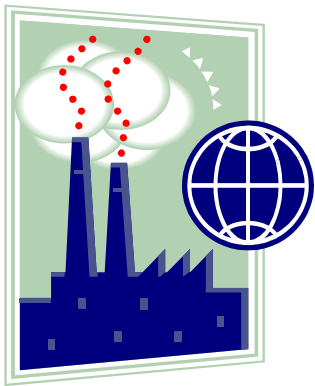


# Precipitator Performance Modeling Basics

Marlin Anderson  
APCO Services, Inc.



# Deutsch-Anderson Equation

$$\square \quad \eta = 1 - \exp(-A/Q)\omega$$

Where: A = Area of collecting surface

Q = Gas flow rate, and

$\omega$  = Migration velocity of particles

$$\omega = qE_p C / 6\pi a \mu$$

q is charge on a particle,  $E_p$  is the field near the plate, C is the Cunningham correction factor, a the particle radius and  $\mu$  is the gas viscosity.

# Modified Equation

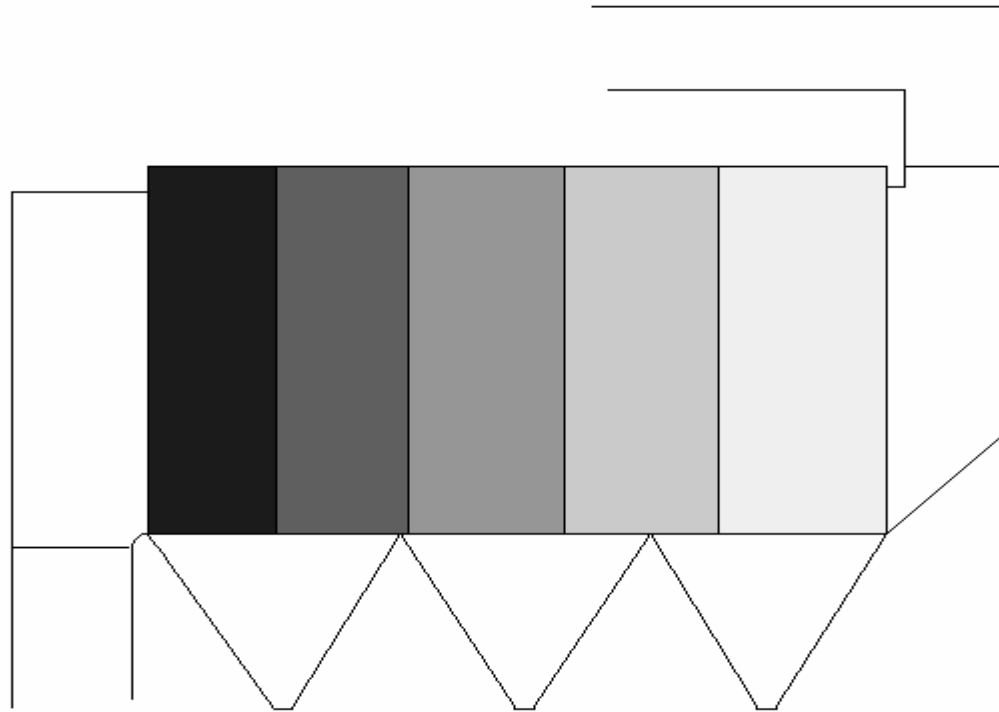
- Deutsch-Anderson equation valid for only a single particle size, i.e. the migration velocity is particle size dependent. To compensate for this, the equation was modified.

$$\eta = 1 - \exp ((-A/Q)\omega_K)^K$$

Where K is a constant that normally ranges from 0.4 to 0.6.



