26th Annual Energy Generation Conference

Humidity Control for Coal / Lignite Boilers

Jeff Bossong - Humidity to Optimization

Objective of Presentation

- Humidity Definitions
- Humidity Sensor Obstacles
  - Sampling & Temperature
  - High Particulate Operation
  - Accuracy & Maintenance
  - Corrosion
  - Cost
  - Software & Control Systems

Objective of Presentation

- Humidity Sensor Applications at Energy Plants
  - Locations
  - Benefits

Humidity Definitions

> **% Volume**
  - Concentration of water in gas stream
  - Volume of water divided by total volume

> **Absolute Humidity (g/m3)**
  - Weight per volume measurement
  - A constant conversion (.12452 at 1 atm) to concentration at constant temperature and pressure

> **Water Vapor Pressure**
  - **Equation 1 - Vapor Pressure**
    Pd = (1-(0.0001(SQRT((0.1*T)+1)+4)))*461.51*(T+273.15)*F*0.00001 where*
    - F = Absolute Humidity (g/m3) - H_2O Reading
    - Pd = Water Vapor Pressure (hPa)
    - T = Dry Bulb Temperature (ºC)

> **Saturation Vapor Pressure**
  - Water vapor pressure exerted at 100% volume at a given temperature

Humidity Definitions

- **Relative Humidity**
  - Water vapor pressure divided by the saturation vapor pressure
- **Dew Point Temperature**
  - Temperature in which water will condense from a gas stream
- **Wet Bulb Temperature**
  - The lowest temperature an object can be cooled to by the process of evaporation
  - Tw = Td - 755 (Ps-Pd) / 0.5 P where 0.5 is a constant based on the psychrometer used

Obstacles

- Particulate
  - Loading high before APC equipment
  - Sample pumps required at high temperatures
  - Compressed air purge and maintenance
- Temperature & Sampling
  - Electronics will degrade at high temperatures
  - Conventional RH substrate sensors lose accuracy as temperatures rise above 212F
  - Sampling Required

Obstacles

- Accuracy
  - High accuracy required for control
  - High accuracy required for sensitivity (tube leaks)
  - A major reason why humidity sensors aren't common in power plant operations
- Corrosion & Fouling
  - Sulfuric acid mist
  - Chlorides (Hg control)

Technologies

- **Polymer**
  - Relative humidity sensors (function of temperature and humidity)
  - Measure capacitance or resistance across substrate
  - Secondary measurement
  - Main issues are accuracy, unresponsive in high temperature, substrate fouling
  - Frequent calibration in harsh environments

Technologies

- **Dew Point**
  - Control temperature of sensor (chilled mirror) to achieve condensation
  - Secondary measurement
  - Main issues are particulate, other compounds condensing (H_2SO_4 condenses before moisture), not suitable for high humidity environments
- **Infrared**
  - Specific IR frequency is absorbed by water
  - Direct measurement
  - Main issue is particulate and maintenance

