

# **REINHOLD ENVIRONMENTAL Ltd.**



## **2010 APC Round Table & Expo Presentation**

July 18-20, 2010, in Concord, NC / Hosted by Duke Energy

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# ***SPECIALIZED ENGINEERING AND LABORATORY SERVICES***

*A World Leader in Innovative Solutions*



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*2010 APC CONFERENCE*

***WHY IS GAS FLOW IMPORTANT IN  
FABRIC FILTER DESIGN***

*Workshop 21*

By: Steve Bowen



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# Agenda

- Introduction
- Discussion of Problems within Fabric Filters
- Benefits of Modeling on Fabric Filter Design
- Physical Modeling
- CFD Modeling
- Discuss modeling techniques



## ABOUT NELS CONSULTING

NELS Consulting Services Inc. had its beginnings as a family business 35 years ago, and has since then grown to a world known leader in air-flow engineering. NELS is an engineering based consulting company located in St. Catharines Ontario Canada.

NELS employs approximately 45 employees at its facilities, and works on over 200 projects a year. Its staff is made up of engineers, technologists, technicians and administration that work together to provide clients with streamlined customer service.

NELS supplies a comprehensive range of engineering, in-field testing, and laboratory services for:

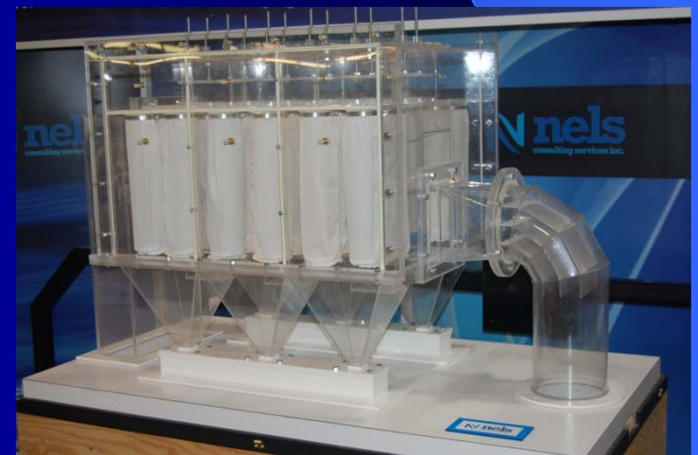
- Efficiency improvements and system evaluations for utility and power generating facilities, and
- Product development and optimization of process equipment, operation and control.





## Services Provided

- To build and test fluid flow models of air pollution control, power generation and all other industrial systems.
- Develop full-scale designs through conceptualization, bench scale, pilot, and prototype testing of innovative, low cost/energy systems for multiple industries throughout North America and the world.
- Consulting services for fluid flow, thermal mixing, stress analysis, structural and mechanical problems as well as fabrication of specialized parts.
- Research and development for aero-dynamic, structural and instrumentation related problems.
- Field testing services for the evaluation of system performance (gas flow, temperature, pressure, particulate, gas concentration etc.) through various gas cleaning installations.
- High Temperature coating application



# FACILITIES

With our continual growth and successes in both the international and domestic markets our facilities have recently been expanded and enhanced so that we can better service our clients needs. Our current facilities are as follows:

- Floor space of 100,000 square feet that accommodates office, drafting, instrument calibration, workshop, and test areas.
- 16,000 square feet of model storage space
- 30,000 square feet at an off site location for pilot system set-ups, experimental coating labs, and additional model testing



## Test Equipment

- EPA method 5 and Method 17 particulate sampling trains.
- Various EPA test Methods from 5 to 29
- Analytical lab for processing of emission test data/samples and filters.
- Portable mass emission continuous monitors.
- Combustion analyzers.
- Traversing hot wire and film sensors for velocity measurements in gas and liquid mediums.
- Vane-type anemometers for gas flow measurements up to temperatures of 500 °F.
- Calibration equipment for all instrumentation.
- Manometers
- Color video, digital cameras and high speed video cameras (16,000 fps)
- KLD DCIII Droplet Measurement Probe



# Laboratory Equipment

- Specialized boiler cameras for combustion monitoring.
- High Speed Video Camera – 16,000 fps
- KLD-DCIII Droplet Analyzer
- Dual Fluid Nozzle Test Tower
- Full size re-circulating mist eliminator and spray facility.
- Boundary layer wind tunnel with temperature control
- Various pumps (total capacity 5000 gal/min)
- Various fans ranging from 10 to 100: w.g. (total capacity 600 000 cfm)
- Assorted strain gauge load cells and thermocouple temperature sensors.
- Full Size Baghouse
- Thermal spray coating equipment



