LA-UR-17-22159

Approved for public release; distribution is unlimited.

Title: (U) Utility of Average Particle Diameter Diagnostic in Ejecta Physics Experiments

Author(s): Wood, William Monford

Intended for: Working group presentation

Issued: 2017-03-14

Disclaimer:

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Utility of APDD:

(U) Utility of Average Particle Diameter Diagnostic in Ejecta Physics Experiments

Wm. M. Wood
Physics Division, P-23
LANL
March 13, 2017

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Outline

- Context: Interest in Particle Size Distributions
- Background on Distributions and What We Measure
- Definition of APDD
- Examples for known particle size distributions
- Calculated APDD for “Uni-sized” particles
- Problems with the APDD number
- How can we take the concept and make it more useful?
- 2D measurements / Time series measurements
- Aside: “Fredholm Integral I” problems
- Parameterized solutions provide “bins”
- Is there significant mass in particles below the diffraction limit?
- Two color optical transmission can answer this.
- Conclusions

Utility of APDD:

Information of Interest for Ejecta Experiments

Ultimately, we want to understand the size distribution of ejecta: (Data from D. Sorenson holography, Sn sheet breakup, 300 kbar) *We are limited by optical diffraction limit ...*

Distribution of *spherical* particles, $N(R)$ gives number of particles with radius “ R ” (we can *calculate* Mie solution ...)

$$\int_0^{\infty} N(R) dR \equiv N_0 \quad \text{Total Number of particles}$$

$$N_0 \langle R \rangle \equiv \int_0^{\infty} R \cdot N(R) dR \quad \text{“First Moment” = Average particle size}$$

$$N_0 \langle R^2 \rangle \equiv \int_0^{\infty} R^2 \cdot N(R) dR$$

$$N_0 \langle R^3 \rangle \equiv \int_0^{\infty} R^3 \cdot N(R) dR$$

Utility of APDD:

Radiographic Mass Measurement

Along a line-of-sight (*spherical*):

$$(\rho R) = \int_{\text{Sizes}} dR \int_{\text{line-of-sight}} \frac{4}{3} \pi R^3 \rho_o N(R, \mathbf{Z}) ds$$

$$(\rho R) = \frac{4}{3} \pi \rho_o N_{\text{total}} \langle R^3 \rangle$$

Utility of APDD:

Optical Transmission Measurement I

Along a line-of-sight (*spherical particles*):

$$T = \text{EXP} \left[- \int_{\text{line-of-sight}} \sigma_{NA}(R) N(R, \mathbf{Z}) ds \right]$$

$$\sigma_{R\text{-big}} \sim 2\pi R^2$$

$$T = \text{EXP} \left[- \int_{\text{line-of-sight}} W(R) 2\pi R^2 N(R, Z) dZ \right]$$

$$-\ln(T) \approx 2\pi N_{\text{total}} \langle R^2 \rangle = 2\pi N_{\text{total}} \langle W(R) R^2 \rangle$$

Utility of APDD:

Optical Transmission Measurement II

Along a line-of-sight (*spherical particles*):

$$T = \text{EXP} \left[- \int_{\text{line-of-sight}} W(R) 2\pi R^2 N(R, Z) dZ \right]$$
$$\sigma_{R\text{-big}} \sim 2\pi R^2$$

Utility of APDD:

Definition of APDD

Based on the large particle radius behavior for optical scattering, we can write:

$$\frac{3\rho R}{-2\rho_o \ln(T)} \approx \frac{\langle R^3 \rangle}{\langle R^2 \rangle} = \frac{\langle R^3 \rangle}{\langle W(R)R^2 \rangle}$$

This ratio defines the APDD in terms of quantities that we routinely measure (i.e. radiographic transmission, or mass, and optical transmission.)

Utility of APDD:

Examples for known particle size distributions

$$N(R) = \frac{1}{\sqrt{2\pi} R \sigma} e^{-\frac{(\ln R - \mu)^2}{2\sigma^2}}$$

$$\langle R \rangle = e^{\mu + \frac{\sigma^2}{2}}$$

$$\frac{\langle R^3 \rangle}{\langle R^2 \rangle} = e^{\mu + \frac{5\sigma^2}{2}} \equiv e^{2\sigma^2} \langle R \rangle$$

$$N(R) = \begin{cases} (n-1)R_{\min}^{n-1}R^{-n} \rightarrow R \geq R_{\min}; n \geq 3 \\ 0 \rightarrow R < R_{\min} \end{cases}$$

$$\langle R \rangle = \frac{(n-1)}{(n-2)} R_{\min}$$

$$\frac{\langle R^3 \rangle}{\langle R^2 \rangle} = \frac{(n-3)}{(n-4)} R_{\min} = \frac{(n-3)}{(n-4)} \frac{(n-2)}{(n-1)} \langle R \rangle; n \geq 5$$

Utility of APDD: Calculated APDD for “Uni-sized” particles

Utility of APDD:

Problems with the APDD number

- For an absorptive material (e.g. metal) the value *for uni-sized particles* has multiple size solutions over limited range
- For a refractory material (e.g. metal-oxide) the value *for uni-sized particles* has multiple size solutions over entire range
- Value is dominated by large size contribution
- Lack of knowledge of distribution *severely* hampers quantitative interpretation

Utility of APDD:

2D measurements / Time series measurements

- In 2D (i.e. an image,) trends in APDD *might* provide physical insight (This amounts to a spatial averaging.)
- In Time series measurements, similar results would be observed...

Utility of APDD:

How can we take the concept and make it more useful?

Development of routine measurement for radiography and optical transmission through ejecta suggests greater utility with *two-color optical transmission measurement* – an *incremental* change to current measurements!

Utility of APDD:

Aside: “Fredholm Integral I”

Fredholm Integral Equation of the First Kind

$$d_i = \int_{Energy} F_i(E) \times S(E) dE$$

$S(E)$ is the Spectrum or distribution of interest

$F_i(E)$ are the Filter/Detector responses

d_i are the Data

Utility of APDD:

Parameterized solutions provide “bins”

8 filters + “No” filter = 9 yield 9 bins

2 filters yield 2 bins!

Utility of APDD:

Is there significant mass in particles below the diffraction limit?

2 “filters” (e.g. Transmission at 500 nm and 800 nm wavelength) create bin boundary $\sim 10^{-7}$ m radius!

Utility of APDD:

Examples of 2-color Expected Results I

For a test particle size distribution with some particles below $R=10^{-7}$ m radius, and some particles above $R=10^{-7}$ m, plot of expected transmission results.

Utility of APDD: Examples of 2-color Expected Results II

Bimodal Square Distribution 2 micron max

Const 2 μ m: T vs. Mass Ratio (small/large) for Sn for Various ρR

Bimodal Square Distribution 20 micron max

Const 20 μ m: T vs. Mass Ratio (small/large) for Sn for Various ρR

Utility of APDD:

Relation to Livermore “Multi Wavelength Extinction” (MWE)

MWE proposes measurement at 8 wavelengths. Potentially increases our knowledge, but much more difficult to demonstrate.

Utility of APDD: Conclusions

- Our interest in ejecta particle sizes drives experimental efforts;
- The Average Particle Diameter Dagnostic (APDD,) though tantalizing, provides little in the way of quantitative information directly. (Note that, as we learn more about distributions, use of APDD as an adjunct in retrospect can be useful.)
- With minor modification, i.e. *two* color optical transmission, we can get significant information about the particle size distribution (note that radiography not necessary for size information...)