Best Practices for Filter Media Analysis: Using ANSI/AWWA B100 for improved specification & filter maintenance development

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Background

- Research Assistant – BSU Advanced Materials Lab
  - Surrogate fuels for nuclear reactors, ceramic nano-powders
  - Particle Size Analyzer (PSA), sampling & analyzing methods
- New Product Development Engineer
  - $20+ million job, media specification issues
  - Worked with manufacturer, engineer, contractor & owner

Learning Objectives

As a result of this presentation, you will be able to:

1. **Understand the key components of the often overlooked process of sieve analysis.**

2. **Identify the most influential factors that affect particle size distribution results.**

3. **Implement recommended procedures from AWWA B100 and various ASTM Standards.**

4. **Provide an outline for filter media sieve analysis procedures to ensure accurate and repeatable results, improving overall filter maintenance programs.**

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AWWA B100 Background

- Granular filter media standard since 1950
- References NSF, ANSI, and ASTM standards
- B100 procedures take precedence to referenced standards
- Not valid for Granular Activated Carbon (GAC)
  - See ANSI/AWWA B604
- Open for interpretation in many statements and recommended procedures

Definitions

- ***Particle Size Distribution*** *– Various size and dimension range description of a filter material determined by standard sieve analysis procedures.*

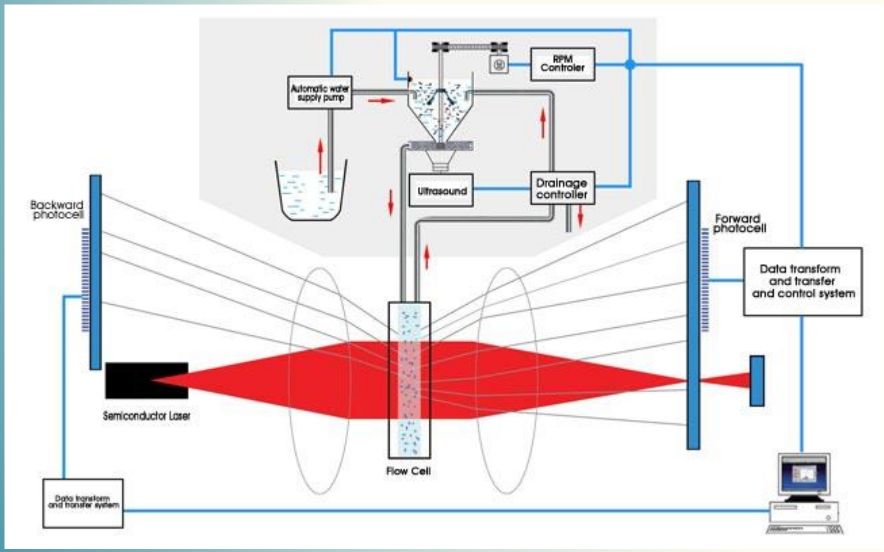
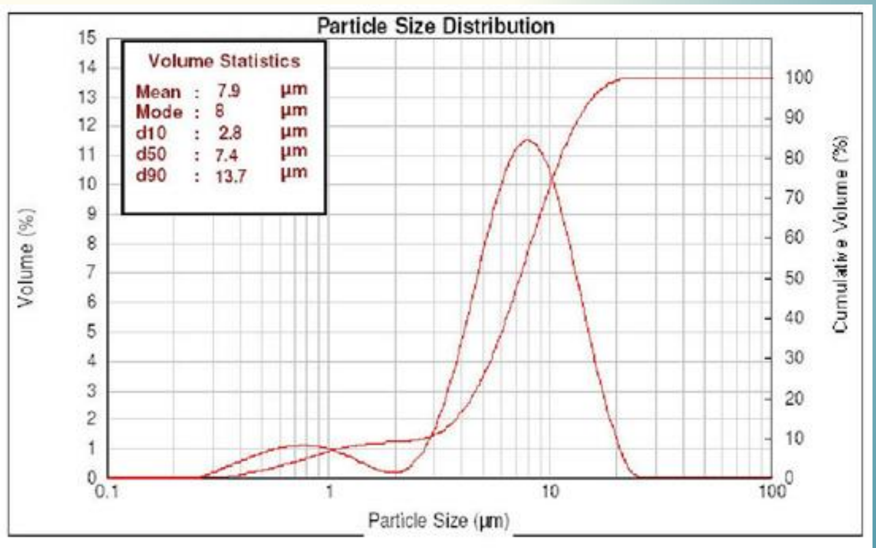


Image courtesy of http://www.analizator.su/



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Definitions

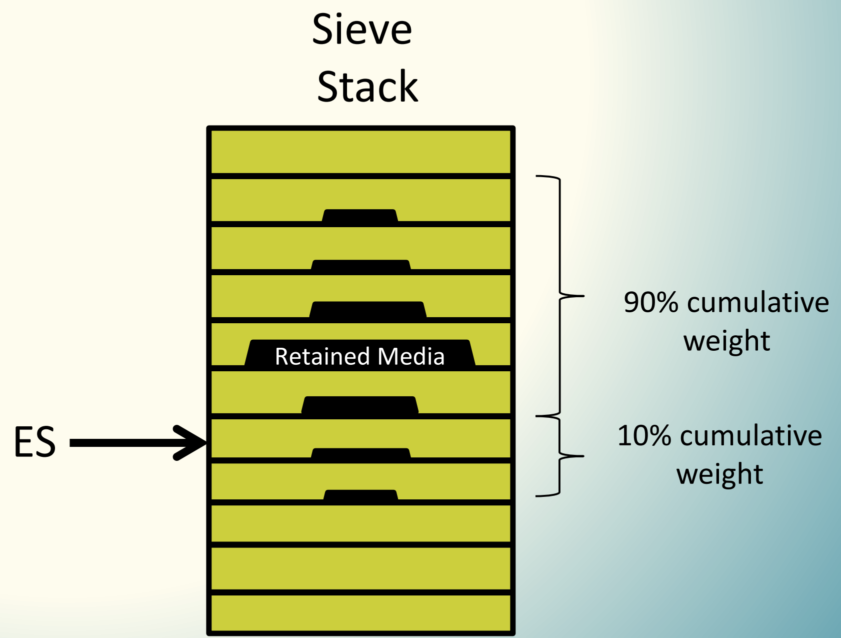
- **<u>Sieve Analysis</u>** – The method by which a dry aggregate of known mass is separated through a series of sieves of progressively smaller openings for determination of particle size distribution.
  - In accordance with ASTM C136, as modified and supplemented by AWWA B100.

- **<u>Sieve Calibration</u>** – A process of verifying the sieve mesh cloth is within allowable tolerances of nominal sizing, either by manufacturer certification or using standard reference material.
  - In accordance with ASTM E11, as modified and supplemented by AWWA B100

What is Effective Size?

Effective Size (ES) - *The screen aperture size which <u>10 percent</u> of a sample will pass (by dry weight).*

Typical specification → sand ES = 0.55 – 0.65 mm, anthracite ES = 1.0 – 1.1 mm

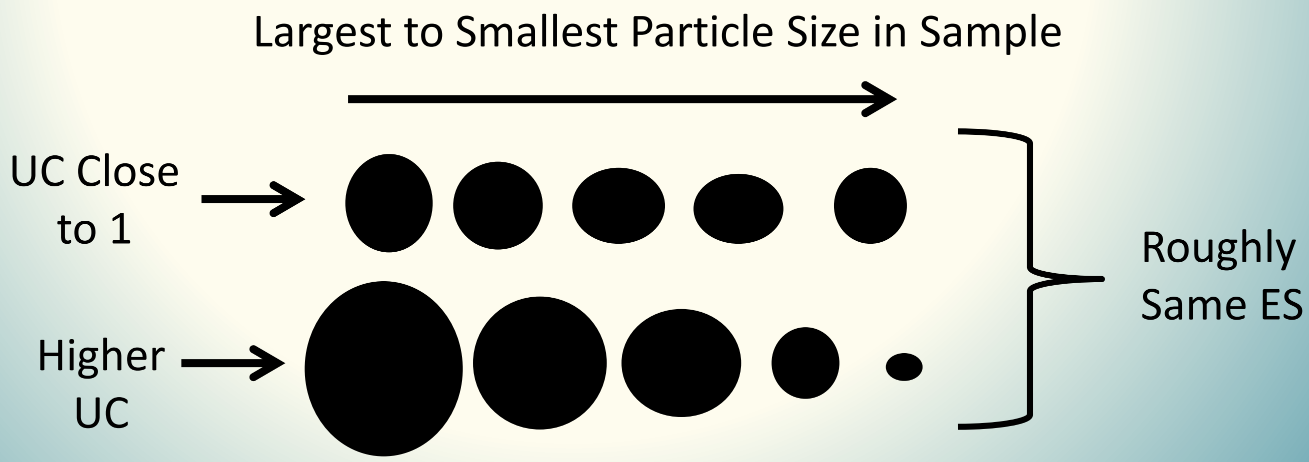


ES = D_{10}

What is Uniformity Coefficient?

Uniformity Coefficient (UC) *- A ratio of the 60 percent and 10 percent passing aperture size (by dry weight). A relative measure of size between largest and smallest particles – 1.0 would be completely uniform and nearly impossible to achieve.*

- *Typical specification → sand & anthracite UC < 1.5*



$UC = D_{60}/D_{10}$

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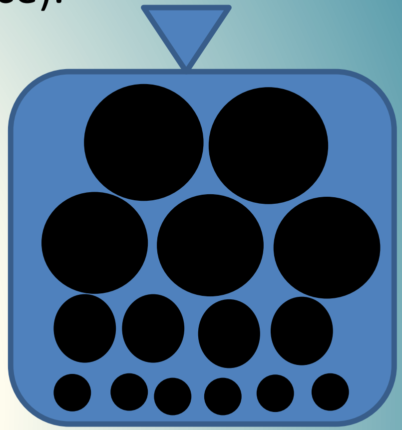
Key Parameters

- ❑Sample Method
- ❑Sample Size
- ❑Sieve Calibration
- ❑Analysis Method

Sample Method

Sampling Factors

- Sample directly off mesh screens at manufacturer's site (best practice).
  - Cross-sectional sampling while loaded into bags/cars
- Transit to jobsite leads to particle segregation
  - Fines tend to settle at bottom.
  - Do not scoop samples from top or collect exclusively from one area.
- Anthracite grains more brittle and susceptible to size degradation
  - Different media probes used for sand and anthracite.
- Make sure media does not fall back into hole which media probe is sampling (Anthracite)
  - Broken grains produce artificial results (smaller)
- Avoid splitting sacks between filter cells.
  - Unload entire sack into cell



