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# Fiber Bed Mist Eliminator Fundamentals versus Real World Operation

October 26, 2016

Mesa Redonda de Plantas de Ácido Sulfúrico, Olmué, Chile

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# What are we going to talk about today?

- What is a mist eliminator?
- A bit of mist eliminator history.
- A bit of mist eliminator applications.
- How do they work? (yes, a little nibble of theory…..)
- Styles and how they effect performance.
- Points of concern (installation and other)

# What does a Brink Mist Eliminator Look Like?

- MECS® products utilizing the impaction mechanism for effective mist capture:

Mesh Pads

CS/CK

- MECS® products using predominantly the diffusion mechanism for mist capture:

HE, ES, XP

# Dr. Joseph A. Brink, Jr. the man who put it all together!

- Received his B.S. & M.S. in Chemical Engineering from Denver University.
- Completed his Ph.D. in Chemical Engineering at Purdue University in 1953.
- Began working for Monsanto in 1954 and solved an emission problem at Monsanto's, Trenton, MI Thermal Phosphoric Acid plant with the first commercial application of the science of mist elimination in ***1958***.
- Brink Mist Eliminators are named after him.
- Monsanto first device patent was in 1967.
- DuPont acquired MECS in 2011.

# Brink's Mindset of Innovation Continues to this Day!

MECS (Under Monsanto, MECS, Inc. and DuPont) has had 13 US Patents on mist elimination technology from the beginning:

US 3,352,778 – Brink HV (1967)
US 3,540,190 – Brink HE (1970)
US 4,086,070 – ES (1978)
US 4,249,918 – ES (1981)
US 4,443,233 – Pre-separation Device (1984)
US 4,818,257 – CS (1989)
US 5,605,748 – FP (1997)
US 7,387,656 – XP #1 (2008)
US 7,416,576 – High Capacity Bed (2008)
US 7,758,665 – XP #2 (2010)
US 8,632,616 and US 8,636,819 – (2014)
US 9,005,340 – Re-entrainment Control Device (2015)

MECS, Inc. has always been committed to innovation in mist elimination technology from the day we introduced it to the world!

# Brink Mist Eliminators

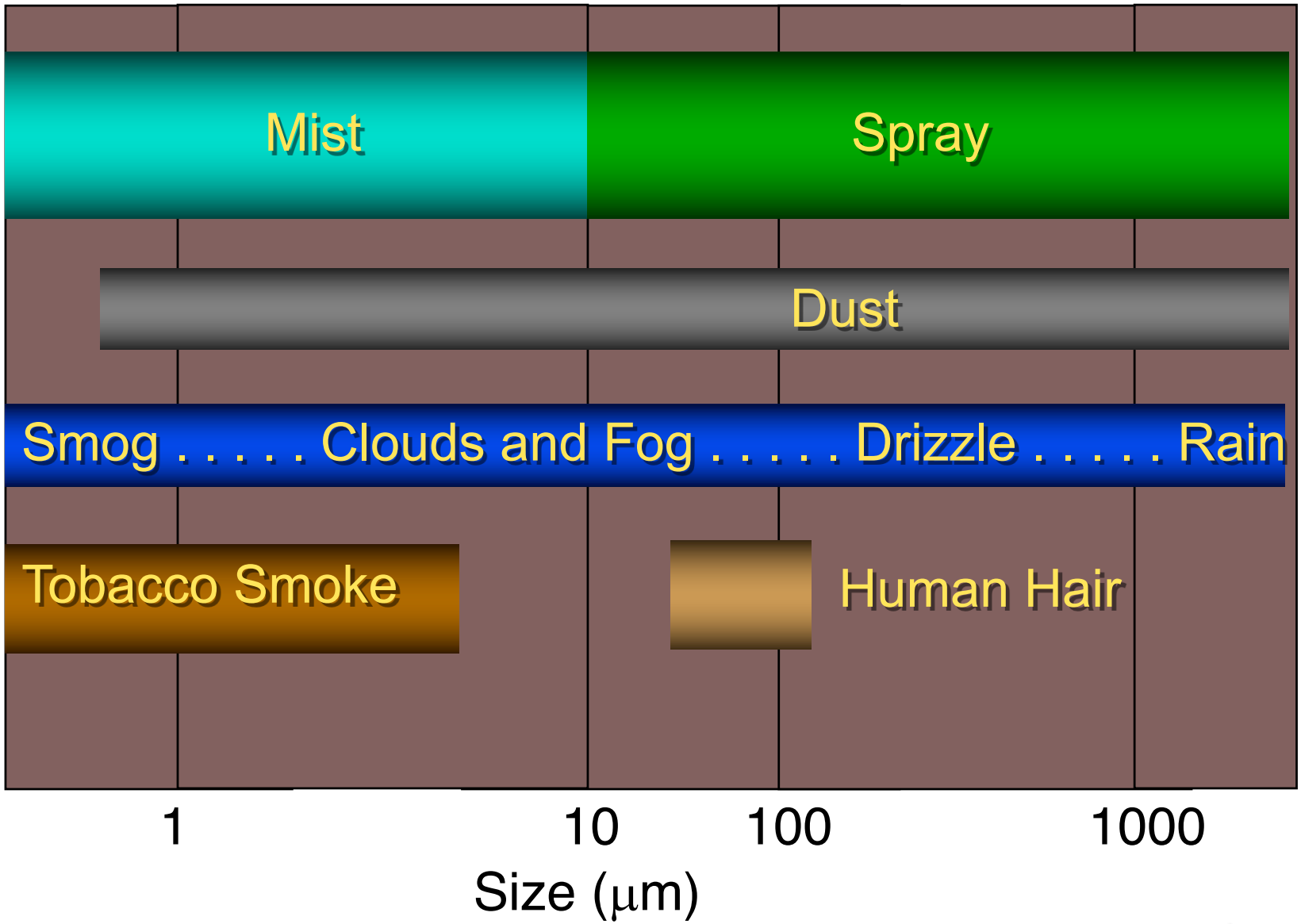
- Developed by Monsanto (MECS was part of Monsanto Central Engineering at that point) in 1950's
- Collect submicron liquid and soluble mists
- 5000+ installations in 300+ applications
- You name it we are in it (more than likely)
- Worldwide manufacturing

# Brink Mist Eliminator Applications

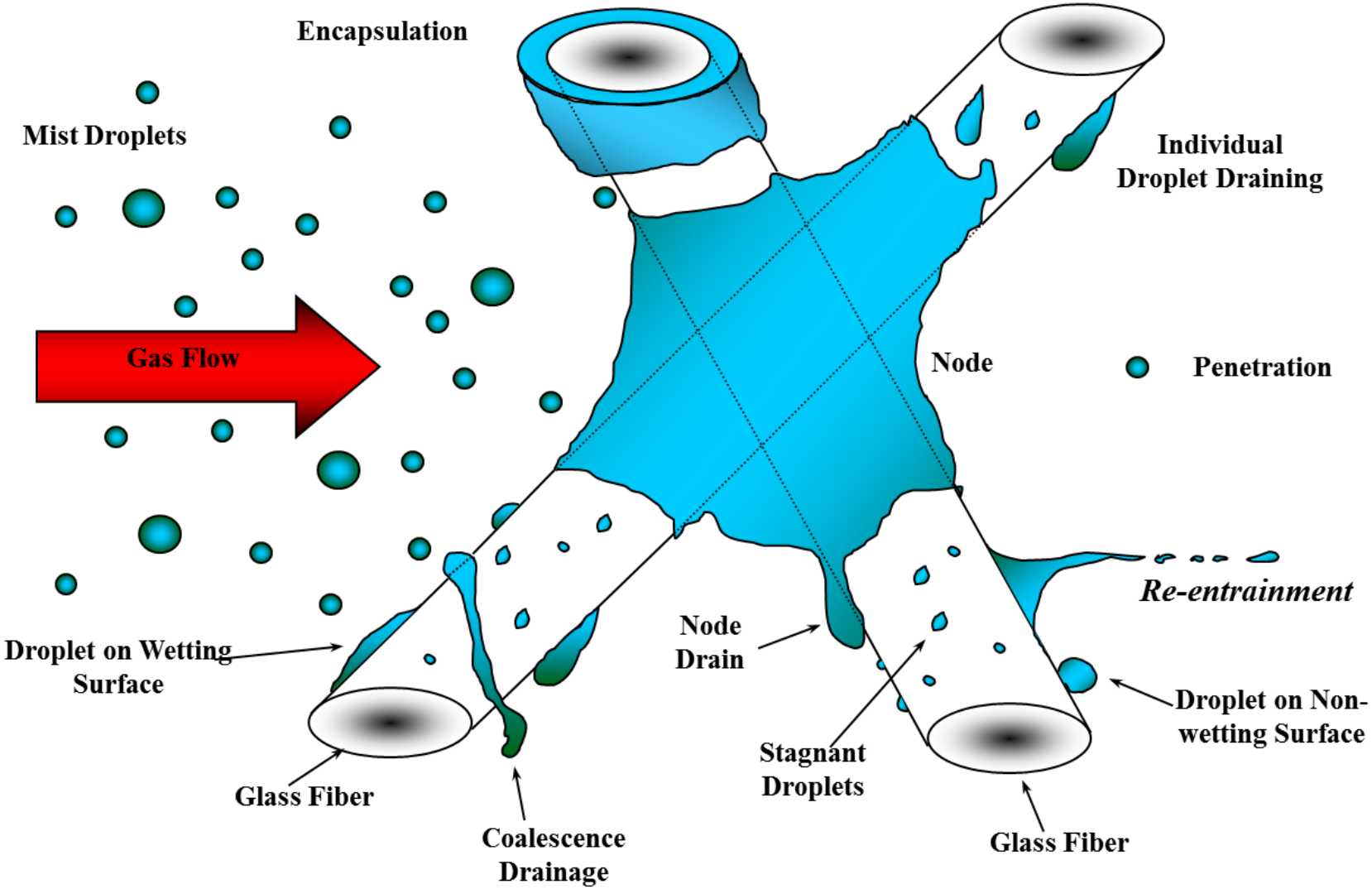
## Sulfuric Acid

Chlorine
Fertilizer (various)
Chemical Incineration Offgas Treatment
Plastics/Resin Production
Asphalt Handling/Storage
Compressed Gas/Vacuum Installations
Nuclear
Turbine Lube Gas Exhaust
And many, many more!