H2O Technology

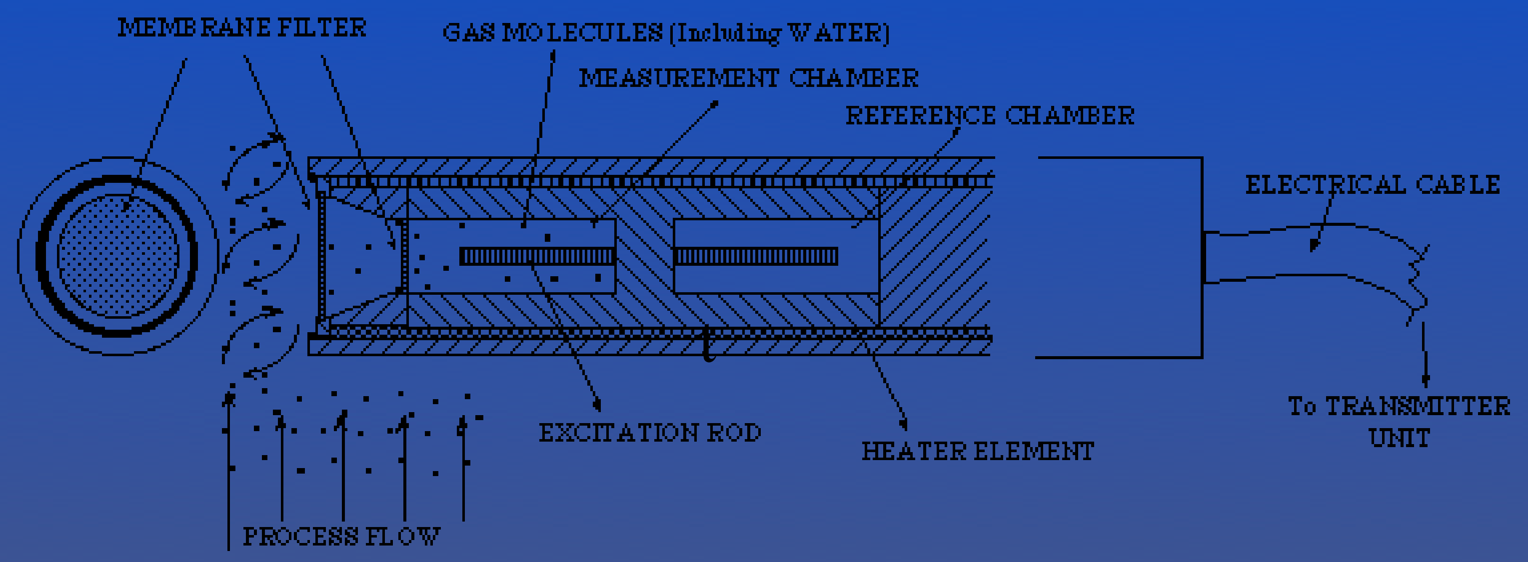
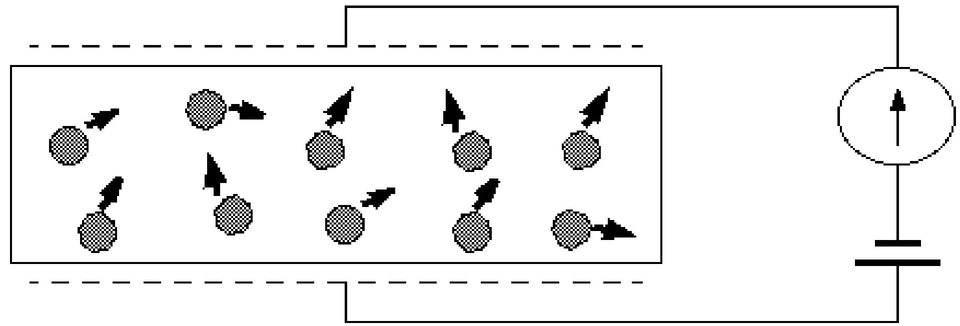


FIG. 3 - PROBE SCHEMATIC

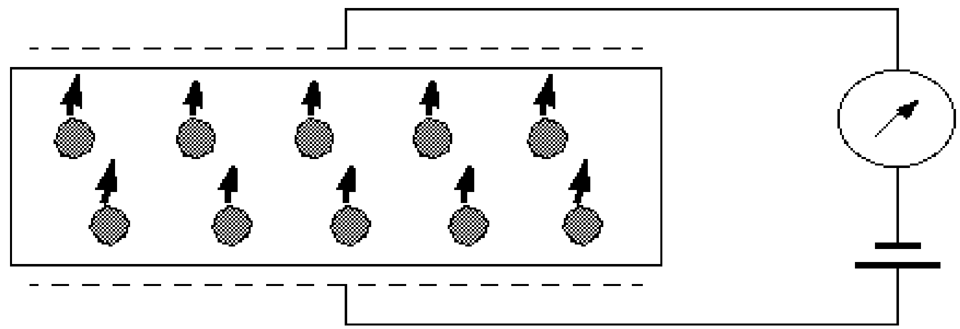
Dipole Measurement

Dipole-Frequency Theory of Measurement -2



Dipole Polarization

- degree of alignment depends on temperature and electric field energy
- at known temperature, number of polar molecules α energy consumed by electric field