# Field Testing and Analytical Services

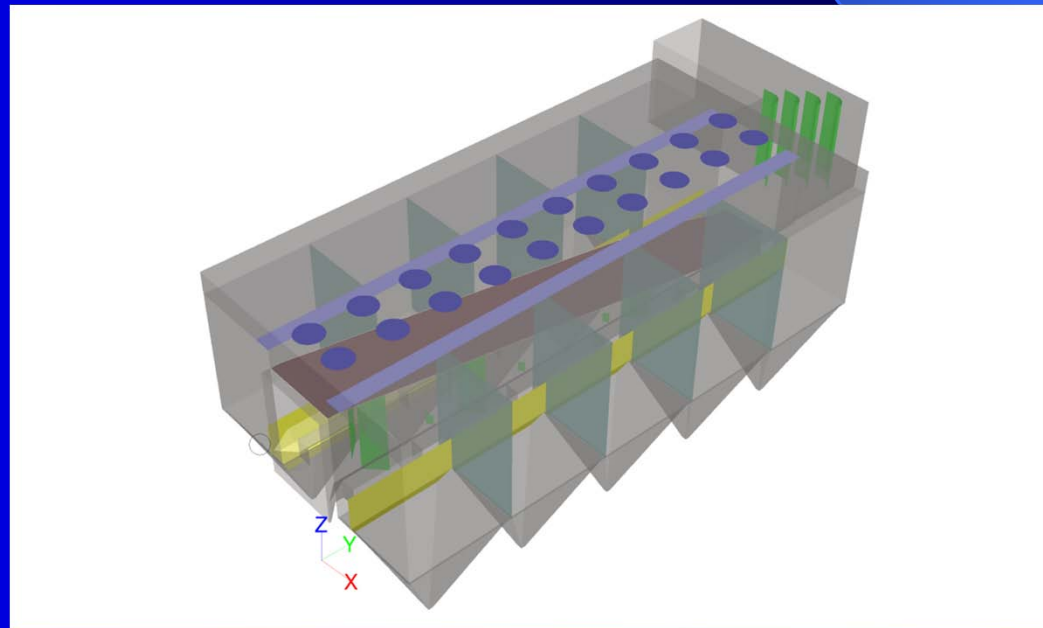
- CEM Evaluation and Optimization
- Boiler Optimization
- Flue / Exhaust Gas Emission Evaluation
- Particulate Emissions
- Gas Analysis (SO<sub>x</sub>, NO<sub>x</sub>, CO)
- Diagnostic and Troubleshooting
- Heavy Metals
- Mercury
- Dioxin Furan
- Ammonia Slip



# OTHER AREAS OF SPECIALIZATION

- Specialized Fabrication Drawings and Parts
- Mathematical Models
- Computational Fluid Dynamics (CFD)

CFD is one of the branches of fluid mechanics that uses numerical algorithms to solve and analyze problems that involve fluid flows.



# Fabric Filters



# Problems in Fabric Filters

## Relating to Gas Flow

- Gas Flow Distribution
  - Inlet flange velocity distribution
  - Compartment Inlet velocity distribution
  - Outlet flange velocity distribution – effect on ID fan
  - Compartment hopper velocity distribution
  - Bag interface plane distribution (Gas / Bag interface). Can cause bag shaking and wear.



# Problems in Fabric Filters

## Relating to Gas Flow

- Pressure Loss
  - Mechanical Baghouse  $\Delta P$
  - Bag  $\Delta P$  due to pluggage
- Ash Distribution & Deposits
  - Ash Loading to each compartment
  - Ash deposition in inlet duct, plenum and compartment inlet. Magnified by moisture carryover
  - Hopper ash re-entrainment



# Problems in Fabric Filters

## Relating to Gas Flow

- Bag Cleaning Cycles
  - Increased frequency due to compartment ash overloading
  - Increased pulsing pressure due to ash loading and filter cake
- Sorbent Injection
  - Imbalanced gas flow and ash loading to each compartment can result in a non uniform sorbent distribution on each filter bag



# Field Images



# Field Images



# Problems in Fabric Filters

## Relating to Gas Flow

- The above issues are the most common relating to poor gas flow conditions in a fabric filter.
- There are likely many other issues with the operation of a fabric filter not caused by gas flow.



# Benefits of Modeling

- To determine the optimum arrangement of internal flow distribution devices and system configuration to reduce any of the previously mentioned problems.
- Cost effective method of design.
- Reduced development time.
- Can be utilized for both New and Retrofit Installations.
- Low risk to the operation of the plant.
- Reduced outage time



# Fabric Filter Model Objectives

- The following is a list of typical modeling objectives for a fabric filter.
- The objectives are based on the typical required criteria to minimize any gas flow related problems in a fabric filter



# Modeling Objectives

- Velocity distribution at the inlet flange of the fabric filter with a RMS deviation less than 15% of the mean velocity.
- Velocity distribution in the compartment inlet duct with a RMS deviation less than 25% of the mean. This location can be difficult depending on the baghouse design.
- Velocity distribution at the outlet flange with a RMS deviation less than 15% of the mean velocity.



# Modeling Objectives

- Velocity distribution at the bag interface plane with no points exceeding 200% of the mean and no row or column averages exceeding 150% of the mean.
- The bag interface criteria differs slightly depending on the fabric filter design.
- Hopper recirculation and high velocity flow patterns must be minimized to reduce ash re-entrainment back onto the bags.



# Modeling Objectives

- Volume flow balance to each of the compartments within +/- 10% of the average
- Ash loading balance to each of the compartments within +/-25% of the average
- Minimize ash deposits in the ductwork, plenum and compartment inlets.
- Minimize the system pressure loss and mechanical fabric filter  $\Delta P$
- Sorbent compartment distribution balanced to within +/-5% of the average, if applicable



# Types of Modeling Techniques

## Physical Modeling

- Utilizes a scale (1/12 typ) Plexiglas model of the system.
- Operated by a fan with representative flow conditions.
- Results obtained by traversing duct with instrumentation

## CFD Modeling

- Utilizes computer software with a 3-D model/mesh of the system.
- Numerical Model that solves the governing differential equations over a finite volume.
- Results obtained by calculation over the desired duct cross section.