# Types of Mist Emissions and Comparison to Everyday Items



# Inside of a Mist Eliminator is Complicated Space



# How do mist eliminators work?

**Key-**

**Impaction Captured Particle**

**Interception Captured Particle**

**Brownian Diffusion Captured Particle**

$\eta$ = efficiency

$$\eta_{total} = 1 - Pen_{total}$$

$$Pen_{total} \approx \sum_{n=1}^{3} \mathrm{Pen}_n$$

$$= e^{\left(\frac{4\alpha(Pen_1+Pen_2+Pen_3)t}{\pi d_{fiber}(1-\alpha)}\right)}$$

Where:

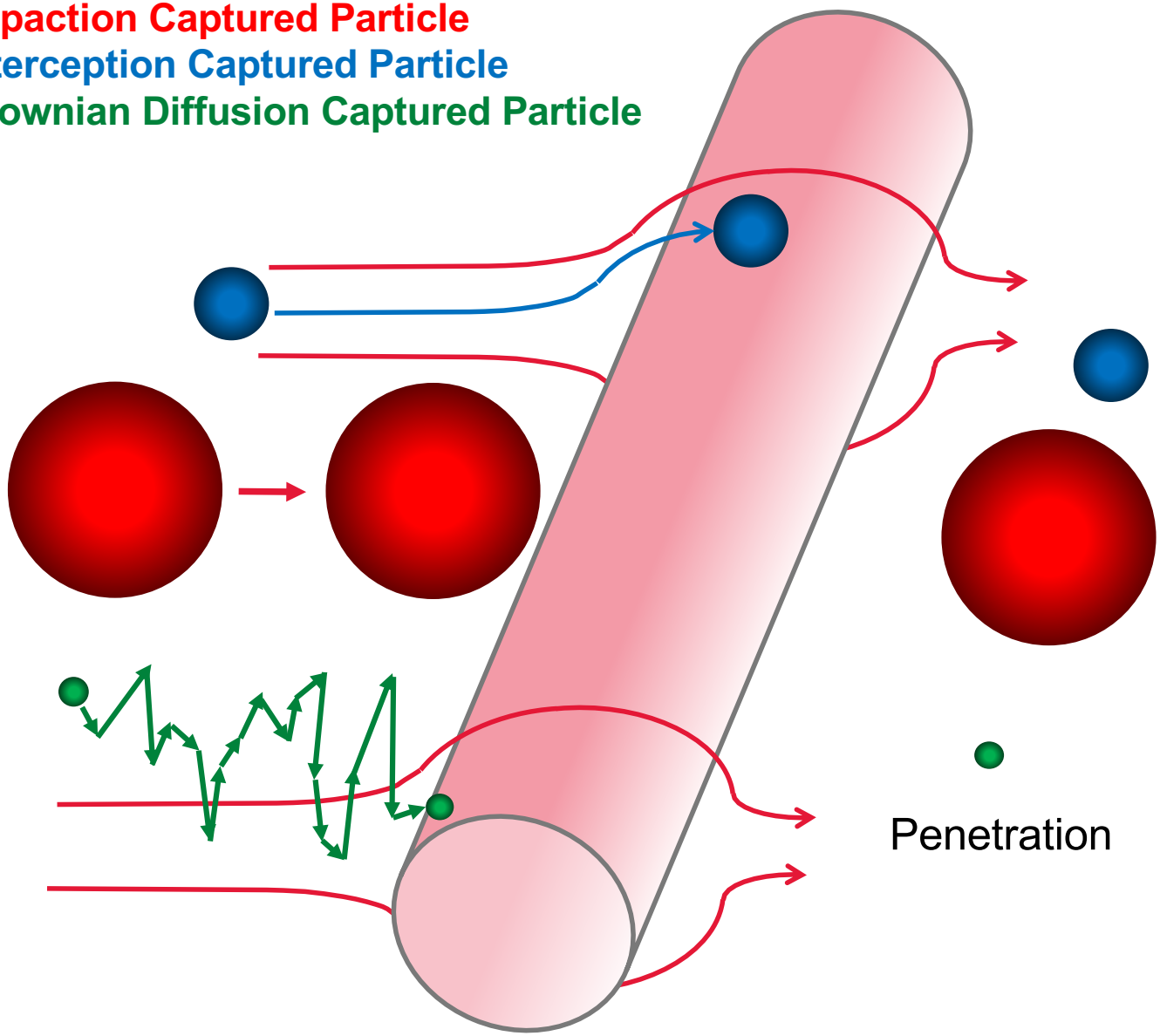
$Pen_1$ = Impaction Penetration

$Pen_2$ = Interception Penetration

$Pen_3$ = Diffusion Penetration

t = bed thickness

$\alpha$ = bed solidity = $\frac{\rho_{bed}}{\rho_{fiber}}$

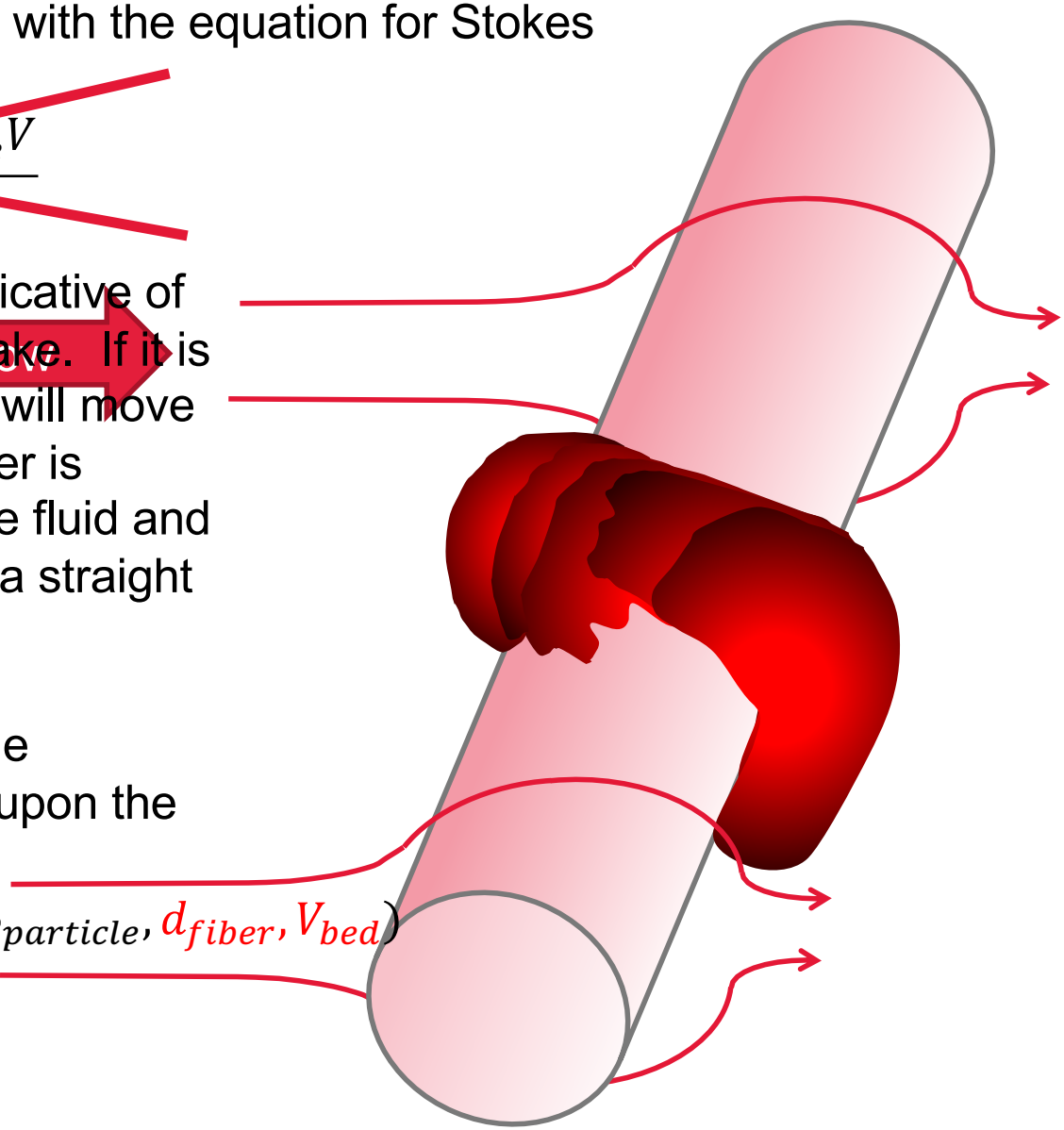


# The Impaction Mechanism – Collision at its best!

Some may try to impress with the equation for Stokes Number

$$N_{Stokes} = \frac{\rho_{particle} d^2_{particle} V}{18 \mu_{gas} d_{fiber}}$$

The Stokes Number is indicative of the motion a particle will take. If it is a small value, the particle will move with the fluid. If the number is larger, it will break from the fluid and move by its own inertia in a straight line.