Calibration

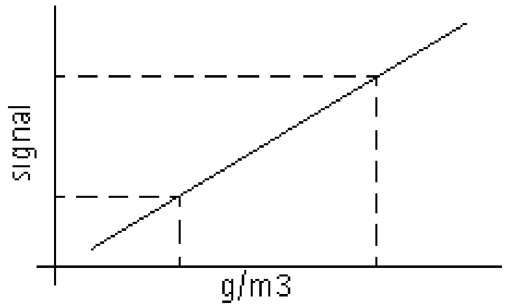
Calibration, Accuracy and Drift

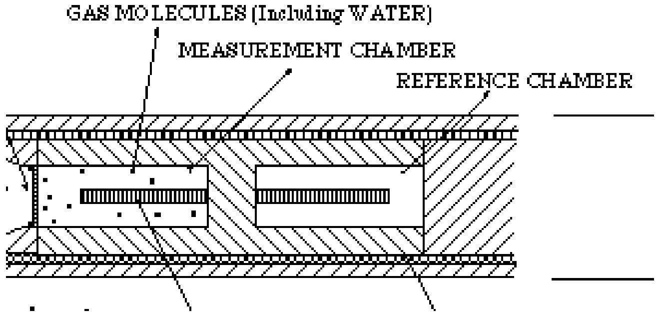
- Measurement signal α mass of water molecules in chamber

  Constant "zero" reference provided by the hermetically sealed reference chamber

  One other point is needed for the measurement range

  Initial calibration is after manufacturing, utilizing pressure and temperature (NIST traceable) measurements of pure steam





Accuracy is thus NIST traceable

As long as sensor and reference chambers are dimensionally intact, there is NO drift

Filter failure leads to "out-of-range" signal indicating sensor has malfunctioned – NO drift

