Fifth ICCT Workshop on Marine Black Carbon Emissions: Brief on Understanding BC Removal by Wet Scrubbers

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San Francisco, California

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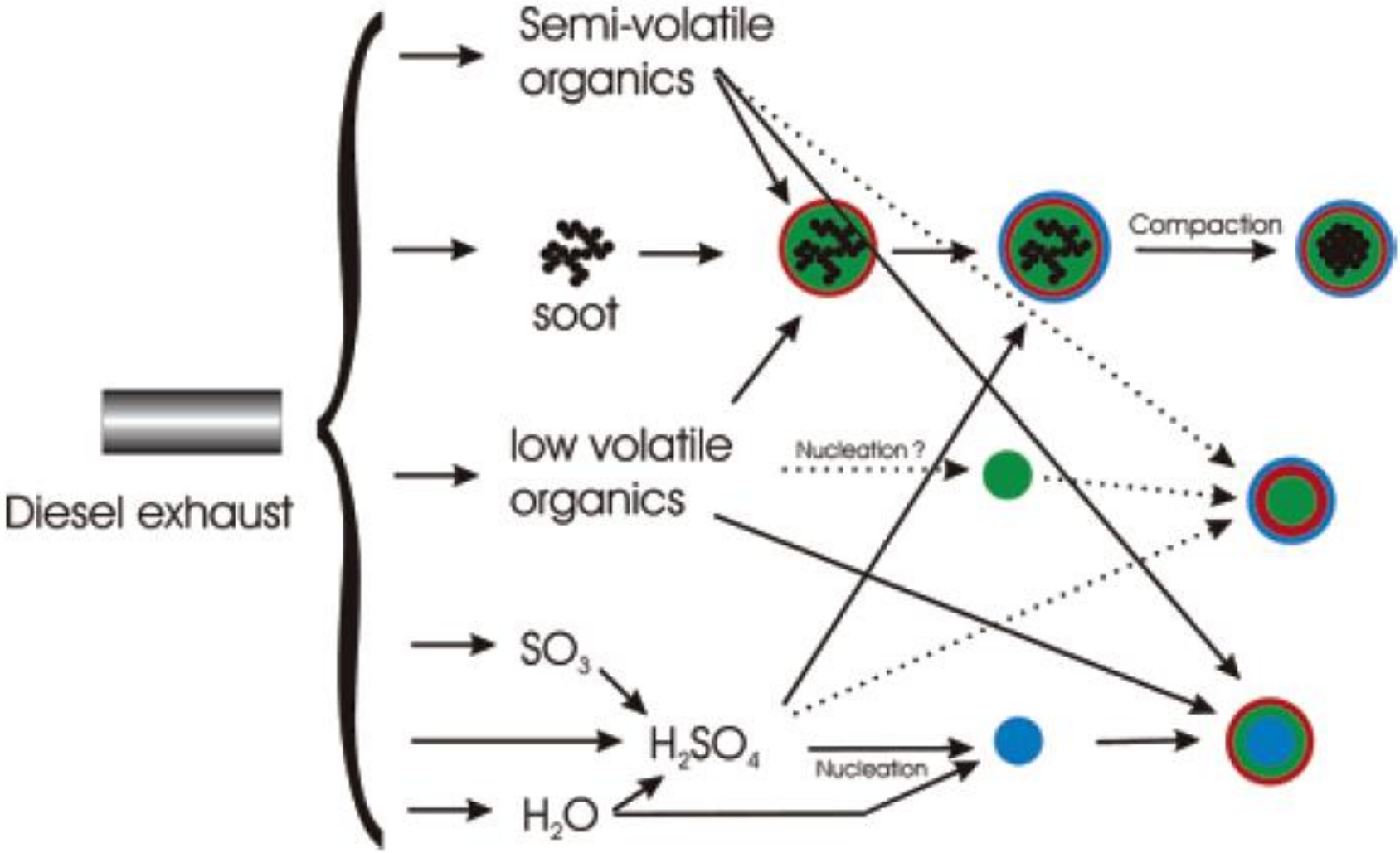
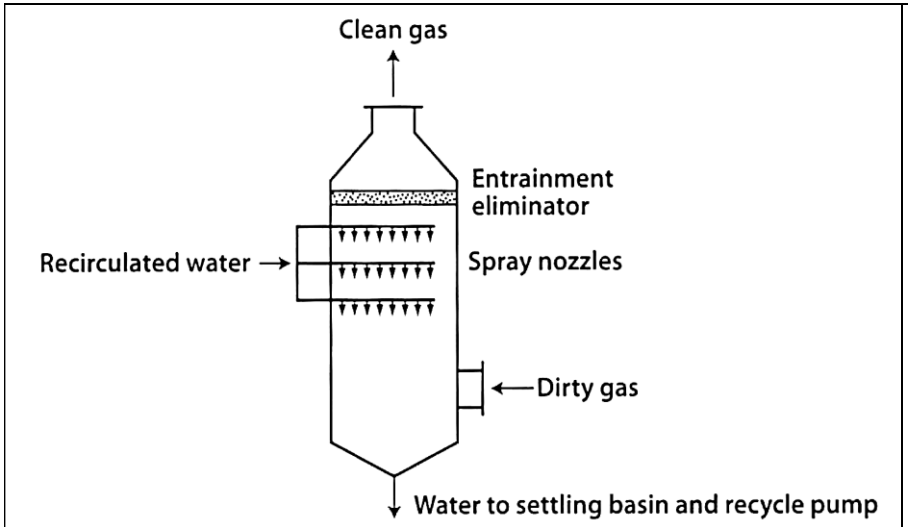
Diesel Exhaust Mixture is Complex