The actual efficiency of the mechanism is dependent upon the following variables

$$\eta_{imp} = f(\lambda, d_{particle}, \mu_{gas}, \rho_{particle}, d_{fiber}, V_{bed})$$

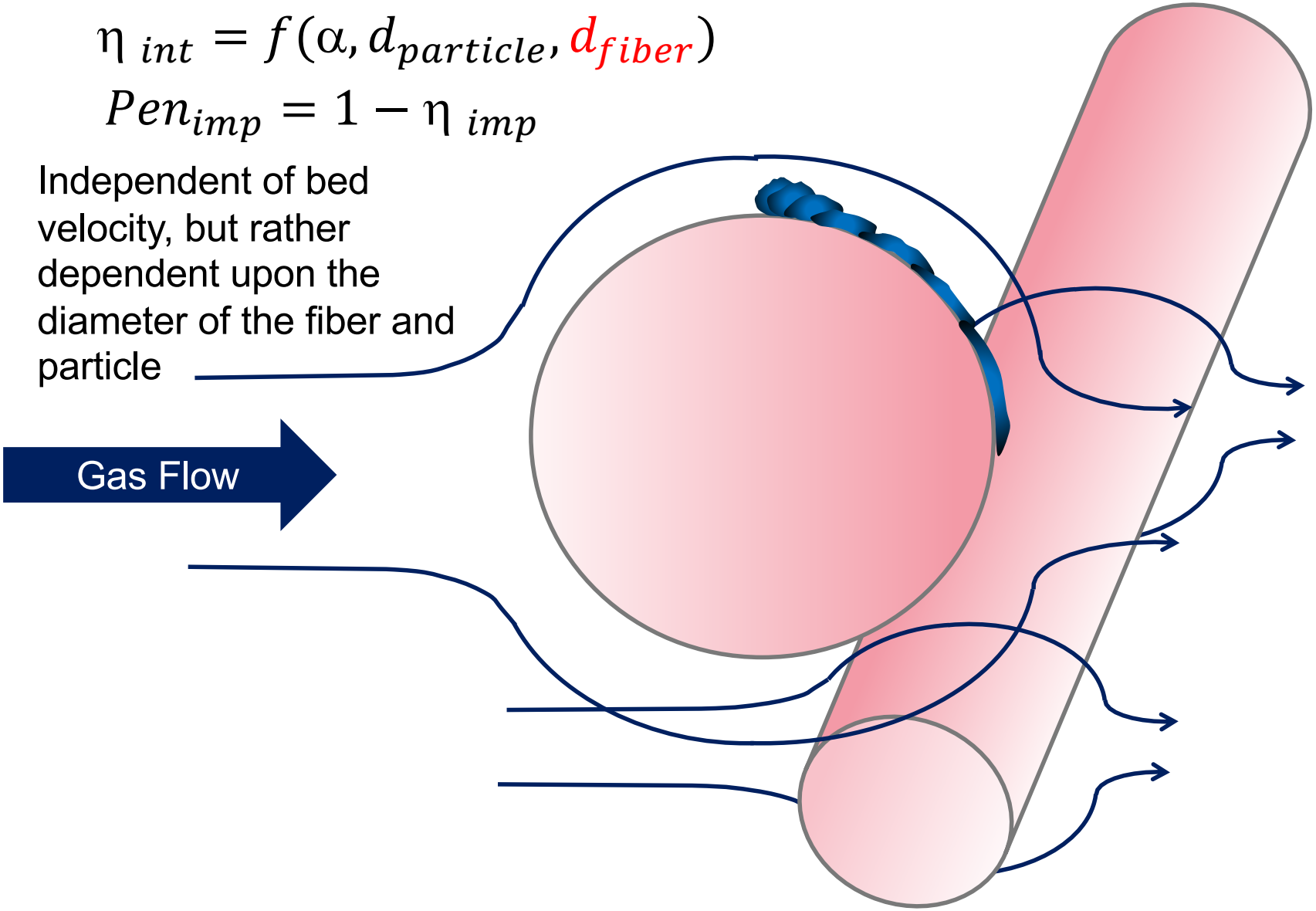
$$Pen_{imp} = 1 - \eta_{imp}$$

# Interception, more useful than in American Football!

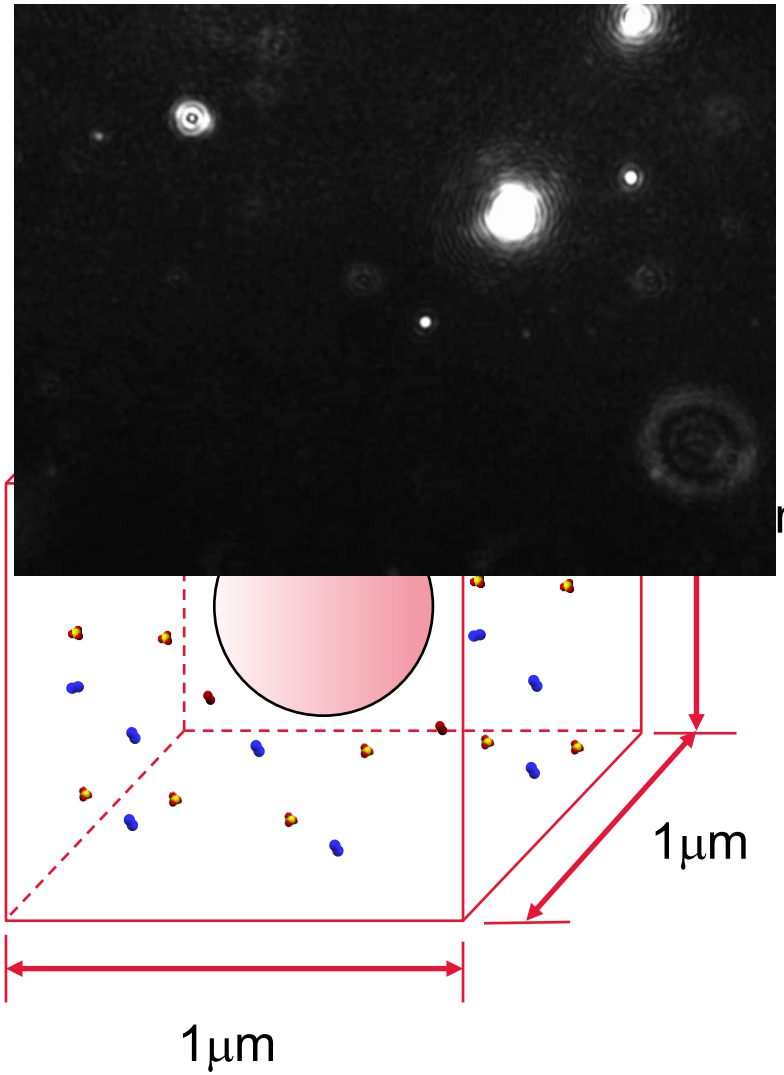
$$\eta_{int} = f(\alpha, d_{particle}, d_{fiber})$$

$$Pen_{imp} = 1 - \eta_{imp}$$

Independent of bed velocity, but rather dependent upon the diameter of the fiber and particle



# Let's Talk About Robert Brown and Einstein….




In 1827, Robert Brown, a botanist, noted the motion of pollen particles on a microscope slide and was unable to explain the motion.

In 1905, Albert Einstein published a paper which explained the motion as the result of molecular motion.

Throughout the later 1800's, various scientists tried to explain the motion with little success.

If you look at the implication of the equations Einstein derived, the position of a suspended particle as a function of time is dependent upon the number of molecules surrounding the particle and the temperature.

In a 1μm$^3$ cube with a 0.5μm diameter particle or droplet suspended in air, there are 20,654,209 molecules of nitrogen and oxygen around the particle. At 80°C, the oxygen and nitrogen are traveling at around 17 m/sec each. Due to the density of the gas and molecular motion induced, the molecules around the particle are colliding with it some 6.5x10$^{13}$ times per second. This imparts a fairly significant amount of cumulative force upon the suspended particle and fully explains the motion.

On x-axis: $\sqrt{\overline{x^2}} = \frac{\int_{-\infty}^{+\infty} x^2 A' e^{\frac{-NMx^2}{2RT}} dx}{\int_{-\infty}^{+\infty} A' e^{\frac{-NMx^2}{2RT}} dx} = \sqrt{\frac{RT}{NM}}$

On all three axes: $\sqrt{\overline{\Delta^2}} = \sqrt{\frac{2R}{N}} \cdot \sqrt{RTt}$

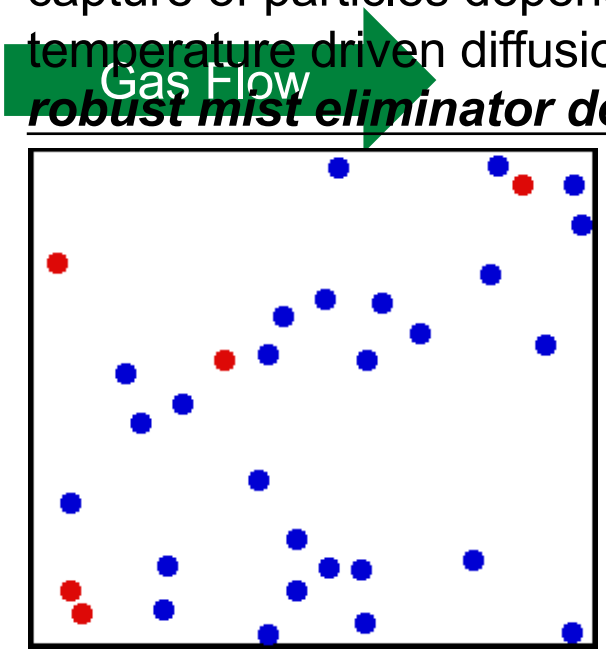
# Brownian Motion – The small things count!