Re-calibration is eliminated

Particulates

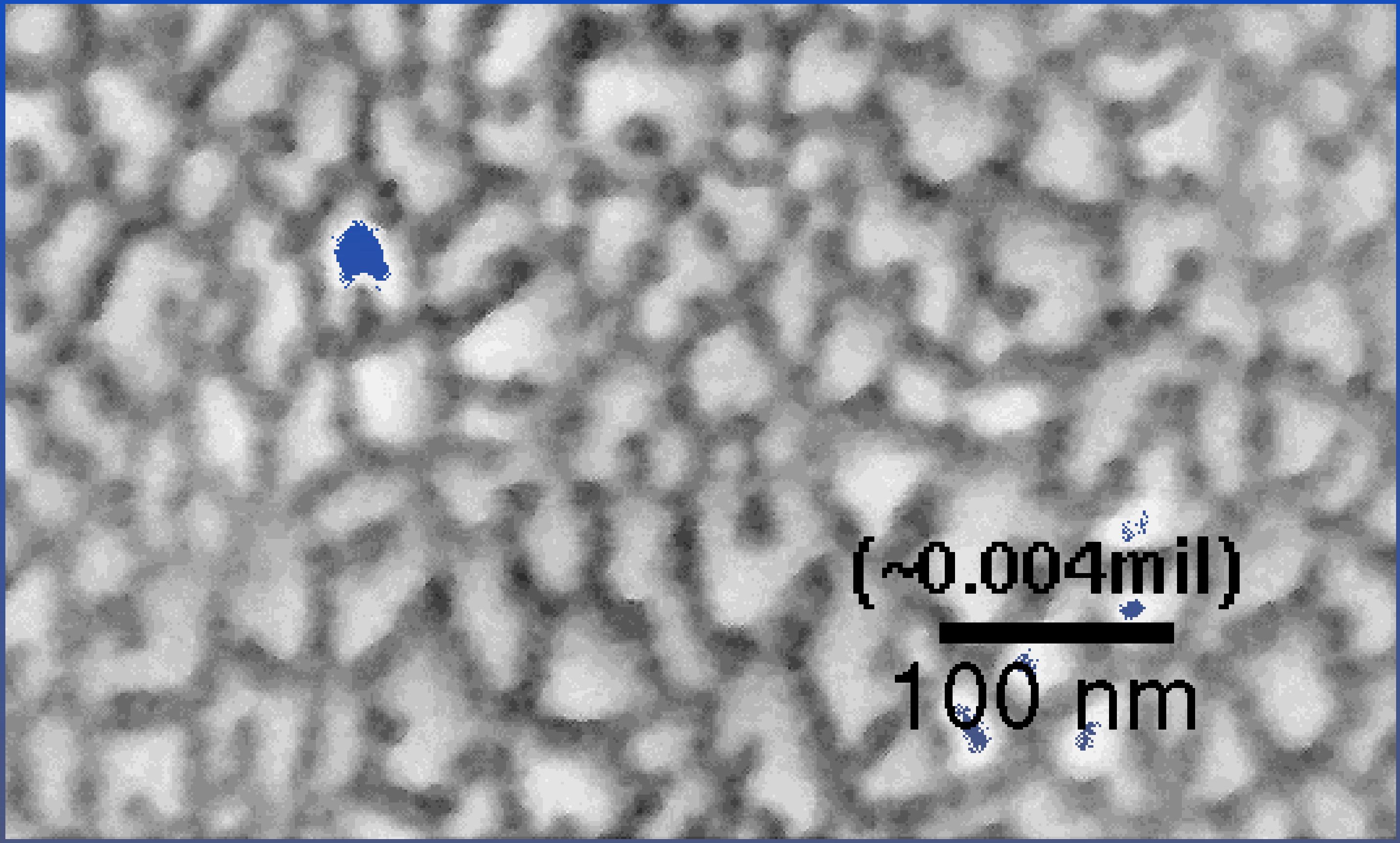


FIG. 4 - ELECTRON MICROSCOPE MAGNIFIED SURFACE OF MEMBRANE FILTER

Corrosion & Installation

- Corrosion
  - Stainless Steel & Inconel Probe
  - Heated Probe (Fixed Above Process Temp.)
  - NEMA 4 Enclosure
- Installation
  - Attach to 4 inch ANSI Port
  - 110 V Power
  - 15 Amp clean power
  - 4..20 mA signal

Accuracy Comparison

Table 1: Accuracy Differences

Temperature	Absolute Humidity	Relative Humidity	Dew Point
325 C	10 % (80 g/Nm3)	0.2% RH	62.2 C
325 C	11.8% (95 g/Nm3)	0.2% RH	66.1 C
100 C	10 % (80 g/Nm3)	13.6 % RH	52.2 C
100 C	11.8% (95 g/Nm3)	16% RH	55.8 C

Moisture Variations

- Fuel Moisture
- Unit Load
- Ambient Moisture
- Tube Leaks
- Soot Blow (steam soot blows)
- Scrubber Moisture
- Baghouse & Air Heater Leaks
- A combination of the listed variables can change moisture by as much as 10% (unlikely though)

Coal Plant Locations

> **Economizer Outlet**
  - Fuel moisture feedback
  - Heat rate calculations (Input / Loss Methods)
  - Tube leak detection
  - Soot blower feedback
  - Process Conditions
    1. 600 - 700 F process temperature
    2. 0 to 401.54 g/Nm3
    3. 0 to 50% by volume

Coal Plant Locations

- Dry Scrubber Outlet
  - Lime optimization
  - Fixed approach to saturation control
  - Baghouse protection
  - Process Conditions
    1. 200 F Probe Temperature Setpoint
    2. 0 to 401.54 g/Nm3
    3. 0 to 50% by volume
  - Design based on approach to saturation

