LOSSES IN THE CATALYTIC STRIPPER

APPLICATION NOTE CI-0009

Background

The Catalytic Stripper (hereon CS) is a vital component of a highly efficient Volatile Particle Remover (VPR) system (shown in the diagram below). Typically, the CS is placed between a two-stage (hot and cold) dilution system, to remove any non-solid particles and gas-phase hydrocarbons. The first dilution stage operates between 150 – 400°C ±10°C, and dilutes by a factor of at least 10. The sample then enters the CS whereby semi volatile organic compounds (SVOCs) in the aerosol and gaseous phase are converted into CO_2 and H_2O. Solid particles (e.g. fractal aggregates such as soot) remain unchanged and pass through the CS into the optional second dilution stage, typically operated at ≤ 35ºC, then the sample passes through to the Particulate Number Counter (PNC).

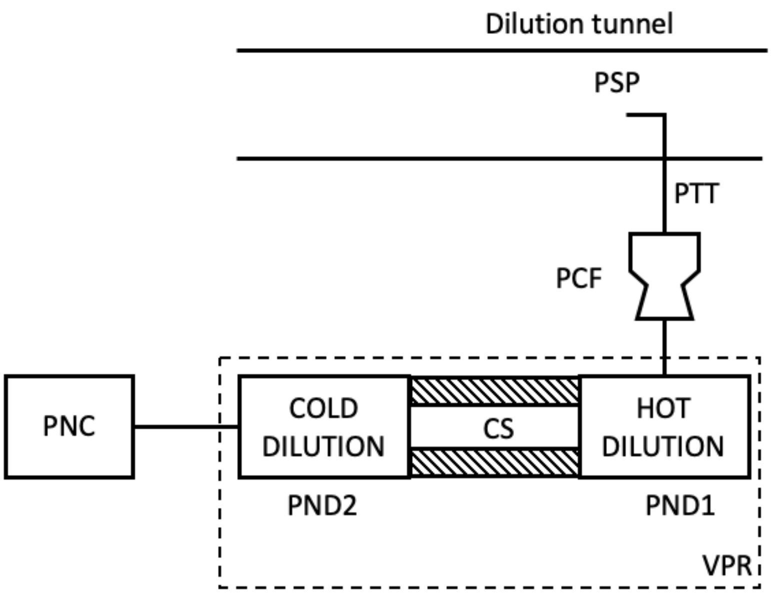

Figure 1: Schematic of the dilution tunnel measurement system in the PMP protocol

Acronym	Definition	Acronym	Definition
PSP	Particle Sampling Probe	VPR	Volatile Particle Remover
PTT	Particle Transfer Tube	PNC	Particle Number Counter
PCF	Particle pre-classifier	CS	Catalytic Stripper
PND	Particle Number Diluter	PND2	Particle Number Diluter 2

Particle Losses

All off-the-shelf CS models (i.e. CS015, CS08, CS10) share the same particle loss curve, as the internal dimensions are scaled for each nominal flow (1.5, 8, and 10 L/min, respectively).

There are two main particle loss mechanisms within the CS; diffusional and thermophoretic loss.

Diffusional Loss

Diffusional loss is the predominant deposition mechanism for particles less than 0.05 µm (50 nm) in diameter and is governed by geometric particle size. The CS is designed to minimise diffusion loss such that particles over around 100 nm experience essentially zero diffusional loss, around 90% of particles pass through the device at 50 nm, and around 70% at 10 nm. Diffusional losses are shown in the graph below, modelled for a CS015 device.