Stokes-Einstein Eq. $D = \frac{k_B T C}{3\pi \mu_{gas} d_{particle}}$

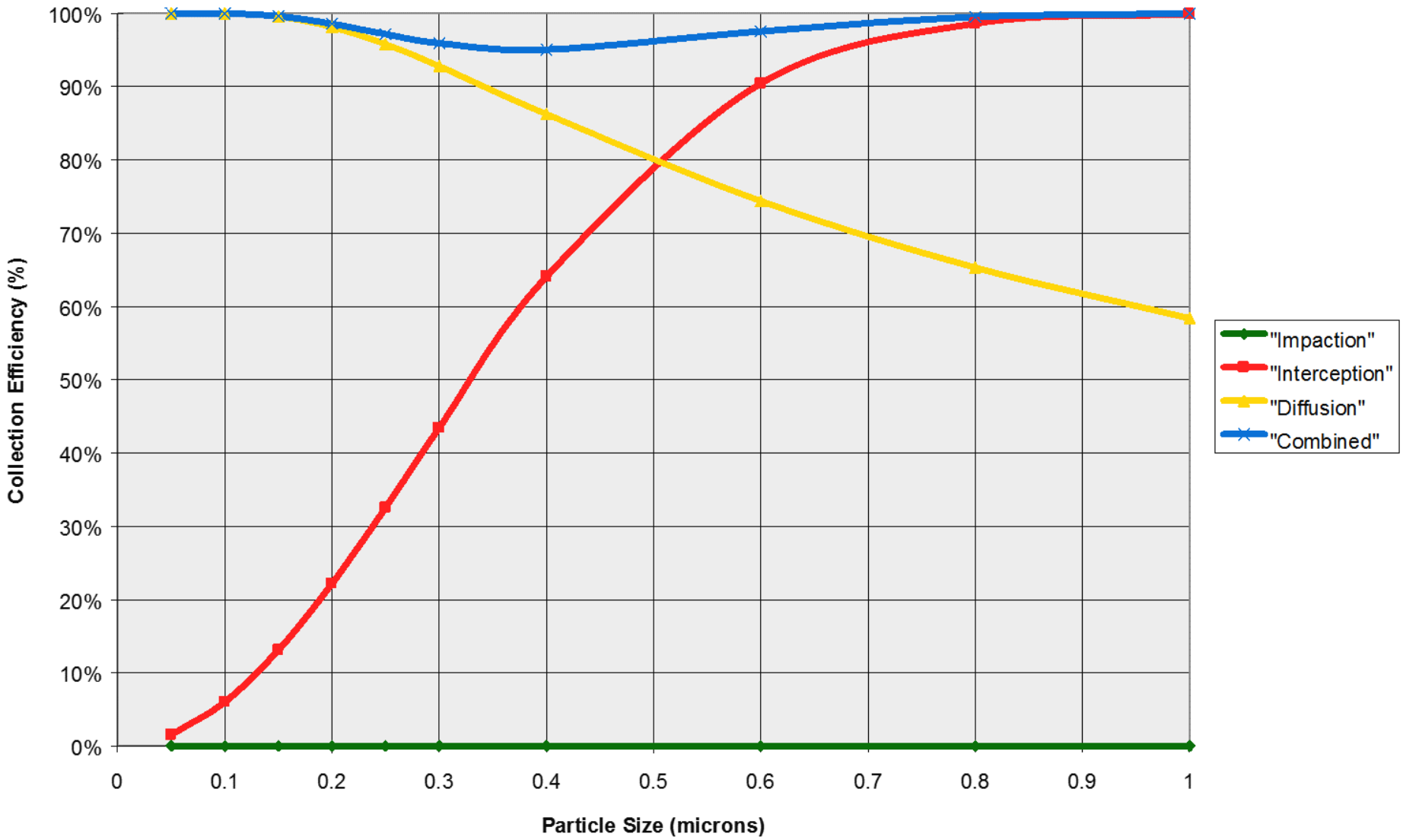
$$\eta_{diff} = f(\alpha, t, d_{particle}, d_{fiber}, V_{bed}, \mu_{gas})$$

$$Pen_{diff} = 1 - \eta_{diff}$$

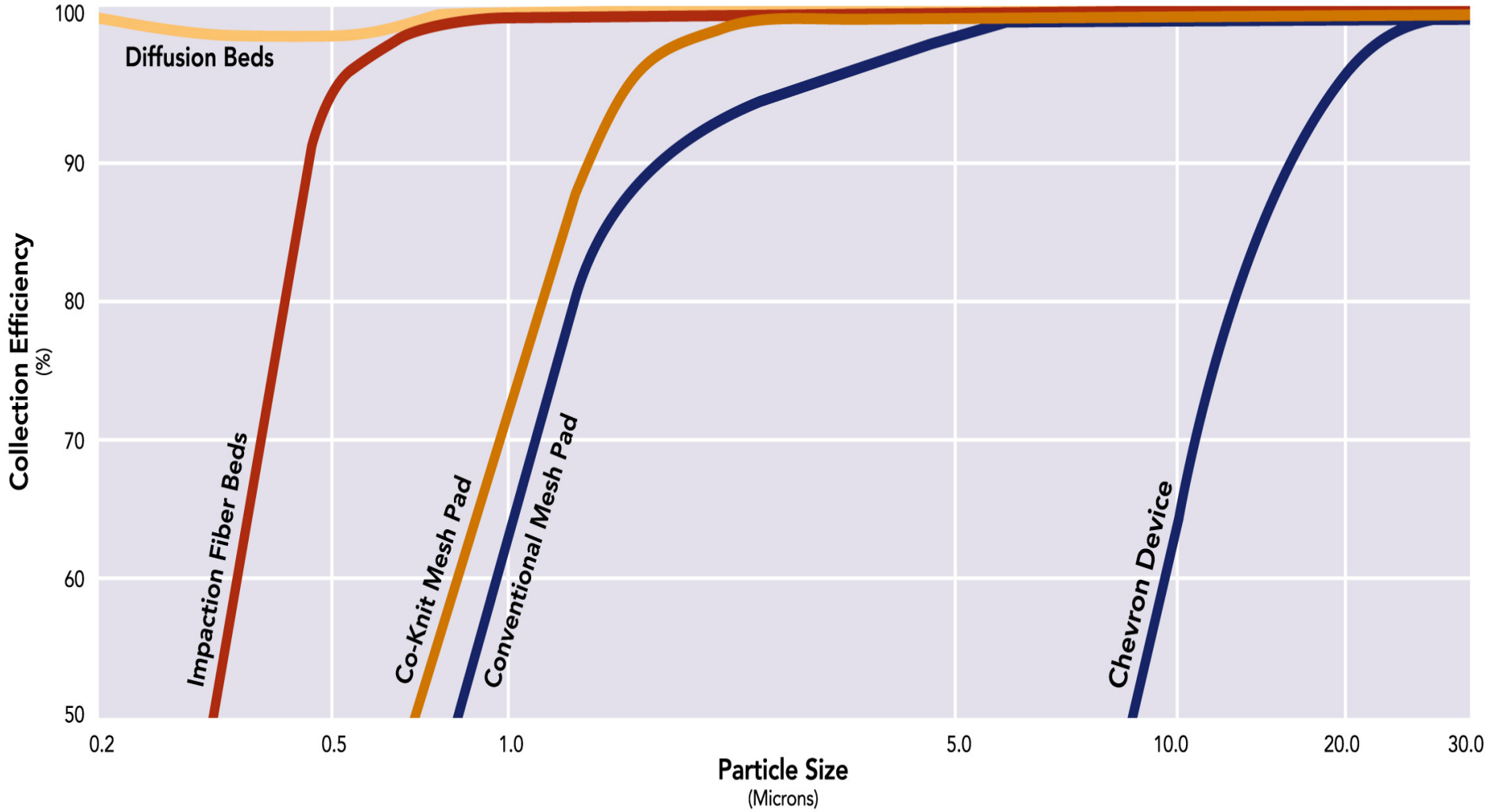
The Stokes-Einstein equation provides the basis of the ability of particles to diffuse in a gas, but particle capture is a different matter altogether. Efficient capture of particles depends upon temperature driven diffusion and ***robust mist eliminator design***.



# Overall Efficiency is an Additive Effect

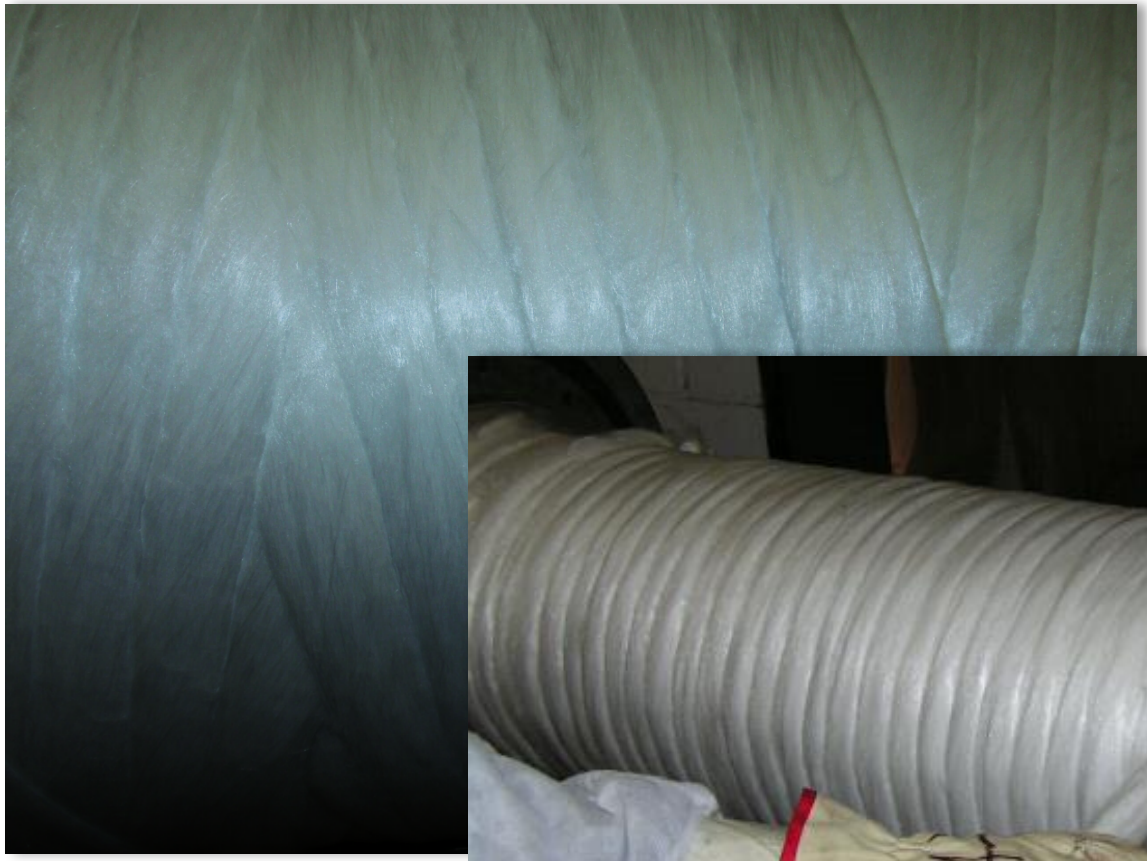


# Diffusion vs. Impaction Efficiency



# Style, It's not Just Important to the Clothing Industry!

There are two methods for placing fiber roving onto a mist eliminator, angle wrap and parallel wrap.  How do these two style look?

