZER 2000

# Result Analysis Report

**Sample Name:**
Lunar Highlands Sim 121 no u/s 1.75/0.1

**SOP Name:**

**Measured:**
Tuesday, July 03, 2007 3:22:13 PM

**Sample Source & type:**

**Measured by:**
cmujat

**Analysed:**
Thursday, July 05, 2007 11:51:59 AM

**Sample bulk lot ref:**

**Result Source:**
Edited

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**Particle Name:**
1.75/0.1

**Accessory Name:**
Hydro 2000S (A)

**Analysis model:**
General purpose

**Sensitivity:**
Normal

**Particle RI:**
1.750

**Absorption:**
0.1

**Size range:**
0.020 to 2000.000 um

**Obscuration:**
5.28 %

**Dispersant Name:**
Water

**Dispersant RI:**
1.330

**Weighted Residual:**
0.573 %

**Result Emulation:**
Off

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**Concentration:**
0.0156 %Vol

**Span :**
2.875

**Uniformity:**
0.886

**Result units:**
Volume

**Specific Surface Area:**
0.252 m²/g

**Surface Weighted Mean D[3,2]:**
23.837 um

**Vol. Weighted Mean D[4,3]:**
157.704 um

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**d(0.1):** 14.336 um **d(0.5):** 120.048 um **d(0.9):** 359.425 um

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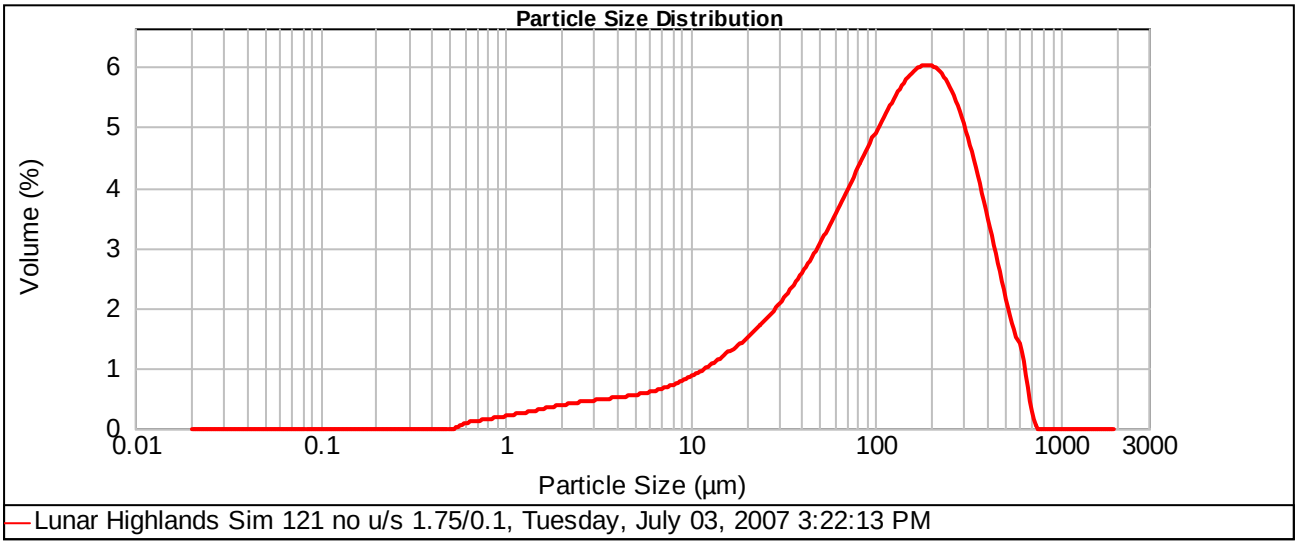


| Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.010 | 0.00 | 0.105 | 0.00 | 1.096 | 0.22 | 11.482 | 0.91 | 120.226 | 5.00 | 1258.925 | 0.00 |
| 0.011 | 0.00 | 0.120 | 0.00 | 1.259 | 0.25 | 13.183 | 1.02 | 138.038 | 5.25 | 1445.440 | 0.00 |
| 0.013 | 0.00 | 0.138 | 0.00 | 1.445 | 0.28 | 15.136 | 1.14 | 158.489 | 5.41 | 1659.587 | 0.00 |
| 0.015 | 0.00 | 0.158 | 0.00 | 1.660 | 0.32 | 17.378 | 1.28 | 181.970 | 5.45 | 1905.461 | 0.00 |
| 0.017 | 0.00 | 0.182 | 0.00 | 1.905 | 0.35 | 19.953 | 1.42 | 208.930 | 5.34 | 2187.762 | 0.00 |
| 0.020 | 0.00 | 0.209 | 0.00 | 2.188 | 0.38 | 22.909 | 1.59 | 239.883 | 5.07 | 2511.886 | 0.00 |
| 0.023 | 0.00 | 0.240 | 0.00 | 2.512 | 0.40 | 26.303 | 1.77 | 275.423 | 4.64 | 2884.032 | 0.00 |
| 0.026 | 0.00 | 0.275 | 0.00 | 2.884 | 0.42 | 30.200 | 1.97 | 316.228 | 4.06 | 3311.311 | 0.00 |
| 0.030 | 0.00 | 0.316 | 0.00 | 3.311 | 0.44 | 34.674 | 2.19 | 363.078 | 3.39 | 3801.894 | 0.00 |
| 0.035 | 0.00 | 0.363 | 0.00 | 3.802 | 0.46 | 39.811 | 2.44 | 416.869 | 2.67 | 4365.158 | 0.00 |
| 0.040 | 0.00 | 0.417 | 0.00 | 4.365 | 0.48 | 45.709 | 2.72 | 478.630 | 1.94 | 5011.872 | 0.00 |
| 0.046 | 0.00 | 0.479 | 0.00 | 5.012 | 0.51 | 52.481 | 3.01 | 549.541 | 1.32 | 5754.399 | 0.00 |
| 0.052 | 0.00 | 0.550 | 0.06 | 5.754 | 0.55 | 60.256 | 3.33 | 630.957 | 0.40 | 6606.934 | 0.00 |
| 0.060 | 0.00 | 0.631 | 0.10 | 6.607 | 0.59 | 69.183 | 3.67 | 724.436 | 0.00 | 7585.776 | 0.00 |
| 0.069 | 0.00 | 0.724 | 0.13 | 7.586 | 0.65 | 79.433 | 4.02 | 831.764 | 0.00 | 8709.636 | 0.00 |
| 0.079 | 0.00 | 0.832 | 0.16 | 8.710 | 0.73 | 91.201 | 4.37 | 954.993 | 0.00 | 10000.000 | |
| 0.091 | 0.00 | 0.955 | 0.19 | 10.000 | 0.81 | 104.713 | 4.70 | 1096.478 | 0.00 | | |
| 0.105 | 0.00 | 1.096 | | 11.482 | | 120.226 | | 1258.925 | 0.00 | | |

**Operator notes:**

MASTERSIZER 2000

# Result Analysis Report

**Sample Name:**
Lunar Highlands Sim 026 no u/s 1.75/0.1

**SOP Name:**

**Measured:**
Tuesday, July 03, 2007 3:51:20 PM

**Sample Source & type:**

**Measured by:**
cmujat

**Analysed:**
Thursday, July 05, 2007 11:53:38 AM

**Sample bulk lot ref:**

**Result Source:**
Edited

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**Particle Name:**
1.75/0.1

**Accessory Name:**
Hydro 2000S (A)

**Analysis model:**
General purpose

**Sensitivity:**
Normal

**Particle RI:**
1.750

**Absorption:**
0.1

**Size range:**
0.020 to 2000.000 um

**Obscuration:**
5.52 %

**Dispersant Name:**
Water

**Dispersant RI:**
1.330

**Weighted Residual:**
0.343 %

**Result Emulation:**
Off

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**Concentration:**
0.0177 %Vol

**Span :**
2.526

**Uniformity:**
0.779

**Result units:**
Volume

**Specific Surface Area:**
0.233 m²/g

**Surface Weighted Mean D[3,2]:**
25.768 um

**Vol. Weighted Mean D[4,3]:**
168.484 um

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**d(0.1):** 16.238 um **d(0.5):** 138.715 um **d(0.9):** 366.565 um