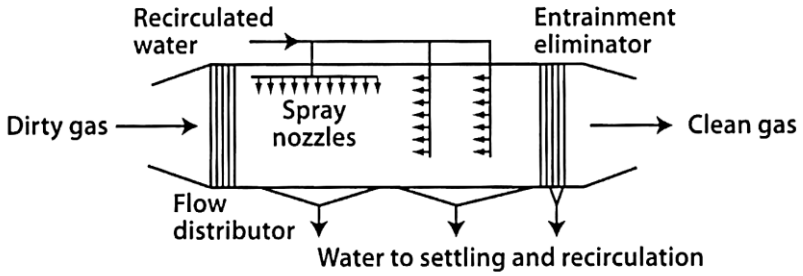


Schneider, J, E. S.&T.2005, 39,6153-6161

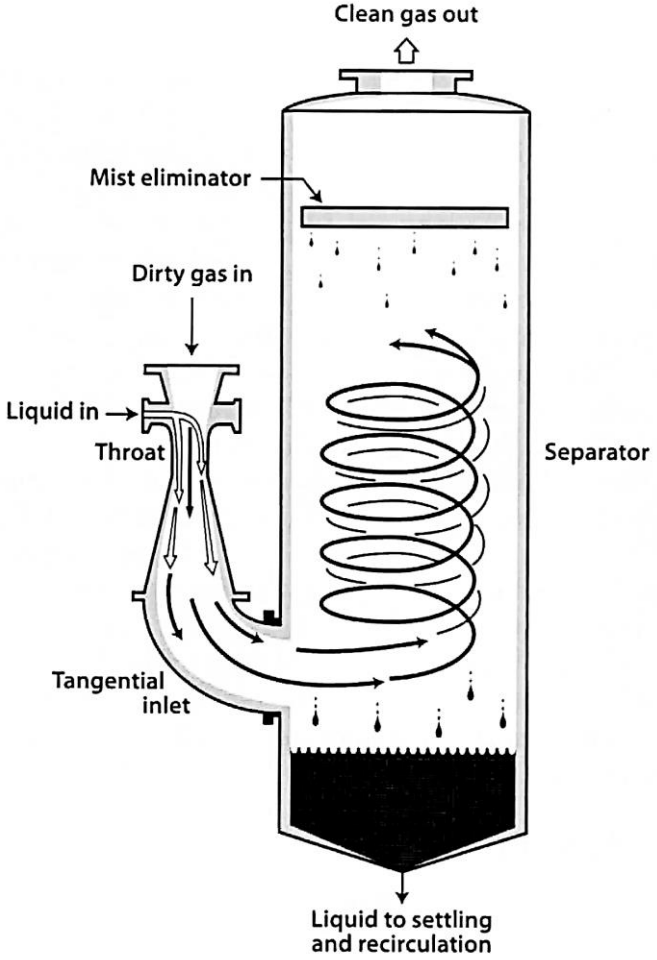
Gas & PM Scrubber Designs



(a) Vertical spray chamber (countercurrent flow)



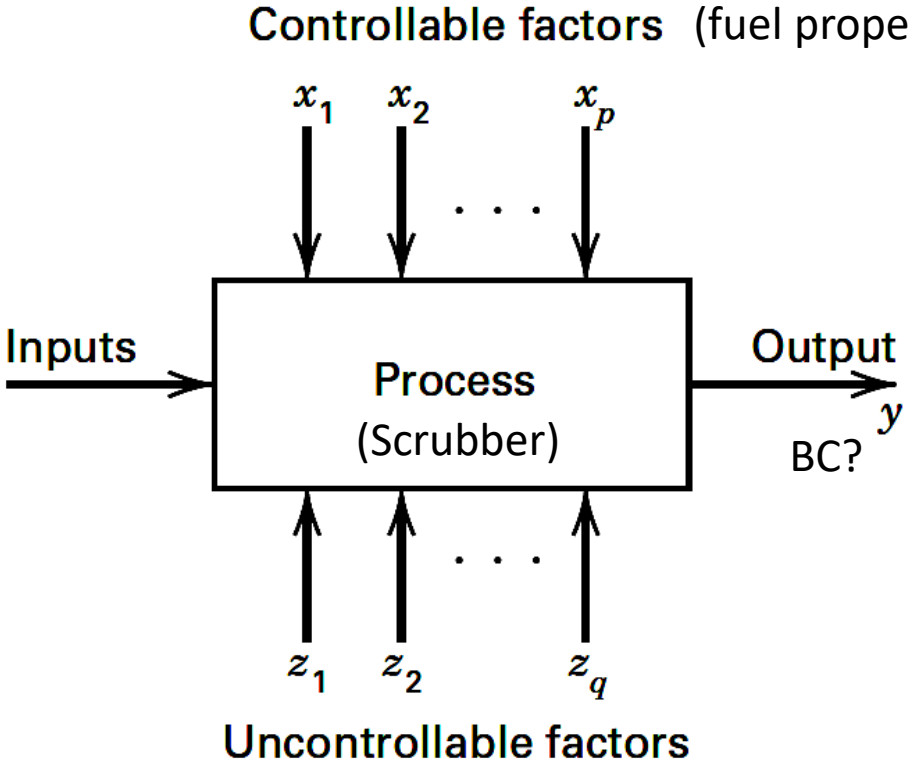
(b) Horizontal spray chamber (cross-flow)