# Physical Modeling

Physical Modeling is completed in 3 Stages

- Model Fabrication
- Model Testing
- Analysis and Optimization



# Physical Modeling

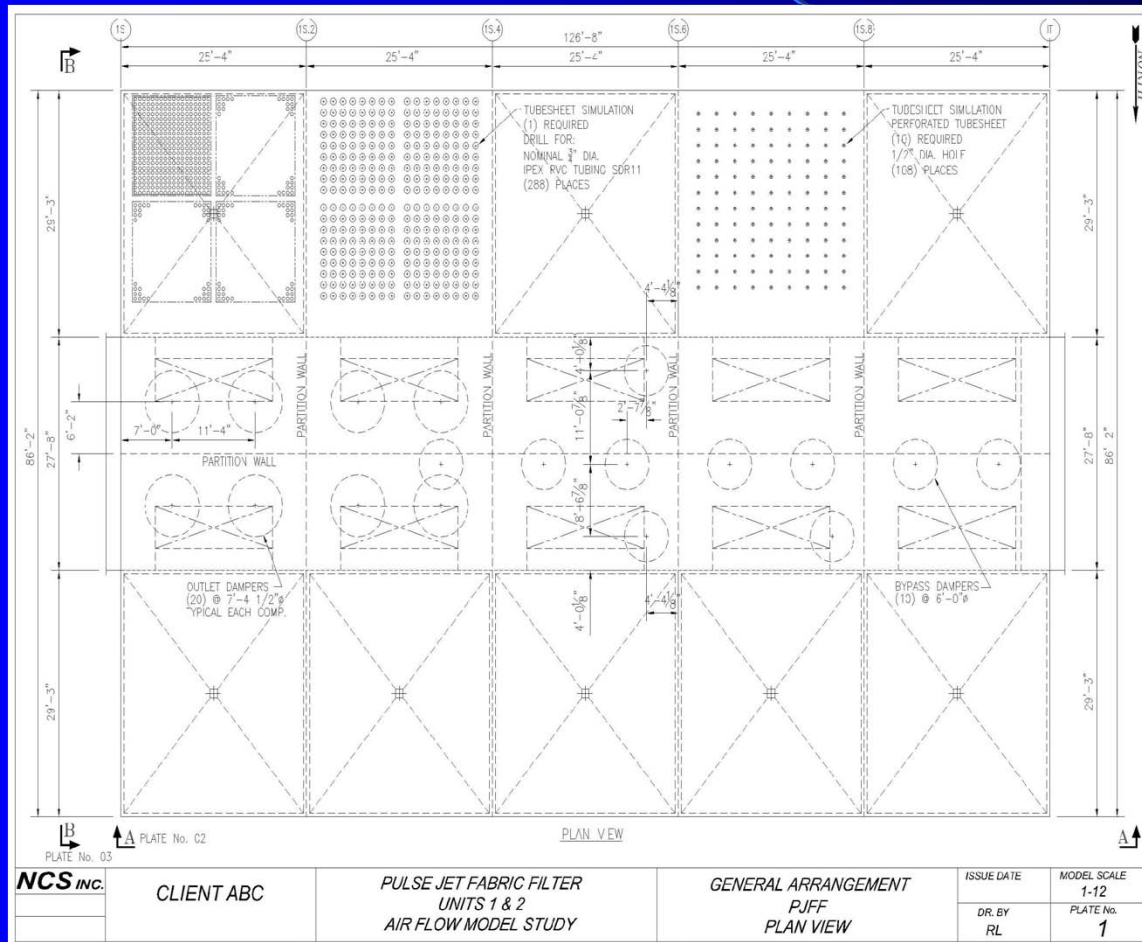


# Model Fabrication

- Details of the operating or new installation are reduced down to the duct walls and components significant to the gas flow.
- Typically all structural members 3” or greater are included in the physical model.
- Model termination points are determined based on the scope, typically for a Fabric filter the model will extend from the air pre-heater outlet to the inlet flange of the ID fan.