# Assumed Dust Distribution Through Precipitator



# Basic Needs for Modeling

- Precipitator geometry:
  - Cell and plate arrangement
  - Plate area per field including plate height and length
  - Plate-to-plate spacing
  - Discharge electrode design and spacing between electrodes
  - Internal baffling (number of baffled sections)

## Operating conditions:

- Gas: flow, temperature, viscosity and flow distribution
- Particle: mass loading, size distribution and density
- Electrical conditions: voltage and currents for each field  
(may be given or calculated)

# Additional Aids for Modeling

- Boiler type and operating conditions
- Coal and ash chemistry
- Ash resistivity
  
- Boiler heat rate and load can be used with coal and ash chemistry to calculate gas flow rate and inlet loading.
- Coal and ash chemistry can be used to calculate flyash resistivity.
- Boiler type and coal chemistry can be used to estimate particle size distribution.

# Model Construction

Typically, the ideal case is treated first and then corrections are made for non-ideal conditions such as: sneakage, deviation in gas flow distribution and rapping re-entrainment.

Each precipitator section is divided into linear increments in the direction of gas flow. Within each increment, the electric field between discharge and collecting electrode is calculated, followed by the calculation of the charge accrued for each particle size where the distribution is divided into several size bands and then collection as a function of particle size is calculated for that increment. The remaining particulate becomes the mass loading for the following increment.

# Input Data Set for Older Model

- 190100000132.00 00 00 00
- Power Station You Guess, Electrical Conditions Calculated from Design Coal
- 0102011515030001010106
- 1020
- 2.879 36.0 99.6 2400.0 100.0 1.2 0.00022 1.0 1500000.2.00E+11
- 0.050.154.000.050.204.000.050.254.000.100.154.000.100.204.000.100.254.00
- 0.10 0.14 0.20 0.28 0.38 0.50 0.70 1.00 1.40 2.00
- 2.80 3.80 5.00 7.00 10.0 14.0 20.0 28.0 38.0
- 16.3 3.6
- 0410101010
- +1.5876E+04+6.4800E+04+9.0000E-02+1.0584E+04+5.2500E-02+7.8750E+00+1.2000E+01
- +4.5000E+00+2.1600E+05+3.1098E+00+3.0000E+02+9.7060E-01+2.2540E-05+9.0000E-01
- +1.5876E+04+6.3100E+04+1.3000E-01+1.0584E+04+5.2500E-02+7.8750E+00+1.2000E+01
- +4.5000E+00+2.1600E+05+3.1098E+00+3.0000E+02+9.7060E-01+2.2540E-05+9.0000E-01
- +1.5876E+04+6.1600E+04+1.7900E-01+1.0584E+04+5.2500E-02+7.8750E+00+1.2000E+01
- +4.5000E+00+2.1600E+05+3.1098E+00+3.0000E+02+9.7060E-01+2.2540E-05+9.0000E-01
- +1.5876E+04+5.7100E+04+2.2900E-01+1.0584E+04+5.2500E-02+7.8750E+00+1.2000E+01
- +4.5000E+00+2.1600E+05+3.1098E+00+3.0000E+02+9.7060E-01+2.2540E-05+9.0000E-01
- 99

# Model Results

SCA = 294 ft<sup>2</sup>/kACFM

Stack Diameter = 32 ft

Average Applied Voltage = 61.7 kV

Average Current Density = 10.63 nA/cm<sup>2</sup>

S(%)	$\sigma$ (%)	$\eta$ (%)	Opacity (%)	Penetration (%)
5	15	99.66	21.0	0.34
5	20	99.62	22.6	0.38
5	25	99.57	24.5	0.43
10	15	99.52	26.3	0.48
10	20	99.46	28.3	0.54
10	25	99.39	30.5	0.61

# Benefits of Using a Model

Precipitator performance models can be used:

- As a diagnostic tool,
- To predict performance for a coal switch,
- To predict performance for a boiler or precipitator upgrade, and
- To determine the impact of added ancillary equipment.