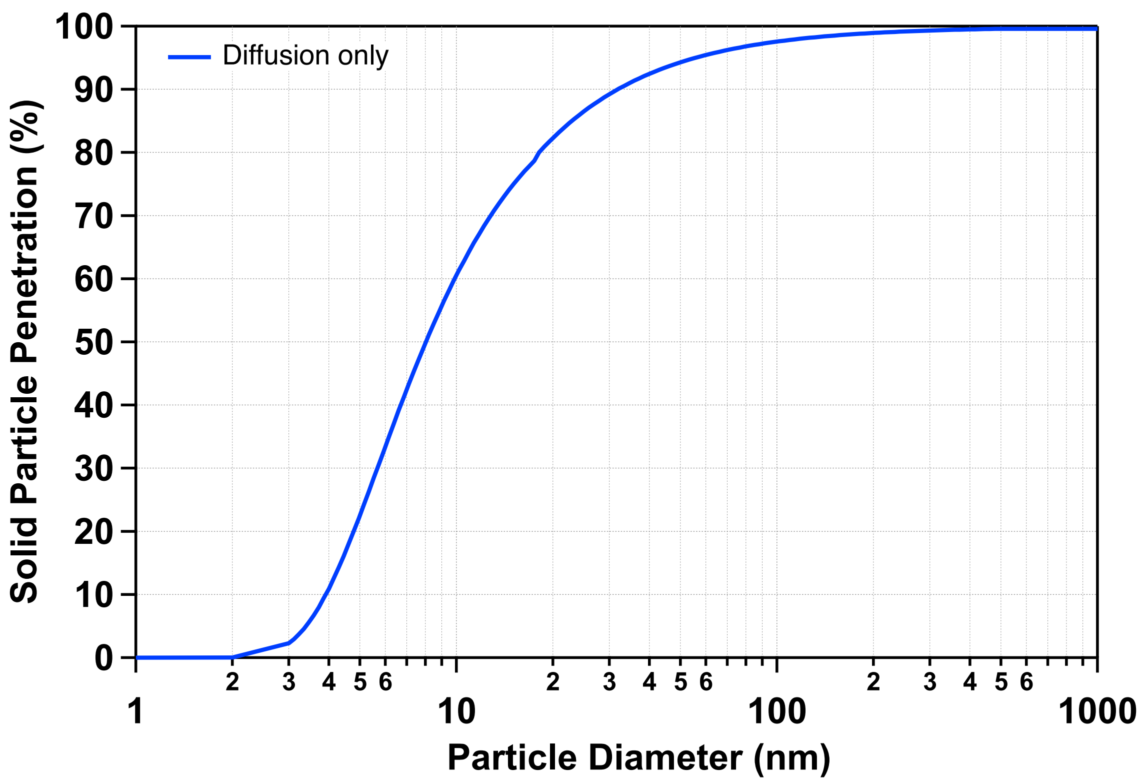

Figure 2: Modelled diffusion loss for a CS015 catalytic stripper

Thermophoretic Loss

Thermophoresis is a phenomenon in which a temperature gradient in a gas causes suspended particles to migrate in the direction of decreasing temperature. This loss effects the entire particle size range, reducing particle penetration further by 25% above 100 nm, 23% at 23 nm, and around 15% at 10 nm. In the CS, the area of decreasing temperature is the **cooling tubing immediately following the catalyst**, which brings the gas temperature back down to ambient, or room temperature.

> Thermophoretic loss is and *unavoidable phenomenon* for evaporation tubes, thermodenuders, and Catalytic Strippers, where we consider *the particle loss of the device to include bringing the sample back down to room temperature in the absence of dilution*.