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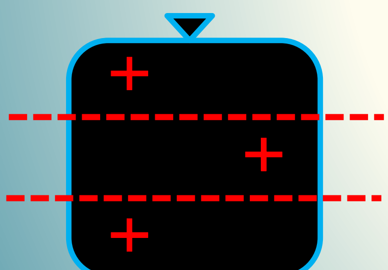
Bag Sampling Method

Supplies Needed

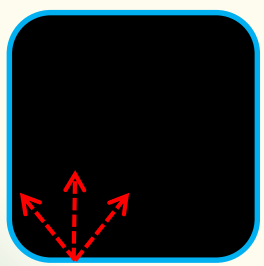
- Permanent Marker
- Plastic Sandwich bags
- Grain Thief (sand) / 3” thin-walled steel pipe (anthracite)
- Rubber Mallet
- Duct Tape
- Running water (anthracite)

Sand Super-Sack



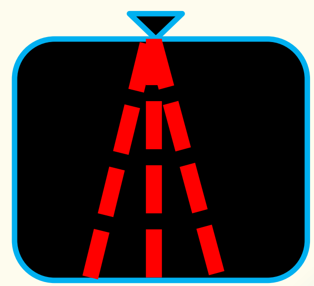
Sample from each third of bag, away from middle of sack

FRONT VIEW



Sample from three directions in each hole

TOP VIEW



Sample three vertical angles

SIDE VIEW

Anthracite Super-Sack

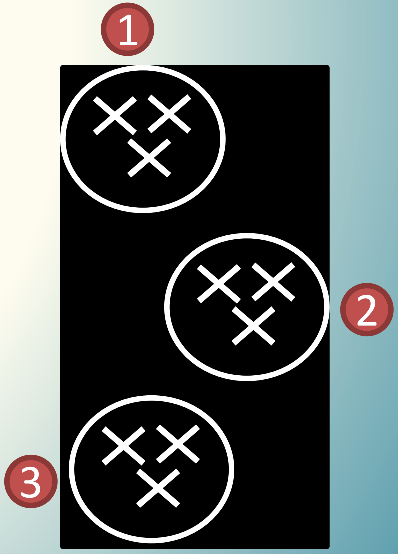
Filter Sampling Method

Supplies Needed

- 4’ x 4’ Plywood
- Golf Tube or thin PVC – 1.5” D
- Sand paper – rough up inside of tube
- Individual plastic sandwich bags
- Permanent marker

Procedure

- Mark each bag in 6” increments, starting at 0”- 6”
- Mark the tube in 6” increments (use Whiteout)
- Place plywood in filter as sampling base
- Use tube to sample first 6” (lightly twist and push down)
- Place sample in bag, continue to media interface
- Sample from 3 locations (combine like-depth samples) from 3 areas within the filter



Key Parameters

- ❌ Sample Method
- ❑ Sample Size
- ❑ Sieve Calibration
- ❑ Analysis Method

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Sample Size

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B100 Sample Size Criteria

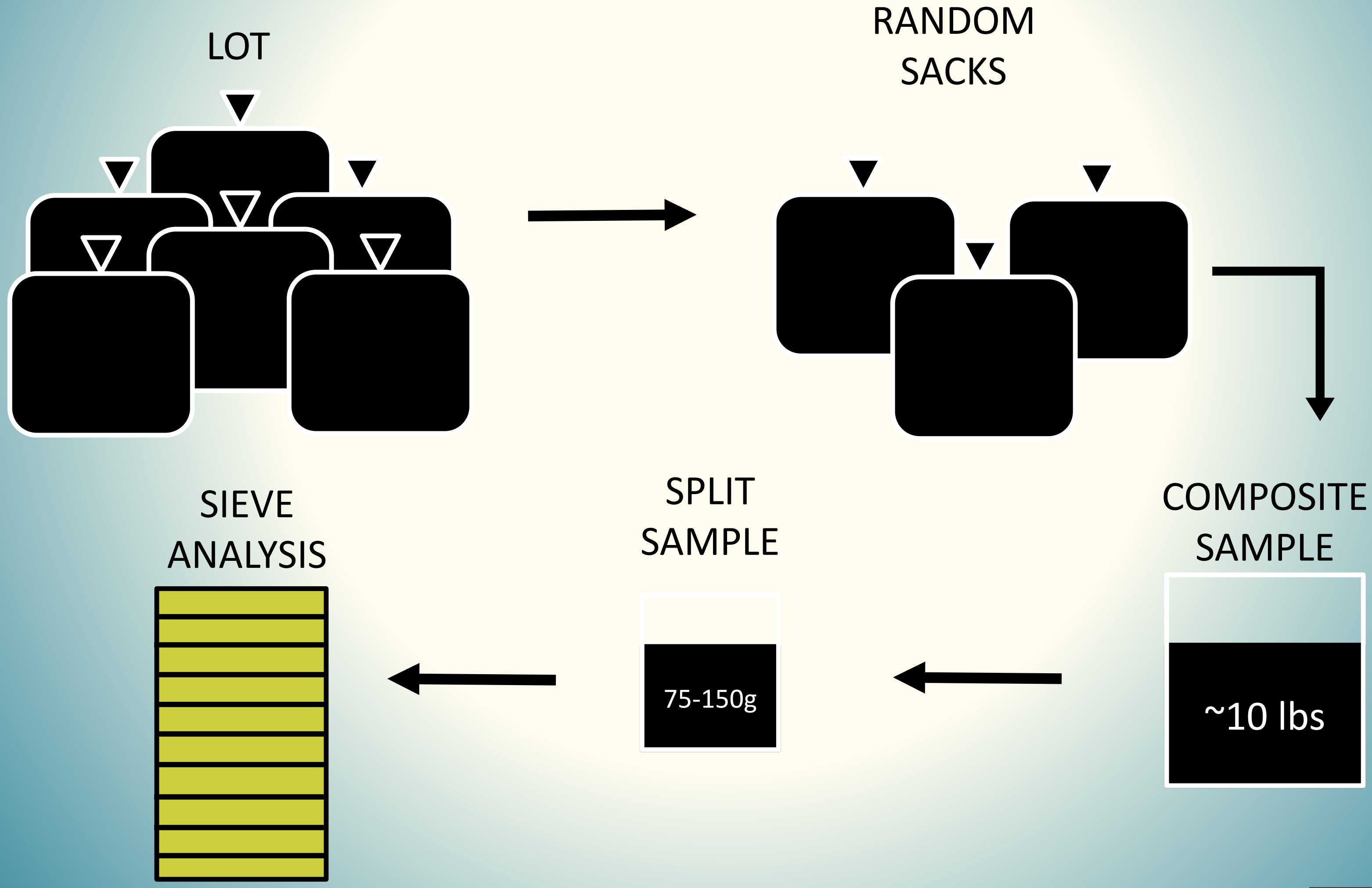
- Lot Size Determination - Supplier and contractor must agree upon lot size.
  - More samples to analyze = more $$$.
  - Large lots, risk rejecting a lot of good material.

- Random Bags - Number of bags to be sampled in composite sample based upon number of bags in lot (Table 4, Section 5).
  - Lot Size = 26 – 50 bags → Sample at least 5 bags from each lot

- Composite sample - Maximum particle size determines minimum sample size, by weight (Table 3, Section 5).
  - Particles 3/8” and smaller → at least 10 lb composite sample

- Sieve Sample - Total weight for sieve analysis (Table 6, Section 5). Use mechanical splitter to divide composite sample into sieve weight required.
  - Particles 2.36 mm or less → 0.17 – 0.3 lb (75-150 g)

Sample Size



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Key Parameters

- ✖ Sample Method
- ✖ Sample Size
- ❑ Sieve Calibration
- ❑ Analysis Method

Sieve Calibration

AWWA B100 Statements

- *"For precise work, sieves should be calibrated annually according to procedures in ASTM E11…"* [1]
- *"If questions of compliance arise when nominal standard sieve openings are used, standard reference materials (glass spheres) certified by the National Institute of Standards and Technology should be used in accordance with their calibration procedure…"* [1]
- *"If standard reference material for calibration is not used, the data shall be replotted using both the maximum and minimum permissible variation of the average opening from the standard sieve designation as shown in Table 1, column 4 of ASTM E11…The material shall be in compliance if either of the plots agree with the purchaser's specifications."* [1]
  - **AWWA B100 values do not match ASTM E11 values for permissible variation. These values were given as percent variation prior to latest revision in 2010. Use B100 table values.**

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Calibration Methods

- **Glass spheres** - Standard reference material provided by National Institute of Standards and Technology (NIST).
  - Accuracy ± 1 µm
- **Optically Measure** – Independently measure or have a certified lab measure.
- **Master Calibrated Sieve Stack** – Run analysis and check against.
- **Certified Calibrated Reference Sample** – Run analysis and check against.
- **Purchase new certified sieves**
  - Test Sieve Grades [4]
    - ***Compliance (66%)*** – manufactured and inspected to be in compliance with Specification E11, standard test sieve.
    - ***Inspection (99%)*** – average aperture size, certificate requires inspection data.
    - ***Calibration** (99.73%)* – number of aperture and wire diameters measured, average aperture size, standard deviation and average wire diameter, certificate requires inspection data.