(c) Typical venturi scrubber with cyclone separator

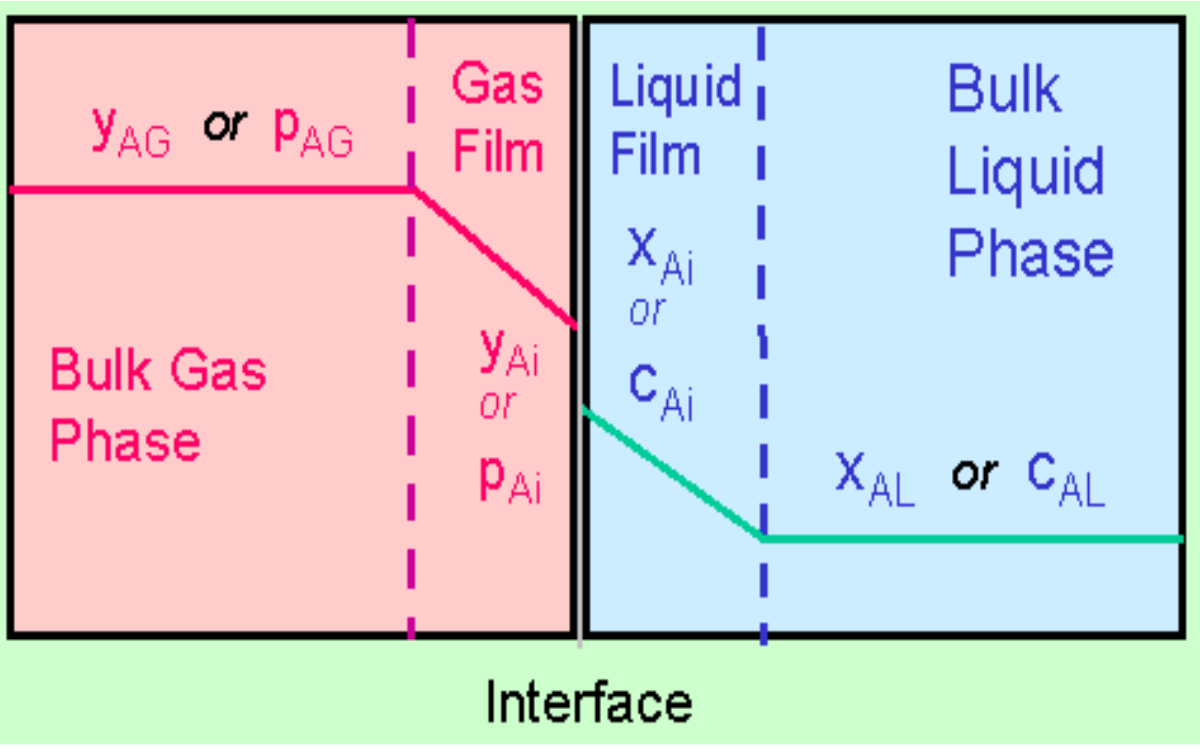
Predicting Gas & BC Removal with a Wet Scrubber

General model of a process or system



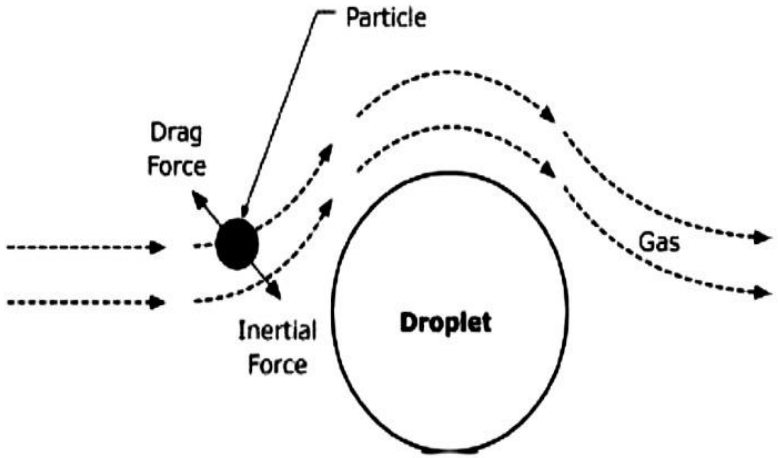
Schematic of Gas Absorption Processes

- One process for controlling sulfur oxides (SOx) emissions is absorption into an aqueous phase.
- Absorption of SOx gases into the aqueous phase is driven by equilibrium and mass transfer rates.
- While equilibrium represents the ultimate state, mass transfer dictates the rate at which equilibrium is approached.