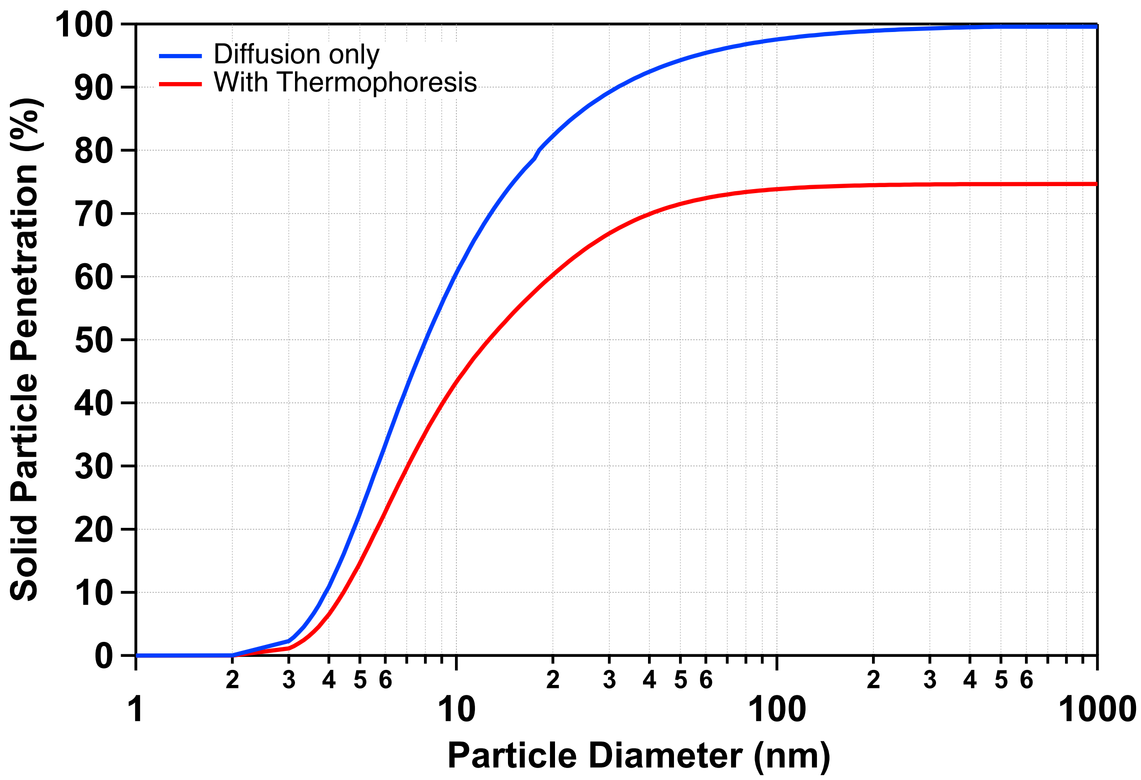

Figure 3: Diffusion (blue) and diffusion + thermophoretic (red) losses for a CS015 Catalytic Stripper

The sum total of diffusional and thermophoretic loss is shown in the graph above, which shows the original diffusional-only loss curve (blue; Gormley, P.G., Kennedy, M, 1949) and the “total loss” (red) by including thermophoretic effects (Housiadas, C., and Drossinos, Y., 2005; Giechaskiel, Barouch, et al., 2020), the modelled total particle loss for the CS.

Measurement

Measurements of particle loss were conducted using high concentrations of silver particles selected by a DMA. The silver particle generator produces spherical silver particles of a sufficiently narrow distribution that after size-selection with a DMA no multiple charged particles are present. A Mass Flow Controller (MFC) made up 1.5 L/min of additional air after size-selection which was mixed with the aerosol samples and then split equally between two lines of equal length; the CS015 and a standard stainless steel 1/4“ OD line, both to 3776 CPCs (which agreed to within 1%).

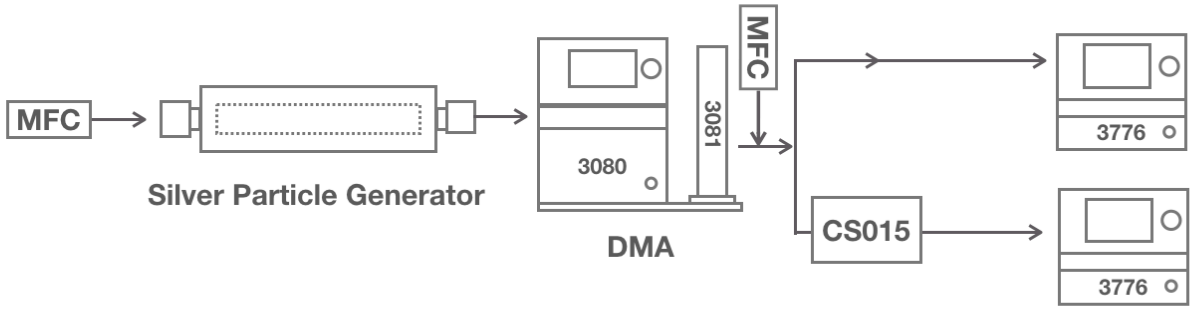

Figure 4: Experimental setup for the measurement of losses within the CS015 Catalytic Stripper