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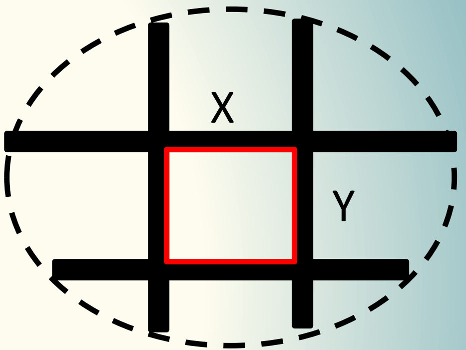
Aperture Sizing

- ***Aperture*** **–** *the dimension defining an opening in a screening surface.* [4]
- Compliance Sieve
  - Standard, mesh measured before mounted in frame
- Inspection Sieve
  - Mesh measured after mounted in frame
- Calibrated
  - Includes certificate listing the actual aperture size to 0.1 µm



$$Z = \frac{X + Y}{2}$$

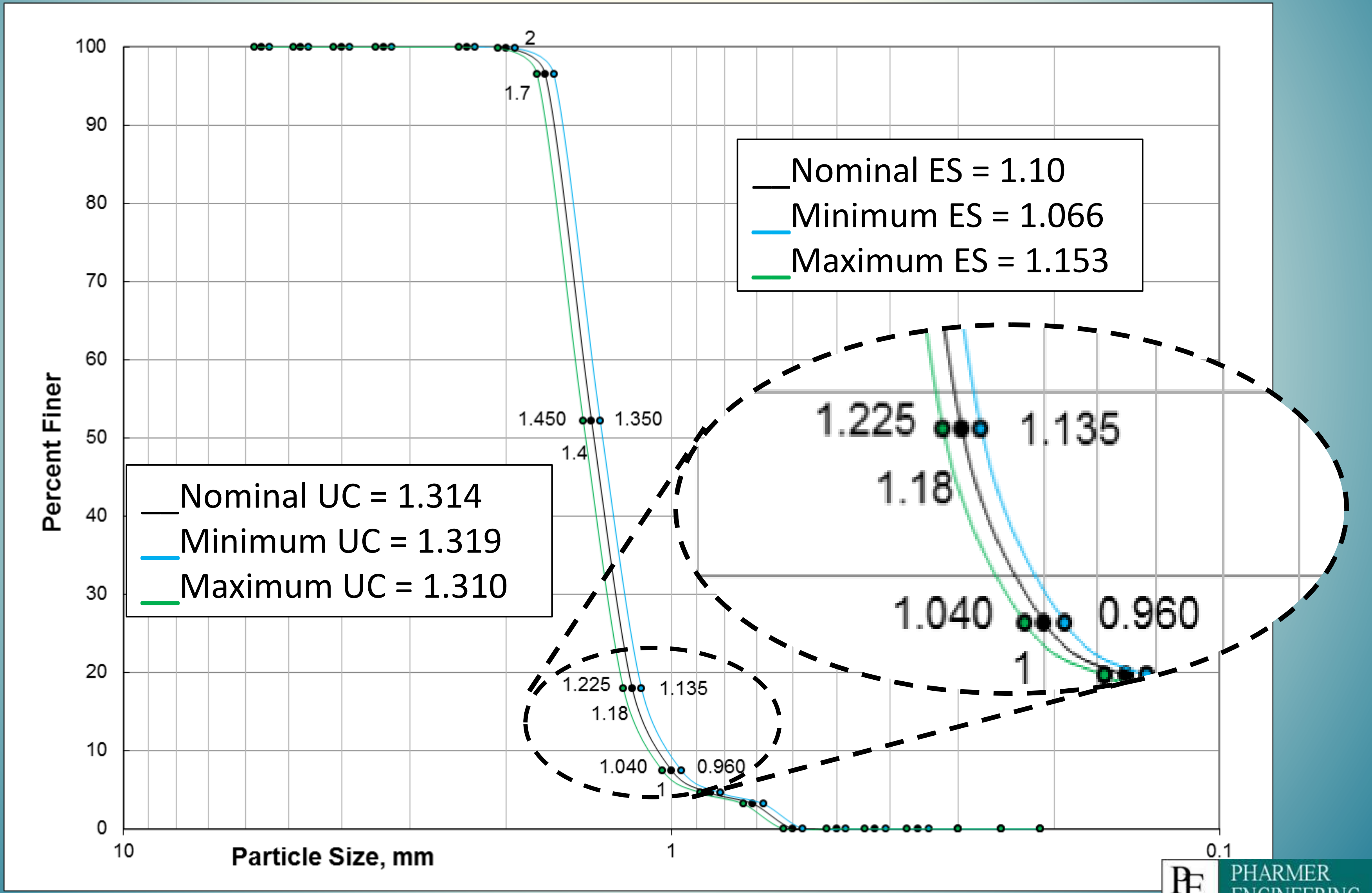
AWWA Mesh Size Standards

Table B.1 Nominal dimensions, permissible variations fc
Standard series)*

Sieve Designation Standard[†]	Sieve Designation Alternative	Nominal Sieve Opening in.[‡]	Permissible Variation of Average Opening From the Standard Sieve Designation
4.75 mm	No. 4	0.187	±0.15 mm
4.00 mm	No. 5	0.157	±0.13 mm
3.35 mm	No. 6	0.132	±0.11 mm
2.80 mm	No. 7	0.111	±0.095 mm
2.36 mm	No. 8	0.0937	±0.080 mm
2.00 mm	No. 10	0.0787	±0.070 mm
1.70 mm	No. 12	0.0661	±0.060 mm
1.40 mm	No. 14	0.0555	±0.050 mm
1.18 mm	No. 16	0.0469	±0.045 mm
1.00 mm	No. 18	0.0394	±0.040 mm
850 µm[‡‡]	No. 20	0.0331	±35 µm
710 µm	No. 25	0.0278	±30 µm
600 µm	No. 30	0.0234	±25 µm

Mesh	Nominal	Min	Max
3.5	5.600	5.420	5.780
4	4.750	4.600	4.900
5	4.000	3.870	4.130
6	3.350	3.240	3.460
7	2.800	2.705	2.895
8	2.360	2.280	2.440
10	2.000	1.930	2.070
12	1.700	1.640	1.760
14	1.400	1.350	1.450
16	1.180	1.135	1.225
18	1.000	0.960	1.040
20	0.850	0.815	0.885
25	0.710	0.680	0.740
30	0.600	0.575	0.625
35	0.500	0.480	0.520
40	0.425	0.406	0.444
45	0.355	0.339	0.371

Nominal – Minimum – Maximum Variation



Common Sieve Stacks

- Adjacent Sieves shall have openings such that the ratio between them is the fourth root of 2 (1.1892). [1]
- Must have a minimum of 6 sieves with the largest not retaining more than 5% of the total sample weight. [1]
- Total weight allowed per sieve after shake test given in Table 7, Section 5. [1]
- Recommended Shake Times
  - Sand about 10 minutes
  - Anthracite about 5 minutes
- All media must be dried entirely, in an oven around 240 °F, before entering sieve stack. [1]

Key Parameters

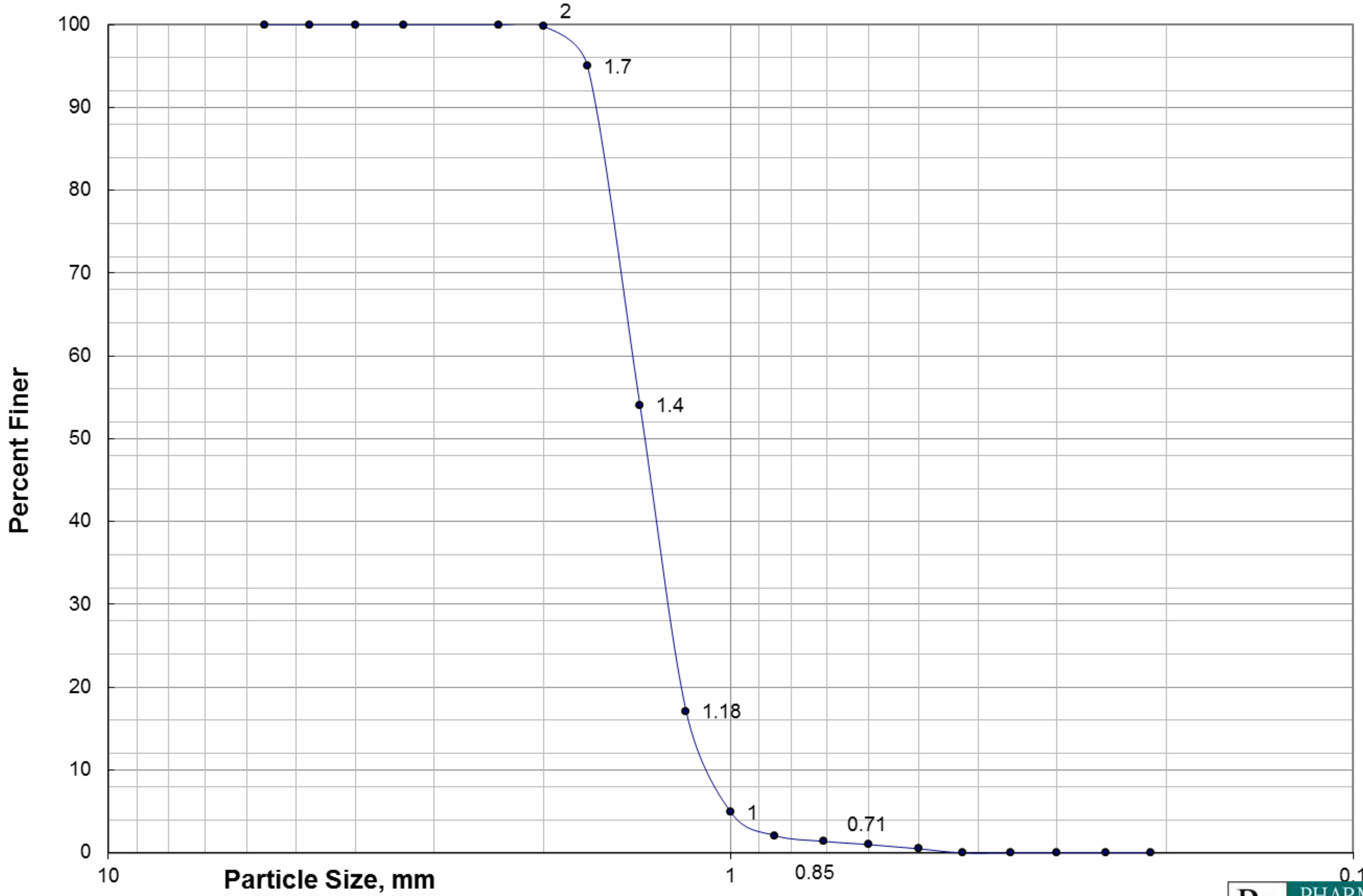
- ☒ Sample Method
- ☒ Sample Size
- ☒ Sieve Calibration
- ☐ Analysis Method

Analysis Method

AWWA Standards

- B100-09 Standards (Latest Revision – 1/09)
  - Sieve data plotted on log-probability, graph paper, or ***comparable computer programs***. [1]
  - No calibration, then replot using ***maximum and minimum permissible variation of the average opening*** from the nominal sieve dimension. [1]
  - A ***smooth curve*** is to be drawn through plotted points. [1]