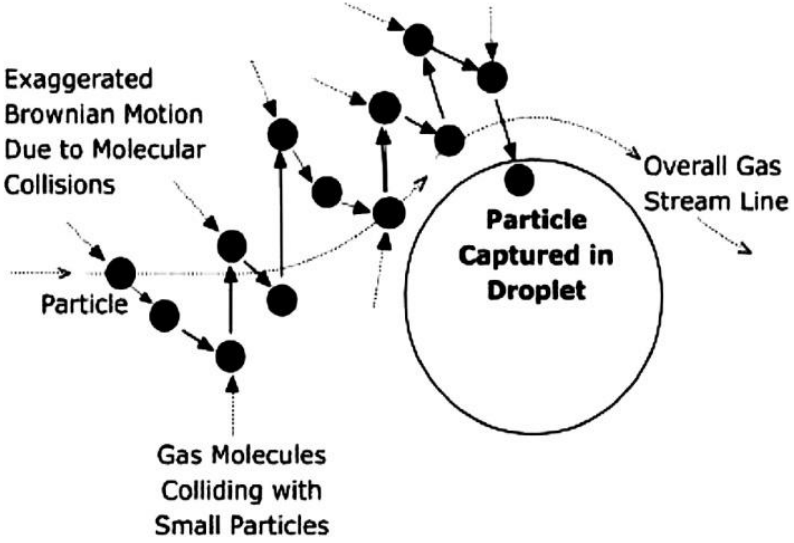


PM Removal Processes

Impaction



Brownian motion



Calvert Equations[1]

Step 1…calculate Sauter diameter

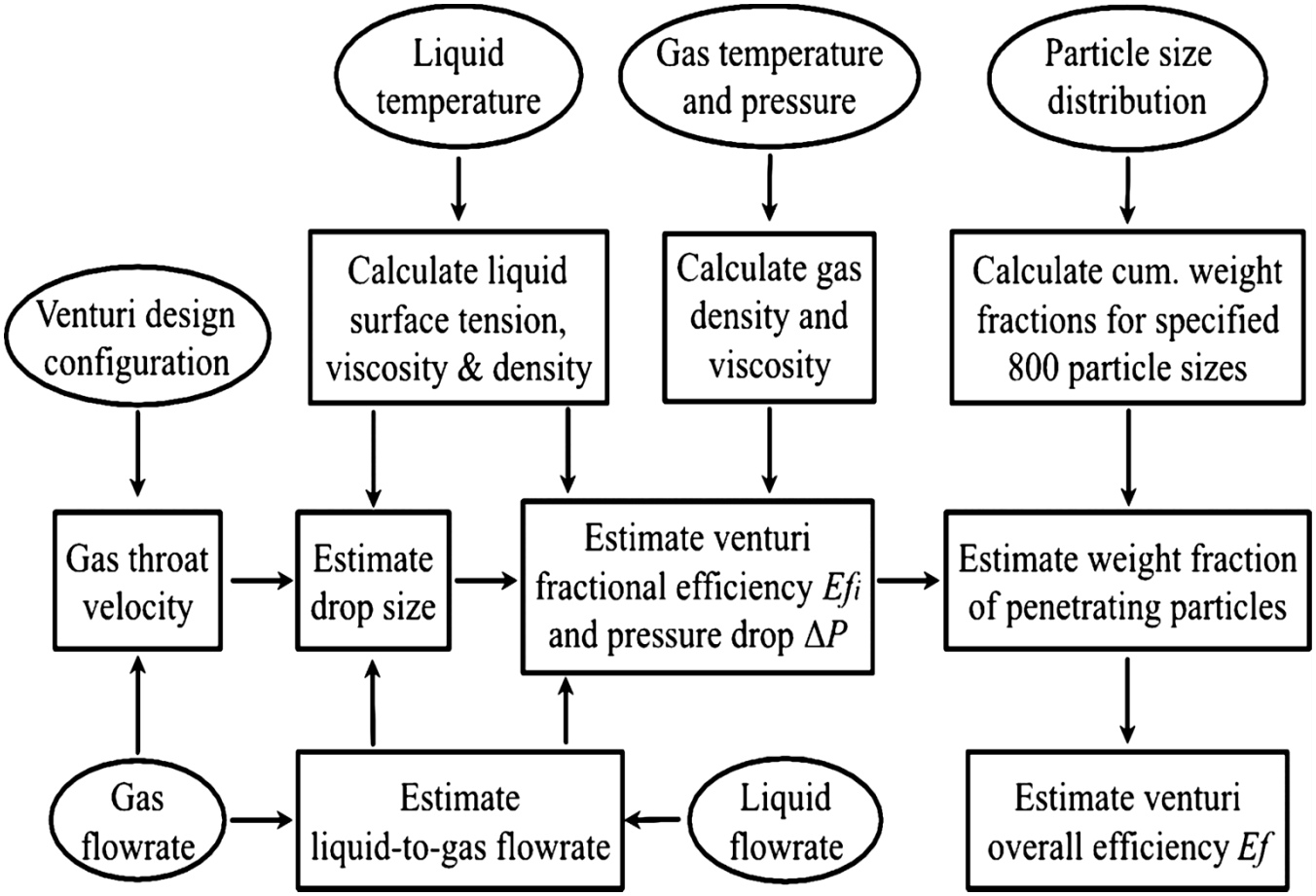
$$d_0 = \frac{16{,}400}{v_g} + 1.45\ (L')^{1.5}$$