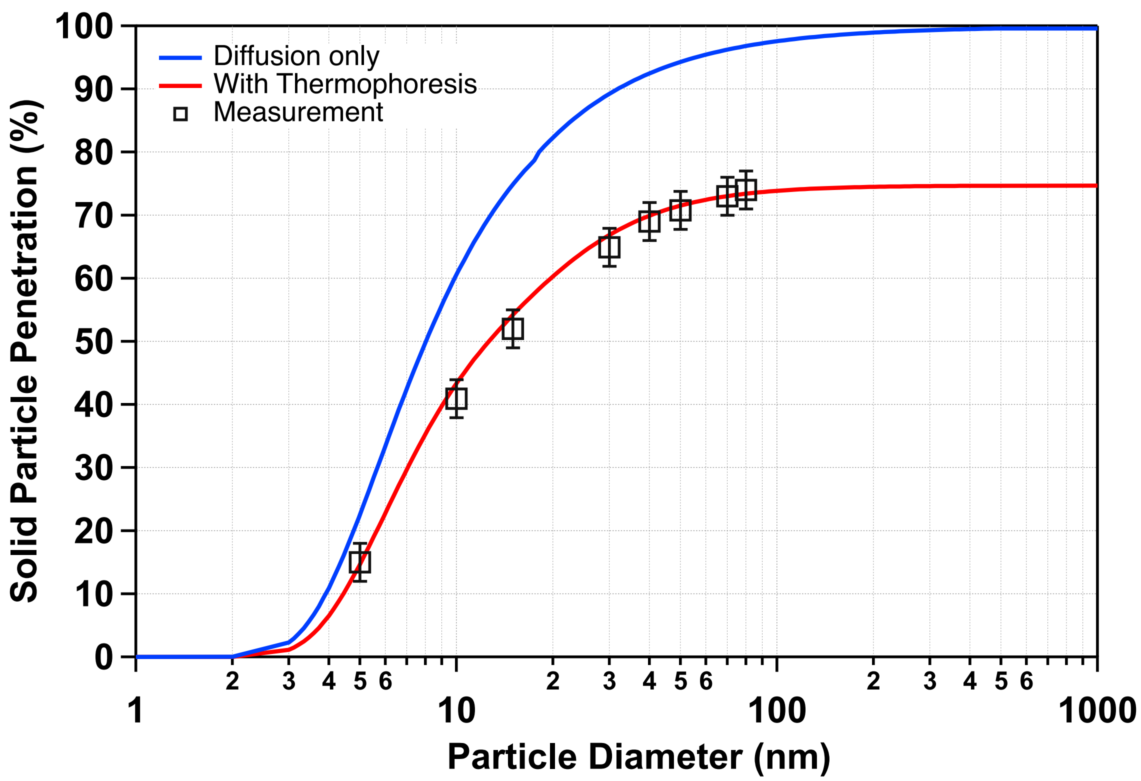

Figure 5: Diffusion (blue), diffusion + thermophoretic (red) losses, and measurement data (grey squares) for a CS015 Catalytic Stripper

Total Loss Correction

The solid particle penetration can be determined for a given particle diameter in order to correct for particle losses in the Catalytic Stripper. This can be done by using Equation 1, below, which is a multivariable fit to the experimental measurements shown above.

$$P = \left(x_1 e^{-\frac{x_2}{D_p^2}} + x_3 e^{-\frac{x_4}{D_p^2}} \right) x_5 \qquad \text{Equation 1}$$

Where P is the particle penetration, variables x are the fitting parameters, and D_p is the particle diameter (geometric diameter, spherical particles). Values for the five fitting parameters are shown in Table 1.

Table 1: Fit parameters for Equation 1

Parameter	Value
x_1	0.190
x_2	499
x_3	0.925
x_4	36.0
x_5	0.670

The result of this fit is the red curve shown in Fig. 5

Summary

The results show that the real solid particle losses in the CS are represented well by the model incorporating diffusional and thermophoretic loss. The CS is optimised to reduce losses due to diffusion, and thus whenever a CS is designed for a new flow rate, the loss curves remain essentially the same due to the aforementioned physical limitations, which would indeed exist for any hot-into-cold tube setup.

Further Reading

Hinds, W. (1982). Aerosol technology: properties, behavior, and measurement of airborne particles. Adsabs.Harvard.Edu.

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Giechaskiel, Barouch, et al. "Sampling of Non-Volatile Vehicle Exhaust Particles: A Simplified Guide." SAE International Journal of Engines, vol. 5, no. 2, 2012, pp. 379–399. JSTOR, www.jstor.org/stable/26278367. Accessed 9 Jan. 2020.

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Housiadas, C., and Drossinos, Y., 'Thermophoretic Deposition in Tube Flow', Aerosol Sci. Techn., 39:304-318, 2005.

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