# Model Fabrication







# Model Fabrication

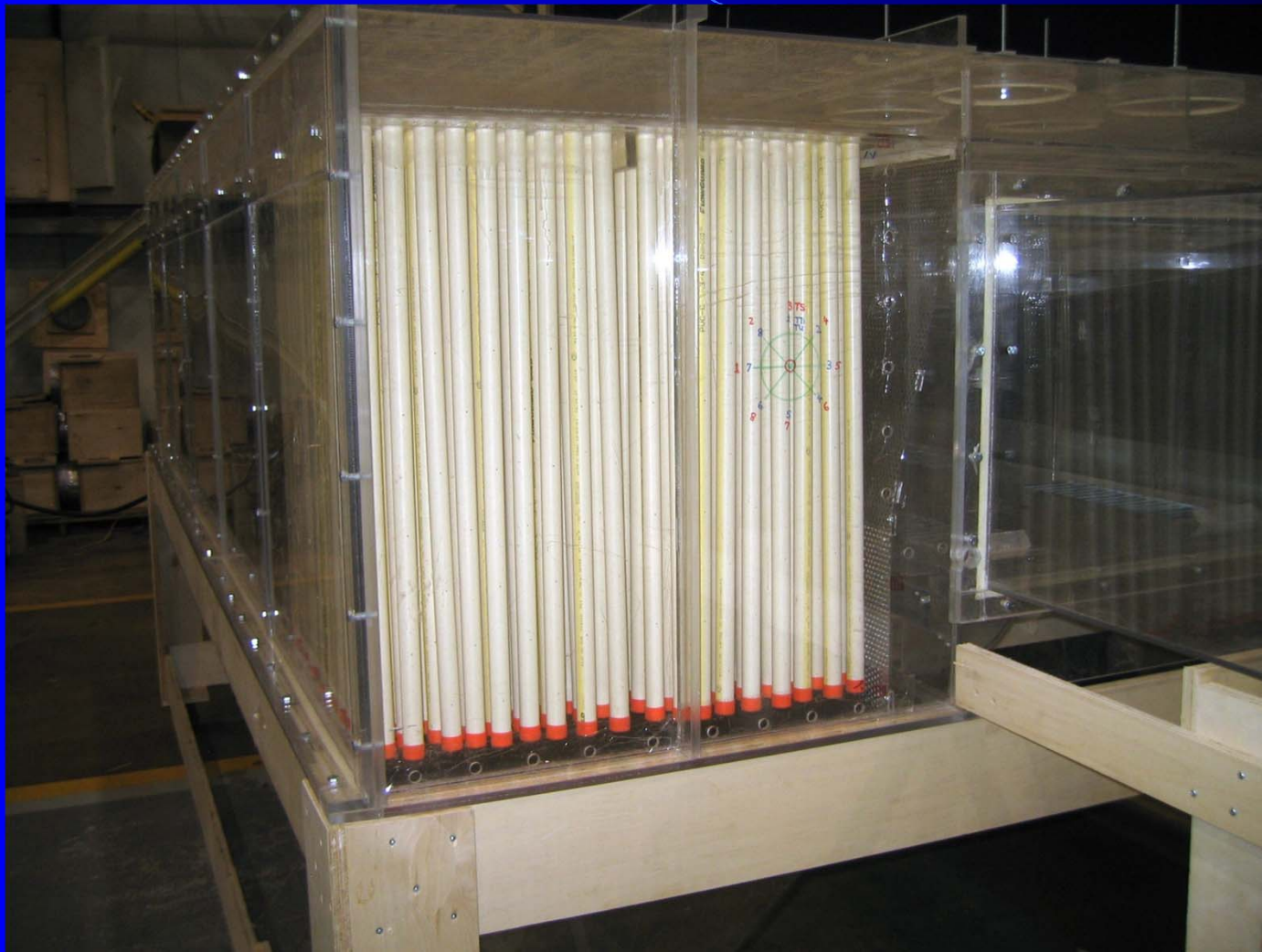


# Model Fabrication Details

- The Air pre-heater outlet is simulated with perforated plate and flow straighteners with the appropriate pressure loss coefficient.
- For overall gas flow testing the tubesheets and bags are simulated with a reduced number of holes with the appropriate pressure loss coefficient. For gas flow testing.
- For ash distribution testing the tubesheets are replaced with a flat filter media to collect the particulate in the compartment.
- For detailed compartment testing the tubesheet and bags are simulated with rigid tubes (approx 1 tube for 4 bags) with equally spaced holes drilled along the length.