# EPRI *ESPM* Software for ESP Performance Modeling

Ralph Altman

**Project Manager**

Particulates & Air Toxics Control

# Model Setup - Mechanical/Electrical Parameters

ESPM for Windows - [Unit Configuration Data]

File Calculate Reports Graphs Window Help

ESP Coal Ash Particle Boiler Flue Gas SRT

TR Voltage/Current Data

Field	Section 1 kV	Section 1 mA	Section 2 kV	Section 2 mA	Section 3 kV	Section 3 mA	Section 4 kV	Section 4 mA
A	41	2720	45	4500	38	3625	55.4	3500
B	39	5326	46.2	4425				
C	35	4950	32	3750				
D	33	5200						

⇓⇓ ESP INLET ⇓⇓

A1	A2	A3	A4
B1	B2		
C1	C2		
D1			

⇓⇓ ESP OUTLET ⇓⇓

Overall Parameters | Field/Section Parameters

Number of Fields:

Design Parameters

Gas Velocity [ft/s]:  WaveForm:

SCA [ft<sup>2</sup>/kacfm]:

ESP Dimensions

Plate Length [ft]:  Plate Area [ft<sup>2</sup>]:

Plate Height [ft]:  ESP Width [ft]:

Stack Diam [ft]:

Master: esptest3 | ESP: esptest3 | Coal: esptest3 | Ash: esptest3 | Part: esptest3 | Boiler: esptest3

# Model Setup - Coal Content

ESPM for Windows - [Unit Configuration Data]

File Calculate Reports Graphs Window Help

ESP Coal Ash Particle Boiler Flue Gas SRT

Mine Name:

Fuel Usage [tons/hr]:  Calculate Fuel Usage

Coal Rank:  Calculate Coal Rank

PRB (Powder River Basin) Coal

**Proximate Analysis [% as-received]:**

Fixed Carbon	<input type="text" value="34.3"/>	Volatile Matter	<input type="text" value="33.0"/>
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**Ultimate Analysis [% as-received]:**

Carbon	<input type="text" value="50.5"/>	Sulfur	<input type="text" value="0.5"/>
Hydrogen	<input type="text" value="4.7"/>	Moisture	<input type="text" value="28.0"/>
Oxygen	<input type="text" value="10.7"/>	Ash	<input type="text" value="5.0"/>
Nitrogen	<input type="text" value="1.3"/>		
Heating Value [Btu/lb]:	<input type="text" value="9310"/>		

Master: esptest3    ESP: esptest3    Coal: esptest3    Ash: esptest3    Part: esptest3    Boiler: espt

# Model Setup - Ash Content

ESPM for Windows - [Unit Configuration Data]

File Calculate Reports Graphs Window Help

ESP Coal Ash Particle Boiler Flue Gas SRT

**Ash Analysis [%]:**

Li2O	<input type="text" value="0.01"/>	CaO	<input type="text" value="23.23"/>	TiO2	<input type="text" value="1.32"/>
Na2O	<input type="text" value="1.22"/>	Fe2O3	<input type="text" value="5.48"/>	P2O5	<input type="text" value="1.01"/>
K2O	<input type="text" value="0.30"/>	Al2O3	<input type="text" value="16.02"/>	SO3	<input type="text" value="15.62"/>
MgO	<input type="text" value="4.97"/>	SiO2	<input type="text" value="30.83"/>		

Calculate Resistivity

Resistivity [ohm-cm]:

Refractive Index

1.5 - 0.01 i       User Defined

1.5 - 0.1 i      Real:

1.96 - 0.66 i (carbon)      Complex:

Master: esptest3    ESP: esptest3    Coal: esptest3    Ash: esptest3    Part: esptest3    Boiler: espt

# Model Setup - Particle Size Distribution

The screenshot shows the 'ESPM for Windows - [Unit Configuration Data]' window. The 'Particle' tab is selected. The interface includes a menu bar (File, Calculate, Reports, Graphs, Window, Help) and a tabbed interface with tabs for ESP, Coal, Ash, Particle, Boiler, Flue Gas, and SRT. The 'Particle' tab contains the following fields and controls:

- Particle Density [g/cm<sup>3</sup>]:
- Mass Loading [grain/acf]:
- Particle Size Distribution:**
  - Method:  Log Normal  Histogram
  - Mass Median Diameter [μm]:
  - Geometric Std Deviation [μm]:
- 