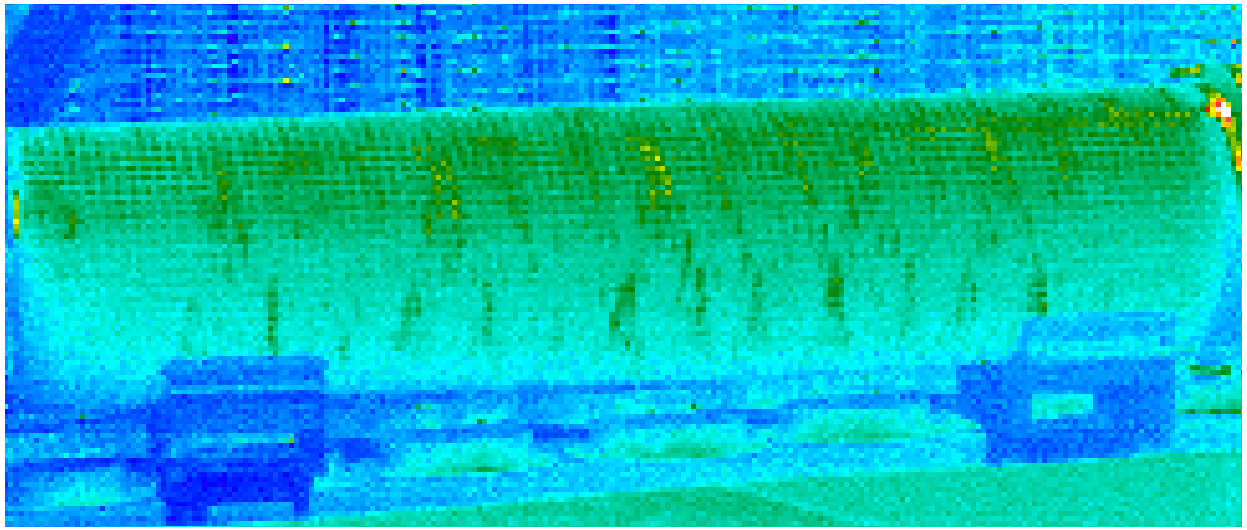


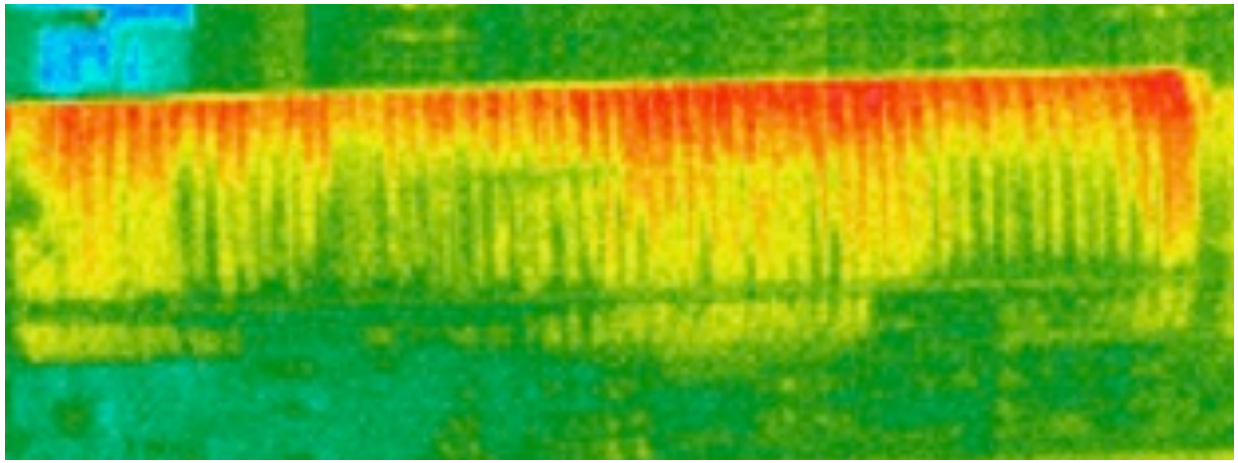
MECS ES Angle Wrapped Mist Eliminator

Parallel Packed Mist Eliminator

# Thermograph Testing – It's only a qualitative test…

This is a typical thermograph of an MECS ES mist eliminator

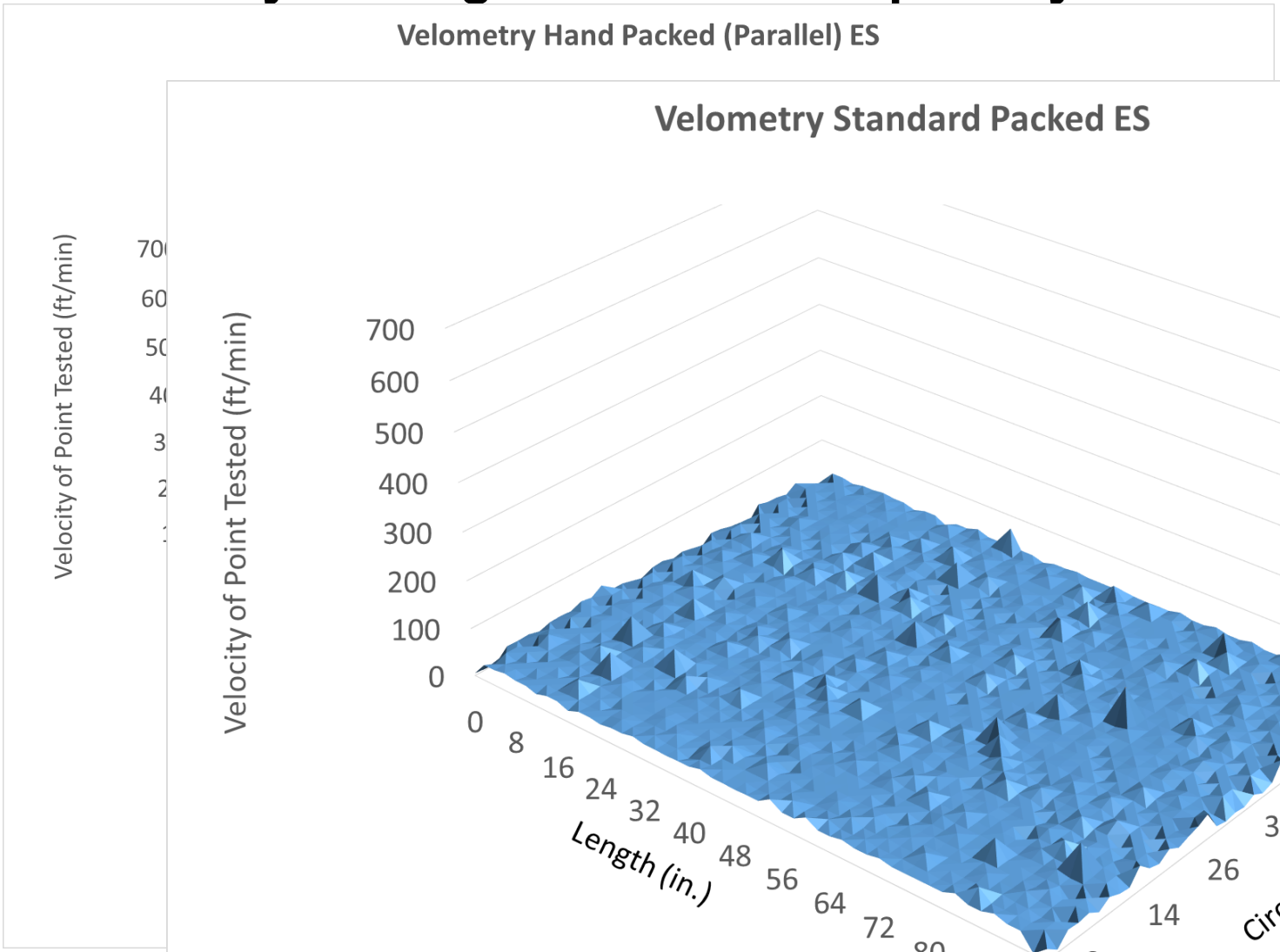




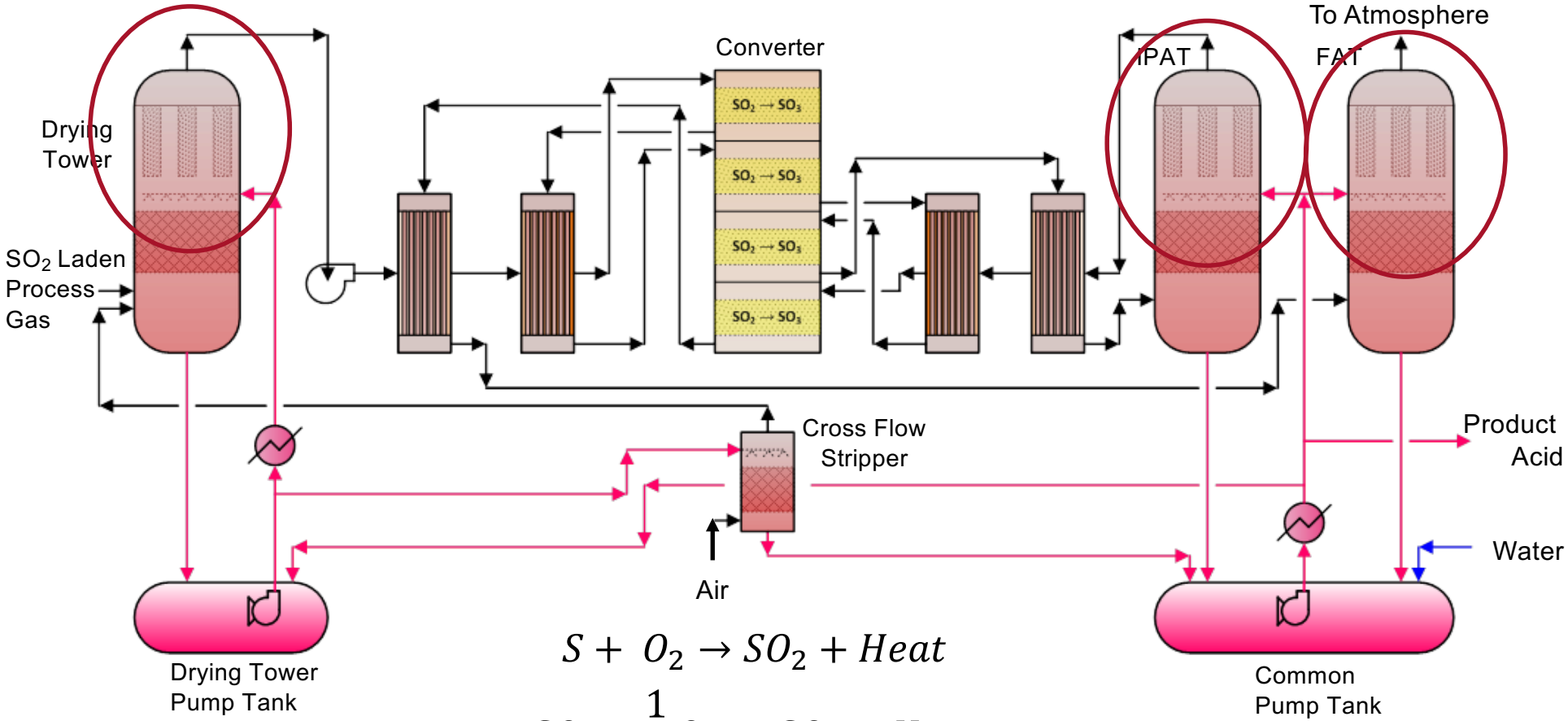
This is a typical thermograph of a competitive parallel packed mist eliminator

The difference is quite noticeable!