# Detailed Tubesheet



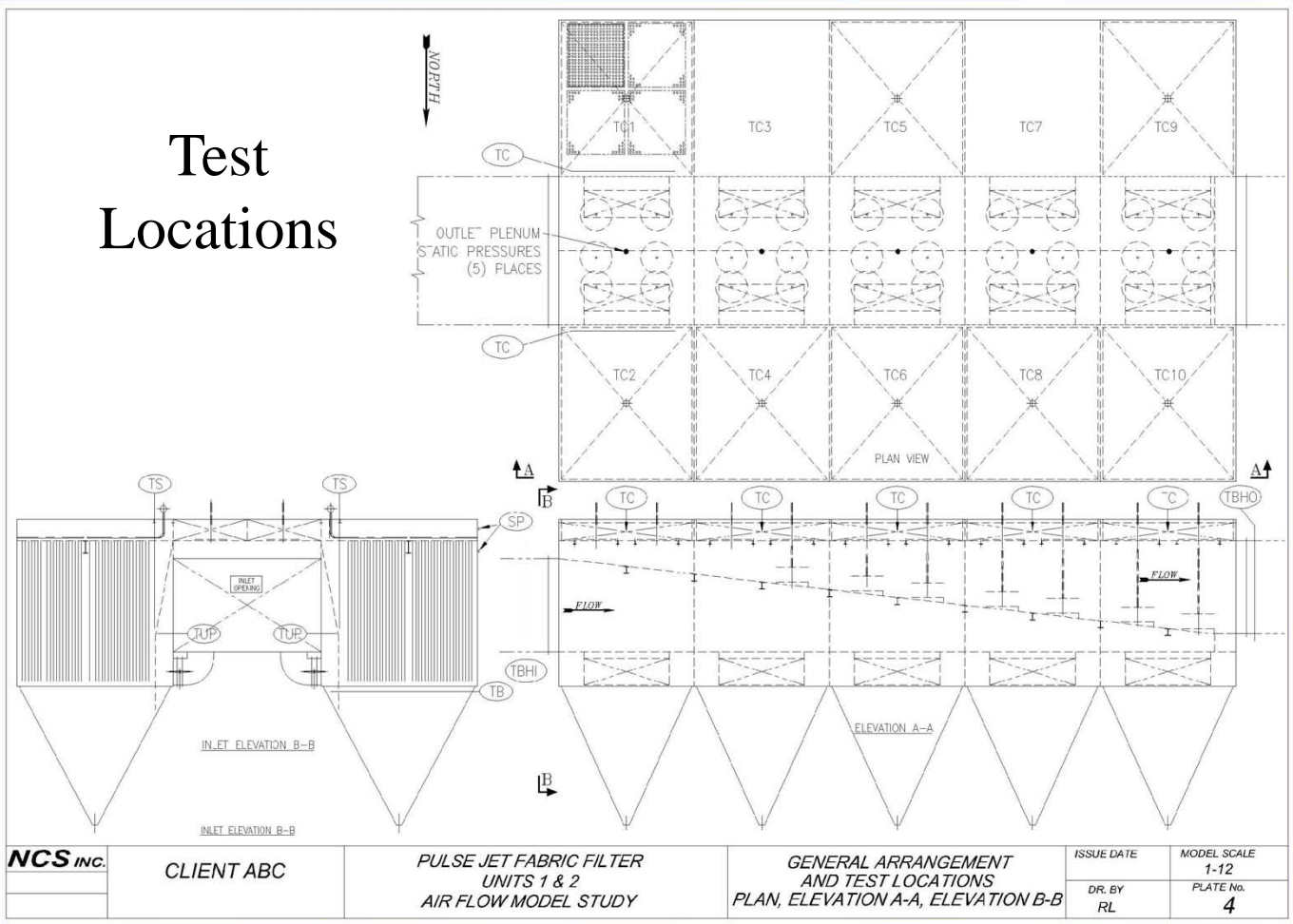
# Model Testing

- The model is setup and initially tested for the “As Designed “ or initial configuration.
- The ductwork is traversed at selected locations, within the ductwork and fabric filter. Typically upstream and downstream of each bend or change in the ductwork.
- The test results are taken by traversing the duct on the center of equal areas with the minimum number of test points being based on  $1.5(\text{Area})^{0.5}$
- Measurements are typically taken with the following equipment
  - Pitot tube and manometer
  - Hot wire anemometer
  - Vane anemometer

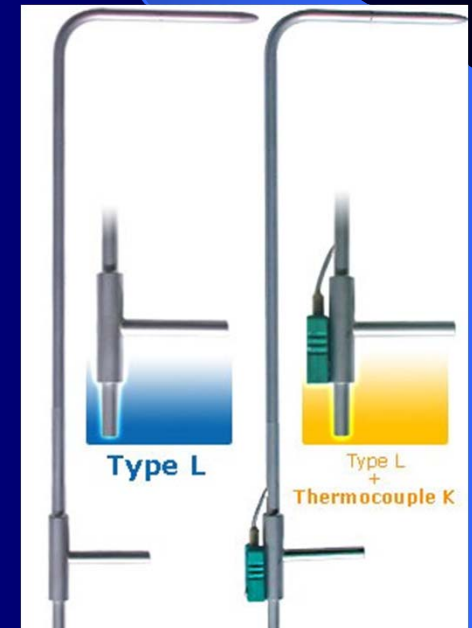


# Model Testing

## Test Locations



# Instrumentation



# Model Test Parameters

## Flow and Pressure Distributions (eg. Ductwork, Supply Air Etc)

- Use Full Size Velocities in Scaled Models for High Reynolds Numbers (>20,000)
- Fully Turbulent Flow Regime with Reproducible Results

$$\text{Re} = \frac{VD}{\nu}$$

## *Conversion of Model Data to Full Size Pressures*

$$P_{Full\ Size} = P_{Model} \times \left( \frac{Q_{Full\ Size}}{Q_{Model}} \right)^2 \times \frac{\rho_{Gas\ Full\ Size}}{\rho_{Air\ Model}}$$



# Model Test Parameters

## Thermal and Species Mixing (eg. Sorbent Injection, Temperature Stratification)

- Set Flow Streams Matching Full Scale Momentum Ratios

### Momentum Ratio, MR:

$$MR = \left( \frac{M_f V_f}{M_c V_c} \right) = \left( \frac{Q_f^2 A_c \rho_f}{Q_c^2 A_f \rho_c} \right)$$

Where:

M = mass flow, ( $\rho Q$ )	f = flue to SDA
V = gas velocity, ( $Q/A$ )	c = PAC injection
$\rho$ = gas density	Q = volume gas flow
A = cross sectional area	

For equality of full size and model momentum ratios,

$$\left( \frac{Q_f}{Q_c} \right)_{\text{Model}} = \left( \frac{Q_f}{Q_c} \right)_{\text{Full Size}} \times \sqrt{\frac{\rho_{c\text{Model}} \rho_{f\text{FullSize}}}{\rho_{c\text{FullSize}} \rho_{f\text{Model}}}}$$



# Model Test Parameters

## •Two Phase Particulate Patterns (eg. Baghouse)

- Set Flow Based on Matching Full Scale Particle Drag/Gravity Ratio OR Trajectory Scaling Based on Scale Factor

### 1. Equating drag and gravitational forces for air and particulates:

$$\frac{DF_P}{GF_P} = \frac{DF_M}{GF_M} \quad \text{where} \quad \begin{array}{l} DF = \text{drag force} \\ GF = \text{gravitational force} \\ P = \text{prototype} \\ M = \text{model} \end{array}$$

Each force is defined as:

$$DF = 0.5 C \rho A V^2 \quad \text{where} \quad \begin{array}{l} C = \text{drag coefficient} \\ \rho = \text{air density (lb/ft}^3\text{)} \\ A = \text{particle frontal area (ft}^2\text{)} \\ V = \text{air velocity (ft/s)} \end{array}$$
$$GF = 62.4 S \text{ Vol} \quad \begin{array}{l} 62.4 = \text{density of water (lb/ft}^3\text{)} \\ S = \text{particle specific gravity} \\ \text{Vol} = \text{particle volume (ft}^3\text{)} \end{array}$$

Letting  $C = 24/RE_P$  (Particulate Reynold's Number) for the Stokesian drag regime,  $RE_P = Vd/\nu$  ( $V$  = air velocity (ft/s),  $d$  = mean particle diameter (ft) and  $\nu$  = kinematic viscosity (ft<sup>2</sup>/s)) and  $A/\text{Vol} = 1/d$ , rearranging terms yields the relationship:

$$V_M = V_P \left( \frac{V_P}{V_M} \right)^{0.6289} \left( \frac{\rho_P S_M}{\rho_M S_P} \right)^{0.8145} \left( \frac{d_M}{d_P} \right)^{1.4434}$$



## Model Particulate Testing

- There are two types of Particulate Tests completed with a Physical Model
  - Compartment Particulate Distribution
  - Ash deposition patterns



# Particulate Distribution Testing

- The model velocity is scaled based on the drag and gravitational force ratio and the particle Reynolds's Number Scaling Theory
- A measured quantity of particulate is injected into the model uniformly through the model inlet.
- The particulate loading distribution to each corresponding compartment is determine by weight.
- The test is repeated at least once to ensure correlation.
- Types of media utilized for the model
  - Fly ash from the plant
  - cork dust
  - Fine granulated salt
  - Pumice



# Ash Deposition Patterns

- The ductwork floor is layered with particulate.
- The model velocity is scaled based on the particle Reynolds's Number Scaling Theory
- The gas flow is ramped up incrementally from
  - 0% - 25% - 50% - 75% - 100%
  - And the resulting deposition patterns noted.



