1

The Product Quality Cleaning Workshop Team

PC Workshop AT PMTS 2025

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  - Cleaning Research Group
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Many (most) manufactured objects require critical cleaning

- Metal fabrication/finishing
- Automotive
- Advanced Automotive
- Aerospace
- Medical devices
- Pharmaceuticals, botanicals
- Electronics, microelectronics
- Optics
- Additive manufacturing

3

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For example

4

4

Critical cleaning and surface prep is straightforward!

- Remove the soil
- Without damaging
  - the product
  - the workers
  - the facility
  - the pocketbook
  - the environment

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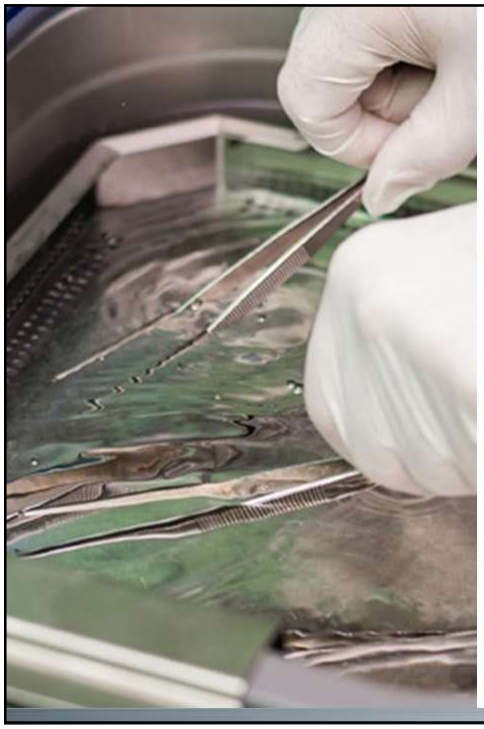

The Five S's

1. **Soil** – matter out of place.
2. **Surface** – ceramic, metal, plastic, glass, wood, paper, textiles, smooth vs rough, soft vs hard
3. **Separator** – (solvent, water, air) separates soil from the surface.
4. **Safety** – skin, eyes, nose, lungs, ears
5. **Sustainability** – expense and environment

6

6

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TACT – Frenemy of Cleaning

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What helps remove soil?

- Temperature
- Action
- Chemistry
- Time

What makes soil stick?

- Temperature
- Action
- Chemistry
- Time
  - Product shape and materials
  - Soils/residue
- Changes in regulations
  - Limits available options

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Balancing forces

What helps remove soil?

- Chemical force
  - Polar / dispersion
- Physical force
  - Impingement
  - Agitation
- Must obtain access to surface with soil

What makes soil stick?

- Chemical force
  - Polar / dispersion
- Physical force
  - Drive particles into substrate (Plastic, glass, and metal)
  - Cleaning / drying / polishing

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Balancing chemicals and soils

What helps remove soil?

- Type of cleaning agent
  - Aqueous / organic solvent
- Solvency
- Wetting / penetration
- Rinsing
- Drying

What makes soil stick?

- Chemical / physical properties of cleaning agents versus the soil
  - Polar / non-polar
  - Density, surface tension, viscosity
- Chemical / physical nature of soil versus the cleaning agent
  - Silicone
  - Proteins
  - Residue – reacted soil
  - Particle size – small particles adhere

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Balancing temperature

What helps remove soil?

- Higher temperatures
  - More vigorous agitation
  - Melting, vaporization
  - Lower viscosity

What makes soil stick?

- Higher temperatures
  - Caramelization (varnishing, polymerization)
  - Flash drying
  - Baked-on soils
  - Reactivity
  - Substrate change

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Balancing time

What helps remove soil?

- More time → more cleaning
- Prompt cleaning

What makes soil stick?

- More time → more damage
- Latency (prior to cleaning)
  - Longer dirty time leads to strong soil adhesion
  - Hold time
  - Time to ship components

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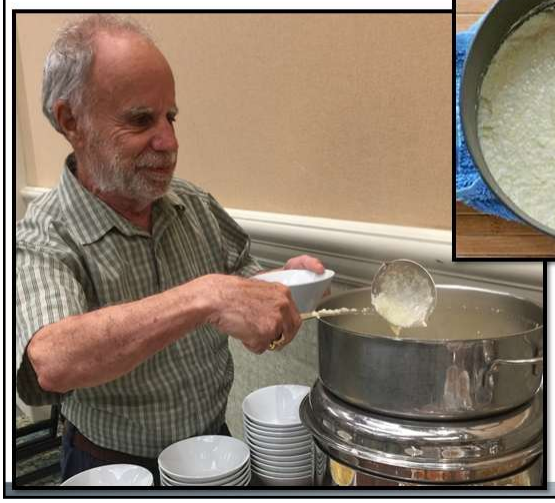
Clean the grits right after you cook them!



(Grits are a porridge made from coarsely ground dried maize or hominy.)

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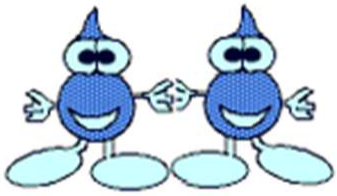
Cohesion and adhesion

- Cohesion is the attraction force between similar molecules
- Adhesion is the attraction force between different molecules



Cohesion

Adhesion

Diagrams from USGS: http://water.usgs.gov/edu/adhesion.html

- Water has strong cohesion
- Water has strong adhesion to many materials

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The Future of Parts Cleaning
Hands-On and In-Depth

Teeny Critters

(biological contamination in cleaning baths, rinse tanks, supply lines, cleaning systems)

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The birds, the bees, the flowers, the trees, and little critters in cleaning process baths

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- Favorable conditions for life
  - Air
  - Water
  - Nutrients
  - Neutral pH
  - Mild heat
- Life is persistent and adaptive
  - Bacteria is found everywhere
    - Mountain tops in Antarctica
    - Deep sea vents

SHSU Colleague Tom Chasteen in Antarctica sampling for bacteria

https://www.shsu.edu/~chm_tgc/Blogs/AB0.html

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A plethora of tiny, adaptive creatures

Microbes

- Bacteria
  - 2 million species in the ocean
  - " ….my guess is there are a billion species and the more I get used to this number, the more I feel it is a gross underestimate. But for now, it is as far as my mind will go, given so little data."

"Species Numbers in Bacteria", Daniel Dykhuizen, Proc Calif Acad Sci. 2005 Jun 3; 56(6 Suppl 1): 62–71, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3160642/

- Fungi
- Algae

Biofilms

- Collaborative consortium of microbes
  - Naturally-occurring
  - Living and non-living components
  - Coordinated, functional community
  - Perform specialized activities
- Adhere to surfaces
- Persistent, inventive

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Microbialite deposits: Lake Salda, Turkey

Similar to deposits found by Mars "Perseverence." rover Picture by NASA (via Wikipedia)

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Biofilms and manufacturing

- Adhere to surfaces
- Dental plaque
- Medical devices
- Plumbing
- Pharmaceutical water systems
- Your process tanks or process lines?

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Sources of teeny critters in cleaning baths

- Coolants, metalworking fluids
  - Some have "cidal" activity
  - **Bio**based oils
- Cleaning agents
  - A few have "cidal" activity
  - Others may not (or should not)
- Process conditions
  - Temperature
  - pH
  - Agitation

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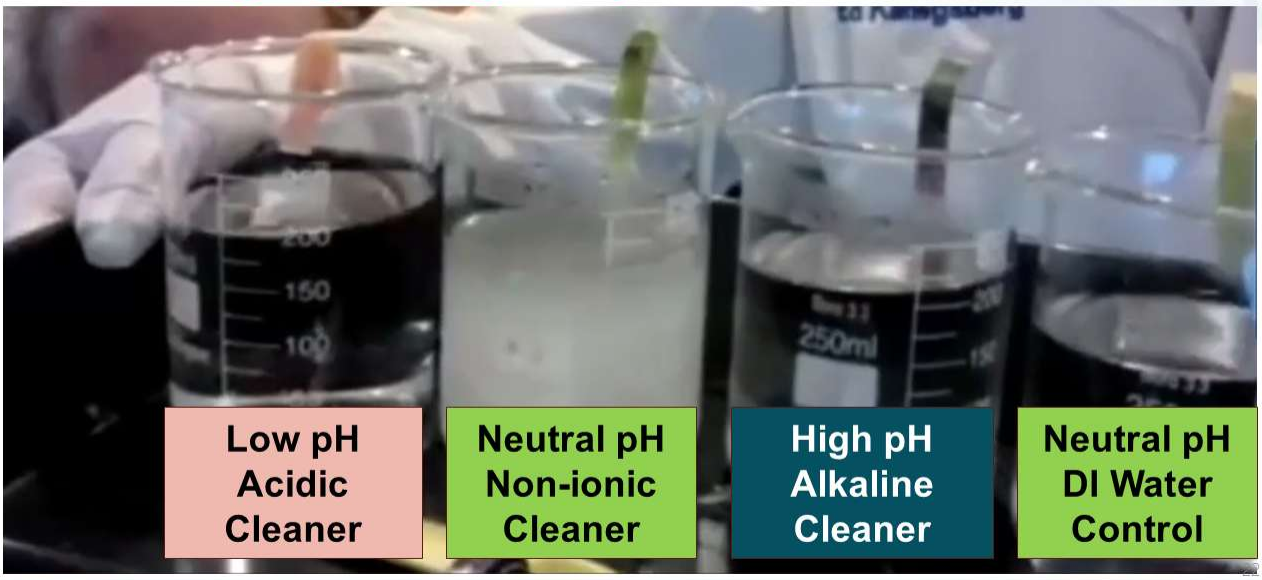
Demo: Something's growing in my bath water!