The status bar at the bottom shows the following configuration: Master: esptest3 | ESP: esptest3 | Coal: esptest3 | Ash: esptest3 | Part: esptest3 | Boiler: espt

# Model Setup - Boiler Parameters

The screenshot displays the 'ESPM for Windows - [Unit Configuration Data]' window. The 'Boiler' tab is selected in the top navigation bar. The main area contains several input fields for boiler configuration:

Parameter	Value
Plant Name	Boiler C
Unit Number	5
Plant Output [MW]:	600
Type of Firing	Tangential
Mean Coal Dia [ $\mu\text{m}$ ]:	50.00
Rosin-Rammler Expt	1.20
Heat Rate [Btu/kWh]:	10250

The bottom status bar shows the following configuration for various components: Master: esptest3, ESP: esptest3, Coal: esptest3, Ash: esptest3, Part: esptest3, Boiler: espt

# Model Setup - Flue Gas Composition

The screenshot shows the 'ESPM for Windows - [Unit Configuration Data]' window. The 'Flue Gas' tab is selected. The interface includes a menu bar (File, Calculate, Reports, Graphs, Window, Help) and a tabbed interface with tabs for ESP, Coal, Ash, Particle, Boiler, Flue Gas, and SRT. The 'Flue Gas' tab contains input fields for 'ESP Gas Temp [\*F]' (290.0) and 'ESP Gas Pressure [atm]' (1.00). Below this is a section for 'Gas Composition [wet basis:]' with a table of gas components and their values. To the right, there is a 'Flue Gas Volume [cfm]' field (1285714.0) and radio buttons for 'Actual' (selected) and 'Normal (@STP)'. A 'Calculate from Coal' button is located below the volume field. The status bar at the bottom shows the following data: Master: esptest3, ESP: esptest3, Coal: esptest3, Ash: esptest3, Part: esptest3, Boiler: espt

ESP Gas Temp [\*F]:  ESP Gas Pressure [atm]:

**Gas Composition [wet basis:]**

N2 (%Vol)	<input type="text" value="72.8"/>
O2 (%Vol)	<input type="text" value="6.2"/>
CO2 (%Vol)	<input type="text" value="10.9"/>
H2O (%Vol)	<input type="text" value="10.1"/>
SO2 (ppm)	<input type="text" value="404.9"/>
SO3 (ppm)	<input type="text" value="1.6"/>

Flue Gas Volume [cfm]:

Actual  Normal (@STP)

Master: esptest3    ESP: esptest3    Coal: esptest3    Ash: esptest3    Part: esptest3    Boiler: espt