# Velometry Testing – It's better to quantify.



# Contact Sulfuric Acid Plant



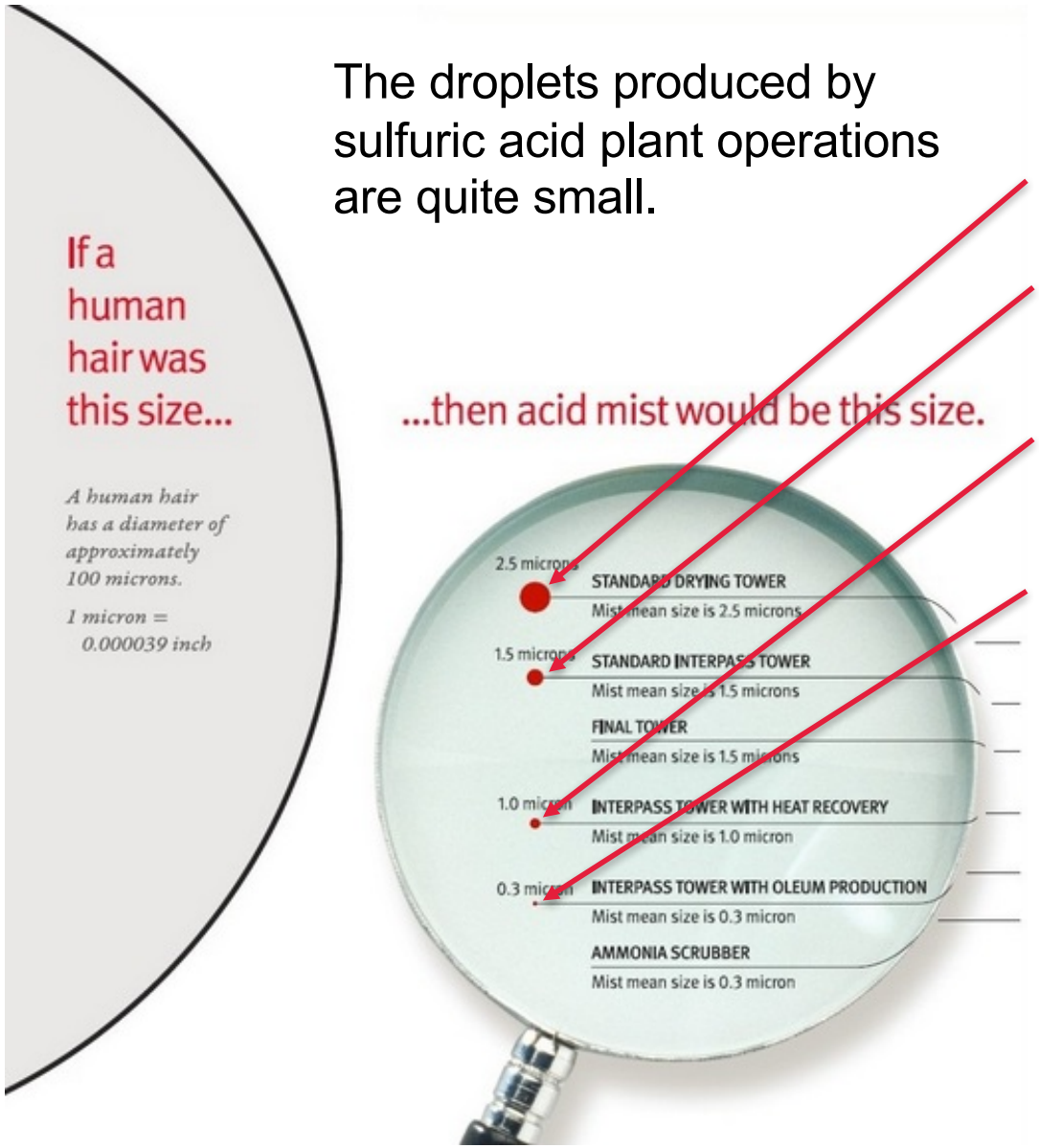

$$S + O_2 \rightarrow SO_2 + Heat$$

$$SO_2 + \frac{1}{2}O_2 \rightarrow SO_3 + Heat$$

$$SO_3 + H_2O \rightarrow H_2SO_4 + Heat$$

# Mating up choice of element efficiency with mist produced in the process

The droplets produced by sulfuric acid plant operations are quite small.




Mean Mist Size Distributions:

- Drying Tower (DT): ~ 2.5μm
- Interpass (IPAT) and Final Absorption (FAT) Towers: ~ 1.5μm
- Heat Recovery (HRS) Tower: ~ 1μm
- Oleum Tower: ~ 0.3μm

*This data cannot be ignored and must be taken into account for proper Mist Eliminator design for the installation!*

# Acid Plant Mist Elimination is a Balancing Act

Operators must balance:

- Process gas inlet temperature
- Acid outlet concentration
- Acid outlet temperature
- Acid circulation rate to packing
- Acid distributor condition
- Situation within the packing (solids buildup management, proper size and quantity)
- And the list goes on an on…..

How do you answer: “Is your acid plant running properly?”

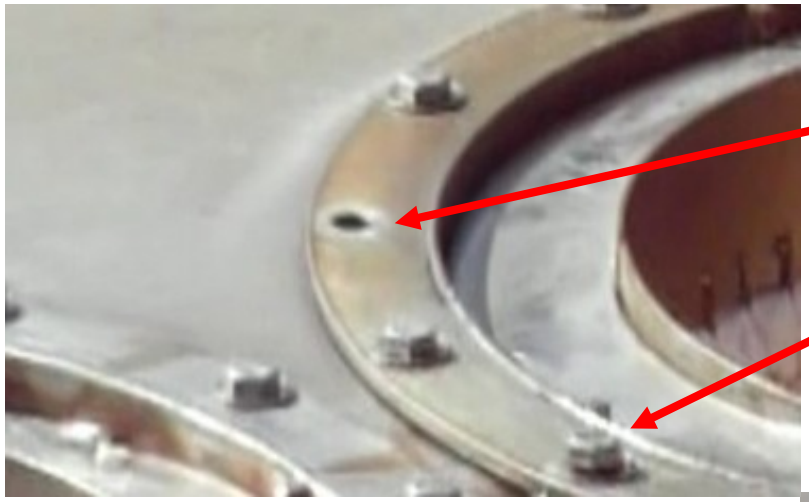
*Yes, this one thing is in specification, so everything is running perfect.*

Or

*You need to pay attention to nearly everything going on in your process to keep your plant operating properly.*

# Why do I mention that you need to pay attention? If you don't pay attention, it can hurt!

# Self Sabotage – The real way to hurt yourself…

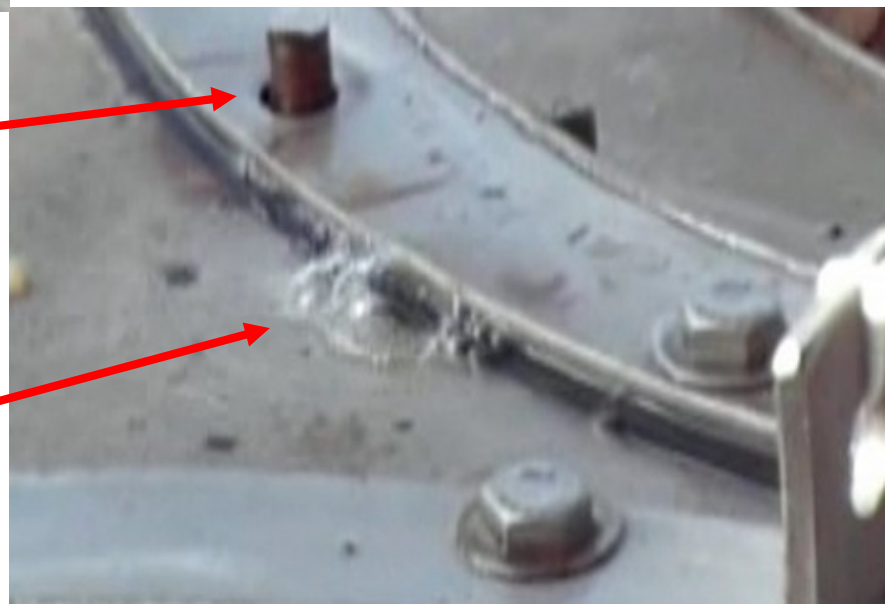


**Missing Hardware**

**Loose Hardware**

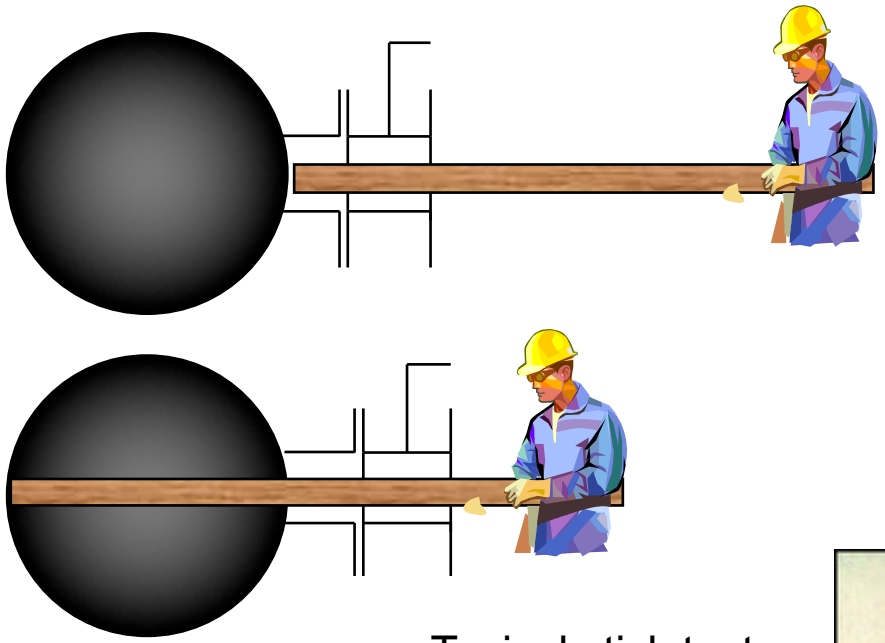
**Missing Hardware**
**In this case, substitution with a threaded rod**