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Critter growth variables

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Each table has:

- 5 bottles
- 2 packets of yeast
- Alconox
- Sugar
- Water
- Sprite®
- Cutting oil
  (to be shared among tables)

Conditions:

1. Yeast and water
2. Yeast, water, cutting oil
3. Yeast water, sugar
4. Yeast, water, sugar, Alconox
5. Yeast, Sprite®

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The Future of Parts Cleaning
Hands-On and In-Depth

Activity
Solvents and Solvent Blends

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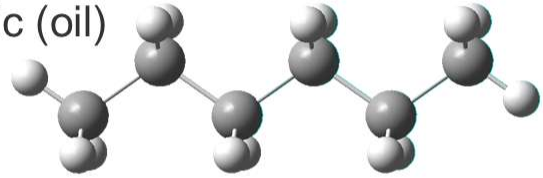
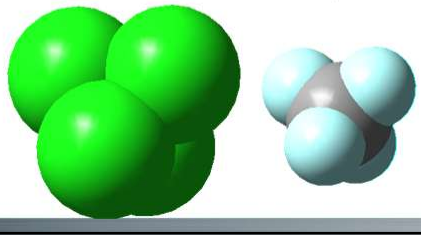
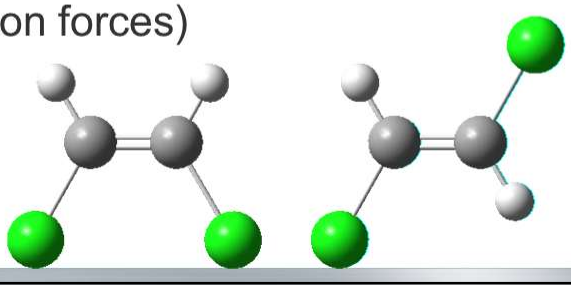
Like Dissolves Like

- How do we know what materials are "alike"?
- We have several familiar terms:
  - Hydrophilic (water) vs hydrophobic (oil)
  - Acidic, basic, neutral pH
  - Ionized vs neutral charge
  - Polar vs non-polar
  - Soft vs hard (London dispersion forces)

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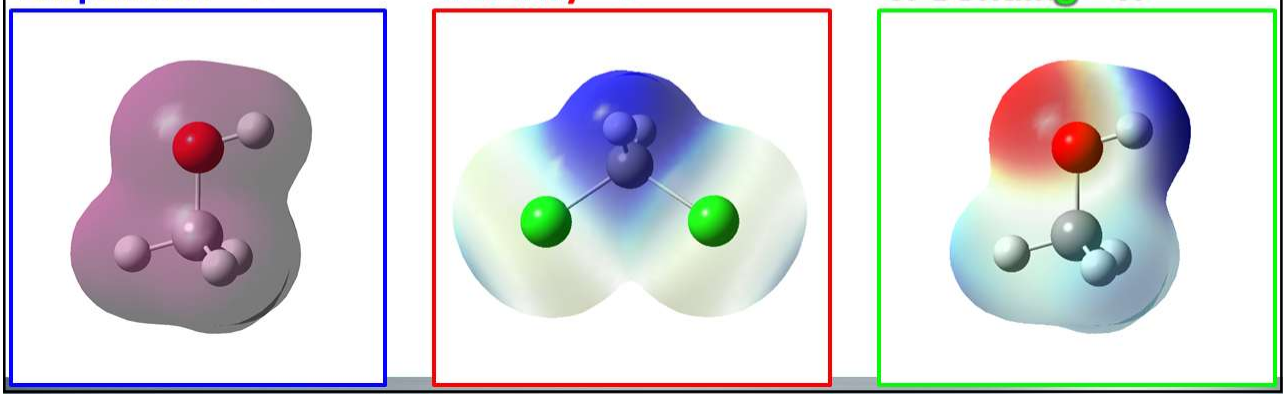
Intermolecular Attractions

- There are three main types
  - Dispersion attractions (e^- cloud flexibility) – whole molecule
  - Polar attractions (positives/negatives) – whole molecule
  - Hydrogen bonding attractions (–NH and –OH) – parts of the molecule

Dispersion = D **Polarity = P** **H-Bonding = H**



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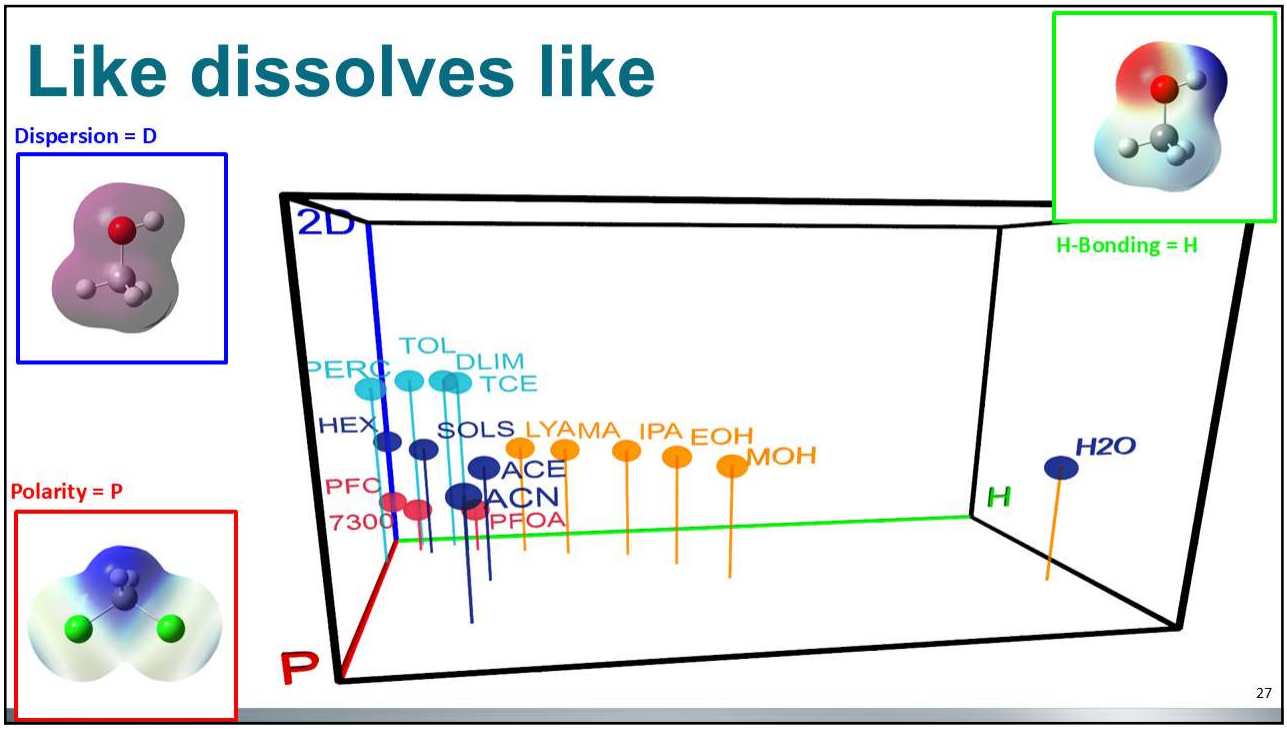

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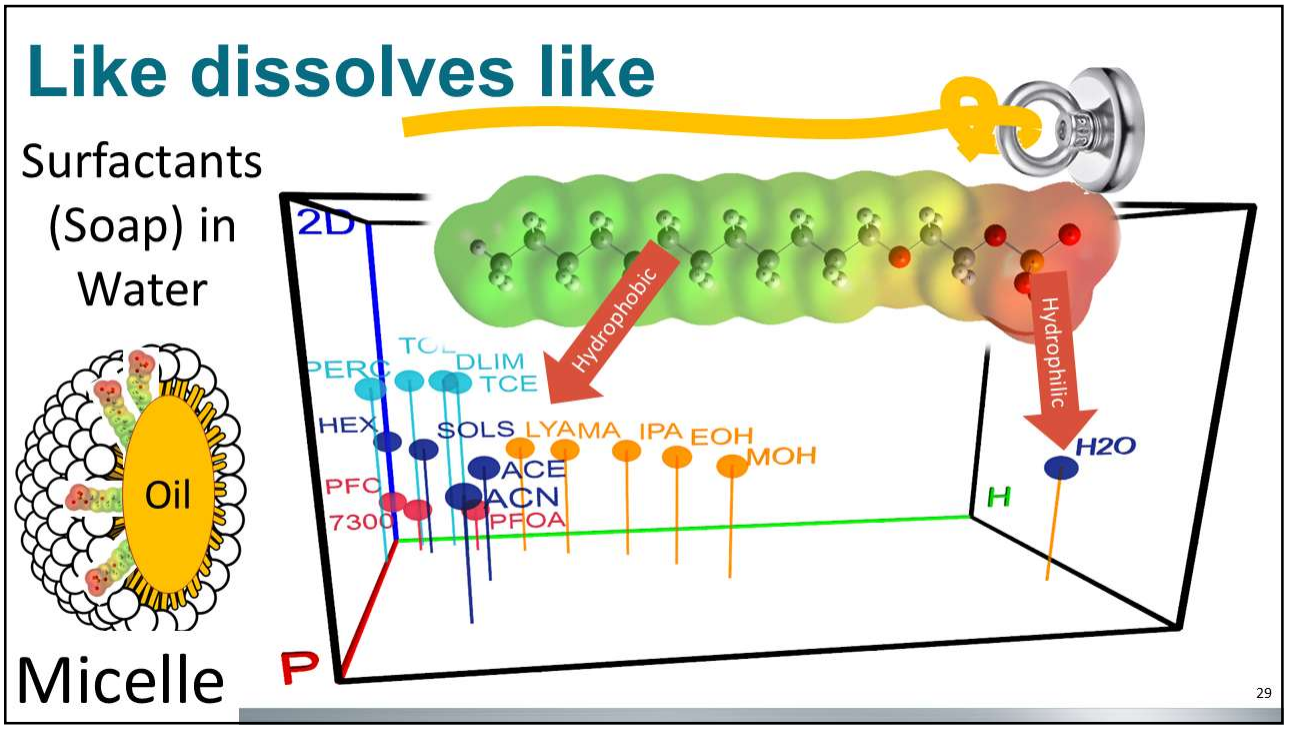