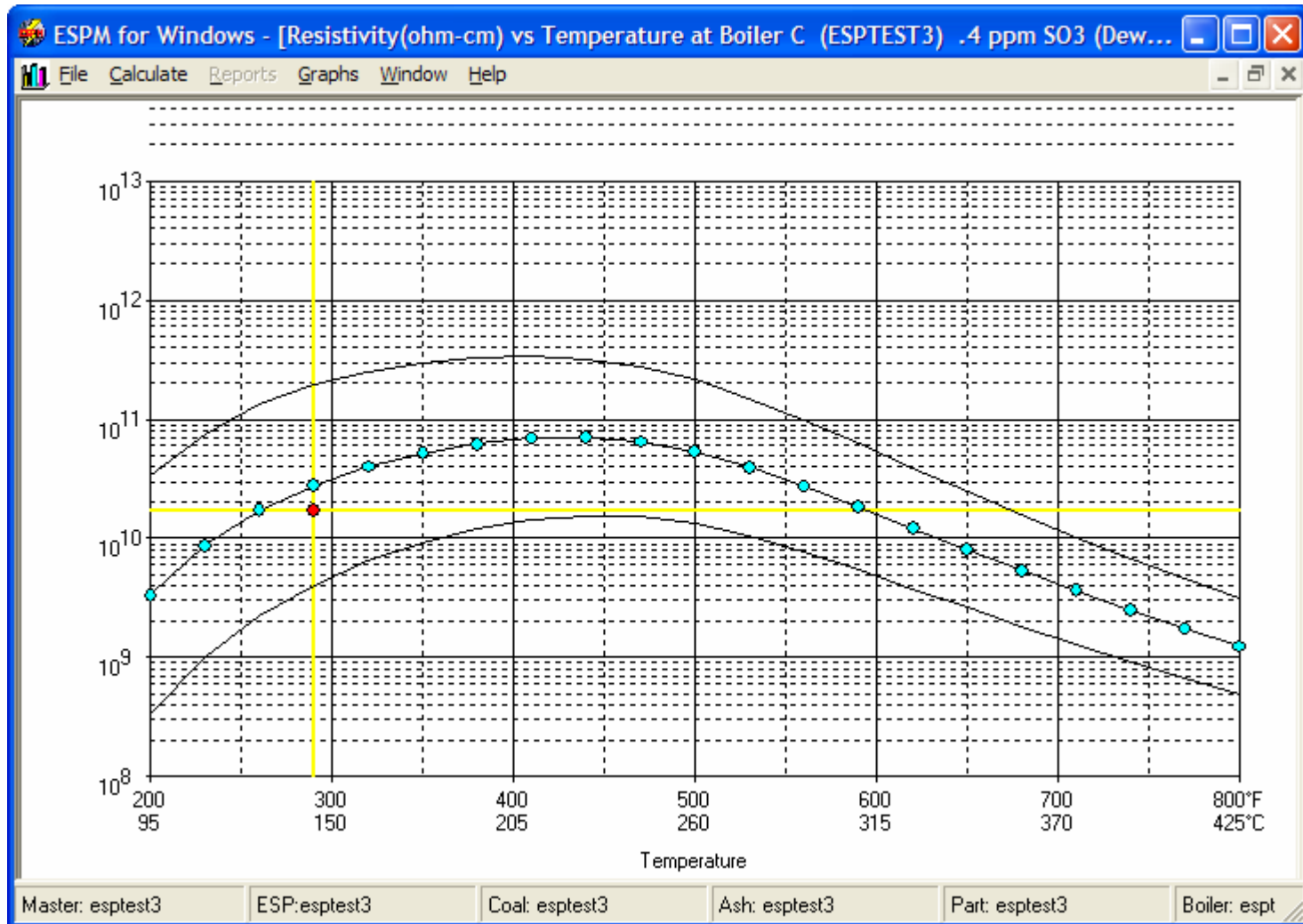
# Model Setup - Calibration Parameters

The screenshot displays the 'ESPM for Windows - [Unit Configuration Data]' window. The interface includes a menu bar with 'File', 'Calculate', 'Reports', 'Graphs', 'Window', and 'Help'. Below the menu is a tabbed interface with tabs for 'ESP', 'Coal', 'Ash', 'Particle', 'Boiler', 'Flue Gas', and 'SRT'. The 'Particle' tab is currently selected. The main area contains a list of calibration parameters, each with a corresponding input field:

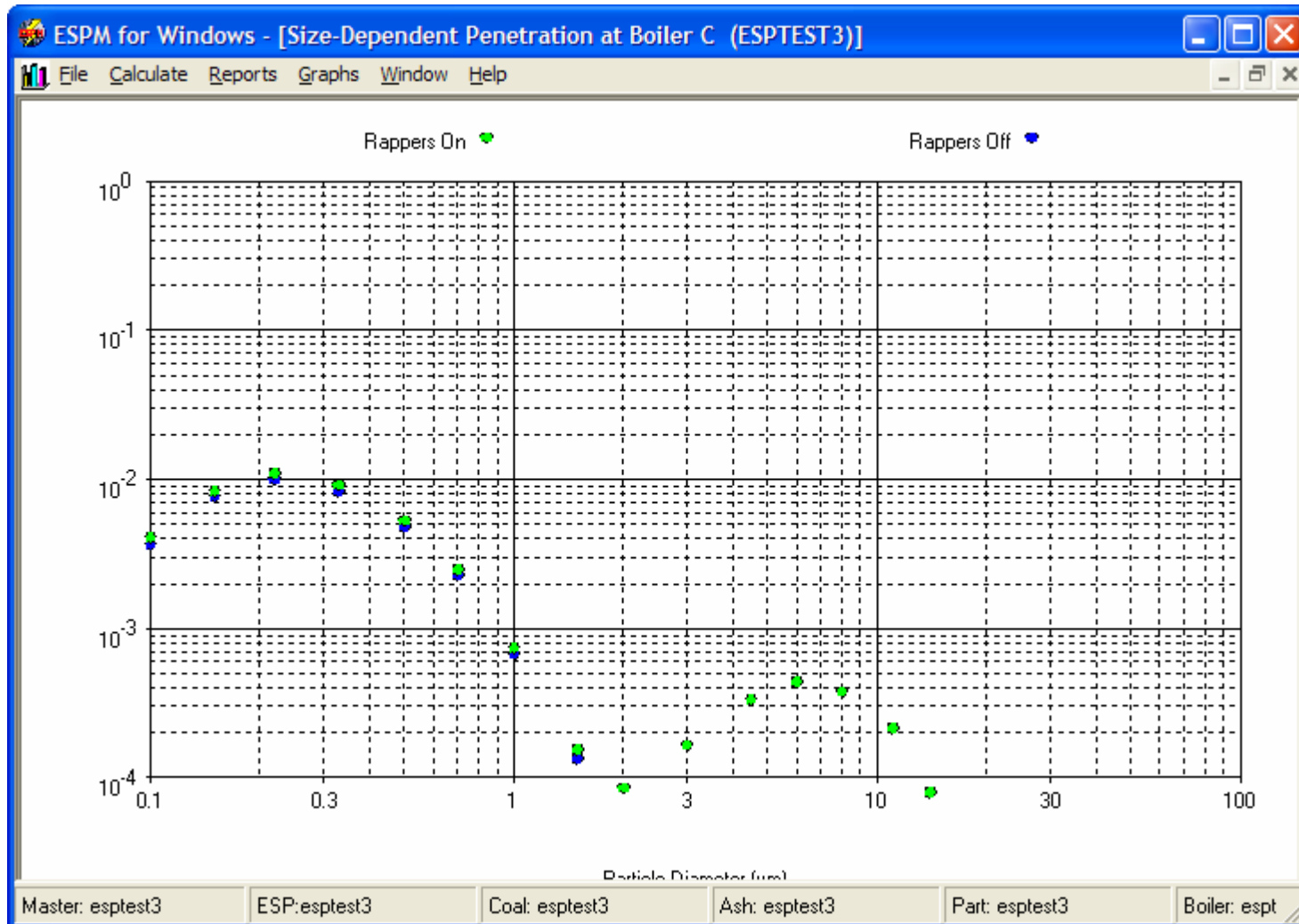
Velocity Std Dev:	<input type="text" value="0.13"/>
Electrode Misalignment [in]:	<input type="text" value="0.00"/>
Fraction Misaligned	<input type="text" value="0.00"/>
Aerodynamic Sneakage	<input type="text" value="0.05"/>
Rap Reentrain Fraction	<input type="text" value="0.05"/>
Particle MMD (Rap)	<input type="text" value="7.0"/>
Geom Std Dev (Rap)	<input type="text" value="1.5"/>
Core Turbulent Number	<input type="text" value="1.00"/>

At the bottom of the window, there is a status bar with the following text: 'Master: esptest3', 'ESP: esptest3', 'Coal: esptest3', 'Ash: esptest3', 'Part: esptest3', and 'Boiler: espt'.