Coal Plant Locations

> Dry Scrubber Outlet

- Dewpoint equations

- **Equation 1 - Vapor Pressure**

  Pd = (1-(0.0001(SQRT((0.1*T)+1)+4)))*461.51*(T+273.15)*F*0.00001 where*

  - F = Absolute Humidity (g/m3) - H2O Reading
  - Pd = Water Vapor Pressure (hPa)
  - T = Dry Bulb Temperature (ºC)

  Equation 2 - Dewpoint Temperature

  *DP = (234.175*LN(Pd /6.1078))/(17.08085-LN(Pd /6.1078)) where*

  - DPc = Dew Point Temperature (ºC)

  Equation 3 - Temperature Conversion to Fahrenheit (DPf)

  (9/5)DPc + 32 = DPf

Coal Plant Locations

Table 2: Summer Ambient Data

Time of Day	Dry Bulb Temperature (F)	Dewpoint Temperature (F)	% Volume
Noon	91	70	2.3
2:00 AM	72	55	1.3

Coal Plant Locations

Table 3: Dew Point Change Based on Ambient Air Conditions

% Volume	Dry Bulb Temperature (F)	Dew Point Temperature (F)
13	199 F	135.3
14	199 F	138.2

Coal Plant Locations

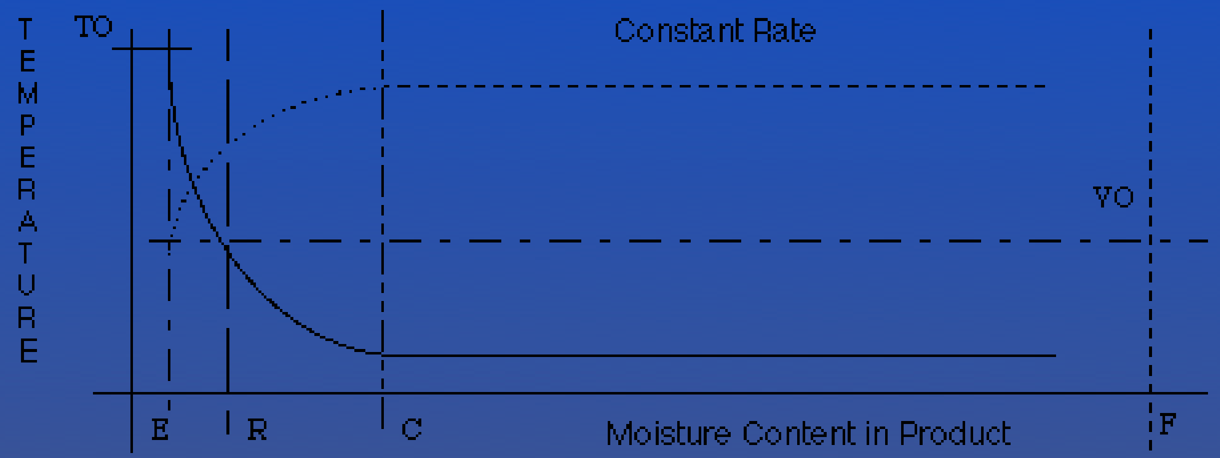
- Exhaust Stack
  - Improved environmental reporting
  - Extractive CEM systems
- Baghouse Protection
  - Inlet humidity more desirable
- Mercury Control
  - Carbon injection - lower temperature