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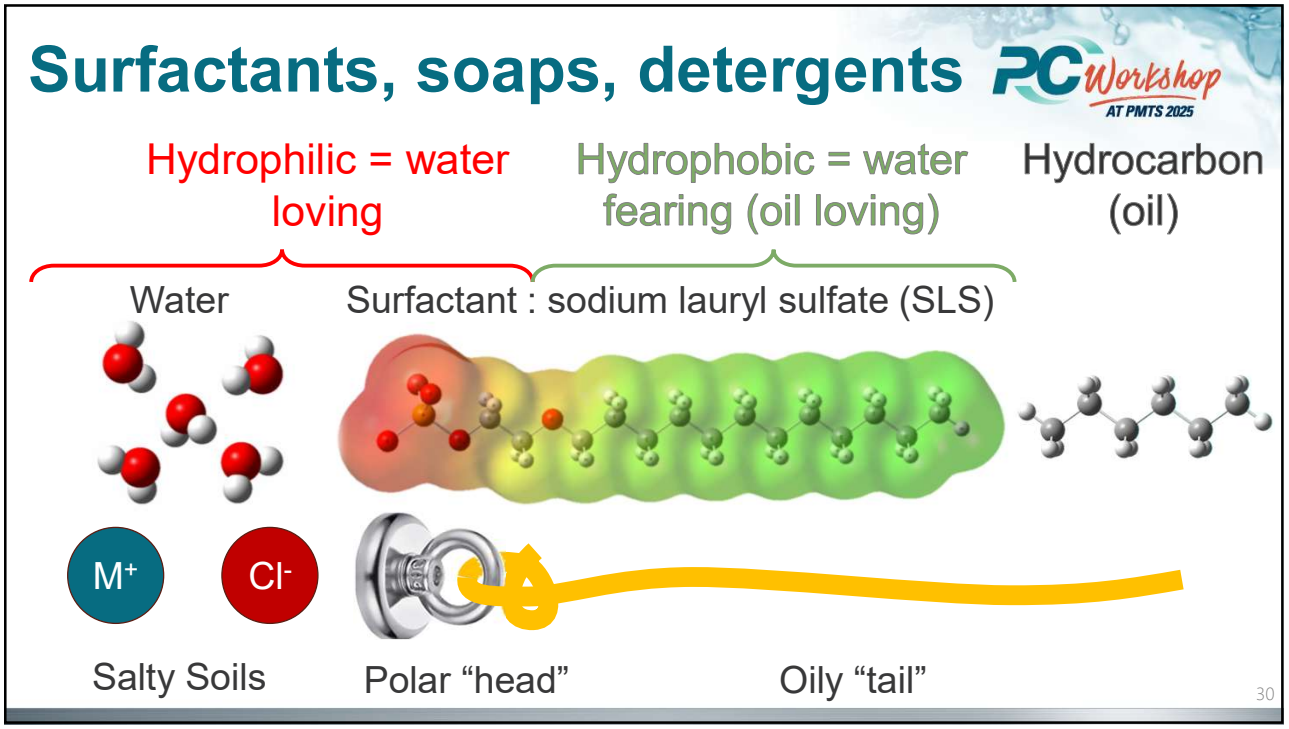

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Micelle formation

- Surfactants form micelles at critical micelle concentration (CMC)
  - Act as aggregates
- 3 dimensional structures formed
- Non-polar materials (oils) held in hydrophobic tail
- Hydrophilic head contacts water, polar materials

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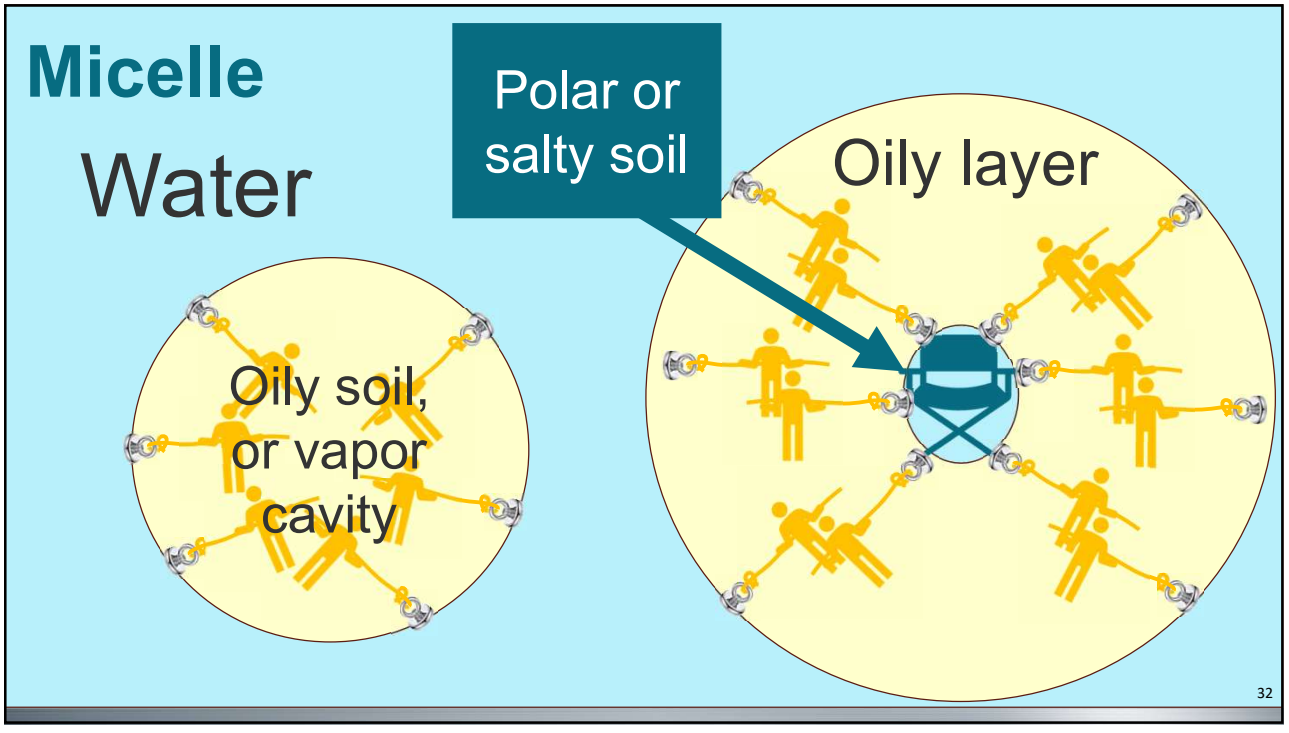

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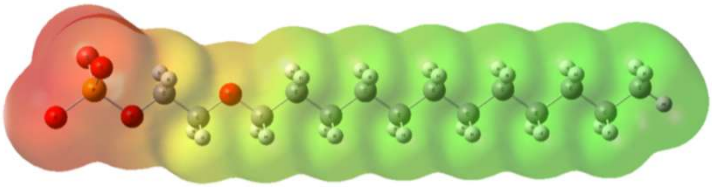
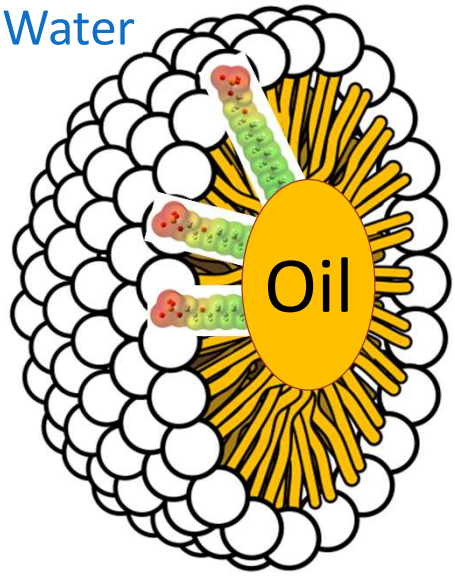
Surfactants, Soaps, and Detergents

- Making oil and water mix



Above the Critical Micelle Concentration (CMC)



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The Future of Parts Cleaning
Hands-On and In-Depth

Activity
Make a Polymer Crystallization, Crosslinking Swelling, and Adhesion

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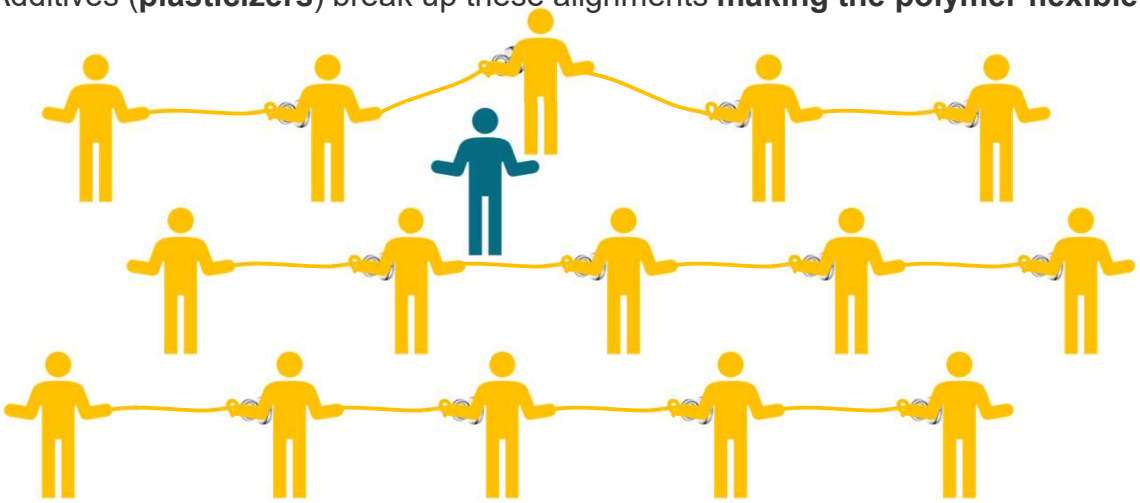
Polymers, Crystallization, Plasticizers

When there is a regular alignment of the polymer, we have a crystalline polymer. Additives (**plasticizers**) break up these alignments **making the polymer flexible**.