# Ash Deposition Patterns

0%  
Flow



35%  
Flow



# Analysis and Optimization

- Upon completion of the initial test program the results are analyzed and compared to the required flow distribution criteria.
- Various modifications are then tested through an iterative process to develop a final solution.



# Analysis and Optimization

- Modifications include:
  - Turning vanes
  - Baffles
  - Deflectors
  - Channels



# CFD Modeling

CFD Modeling is completed in 4 Stages

- 3-D Model Generation
- Meshing
- Simulation / Iteration
- Analysis and Optimization

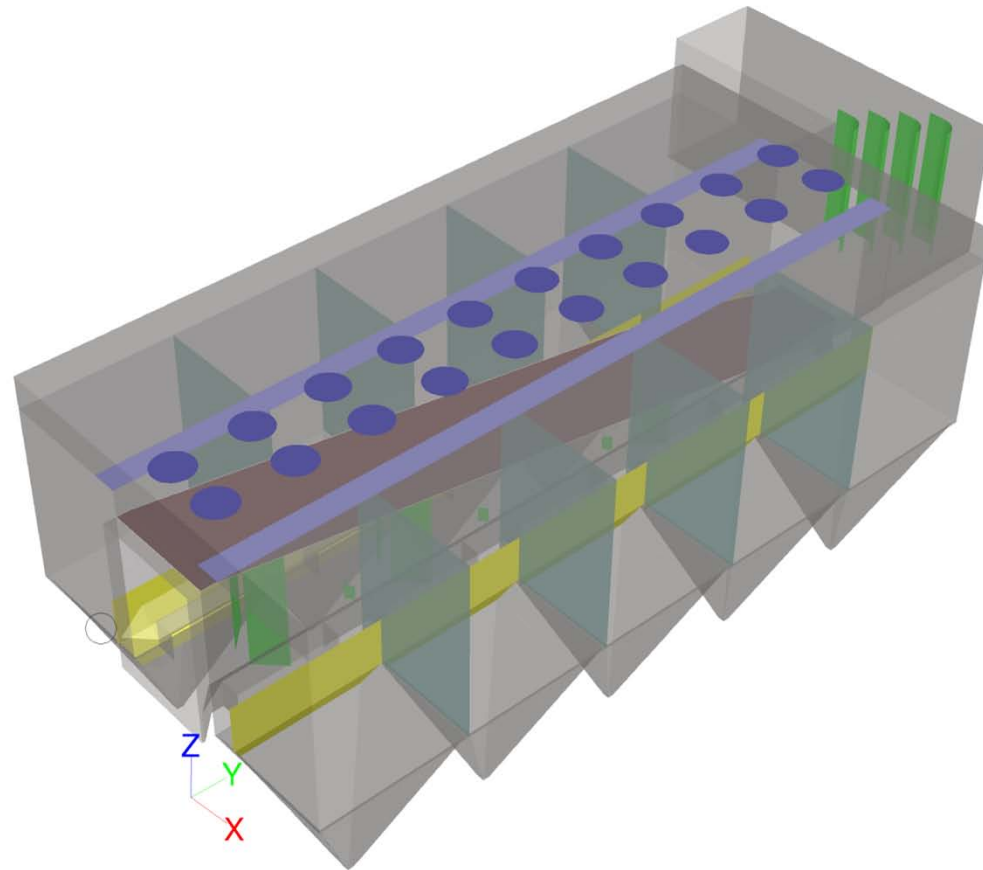


# 3-D Model Generation

- Details of the operating or new installation are reduced down to the duct walls and components significant to the gas flow.
- Typically all structural members 6” or greater are included in the CFD model. More detail results in more computational demands.
- Model termination points are determined based on the scope, typically for a Fabric filter the model will extend from the air pre-heater outlet to the inlet flange of the ID fan or the FF inlet flange to outlet flange .