Step 2…calculate the penetration

$$\mathrm{Pt}_d = \exp\left\{\frac{Q_L V_G \rho_L d_d}{55 Q_G \mu_G}\left[-0.7 - K_p f + 1.4 \ln\left(\frac{K_p f + 0.7}{0.7}\right) + \frac{0.49}{0.7 + K_p f}\right]\frac{1}{K_p}\right\}$$

1…Seymour Calvert, *Venturi and Other Atomizing Scrubbers Efficiency and Pressure Drop*, AlChE Journal Vol. 16, No. 3 392-396 (1970)

Other Design Approaches[1]



1…Economopoulou, A. A., Harrison, R. M**.,** *Graphical Analysis of the Performance of Venturi Scrubbers for Particle Abatement. Part I: Rapid Collection Efficiency Evaluation* Aerosol Science and Technology, 41:51–62, (2007

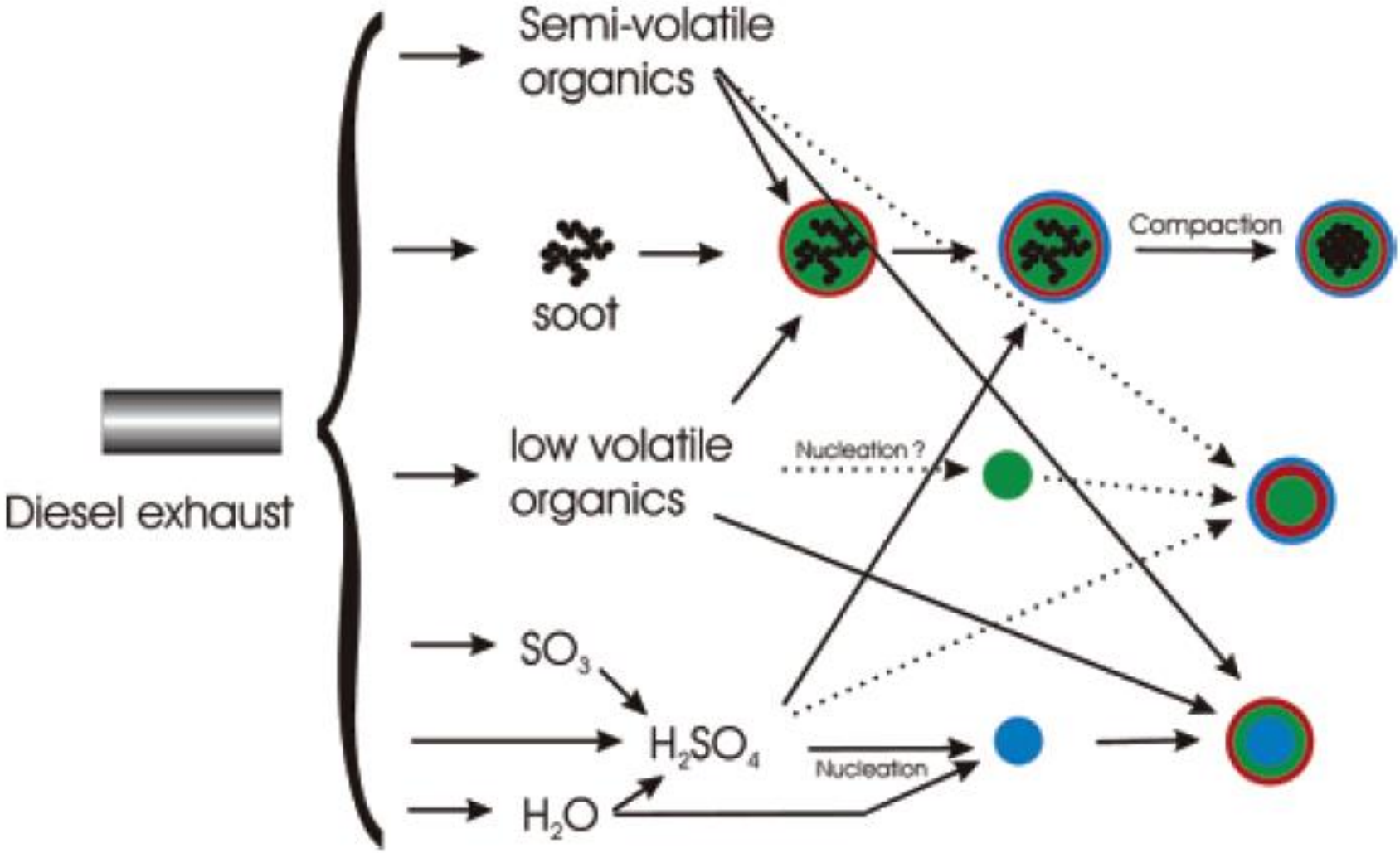
Condensible PM Adds Complications

- ***Case Studies with an Alpha Laval scrubber***
  - *Case 1….DR of 5 and dilution temperature of 50C showed 8-12% PM mass removed.*
  - *Case 2…DR of 110 and estimated dilution temperature of 200C showed 75% PM mass removed.*

- "FGD process equipment rapidly cools or quenches flue gas, condensing a significant portion of the sulfuric acid into submicron droplets that can escape the process environment, confounding capture. Srivastava (2004) suggests that the condensed submicron droplets, once formed, are sufficiently small so that they follow the flow streamlines and avoid contact with the remaining wetted walls, liquid sheets, and droplets in the flow path. Removals range from 14% to 78%, with an average of about 50%." (ref 1)

1…Naomi Goodman, *Estimating Total Sulfuric Acid Emissions from Stationary Power Plants*, Electric Power Research Institute (March 2018)

Diesel Exhaust Mixture is Complex



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Summary

- Ship scrubbers are designed primarily to remove sulfur oxides.
- PM removal will be highly variable and depend strongly on design and operating conditions.
- Predicting BC control efficiency with scrubbers is complex and will improve as more units are installed.
- Caution must be exercised when sampling streams with condensible particles.