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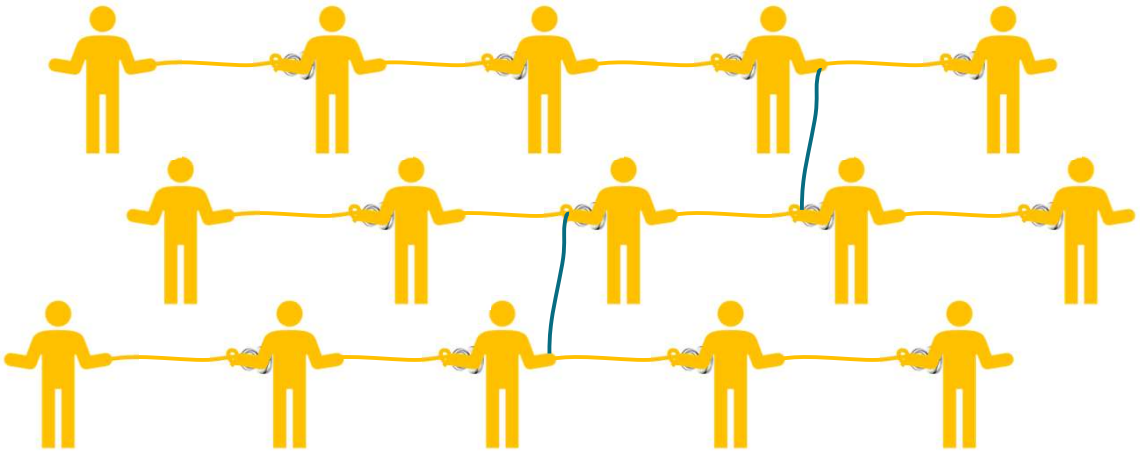
Crosslinking a Polymer

Heat, oxygen, friction can create polymers and can crosslink polymers. These **TWO crosslinks** have **TRIPLED** the weight of this polymer



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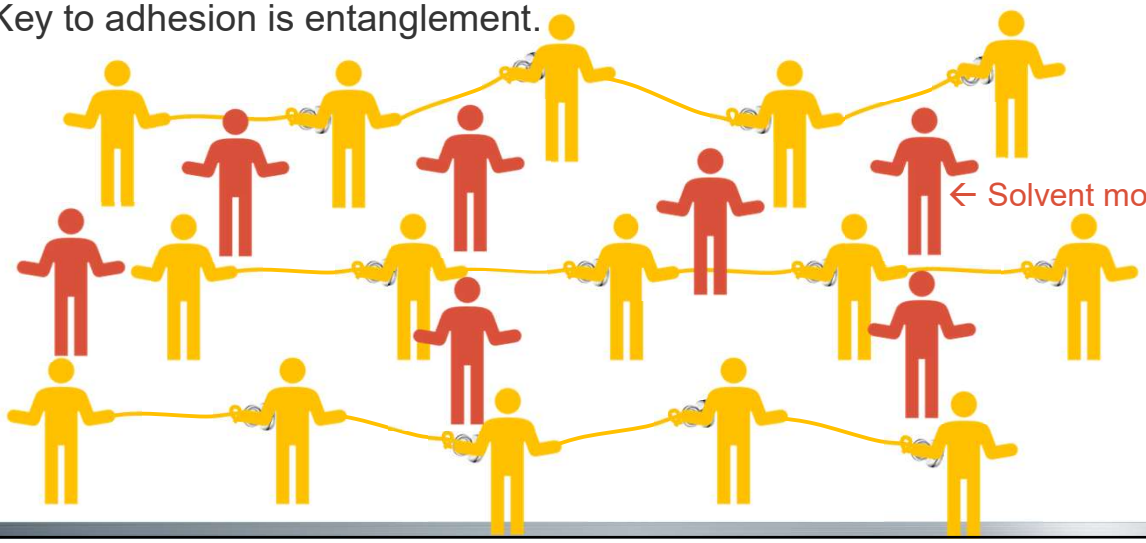
Swelling and Material Compatibility

When you want to remove a sticky polymeric soil, swelling is **GOOD**.
When you DON'T want polymer degradation (e.g. **seals**), swelling is **BAD**!
Key to adhesion is entanglement.



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The Future of Parts Cleaning
Hands-On and In-Depth

Speeding up the ACTION with ultrasonic energy

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Fast Scrubbing Saves Time

- You might scrub at 5-10 Hertz (scrubs/s)
- Sonicare toothbrush: 1000 Hertz (scrubs/s)
- Industrial Ultrasonic Cleaners: 40,000 Hertz

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Balance: Cavitation & Acoustic Streaming

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Both are present

- Ultrasonic “cavitation” is omni-directional
  - Dominant at lower frequencies
- Acoustic streaming is uni-directional (line of sight)
  - Dominant at higher frequencies, megasonics (400 → 500 kHz)
- Higher frequency, smaller cavities, more acoustic streaming

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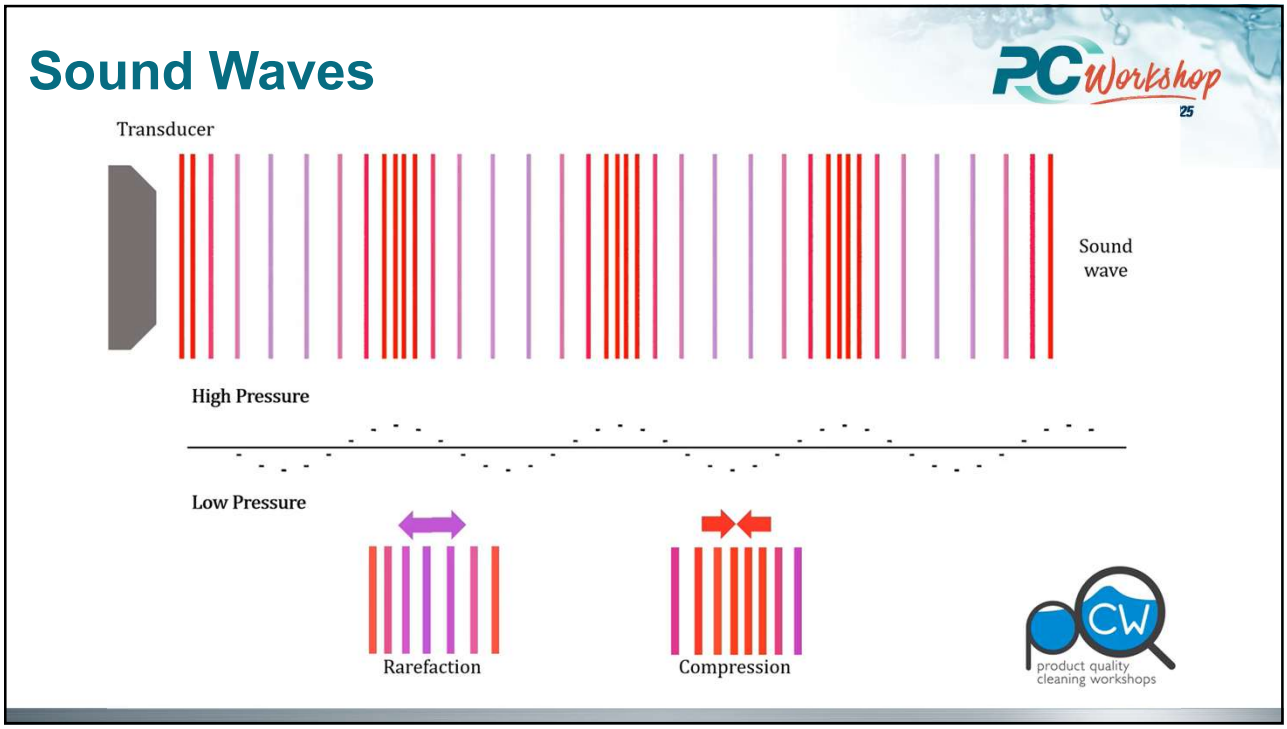

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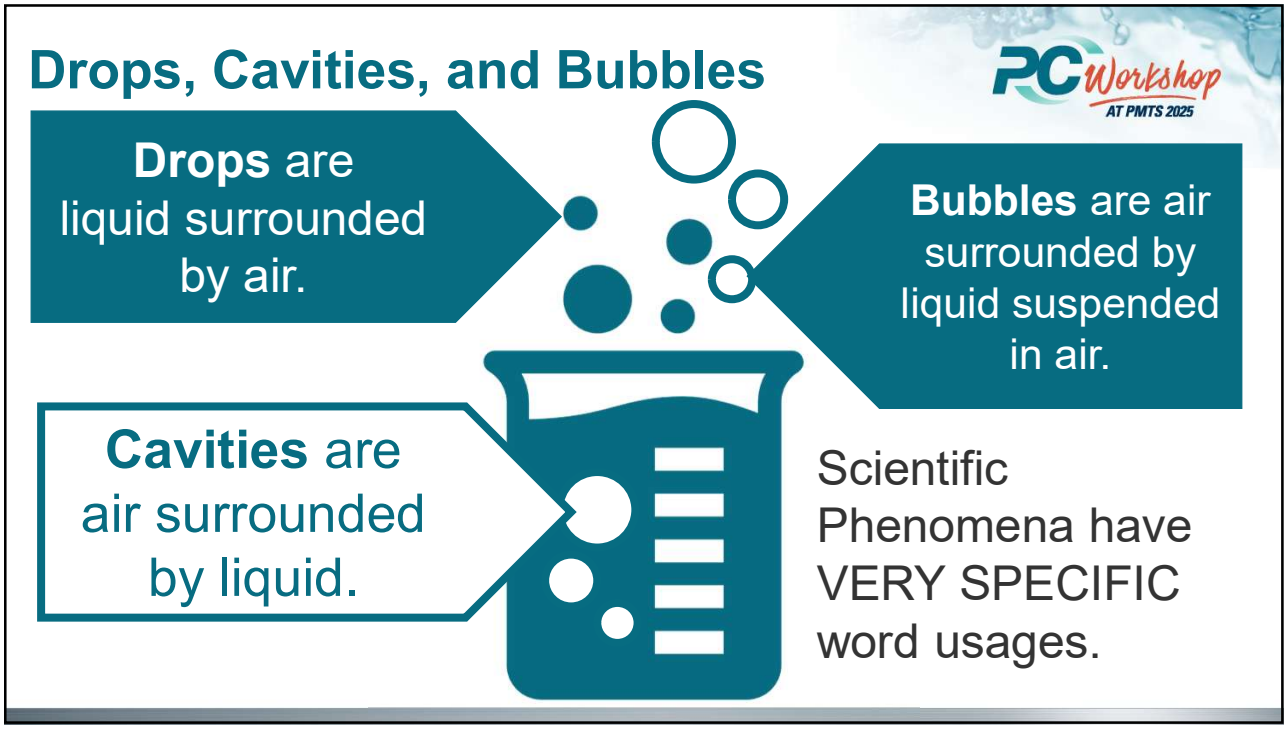

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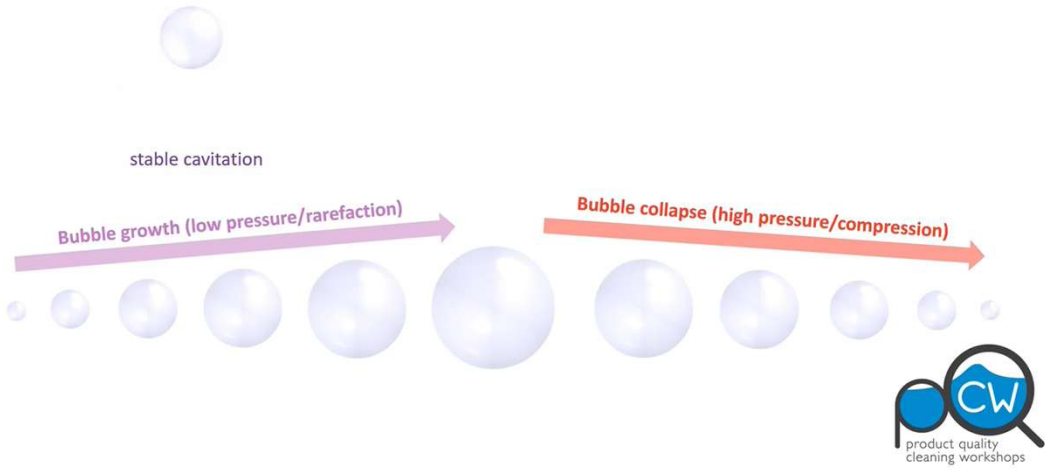
Stable and Transient Cavitation