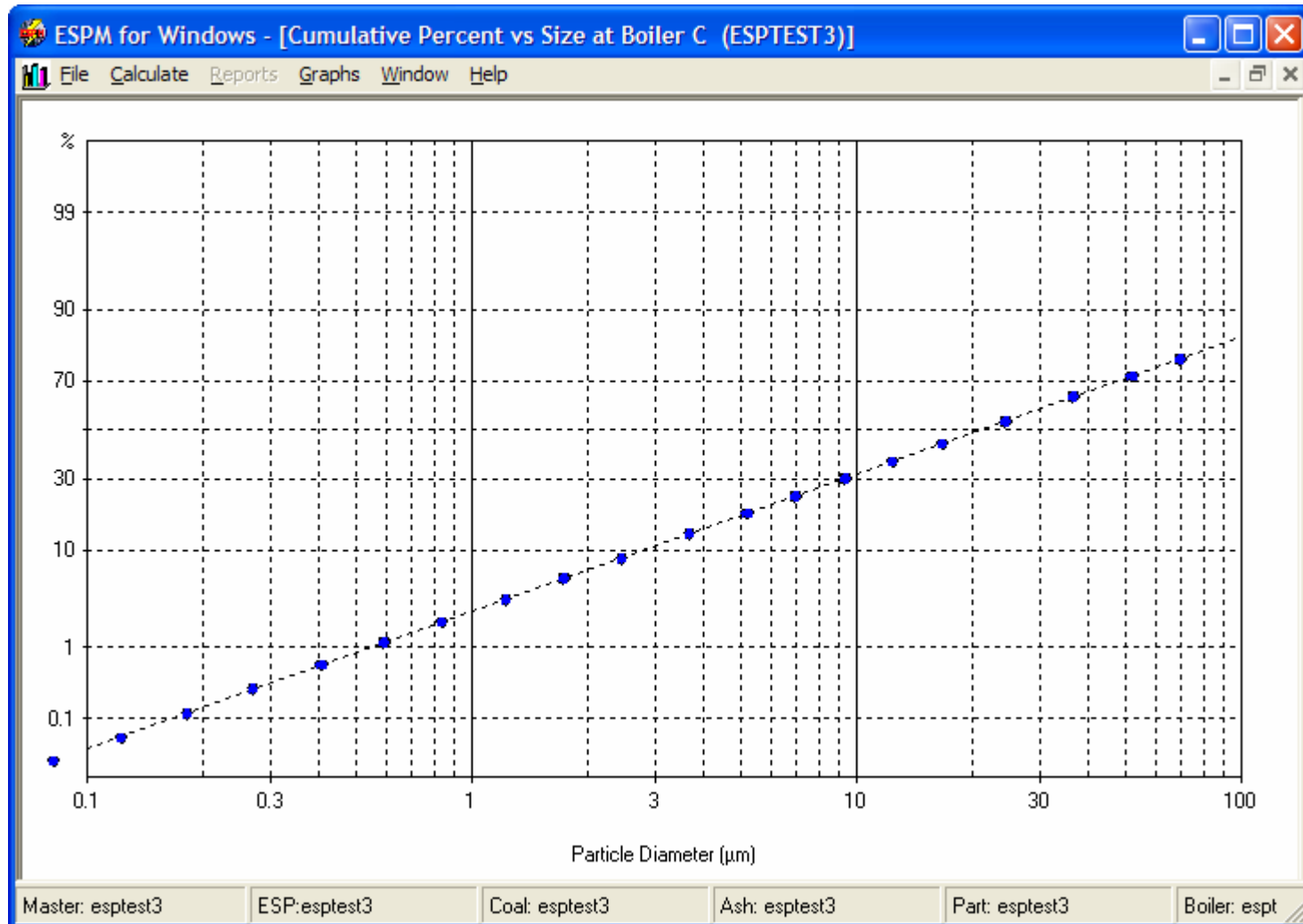
# Graphing Features - Particle Resistivity



