Flow Modeling Of Wet Scrubbers

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rev.2

presented at WPCA/Duke Energy Scrubber Seminar
3-4 June 2004
Charlotte, NC USA

Outline

- Purpose
- Levels of Complexity
- Physical Model Overview
  - Modeling Challenges
- CFD Model Overview
  - Modeling Challenges
- Summary
- Questions

Source: B&W

Purpose

- Flow Uniformity
- Droplet Evaporation and Impingement
- Thermal Prediction

Levels of Complexity

1)Model of inlet duct only

– Assumption that internal flows already optimized by vendor
– Very simple model; entire scrubber generally not included
– Probably not appropriate unless scrubber is oversized

Levels of Complexity

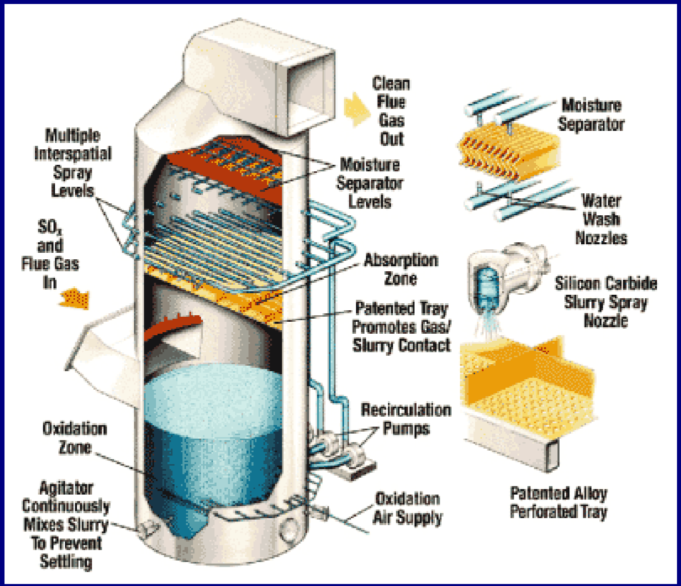
2)Model of flow through scrubber

- Assures optimum flow without water
- Assumption that water droplets do not affect flow uniformity is not actually valid
- Field-verifiable
- No droplet impingement
- Similar complexity to an ESP model, simpler than an SCR model

Levels of Complexity

3)Model including water injection

- Includes the ability to evaluate droplet impingement
- Can include the effects of injection on gas momentum
- Can include evaporative cooling
- Very difficult model, more difficult than ESPs or SCRs



Source: Power Engineering

Physical Model Overview

- Scale model, typically 1/12
- Ambient air drawn through the model
- Flow measurements made with hot wires, vane anemometers, pitot tubes, venturi flow meters, or other devices
- Sometimes air only; sometimes water is sprayed

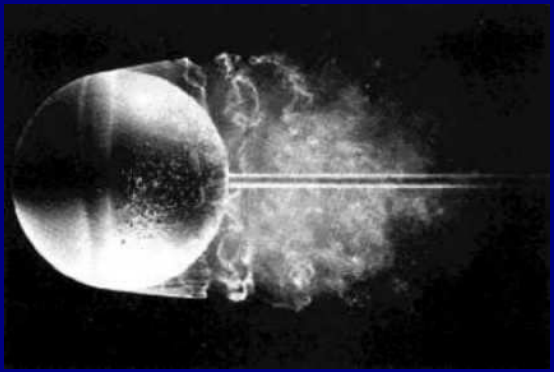
Video courtesy of Marsulex Environmental Technologies

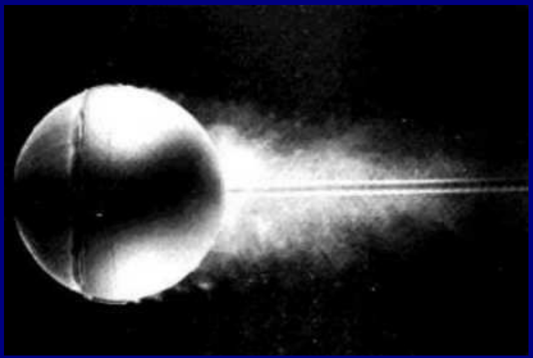
Physical Modeling Challenges

- Droplet evaporation not possible in a physical model since model is cold flow.
  - Temperature distribution is not possible
- Too many parameters to fully model in scale

Too many parameters ...