Standard Particle Distribution Curve



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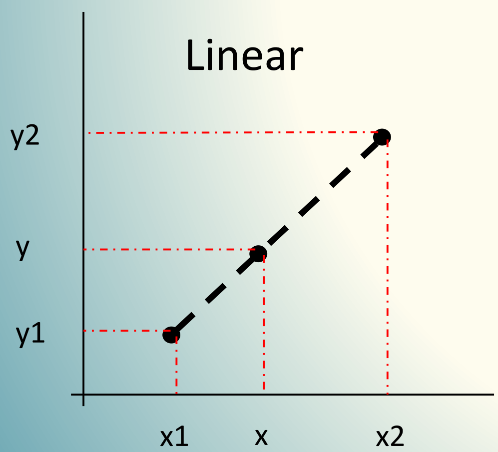
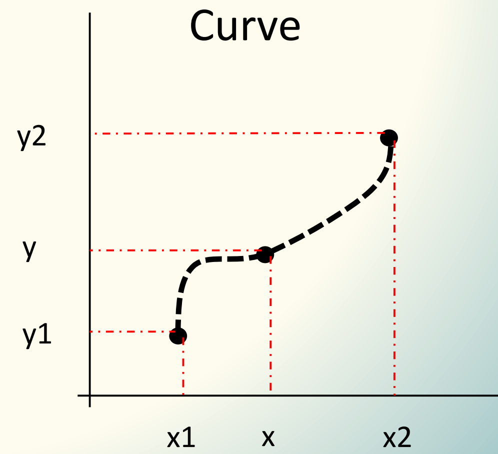
Interpolation Methods

Mesh	Sieve, mm	Retained, g	% Passing
8	2.36		100.0
10	2.047	0.70	99.3
12	1.73	13.10	86.2
14	1.374	47.80	38.5
16	1.199	27.50	11.0
18	1.01	7.50	3.5
20	0.868	1.90	1.6
25	0.696	0.80	0.8
30	0.601	0.80	0.0

ES found through interpolation



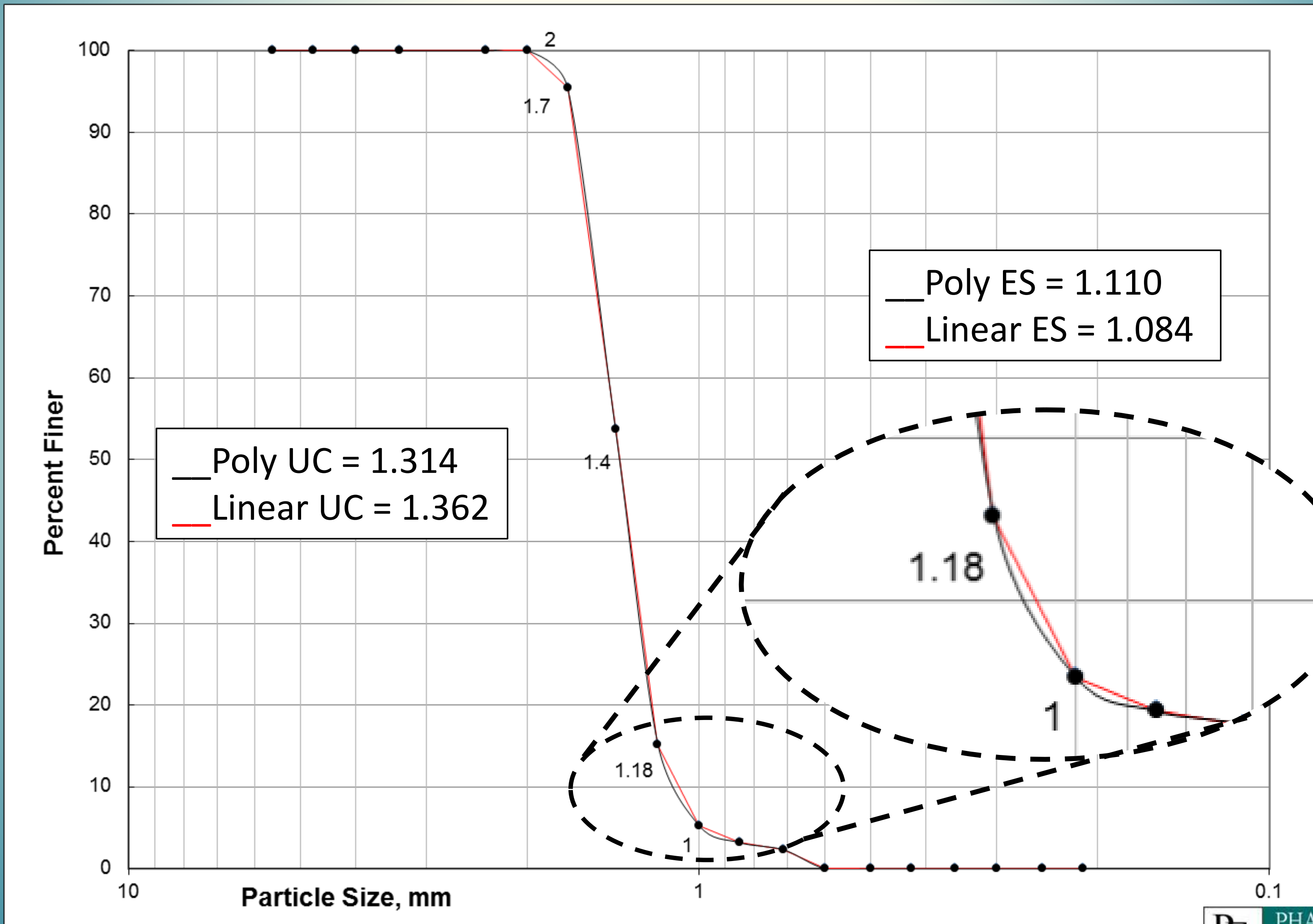


Two solutions!

$$y = mx + b \longrightarrow \frac{y - y1}{x - x1} = \frac{y2 - y1}{x2 - x1}$$

$$y = ax^2 + bx + c \longrightarrow x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Linear – Polynomial Variation



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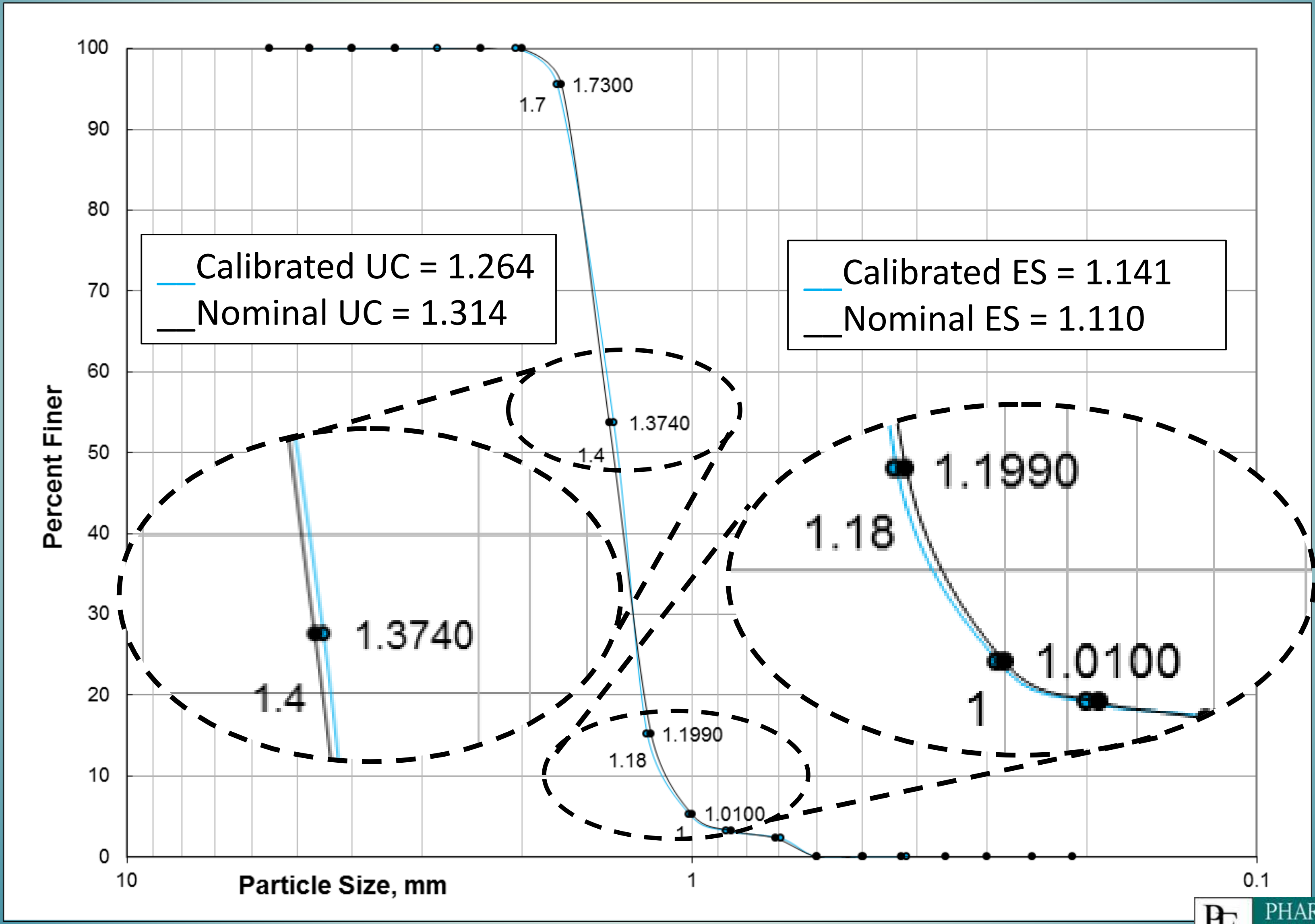
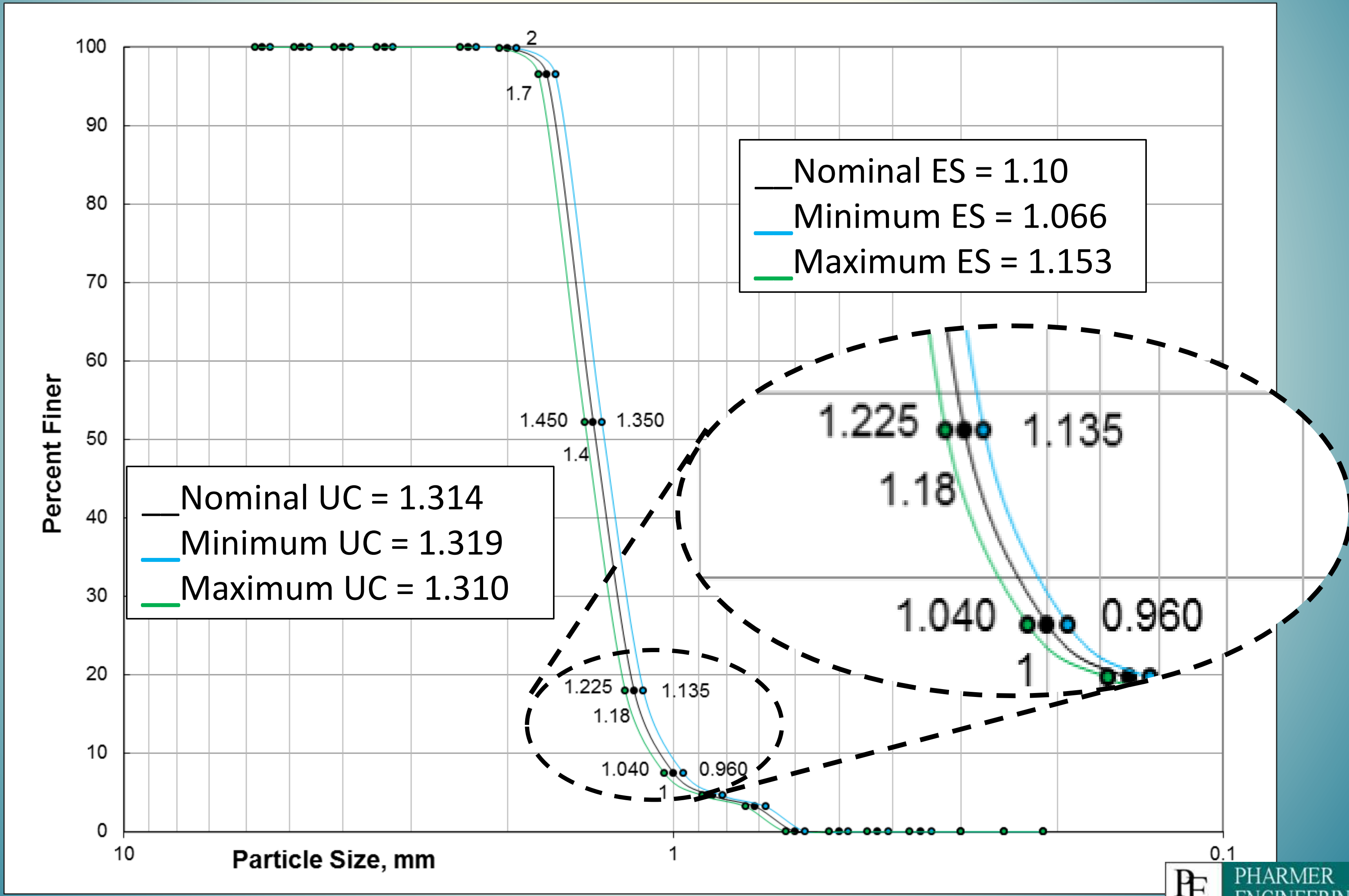
Calibrated – Nominal Variation