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Stable Cavitation

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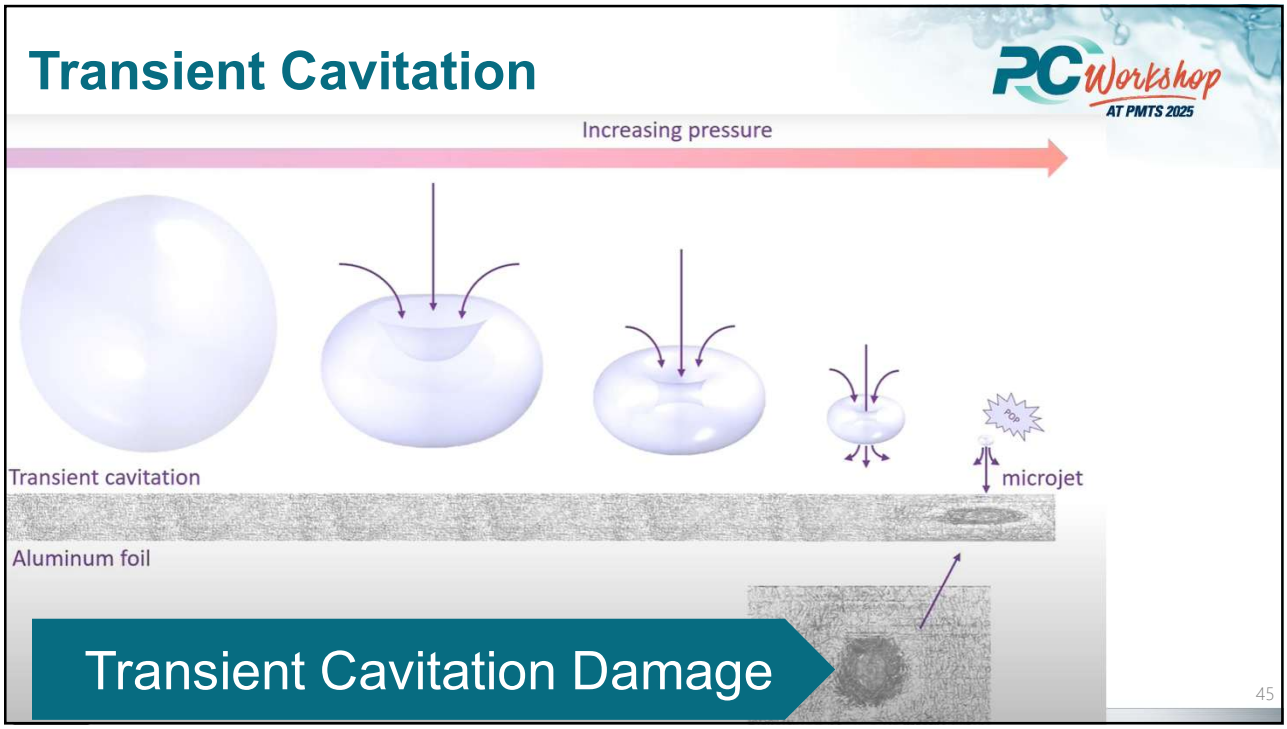

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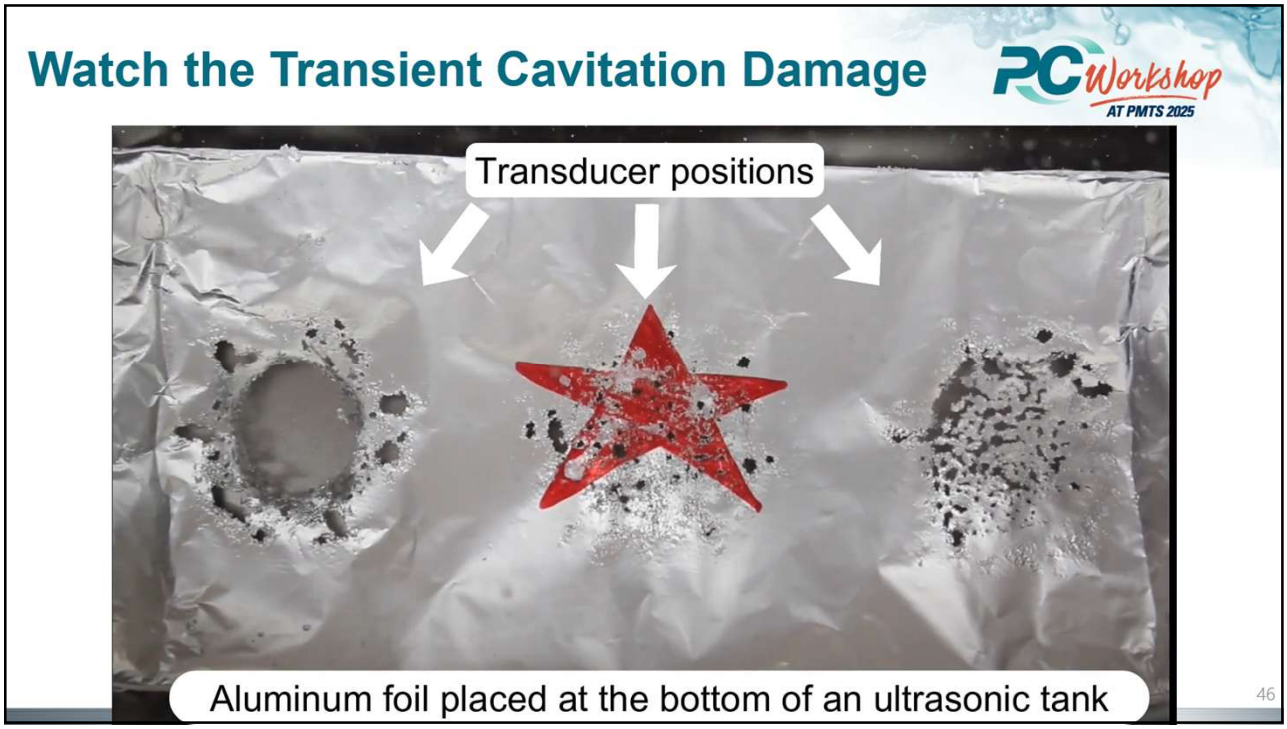

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The Future of Parts Cleaning
Hands-On and In-Depth

Activity
Foil erosion, graphite removal, and graphite sandwich tests

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Foil Erosion Test

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- Take a **before photo** of your foil strip.
- Label your square bottle with your name.
- Fill bottle with some degassed water from the tank.
- Place your foil strip into the bottle.
- Close the lid.
- Place the bottles in the tank.
- Turn on the ultrasonics for one minute. (Each table choose a different sonic power.)
- Take an **after photo** of your foil strip.

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Graphite on Frosted Glass Test

- Cover the frosted area of a microscope slide with graphite.
- Take a **before photo** of your dirty microscope slide.
- (Use of the bottle is optional)
- Turn on the ultrasonics.
  (Each table choose a different sonic power.)
- Take turns putting your slide into different regions of the tank.
- Watch the cleaning action carefully.
- Take an **after photo** of your cleaned slide.

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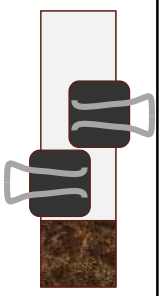
Graphite Sandwich Test

This tests the omni-directional nature of ultrasonics.

- Soil TWO microscope slides with graphite.
- Place the graphite “face to face”.
- Clip the sandwich together.

- Take a **before photo** of your dirty sandwich.
- (Use of the bottle is optional)
- Take turns putting your sample into the tank.
- Watch the cleaning action carefully.
- Take an **after photo** of your cleaned sandwich.



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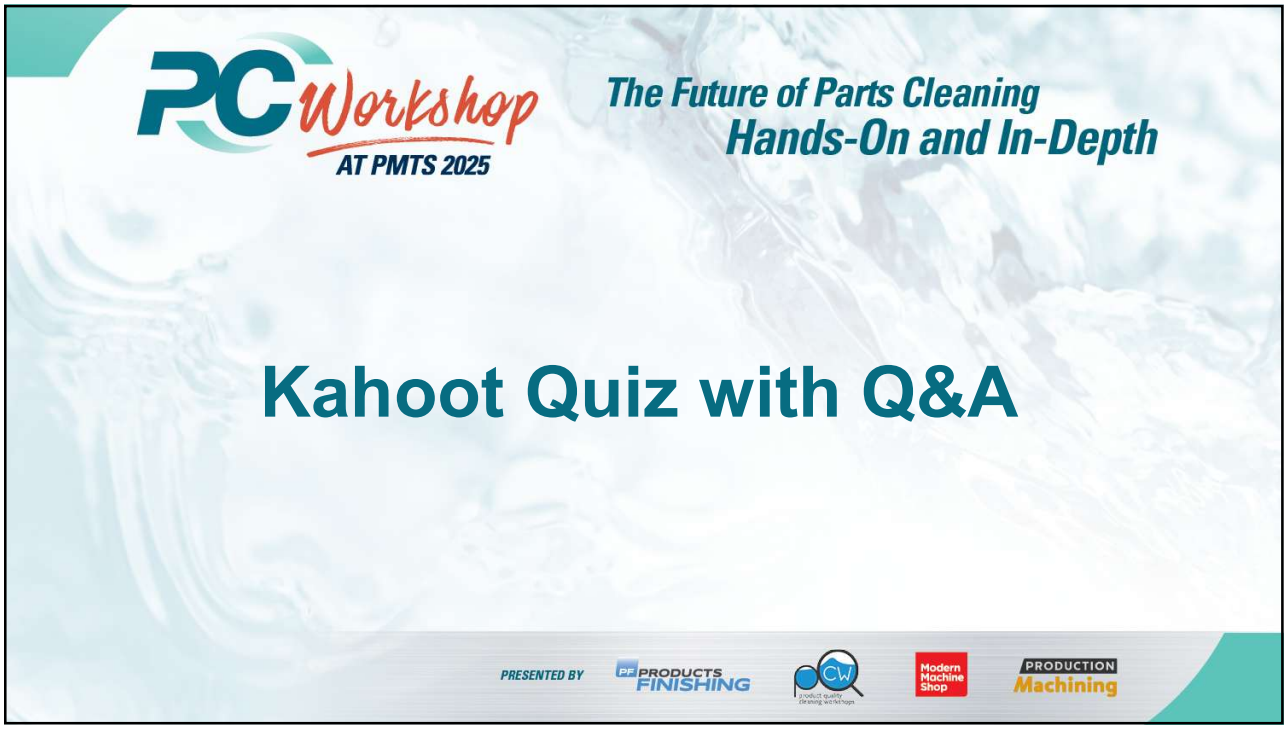