Coal Plant Locations

> Pulverizer Control

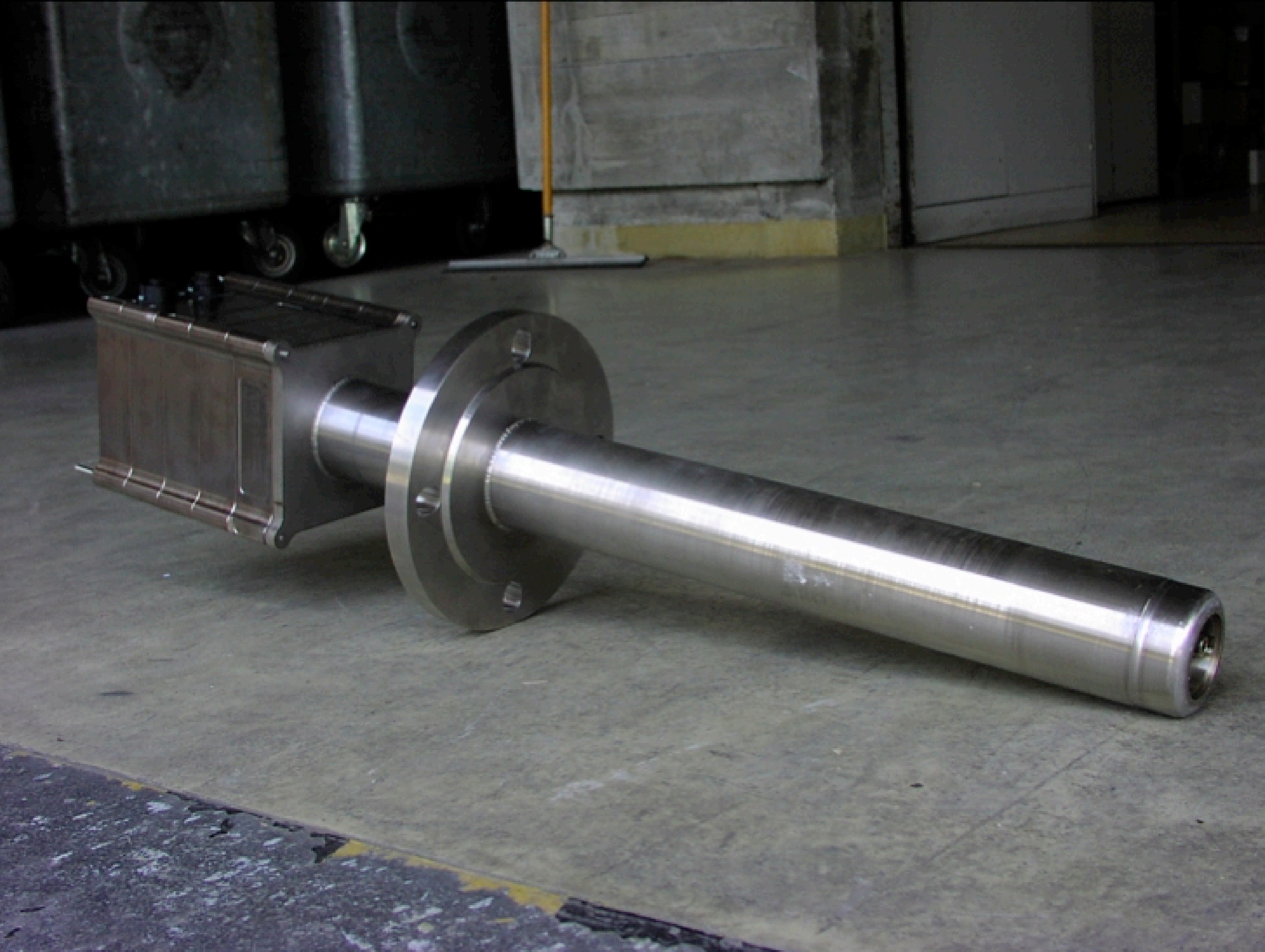
- Coal dryer
- Vapor pressure differential
- Fuel optimization & selective bunkering
- Upset conditions

Drying Curve



E = Equilibrium Conditions
R = Residual Moisture content in product leaving dryer
C = Critical Point

TO = Outlet dryer temperature
VO = Outlet Vapor Pressure (% Vol Humidity)
F = Feed conditions



Installations

Installations (cont.)

Open Discussion & Questions

> Plant Applications
  - Duct Installations
> Plant History with Humidity Sensors