1. Gas flow similarity requires matching Reynolds number, or at least keeping in turbulent range (Re > 7000).

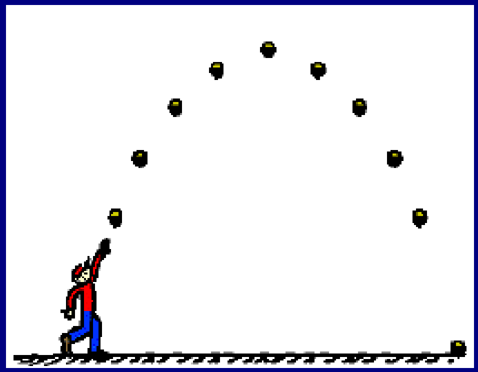




Source: The University of Iowa

Too many parameters ...

2. Droplet path similarity requires matching two parameters
   – Dragless projectile motion (ratio of inertial-to-gravity forces on a particle). For a typical model this leads to the requirement that the injection velocity should be about 29% of the full-scale injection velocity.



Source: "The Physics Classroom"

Too many parameters ...

2. Droplet path similarity requires matching two parameters
   - Aerodynamic forces on a particle, or Bagnold number (ratio of drag-to-weight on an individual particle). For a typical model this leads to the requirement that the droplet diameter in the model should be 11% of the size of the full-scale droplets.

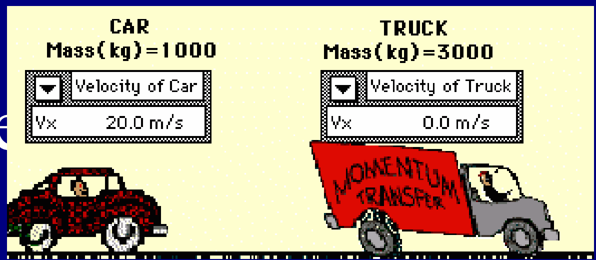
Source: www.tera-web.co.uk

Too many parameters ...

2. Droplet path similarity requires matching two parameters
   – Dragless projectile motion. Injection velocity should be 29% of the full-scale injection velocity.
   – Ratio of drag-to-weight on a particle. Droplet diameter should be about 11% of the size of the full-scale droplets.
   – Not feasible due to nozzle availability
   – Even if suitable nozzle were found, can only be tracked near the nozzle due to lack of evaporation

Too many parameters ...

3. Momentum transfer between water and gas requires matching momentum ratio (total injection momentum to gas momentum)
   - Locally very important to gas flow in scrubbers
   - In a typical case, need 7 times as many nozzles in model than in full-scale unit
   - Momentum transfer is sometimes simulated with perforated plates, but this makes model flow uniformity better than full-scale



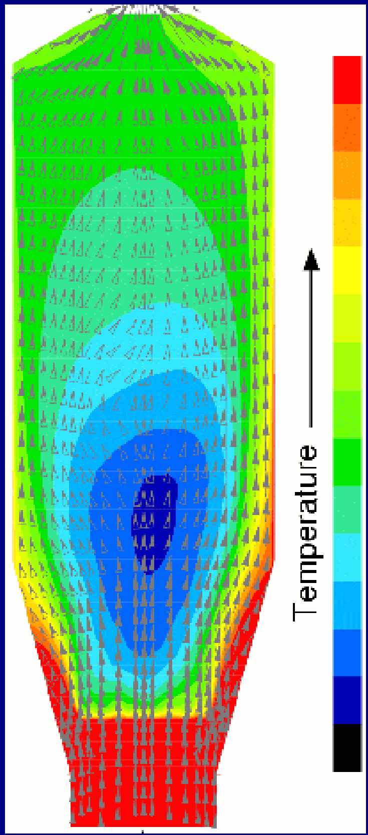
Source: "The Physics Classroom"

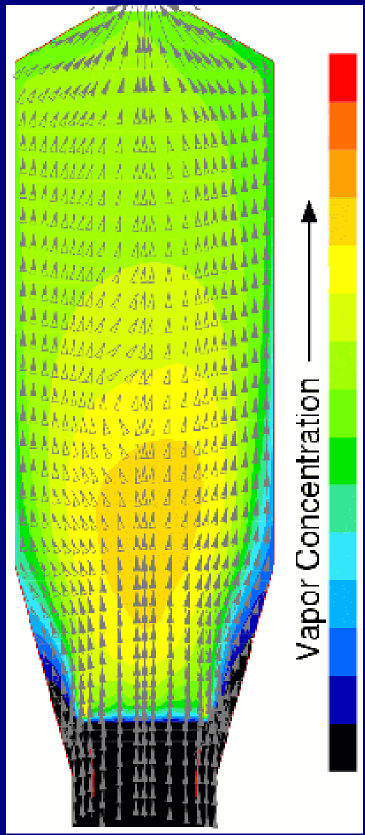
Too many parameters ... Summary

1. Reynolds number (Re > 7000).
2. Droplet path similarity very difficult or impossible
3. Momentum transfer between water and gas requires matching momentum ratio using many nozzles