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Assignment: Interact with Vendors at PMTS/PCw

Do this

- Interact with at least 3 providers of products / services related to critical cleaning / surface prep
  - On show floor & at PCw
- Obtain actionable information
- Interact in person
  - Find people who can help you

Not sufficient

- Scanning your card
- Grabbing brochures
- Loading up on swag

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Interact with vendors: categories

Categories

Aim for 3 interactions
(not 3 per category)

- Cleaning agents
- Water prep / water management / chemical management
- Cleaning equipment
- Cleanliness measurement / inspection

Be efficient

- Your questions and notes are the most important
  - Make them relevant to your needs
  - Consider upstream suppliers and downstream customers
- Our questions are there for ideas
  - Don't try to address all the questions
  - Please don’t recite our questions to vendors

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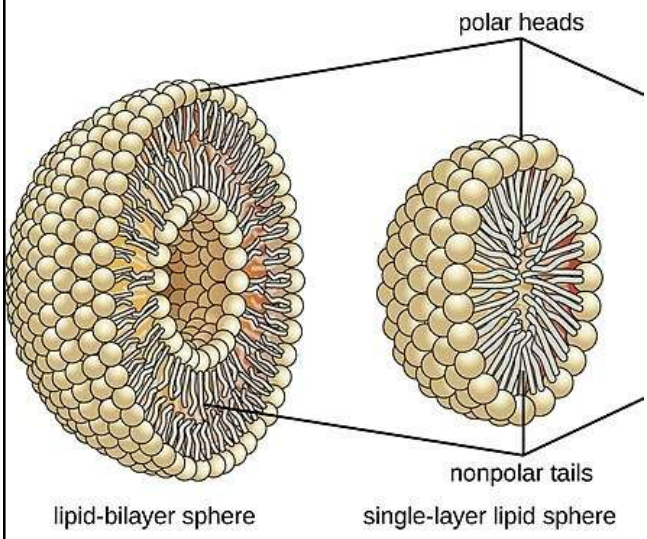
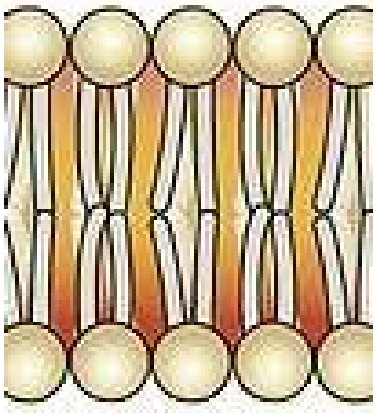
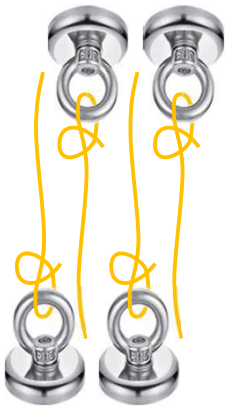
Micelles – residue potential







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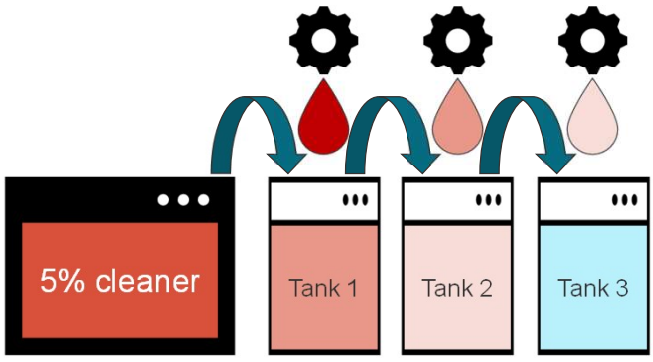
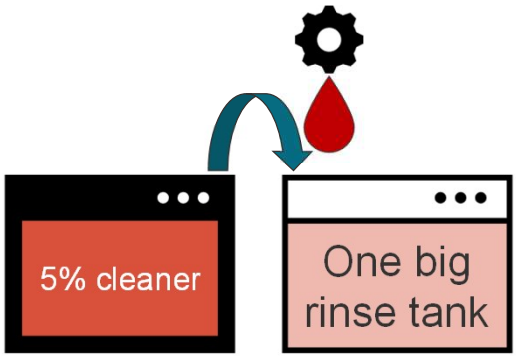
It is better to have many small rinses

- All parts carry liquid from one tank to the next.

Three Small Rinse Tanks



One Big Rinse Tank



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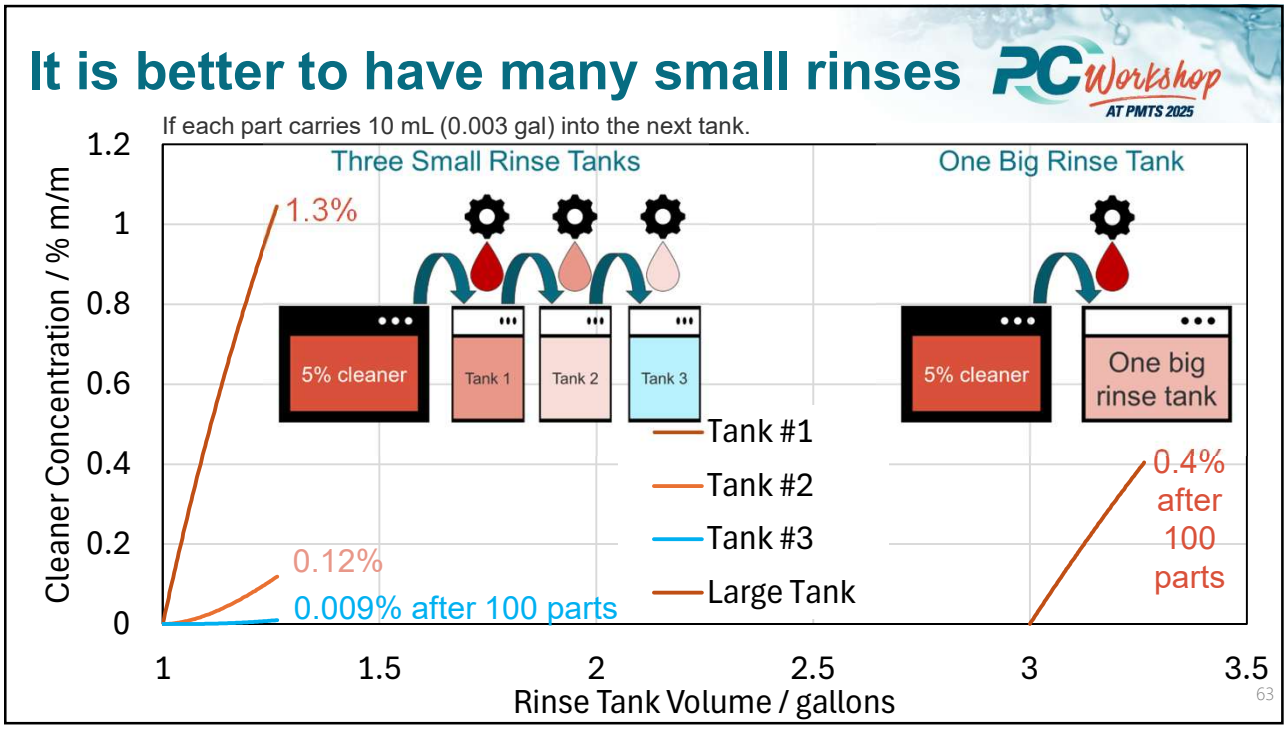

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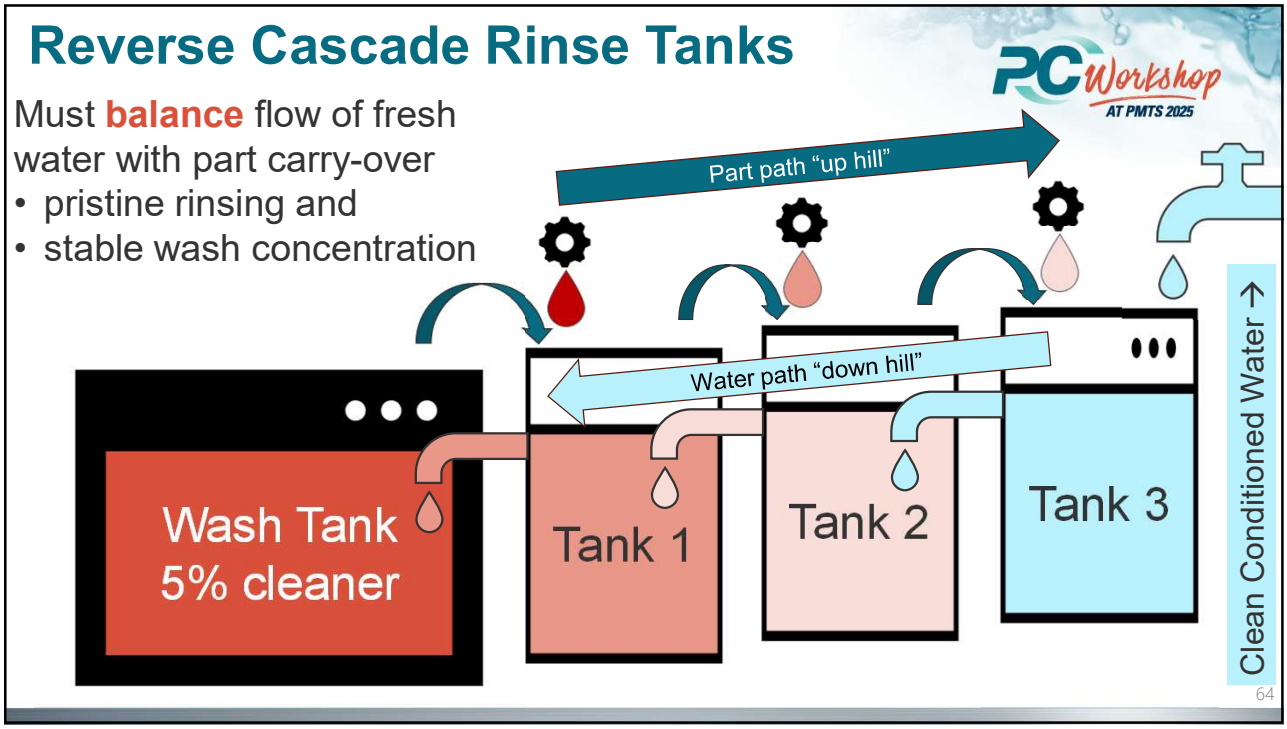