Nominal – Minimum – Maximum Variation



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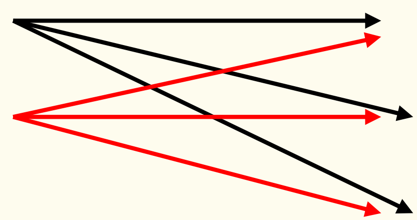
What's The Big Deal?

- Methods
  - Linear
  - Curve

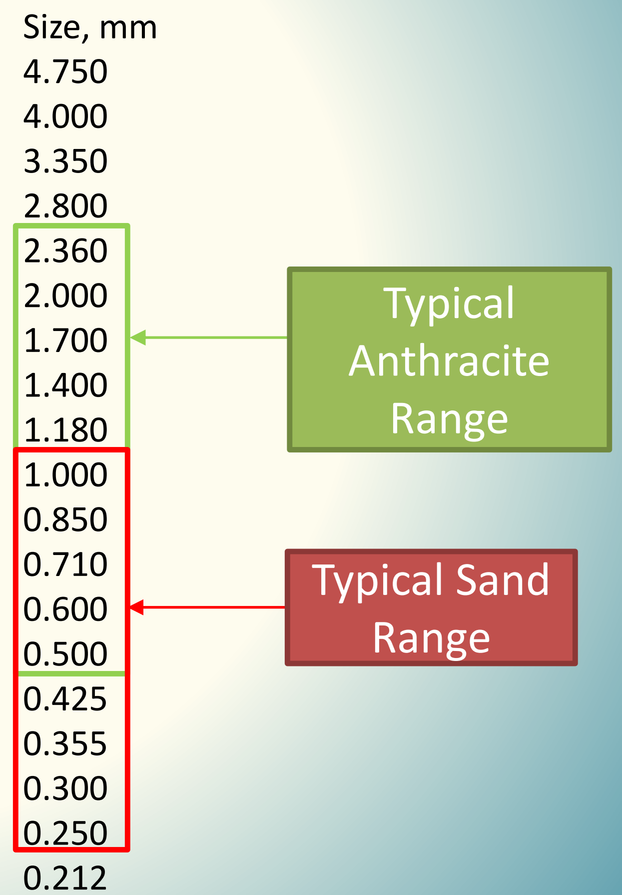


- Size Designation
  - Nominal
  - Calibrated
  - Minimum/Maximum

- 6 results from one sample
- ES range usually 0.1 mm in project specifications

Sand vs. Anthracite

- Sieve step size larger for anthracite
- Interpolation differences more noticeable with larger size range
- Sand sieve results generally more precise no matter what method used



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Why Curve Fit?

- Proportionality

  $y = mx + b$

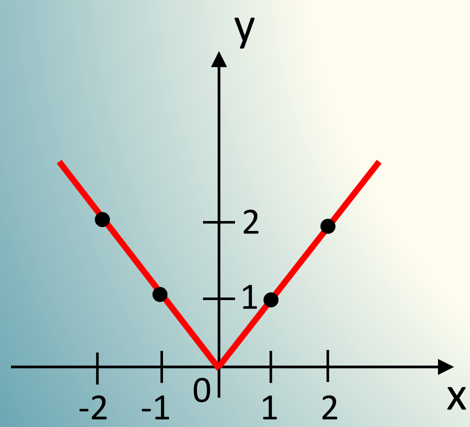
  $y' = m$ (slope)

- Parabolic

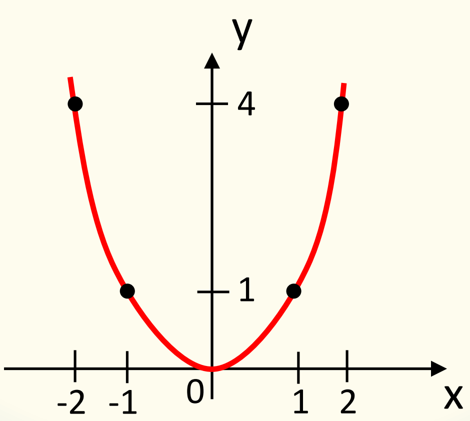
  $y = x^2$

  $y' = 2x$

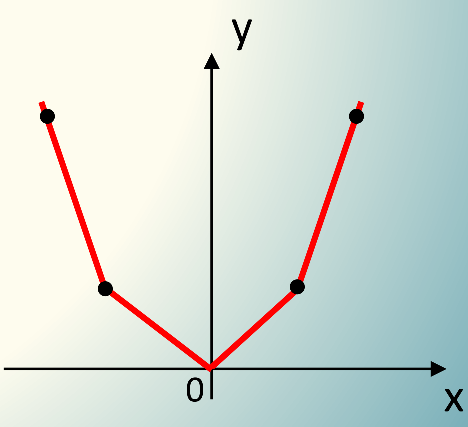
- Why not this?
  - Derivatives (rate of change)



$y = |x|$



$y = x^2$



$y = x^2$??

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Calculus Overview

- Curve fitting assumes continuous function for all data points (percent passing) in interval (sieve size designations), assuming infinite number of sieve sizes in stack to create a smaller step-size, producing a smooth curve.

- Limited data points means interpolating to project results, assuming data points do not fall exactly on known values.

Curve characteristics between data points:

- **First Derivative Test**

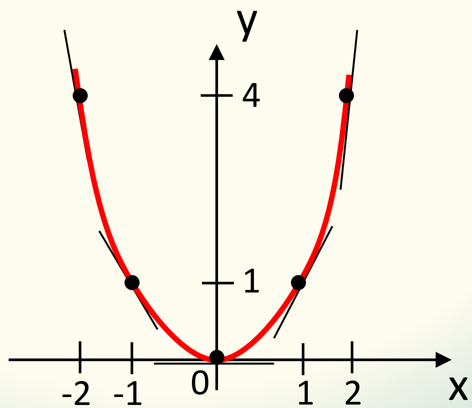
Increasing $y' < 0$ Decreasing $y' > 0$

Local maximum/minimum $y' = 0$

- **Second Derivative Test**

Concave up $y'' > 0$ Concave down $y'' < 0$

Tangent lines (slope)



	x = (-∞,0)	x = (0, ∞)
$y = x^2$	+	+
$y' = 2x$	-	+
$y'' = 2$	+	+

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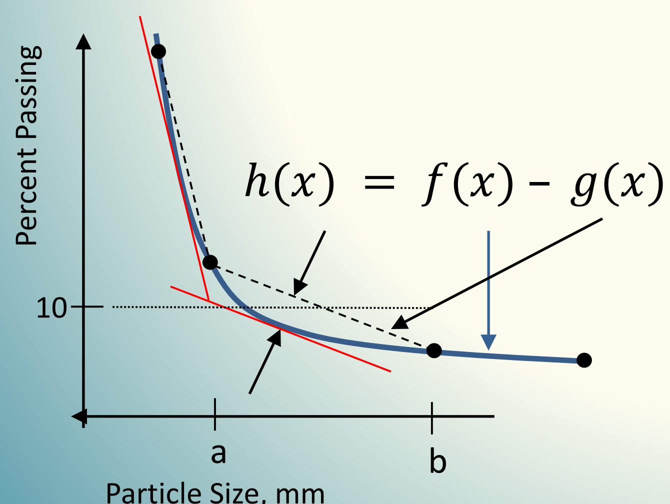
Mean Value Theorem