**Issues with Gasket or Flange or T/S deformation causing Improper Element Seal to T/S**



# Obvious Problems Can Be Overlooked

# Easy Diagnosis - Open up and say, “Ahhhhhh”



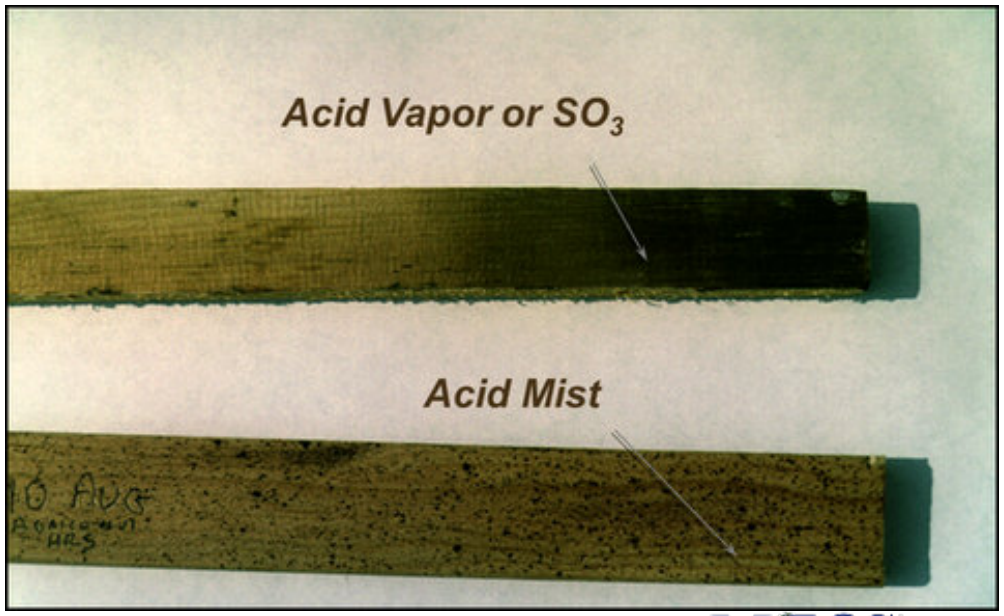
Typical stick tests are 15, 30 and 60 seconds.

Safety measures are imperative, including more PPE than the drawing above shows.

Stick tests use pine sticks to look for large mist carryover, or acid vapor and $SO_3$ in gas streams in acid plants.

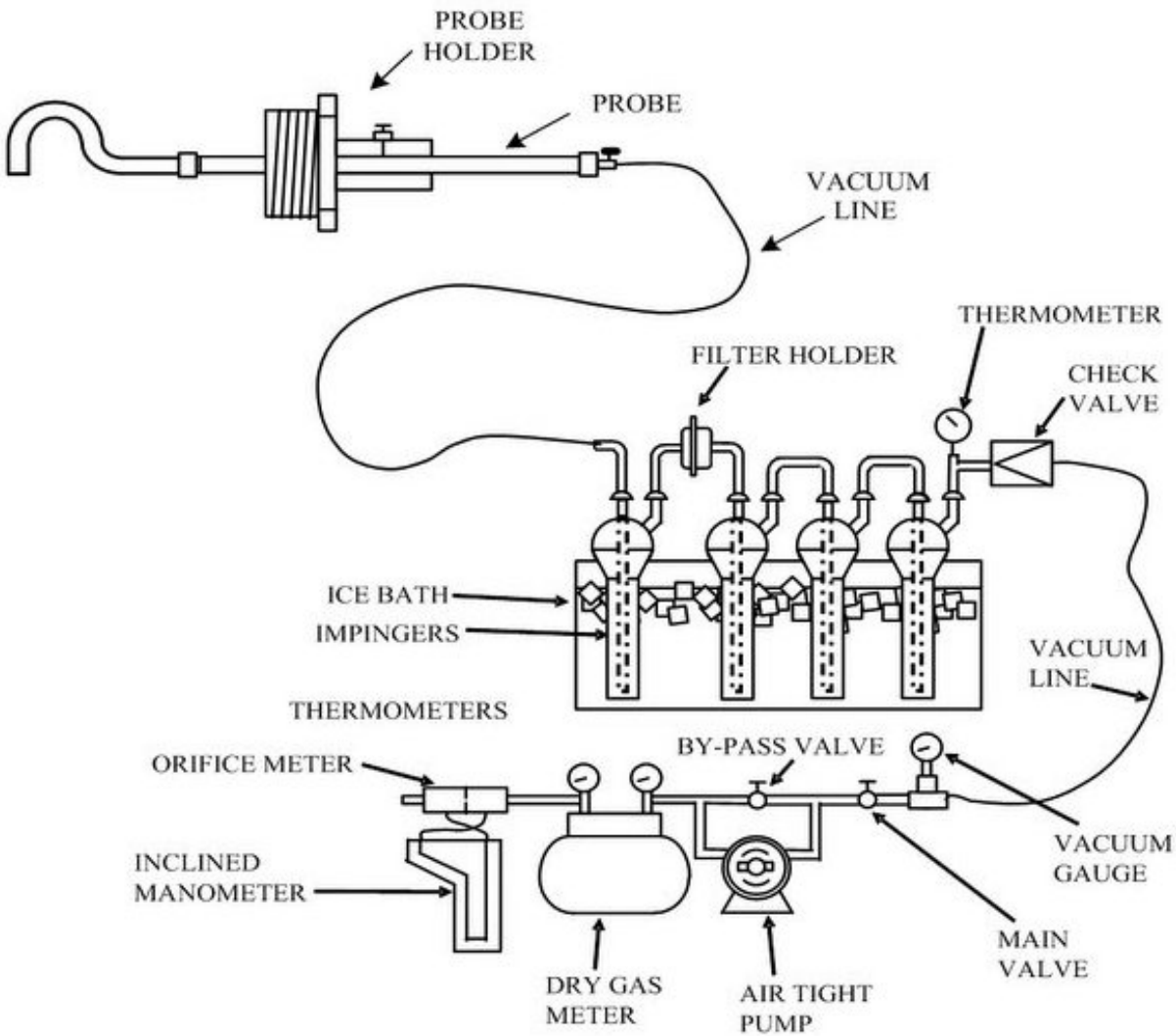
This method is good for checking for leaks around mist eliminators, but does not show particles less than 5 microns.

Cheap and easy to perform.



# Sampling Methodologies

# Simplified EPA Method 8 Diagram




Proper setup includes:

- Heated probe including thermocouples and embedded electric heater
- S-Type Pitot tube to measure continuous stack velocity

All emissions are reported as 100% $H_2SO_4$ and $SO_2$

# Common Misconceptions about EPA Method 8

- "Method 8 is a good indicator of problems in plants"
  - Actually used to verify stack emission compliance
  - High emission numbers indicate an issue in the plant *but not its source*

- "Method 8 does a great job of separating mist from vapor, $SO_3$ and $SO_2$"
  - Only if a filter is placed prior to first impinger and analyzed separately
    - This modification is not always accepted by the regulatory agency

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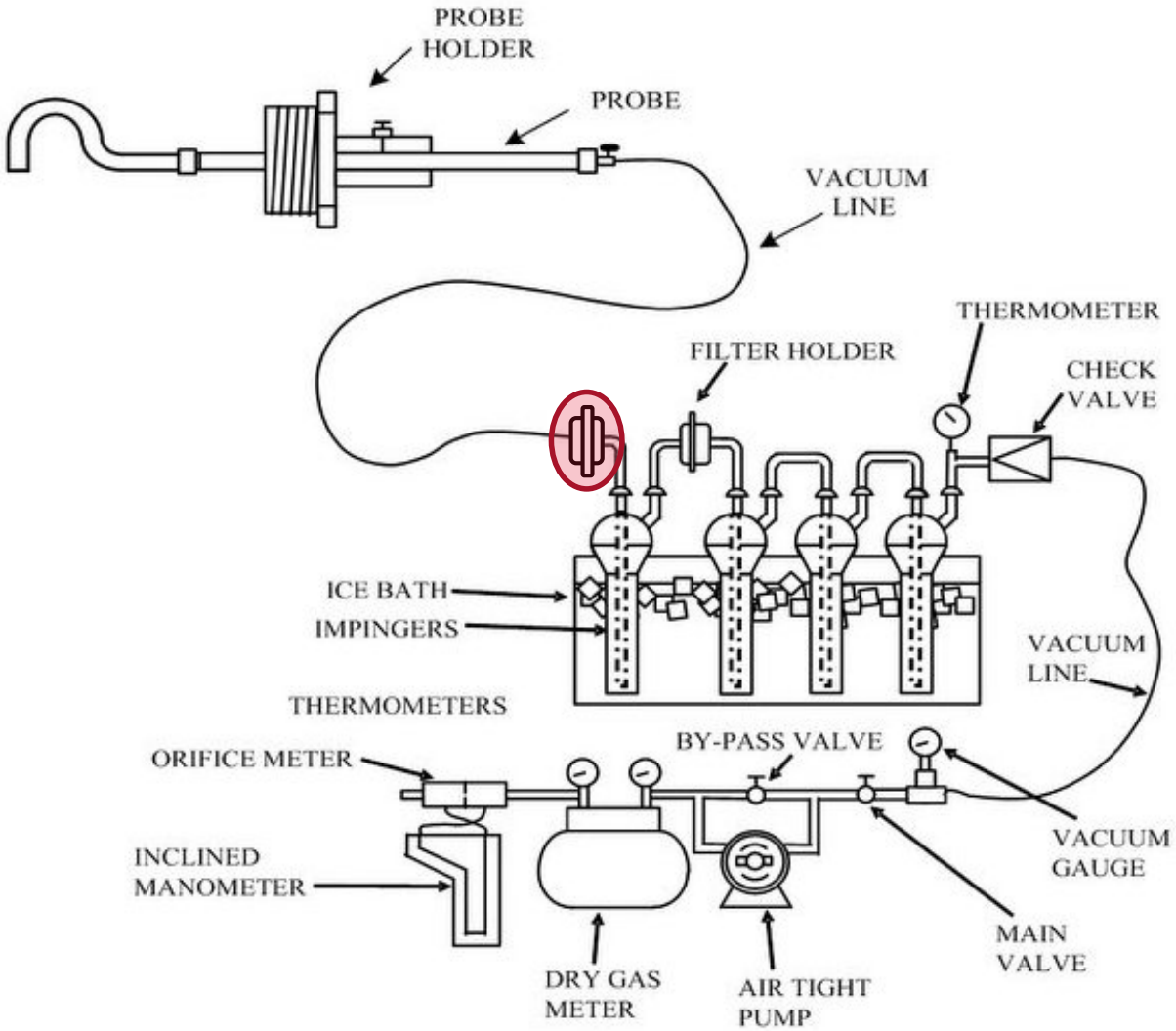