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The Future of Parts Cleaning
Hands-On and In-Depth

Demonstration of rinsing scenarios using food coloring

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Demo: 3 Small Tanks vs 1 Large Tank

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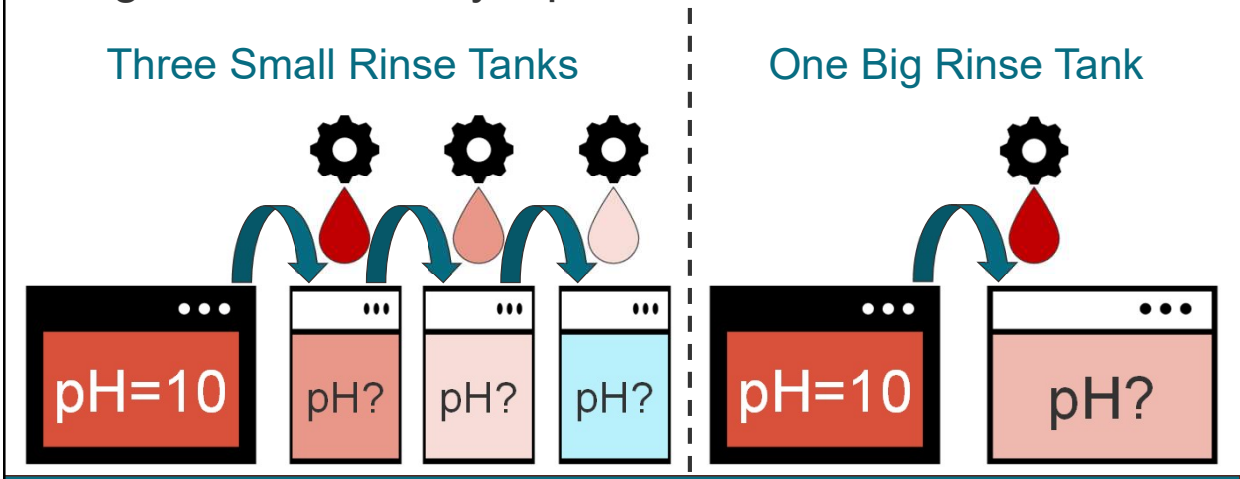
Using a straw to carry liquid over to the rinse tanks



This demonstration was performed using food coloring to show the carryover effects. 66

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The Future of Parts Cleaning
Hands-On and In-Depth

Cleanliness Inspections and Verification

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Cleanliness Inspection/Verification

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- Direct observation: visual, photography, microscopy
- Indirect methods
  - Contact angle, reflectance, fluorescence, spectroscopy (FTIR, Raman, UV-Vis, SEM:X-ray)
- Extraction methods
  - Extraction & filtration of particles (Technical Cleanliness)
  - Extraction & concentration of residues
- Witness coupon methods
  - Challenging shapes, features, multi-material assemblies

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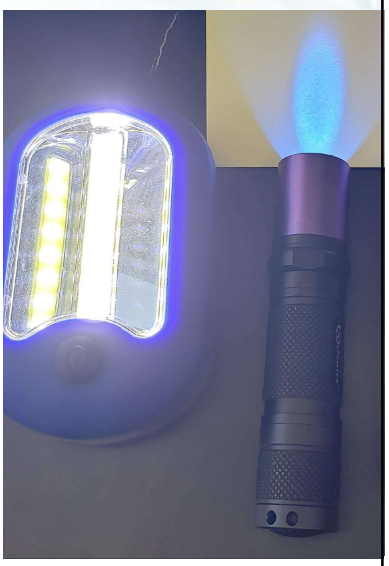
Direct Observation

- ALWAYS take before & after images
- Bright light (or laser light)
  - Discoloration (diffuse reflectance)
  - Roughness (specular reflectance)
  - Grazing angle for particles
- UV light
  - Fluorescent soils
  - Fluorescent dyes (added intentionally)
  - Fluorescent particles



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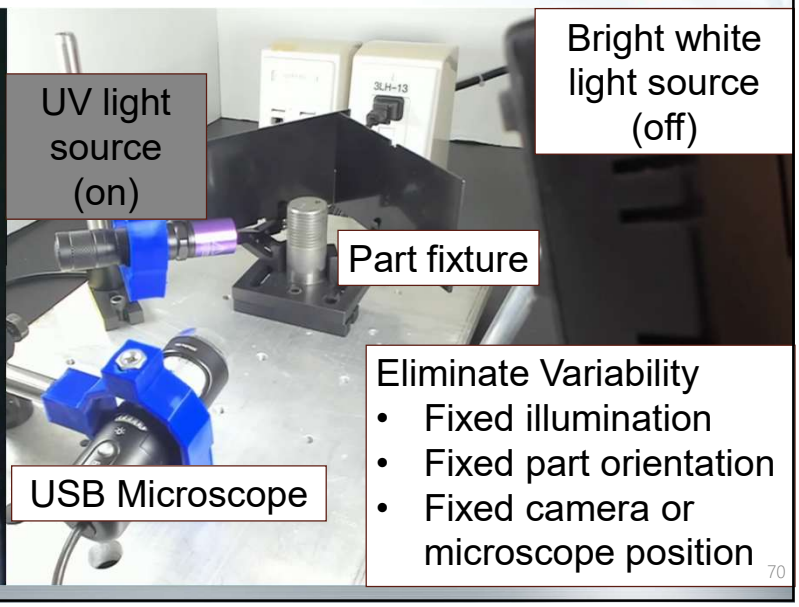
Standardized Photography



Eliminate Variability
- Fixed illumination
- Fixed part orientation
- Fixed camera or microscope position

70

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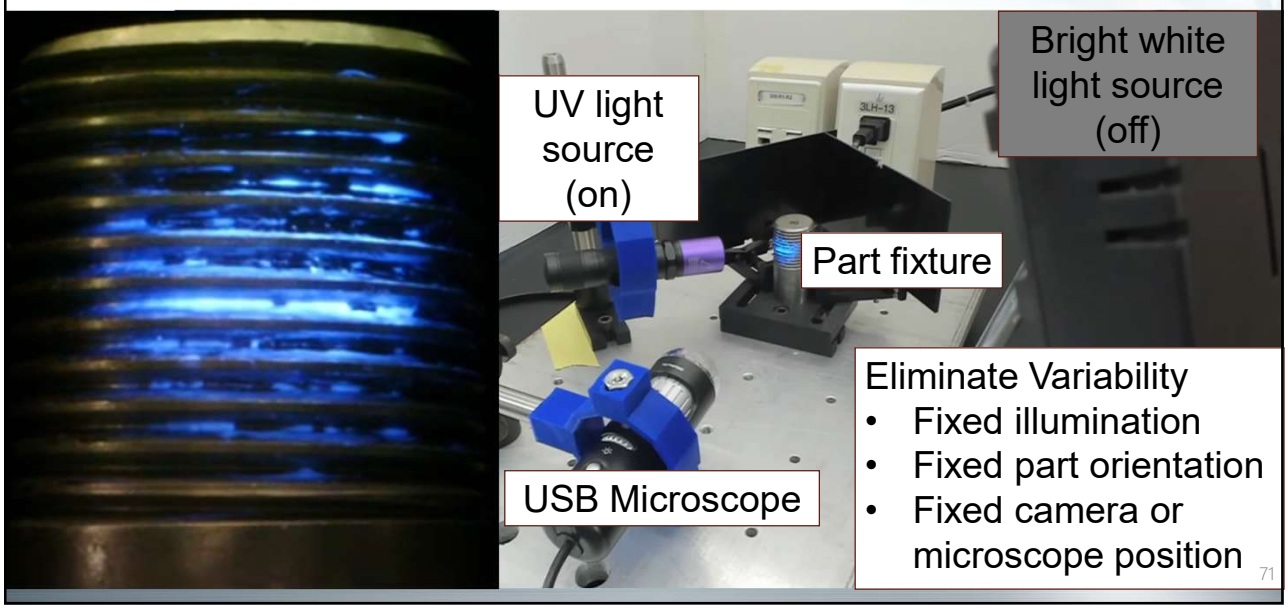
Fluorescence Imaging



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Hands-On and In-Depth

Demonstration of a simple USB microscope

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Particle Extraction, Counting, and Characterization

Technical Cleanliness Stds (VDA 19 and ISO 16232)

- Clean the parts
- Extract particles
- Collect them on a filter disk
- Count and characterize them