- First introduced by Joseph-Louis Lagrange in the late 1700’s. [3]
- Guarantees there is a point where the tangent line to the curve is parallel to the chord connecting two given data points. [3]

$$f'(c) = \frac{f(b) - f(a)}{b - a}$$



Linear Interpolation

$$g(x) = f(a) - \frac{f(b) - f(a)}{b - a}(x - a)$$

Polynomial Curve

$$f(x) = ax^2 - bx - c$$

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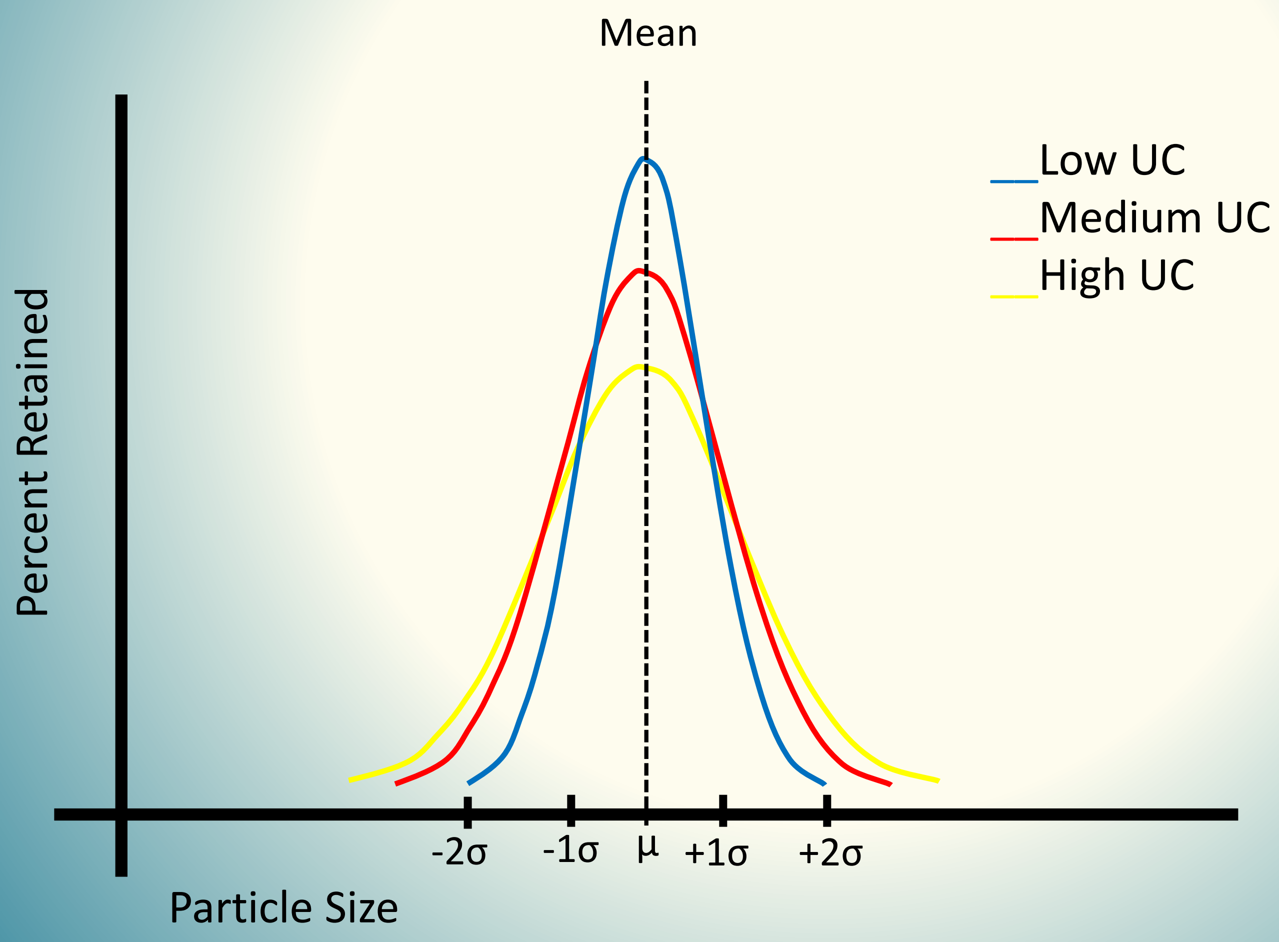
The Power of R^2

- R^2 is a statistical measurement to determine how well a trendline predicts real data points. R^2 values range from 0 (worst) to 1 (best).
- In sieve analysis, certain ranges of data are of interest (D10, D50, D60, D90). By fitting and interpolating specific sections along the distribution curve, a better R^2 value can be produced.
- Polynomial fitting has proven to be best for sieve analysis producing an R^2 value of 1 nearly every time.

<u>Trendlines</u>

- Polynomial
- Power
- Exponential
- Root
- Logarithmic
- Linear

Normal Distribution Curve



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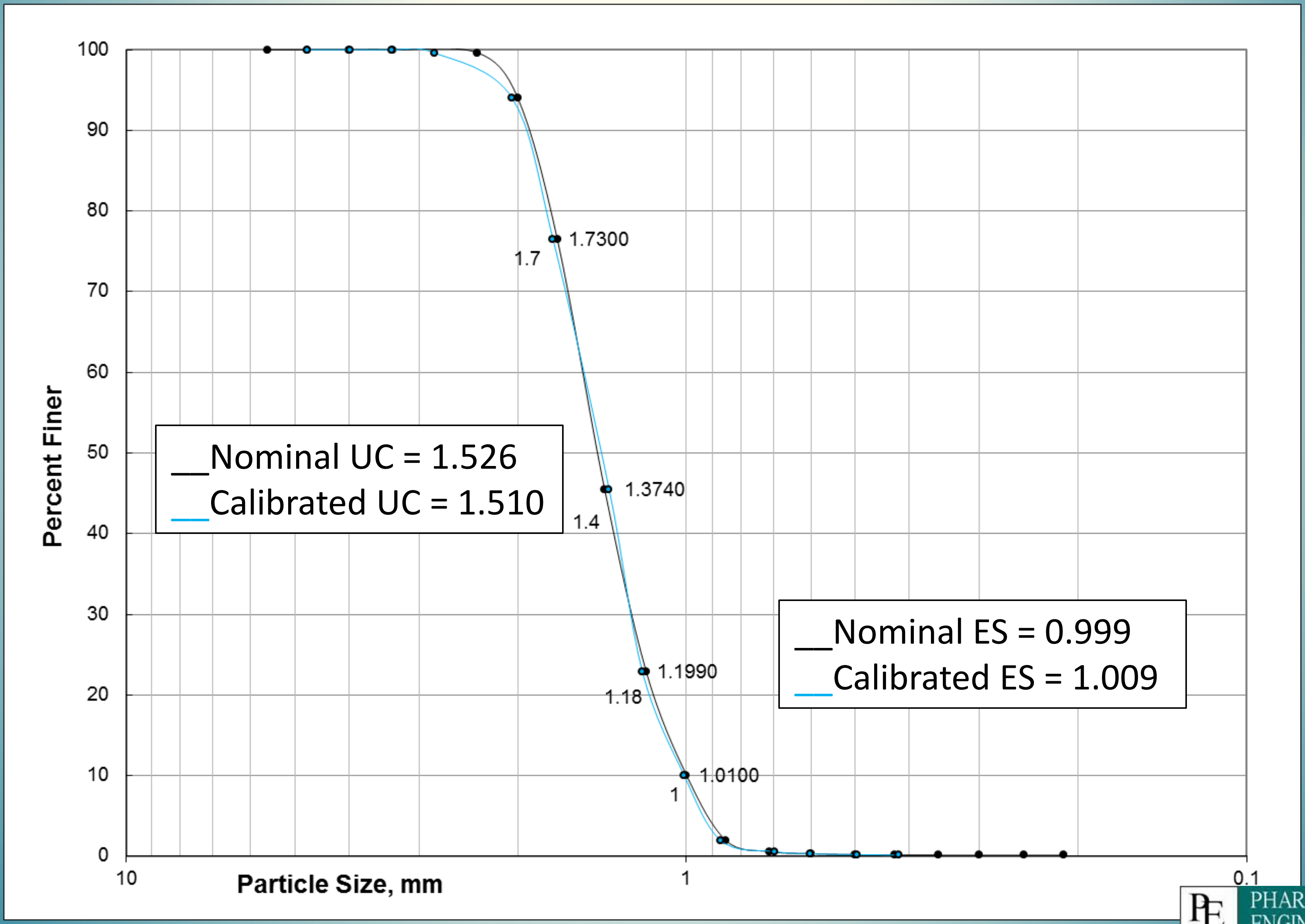
High UC – Nominal vs Calibrated



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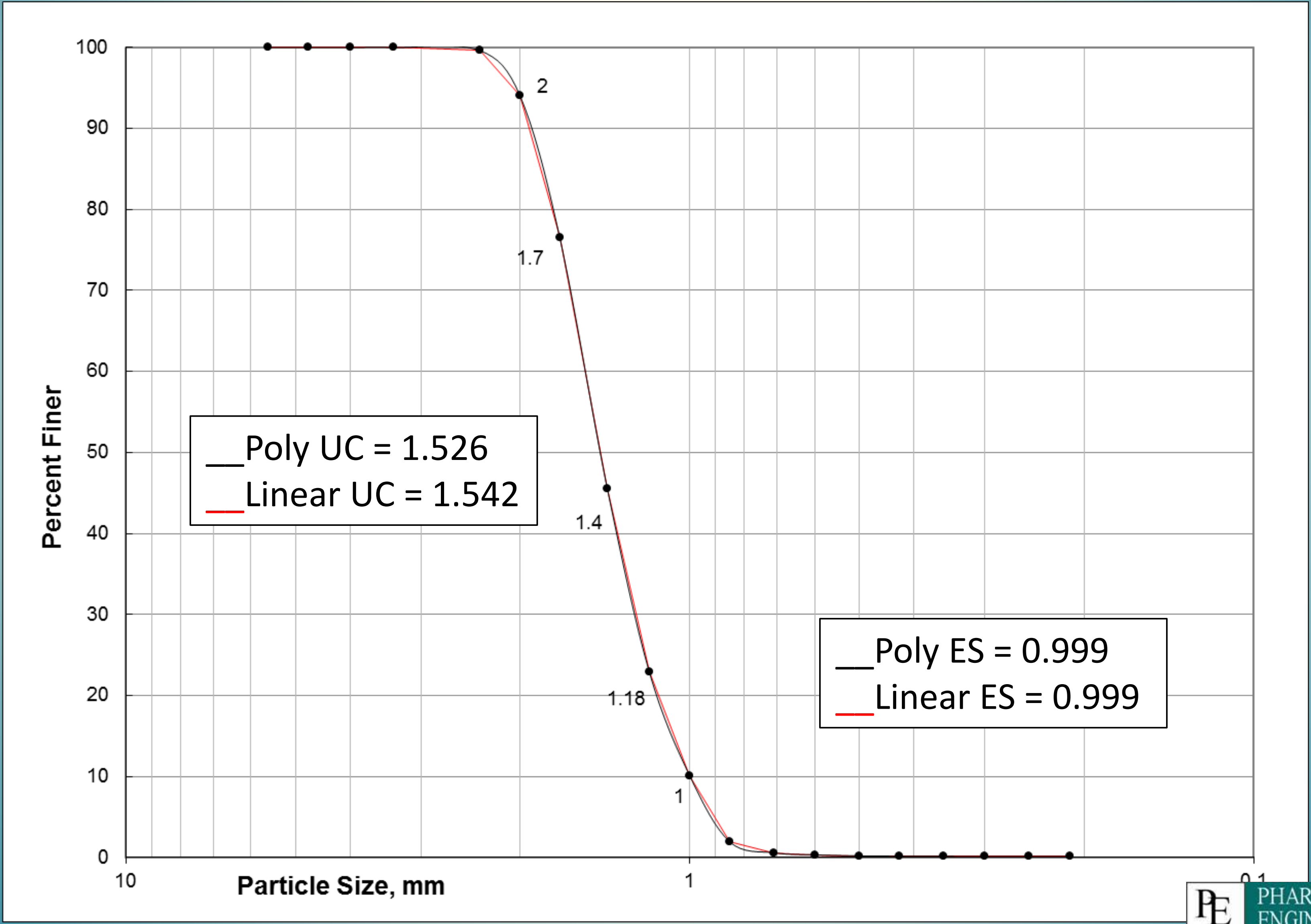
High UC - Nominal