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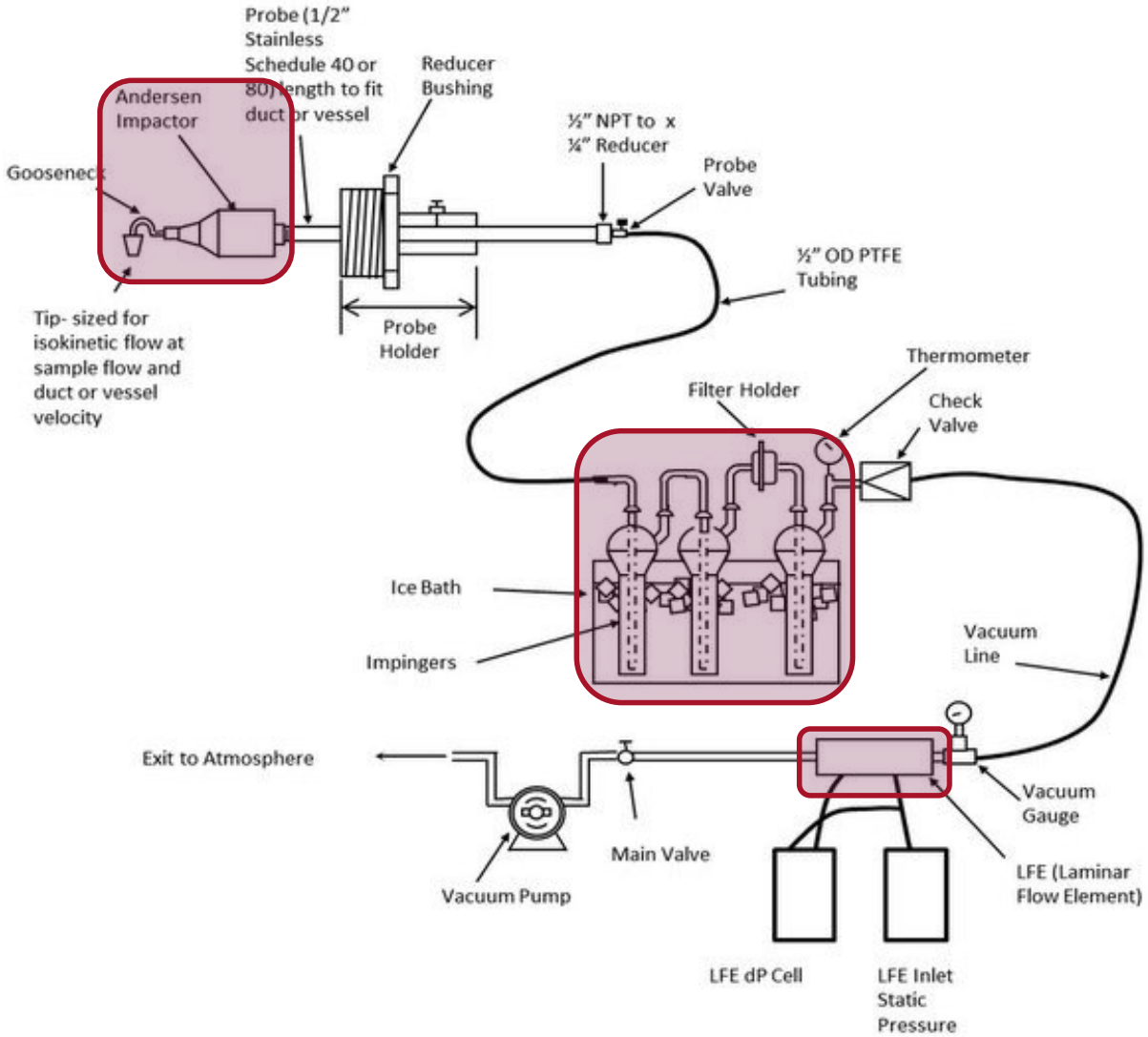
- "Every sampling company performs Method 8 exactly as the EPA method specifies"
  - Tremendous variability in the experience and knowledge
  - Unaware of portions of the official Method 8
    - Only learned from other members of their staff
    - In one case the samplers had never actually read a copy of the procedure!

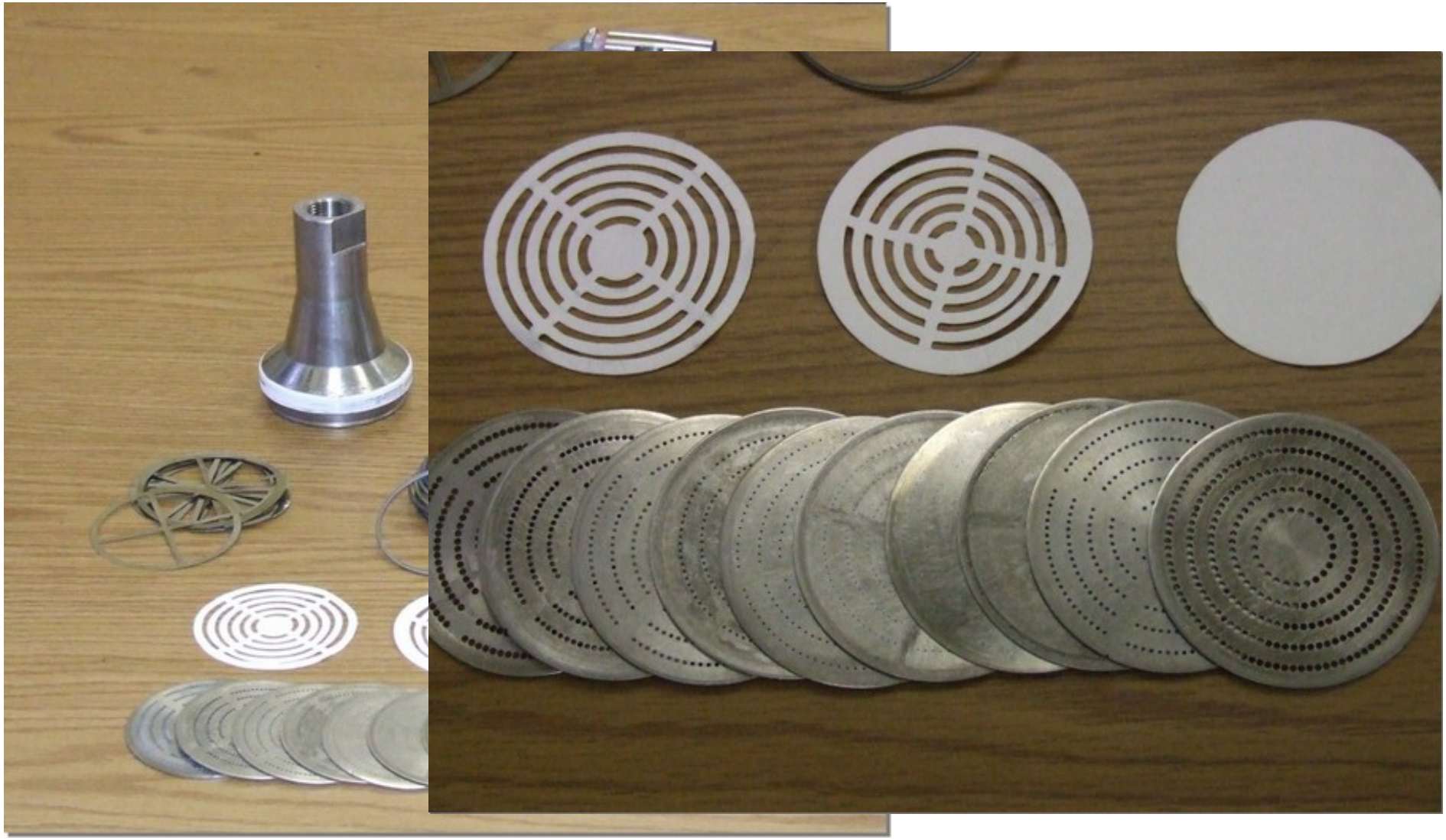
# MECS Method 104




Key differences between EPA Method 8 and MECS Method 104:

- Andersen Impactor used for PSD
- Fewer Impingers (no $SO_2$ measurement)
- Simplified gas flow measurement
- Not for compliance testing
- Can run at both inlet and outlet of filter installations

# Andersen Impactor Details



## Sampling for the Right Reasons

Sampling does not determine how to troubleshoot issues

- Sampling can be very expensive ($20,000 to $30,000)
- Results can be tainted by the experience of the sampling crew
- Sampling is the last resort

A thorough troubleshooting plan is more effective:

- Review operating data vs. design criteria with plant / system designer
- Check control equipment
- Review of maintenance requirements
- Examination of change and effects on the plant
- Stick testing including comparison to previous sticks
- Review of mist eliminator operation history

# Why Should I Care?

- Mist Eliminators are a fixed efficiency device intended for capture of liquid mist in acid plants, not $SO_3$ and acid vapor! You need to meet your emissions requirements!
- The theory of operation is a bit complicated and Einstein has his part in the explanation of the mechanism of operation of the devices.
- Your plant needs to operate properly in order to assure proper emission compliance.
- Many factors, including the way in which the fiber is placed upon the mist eliminator play a part in the way in which mist eliminators work.
- Mist eliminators must be properly designed, manufactured, installed and operated to achieve their rated mist removal efficiency.

# ¿Preguntas?