# 3-D Model Generation

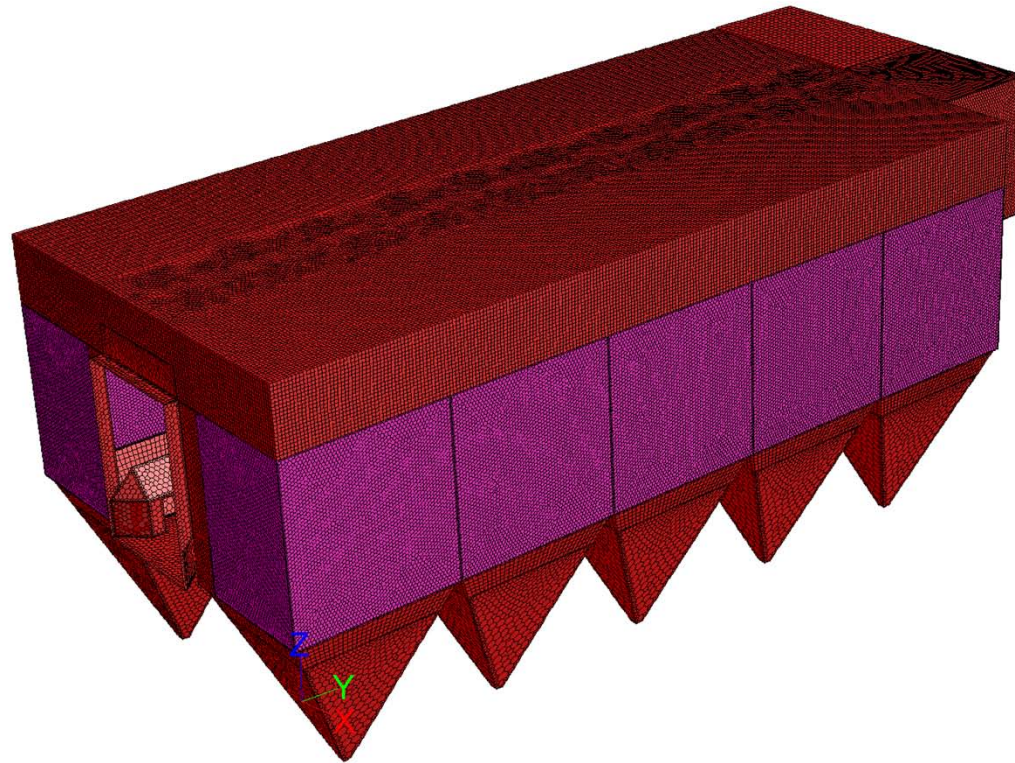


# Meshing

- The 3-D model is then broken up into a set of finite control volumes in order to calculate the rate of change for each of the governing conservation equations until the error between each of the cells is less than the convergence criteria.
- The resolution of the mesh will govern the accuracy of the model to resolve the flow field.
- Typical Fabric Filter meshes are between 2 million and 5 million cells.



# Meshing



# Boundary Conditions

- The model inlet is defined as a velocity inlet face with a known distribution either from a previous CFD model of the upstream components or from other data, physical or field.
- The model outlet is defined as a pressure outlet face with known pressure.
- Perforated plates are defined as either porous jump faces or porous media with the appropriate pressure loss coefficient.
- The bag zone is typically defined as a porous media that is representative of the bag zone. The pressure loss coefficient for this zone is setup is such a way that it will represent the gas flow through the bag and tubesheet.
- All turning vanes and flow distribution devices are defined as wall faces.



# Simulation / Iteration

- The appropriate flow simulation models are selected for the fabric filter model
  - Turbulence model
  - Energy model
  - Discrete Phase Model
  - Species Transport Model
- The model is setup and initially iterated for the “As Designed “ or initial configuration.
- The model will be iterated several times until the residuals for the various conservation equations are less than the convergence criteria. The typical convergence criteria is achieving residuals less than  $1E10^{-3}$
- The test results are calculated based on cut planes taken throughout the model at selected locations of interested, the same locations as the physical model.
- Multiple data categories can be extracted from the converged model quickly and easily.

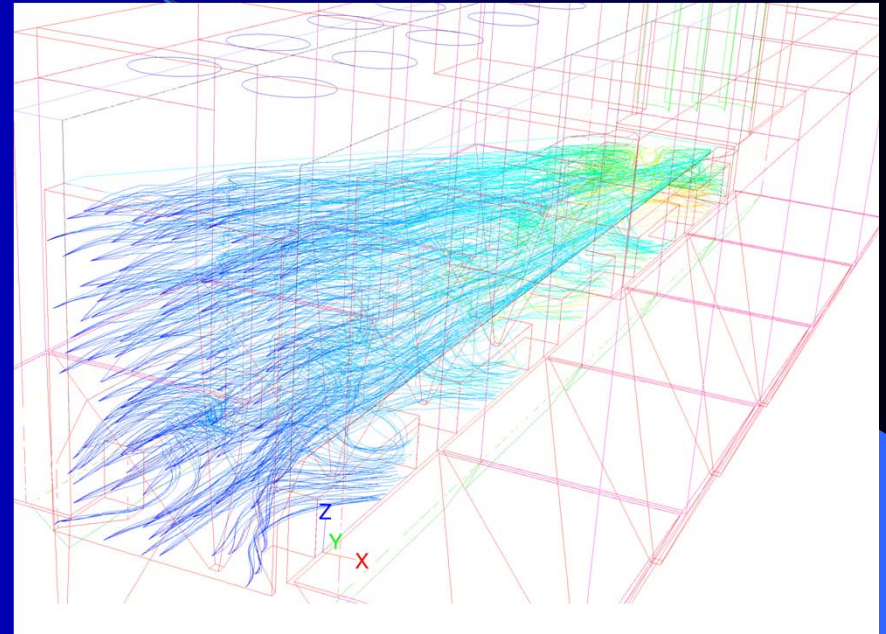
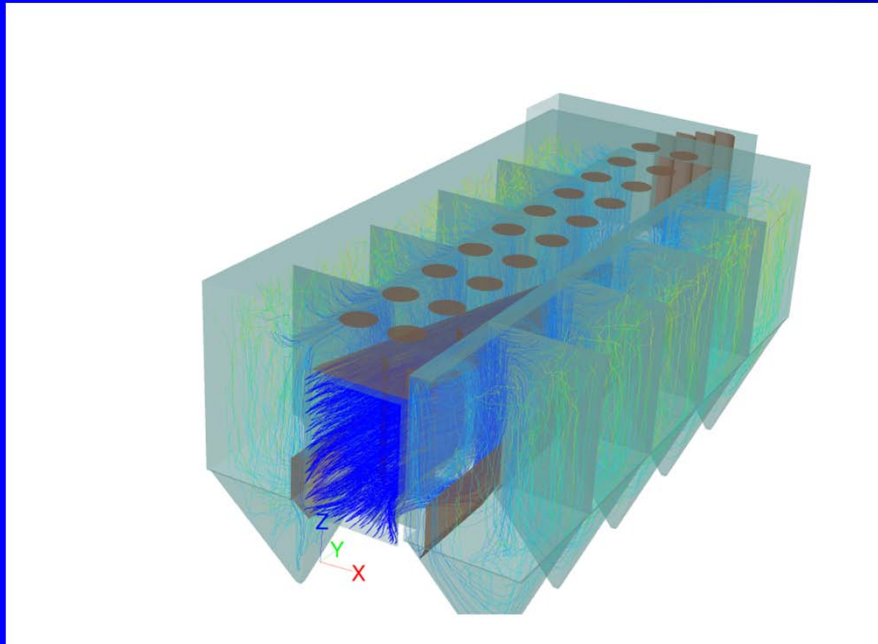