CFD Overview

- Computationally solve equations for conservation of mass, momentum, and energy throughout a domain
- Flow observations made by query, plots, animation, and numeric integration





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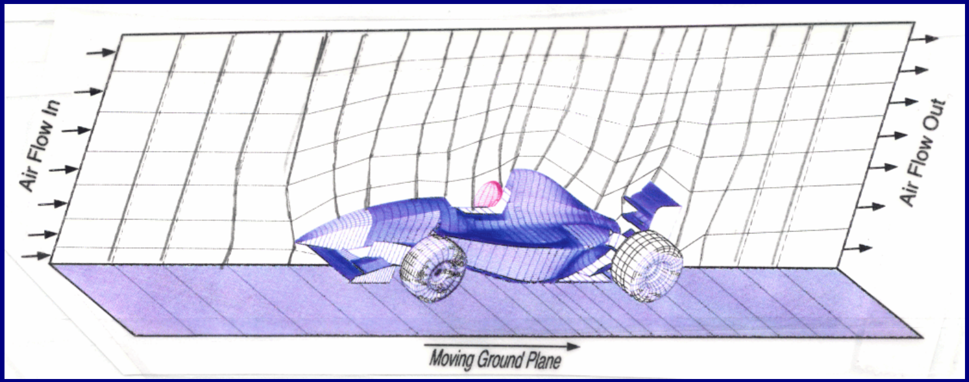
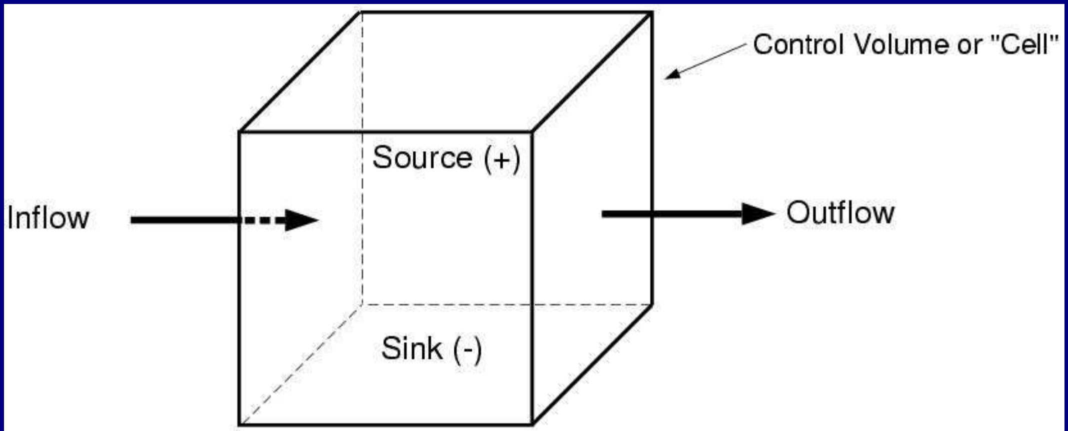
CFD Overview

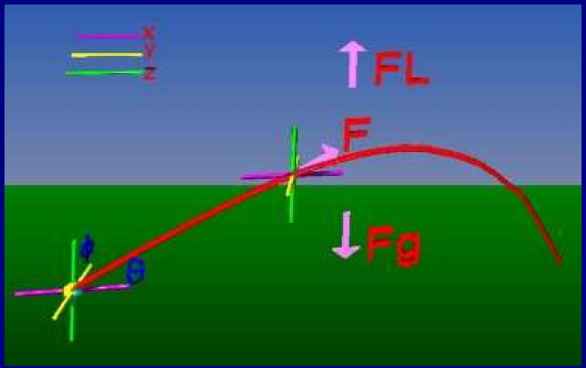
- Gas flow modeled in an Eulerian frame
  - Gas is considered to be a continuous medium, and properties are tracked in a geometrically fixed region





CFD Overview

- Particles are commonly modeled in a Lagrangian frame
  - Individual particles are tracked through time (or pseudo-time), interacting with the flow field and/or each other