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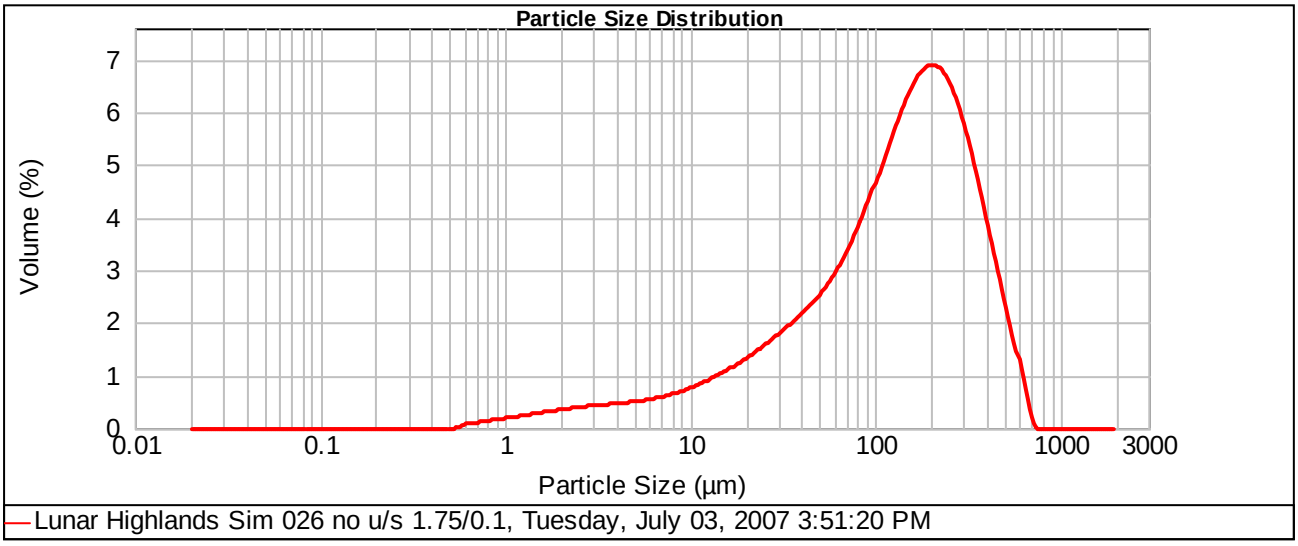


| Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % | Size (µm) | Volume In % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.010 | 0.00 | 0.105 | 0.00 | 1.096 | 0.20 | 11.482 | 0.81 | 120.226 | 5.21 | 1258.925 | 0.00 |
| 0.011 | 0.00 | 0.120 | 0.00 | 1.259 | 0.23 | 13.183 | 0.91 | 138.038 | 5.69 | 1445.440 | 0.00 |
| 0.013 | 0.00 | 0.138 | 0.00 | 1.445 | 0.26 | 15.136 | 1.02 | 158.489 | 6.04 | 1659.587 | 0.00 |
| 0.015 | 0.00 | 0.158 | 0.00 | 1.660 | 0.29 | 17.378 | 1.14 | 181.970 | 6.22 | 1905.461 | 0.00 |
| 0.017 | 0.00 | 0.182 | 0.00 | 1.905 | 0.32 | 19.953 | 1.27 | 208.930 | 6.16 | 2187.762 | 0.00 |
| 0.020 | 0.00 | 0.209 | 0.00 | 2.188 | 0.35 | 22.909 | 1.41 | 239.883 | 5.86 | 2511.886 | 0.00 |
| 0.023 | 0.00 | 0.240 | 0.00 | 2.512 | 0.37 | 26.303 | 1.55 | 275.423 | 5.33 | 2884.032 | 0.00 |
| 0.026 | 0.00 | 0.275 | 0.00 | 2.884 | 0.39 | 30.200 | 1.71 | 316.228 | 4.60 | 3311.311 | 0.00 |
| 0.030 | 0.00 | 0.316 | 0.00 | 3.311 | 0.41 | 34.674 | 1.87 | 363.078 | 3.77 | 3801.894 | 0.00 |
| 0.035 | 0.00 | 0.363 | 0.00 | 3.802 | 0.43 | 39.811 | 2.04 | 416.869 | 2.91 | 4365.158 | 0.00 |
| 0.040 | 0.00 | 0.417 | 0.00 | 4.365 | 0.45 | 45.709 | 2.25 | 478.630 | 2.05 | 5011.872 | 0.00 |
| 0.046 | 0.00 | 0.479 | 0.00 | 5.012 | 0.47 | 52.481 | 2.49 | 549.541 | 1.24 | 5754.399 | 0.00 |
| 0.052 | 0.00 | 0.550 | 0.05 | 5.754 | 0.50 | 60.256 | 2.80 | 630.957 | 0.32 | 6606.934 | 0.00 |
| 0.060 | 0.00 | 0.631 | 0.10 | 6.607 | 0.54 | 69.183 | 3.17 | 724.436 | 0.00 | 7585.776 | 0.00 |
| 0.069 | 0.00 | 0.724 | 0.12 | 7.586 | 0.59 | 79.433 | 3.61 | 831.764 | 0.00 | 8709.636 | 0.00 |
| 0.079 | 0.00 | 0.832 | 0.15 | 8.710 | 0.65 | 91.201 | 4.12 | 954.993 | 0.00 | 10000.000 | |
| 0.091 | 0.00 | 0.955 | 0.18 | 10.000 | 0.72 | 104.713 | 4.67 | 1096.478 | 0.00 | | |
| 0.105 | 0.00 | 1.096 | | 11.482 | | 120.226 | | 1258.925 | 0.00 | | |

**Operator notes:**