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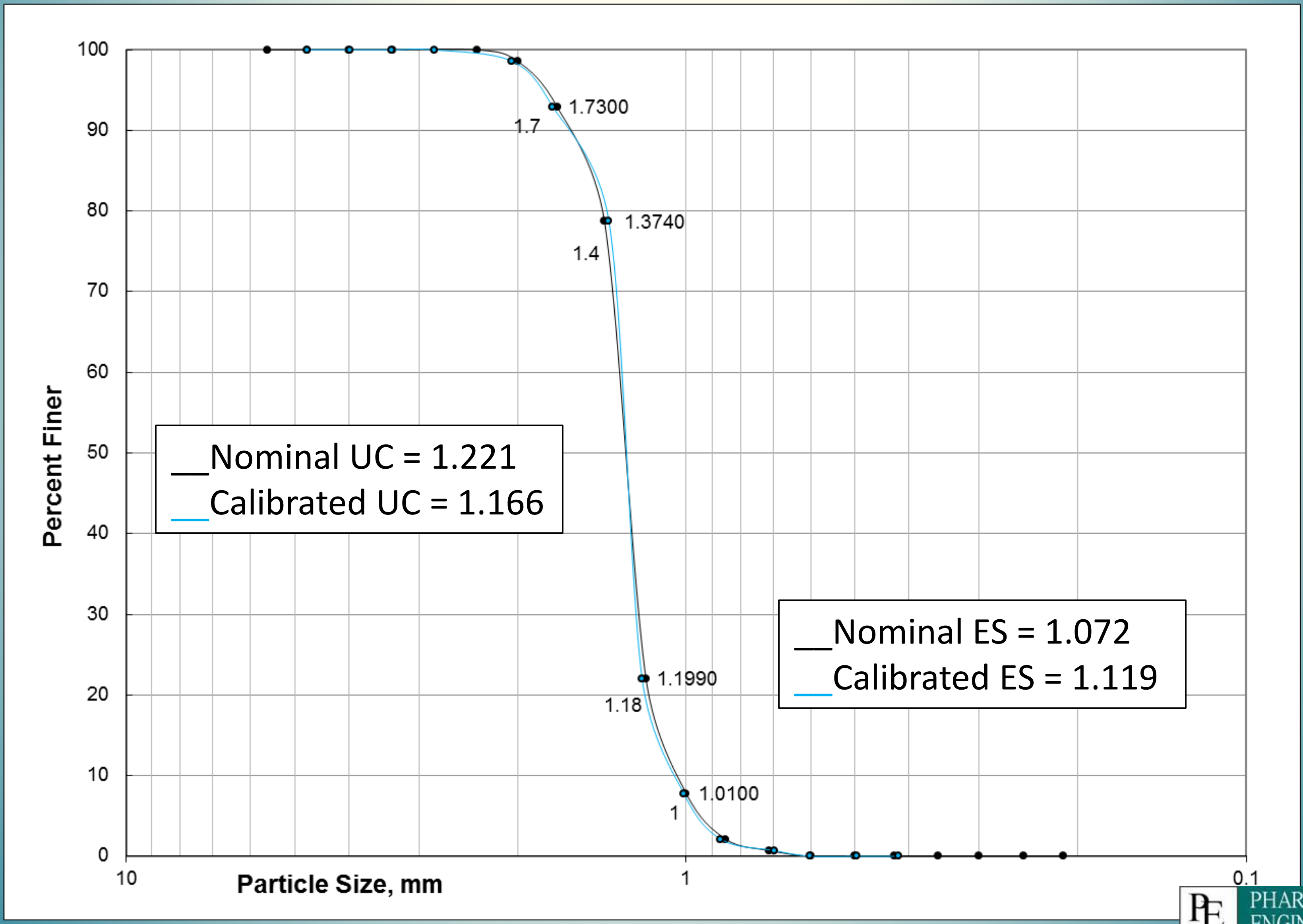
Low UC – Nominal vs Calibrated



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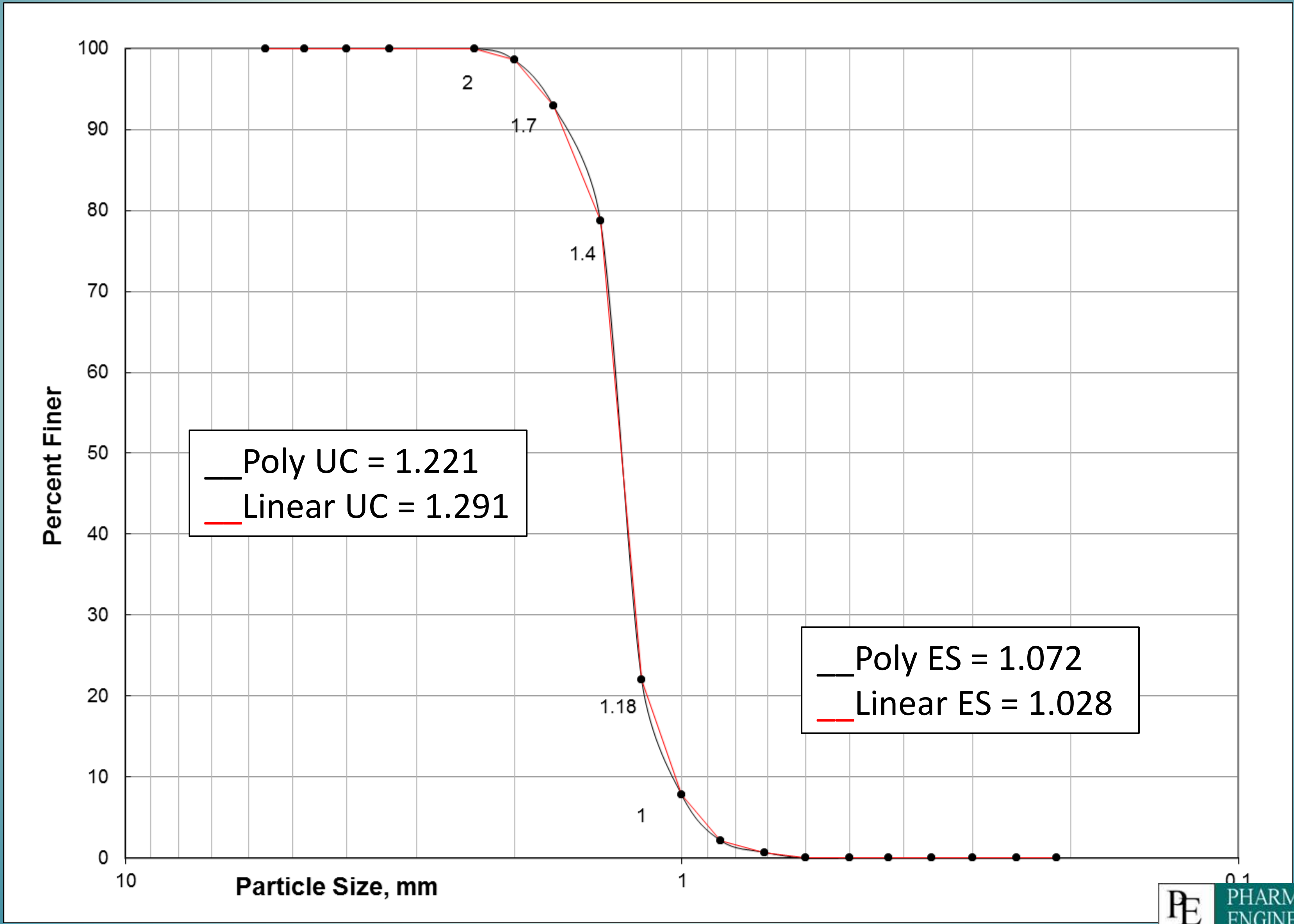
Low UC - Nominal