Source: "The Physics of Paintball" website

Source: cnn.com

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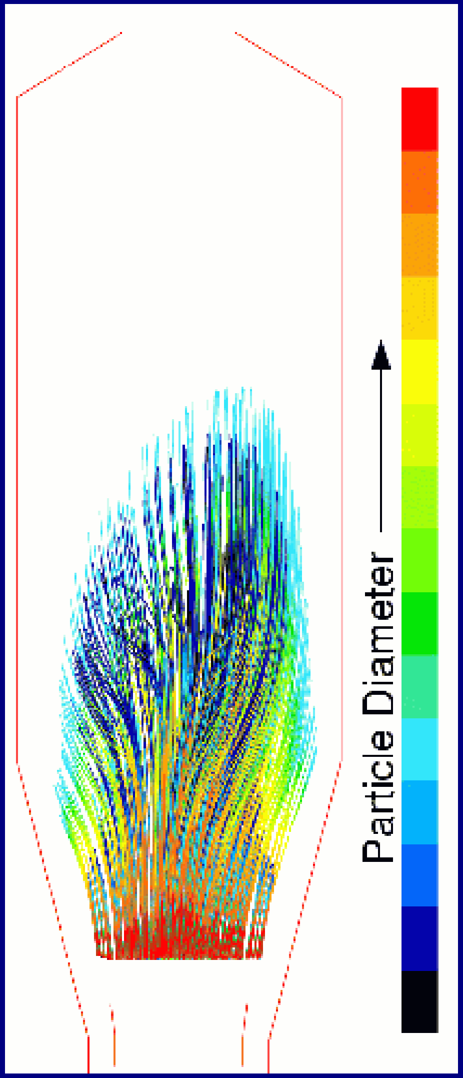
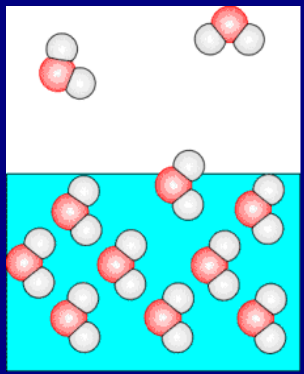
CFD Modeling Challenges

- Droplet evaporation and momentum transfer to the gas is possible in a CFD model, but practicality highly dependent upon consistent two-phase and evaporation submodels



Droplet Tracking

- Droplet evaporation and momentum exchange
  - All major codes can predict the trajectories and evaporation.
  - Most can reasonably predict water evaporation, but the salts often present in scrubbers make some evaporation models less than ideal.



Source: historyoftheuniverse.com

Droplet Tracking

- Droplet evaporation and momentum exchange
  - Interpolation schemes that may be appropriate for particle tracking in other industrial applications may not be sufficient for scrubbers.
  - Some commercial packages are only equipped with interpolation schemes that can make convergence impossible
    - Typical fix is to decouple the particles from affecting the gas momentum, which is inappropriate for some important regions within scrubbers, especially near the nozzles

Similarity

- Similarity trivial
  - Reynolds number matches
    - Full-scale geometry
    - Actual flow conditions
      - online temperatures
      - online viscosity
      - online density
      - online flow rate

Similarity

- Similarity trivial
  - Reynolds number matches
  - Droplet path similarity automatically
    - Droplet size and velocity must be known as model inputs
    - Information often hard to get from many nozzle manufacturers

Similarity

- Similarity trivial
  - Reynolds number matches
  - Droplet path similarity automatically
  - CFD SCR models are often criticized for excess diffusion near the injectors. Due to the Lagrangian frame used for droplet tracking, this is not nearly as prominent of an effect for scrubbers.
    - Grid resolution near injectors is important if the effects of injection air or steam is required (air or steam are tracked in Eulerian frame)

Impingement

- One major hurdle for CFD: impingement criteria. What to do with a particle numerically when it hits a wall?

  1. Particle disappears
     - Commonly done, but wrong in some cases. Equivalent to droplet immediately falling into the water below. If this is not a valid assumption, then causes incorrect average exit temperature due to lack of complete evaporation.

Impingement

- One major hurdle for CFD: impingement criteria. What to do with a particle numerically when it hits a wall?
  1. Particle disappears
  2. Particle bounces
     - Better, but not fully realistic. Technology already exists with some modelers. Rebound conditions need to be carefully handled. Particles can be made to lose almost all kinetic energy then either slip down due to gravity or fully evaporate

Impingement

- One major hurdle for CFD: impingement criteria. What to do with a particle numerically when it hits a wall?
  1. Particle disappears
  2. Particle bounces
  3. Particles collide with each other, stick to wall, form droplets, drip down
     - Most accurate, very cutting edge, very computationally expensive right now. Very few industrial applications have been made. Should be expected in 5-10 years.

Scrubber Modeling Summary

- Air only models can be done well with either physical or computational models
- Including accurate effects of water injection is nearly impossible in a physical model
- Including accurate effects of water injection is challenging but feasible with current technology in a CFD model
  - certain phenomena must be simplified

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