# Particulate Distribution Testing

- The typical particulate injection method for a fabric filter is to define the particle properties for a given injection plane.
  - Need to know, in good detail the particle properties.
- The DPM model allows the release of the particles into the flow field and the resulting flow path of each particle will be calculated based on the gas flow.
- The released particles are then tracked through the model where the statistics of the particles passing through a given face can be easily determined.
- The particulate loading distribution to each of the compartment inlet faces will determine the overall ash distribution.



# Particle Tracks



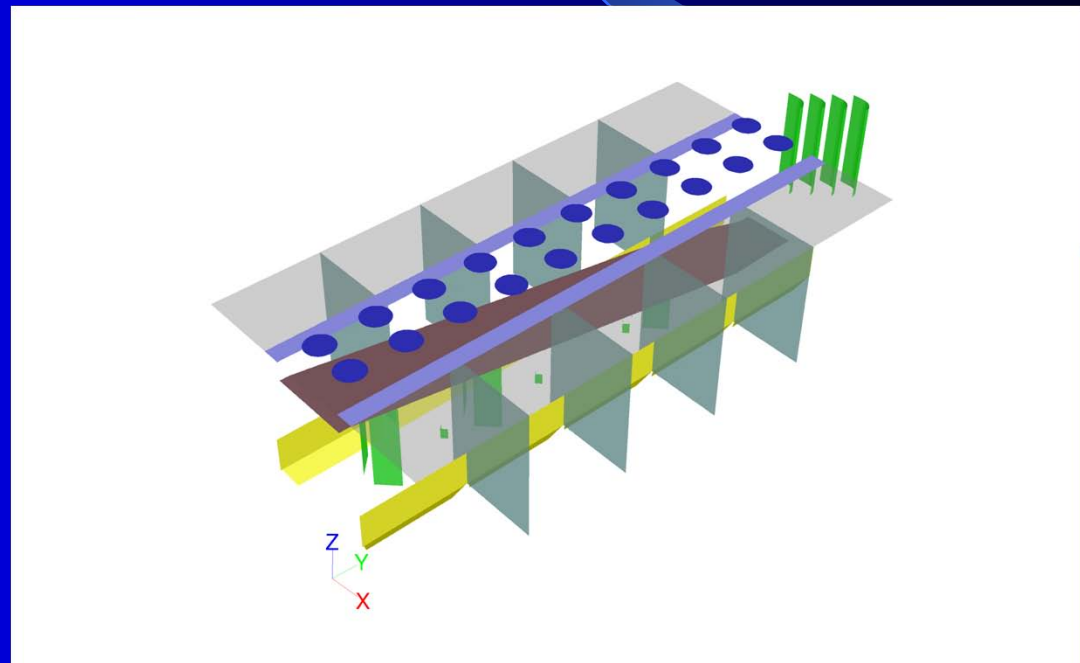
# Analysis and Optimization

- Upon completion of the initial test program the results are analyzed and compared to the required flow distribution criteria.
- Various modifications are then calculated through an iterative process to develop a final solution.
- For each modification the system geometry and mesh has to be altered and the model re-iterated.



# Analysis and Optimization

- Modifications include:
  - Turning vanes
  - Baffles
  - Deflectors
  - Channels



# Physical vs. CFD Flow Models

## Physical Models

### Pros

- Matches Physical Geometry Very Accurately
- Excellent Visualization
- Faster Development
- Two Phase Flow and Deposition
- Intuitive and Practical Solutions

### Cons

- Can Be More Costly
- Measurement Limitations in Detailed Areas
- No Heat Transfer Capability
- Combustion Process Limits
- Not as Flexible with Variable Inlet Conditions

## CFD Models

### Pros

- Can detail small areas (no instrumentation limits)
- Heat Transfer/Reaction and Combustion
- Good Graphical Output of Data

### Cons

- Slower Development (long run times)
- Struggles with Multiple Geometries/ Flow Conditions
- Rapid Expansion and Perforated Plate Physics
- Geometry Limits Due to Meshing/Computer Memory
- Weak for Two Phase Flow and Cannot predict Deposition
- Not as intuitive can lead to Non Practical Solutions
- “Garbage In – Garbage Out”



# Fabric Filter Modeling

- Important Keys to Fabric Filter Modeling
  - Design Devices to minimize problems in the operating unit.
  - Optimize gas and ash distribution to each compartment.
  - Minimize System Pressure Loss where possible.
  - Minimize compartment recirculation patterns
  - Review Gas Conditions in the operating unit before completing any study.



***THANK YOU***