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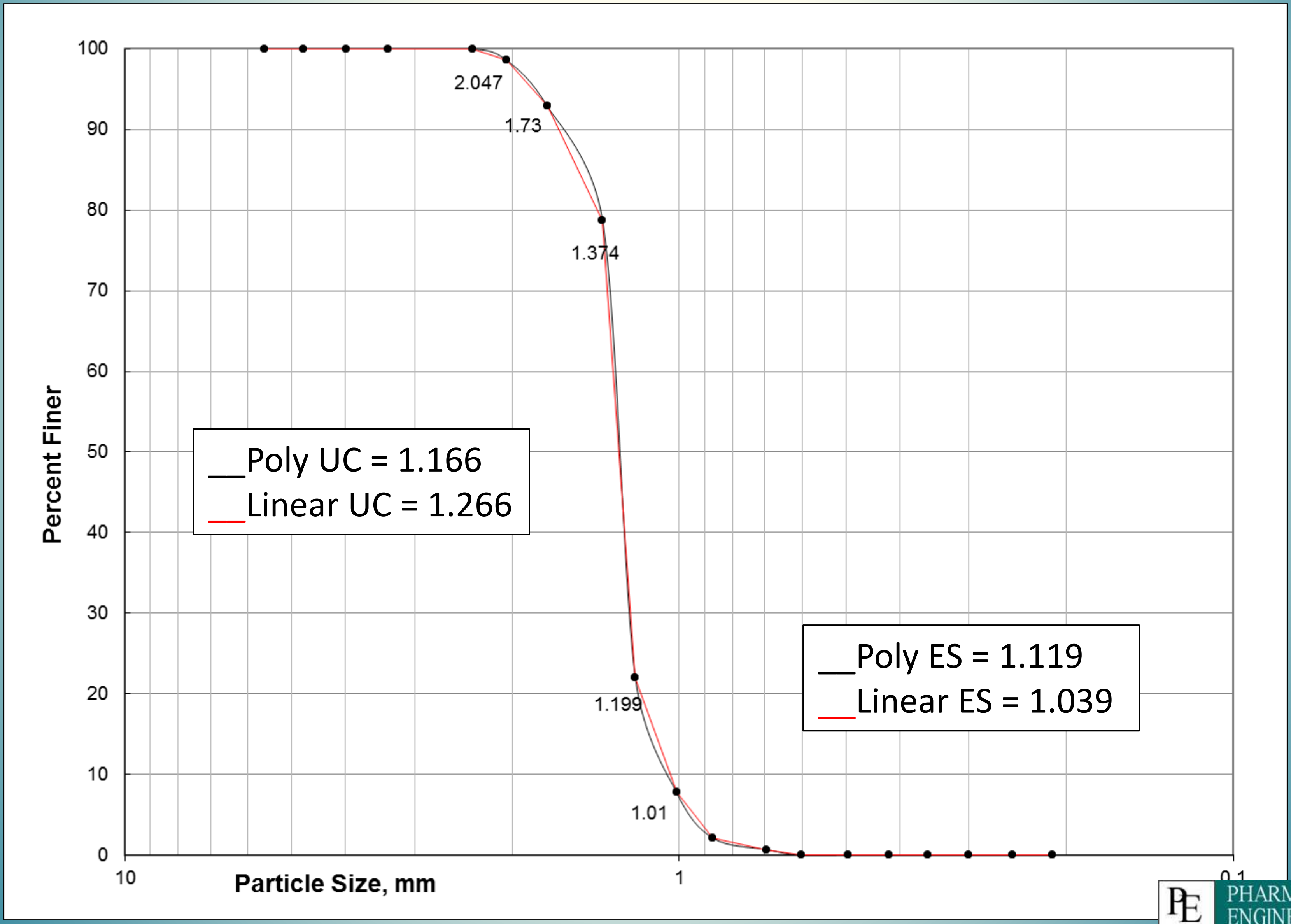
Low UC - Calibrated



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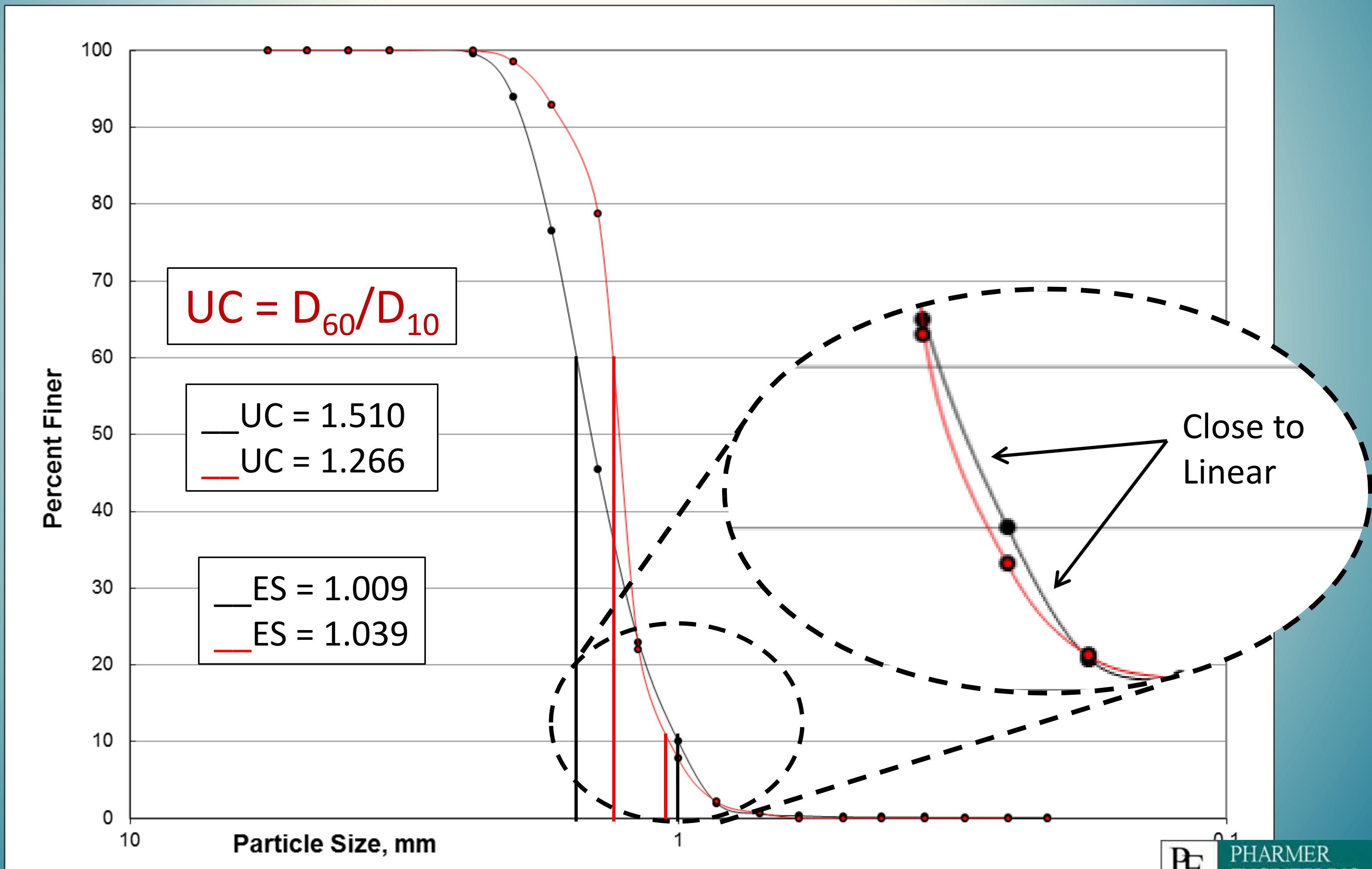
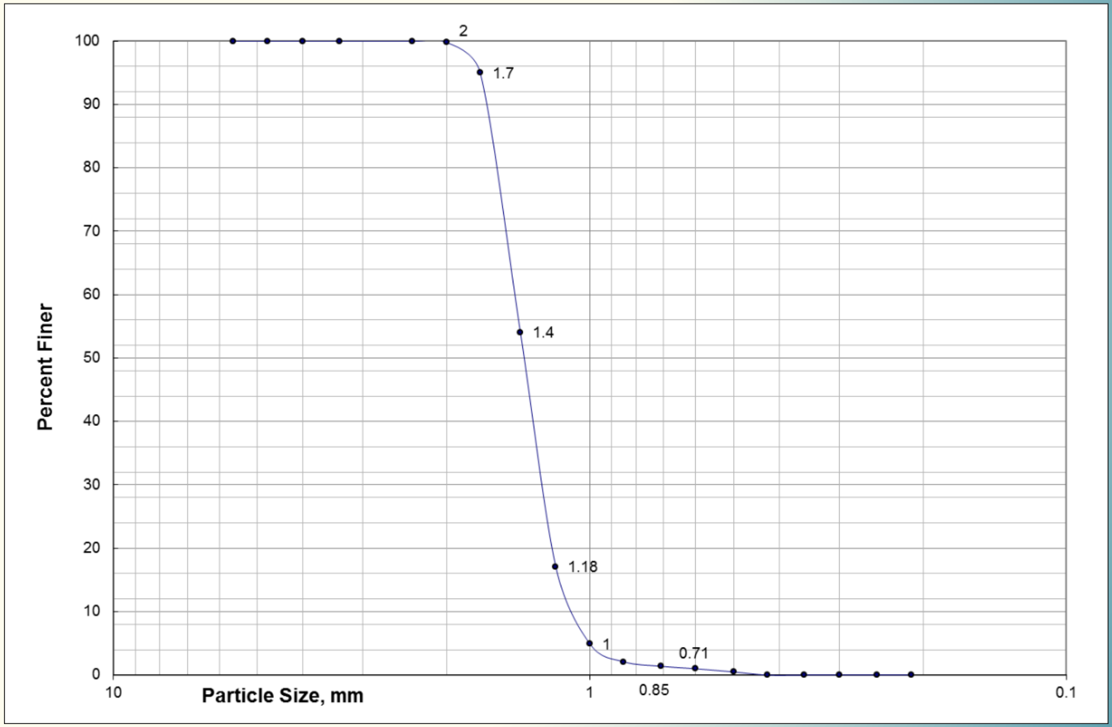
High vs Low UC



Key Graph Attributes

- Data point location versus major gridline
- Slope of graph
  - Steep (Lower UC)
  - Flat (Higher UC)
- Data range to interpolate
  - Anthracite vs Sand
  - Interpolate correct range
- Method
  - Linear vs Curve
- Sieve Size Designation
  - Calibrated, Nominal, Max/Min



- Number of sieves = number of data points for analysis
- Significant Figures

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Key Parameters

- ✖ Sample Method
- ✖ Sample Size
- ✖ Sieve Calibration
- ✖ Analysis Method

Conclusions

- Lower UC material will have major fluctuations between interpolation and calibration methods.
- Methods less important for higher UC material.
- Variance between methods not as noticeable with higher UC samples.
- Sampling methods can vary results.
- Sample size is important to identify and can lead to varied results.
- Equipment calibration can lead to varied results.
- Different analyzing methods can produce varied results.

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What does it all mean?

- Tighten quality assurance and enhance performance of filter.
- Increase communication and trust between customer, engineer, contractor, and supplier.
- Saving money and time for all involved with project.

Who Benefits?

- Customer
  - Receive verified product
  - Future maintenance
  - Less impact on schedule
- Engineer
  - Provide more concise specifications that protect everyone
  - Less impact on schedule
- Contractor
  - Upfront instructions on sampling methods
  - Less impact on schedule
  - Avoid multiple interpretations of ambiguous testing criteria
- Supplier
  - Product is fairly and consistently tested
  - More comfortable to bid job
  - Less impact on schedule

Recommendations

- Consistent method for all parties involved with sieve analysis on project
  - Sampling Techniques
  - Sample Sizing
  - Sieve Sizing or Calibration
  - Analysis Interpolation Method
- Implement maintenance program that contains proper sampling and analysis techniques
- Ask for calibration certificates and analysis methods from lab

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References

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Questions?