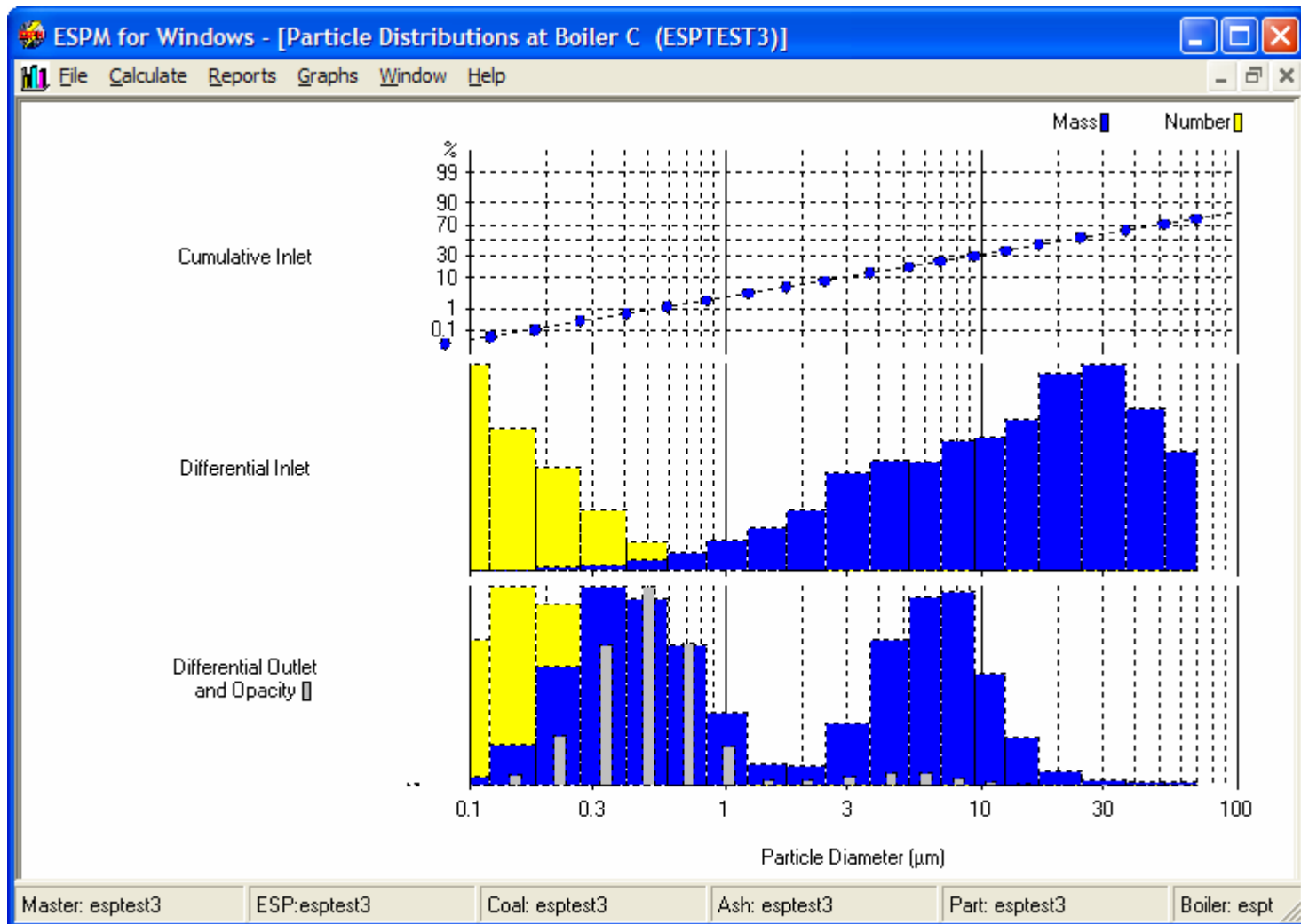
# Graphing Features - Particle Penetration



# Graphing Features - Inlet Size Distribution



# Graphing Features - Particle Distribution Summary



# Validation of Model

- Before using the model to project performance with a different coal or new configuration, the model should be validated using known:
  - Inlet loading and particle size
  - Gas flow distribution
  - Operating currents and voltages
  - Gas conditions
  - Known outlet emissions and opacity