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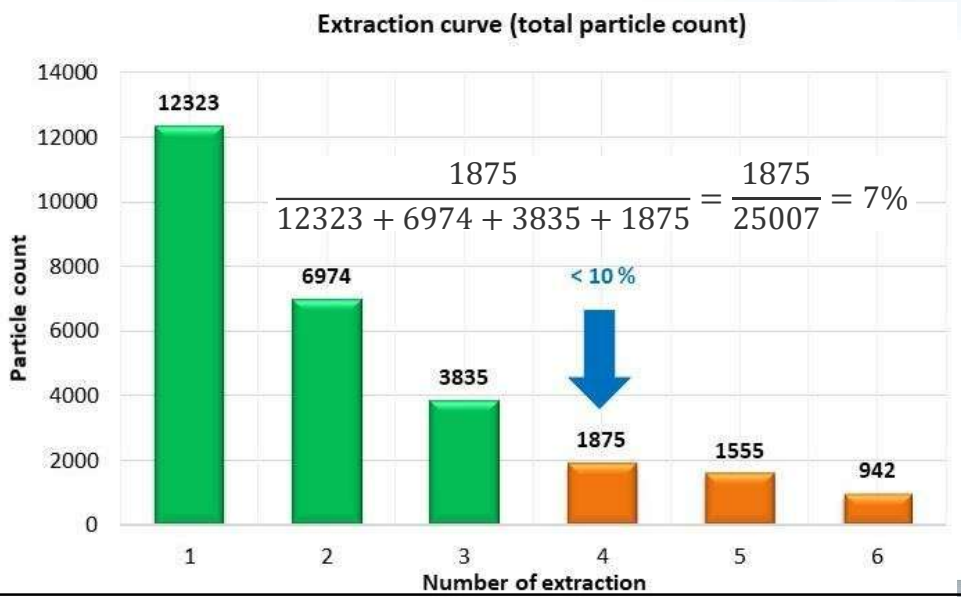
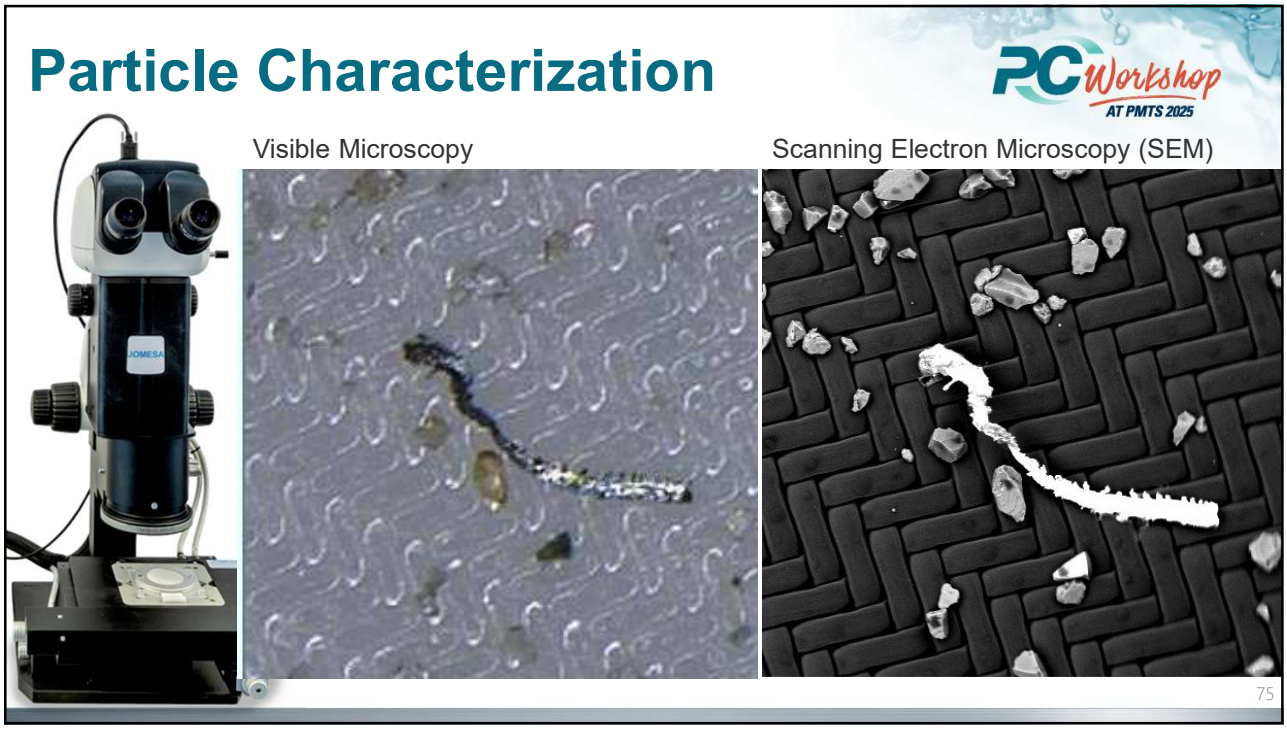
Particle Counting Decay Curve



$$\frac{1875}{12323 + 6974 + 3835 + 1875} = \frac{1875}{25007} = 7\%$$

74

74



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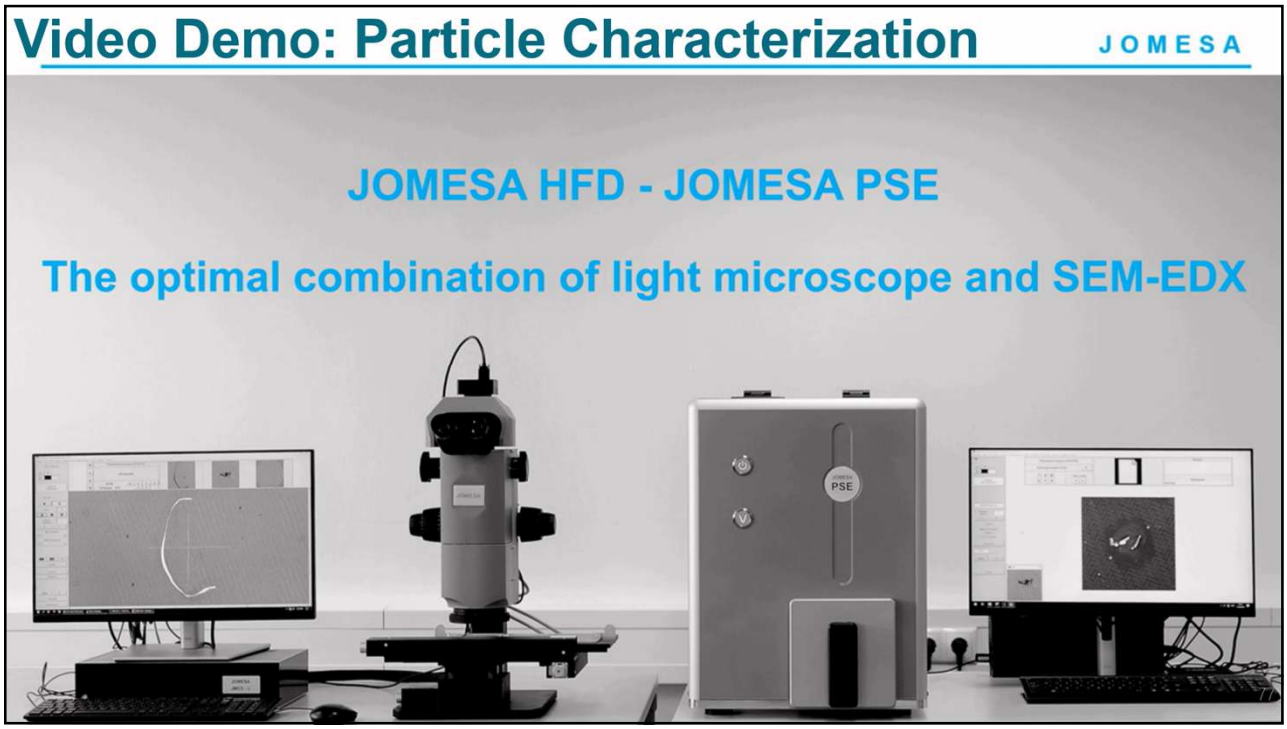

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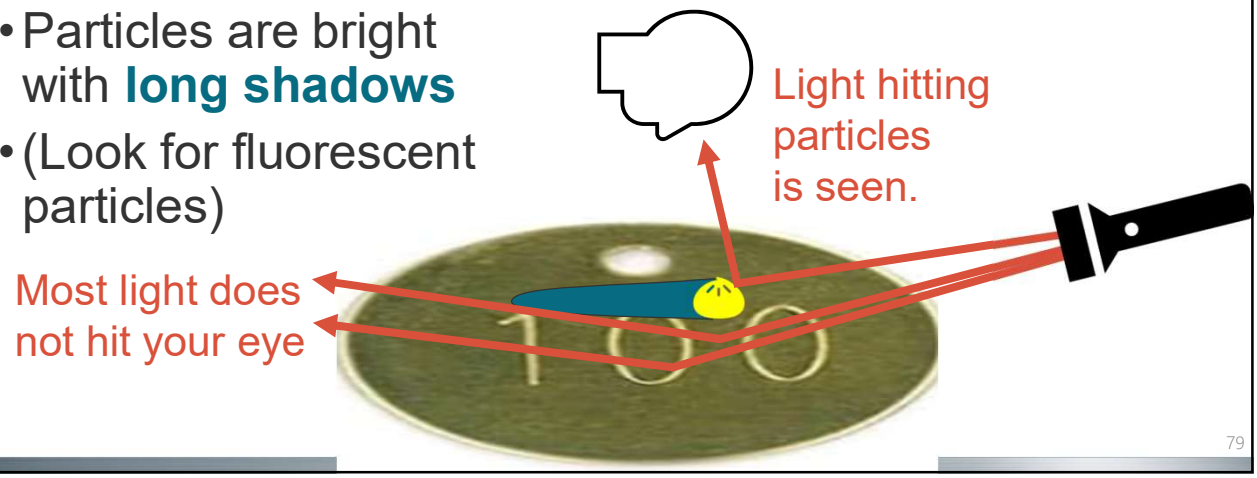
Inspect work area for particles

- Use grazing angle illumination to find particles in your work area and on your coupons.
- Particles are bright with **long shadows**
- (Look for fluorescent particles)



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Activity
Use the UV flashlights to observe fluorescent soils

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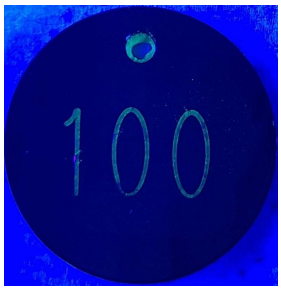
Fluorescent Soils

- Fluorescent particles:
  - Skin cells & fluorescent materials
- Fluorescent dyes (added to process fluids)
- Peanut butter is an “excellent dirt”
  - Oily
  - Proteinaceous
  - Insoluble solids
  - Sticky paste
  - Fluorescent



UV Fluid Leak Detection Dye, 8 Oz

Color Coding Dye, Red, 4 oz.
★★★★½ 68

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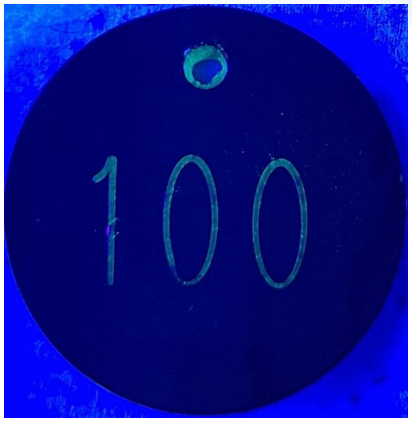
UV Fluorescence Inspection

- Take a **before photo** of your metal coupons
- Smear some coupons with the peanut butter soil. (Don’t overdo it. Wipe off the surface.)
- If you are allergic to peanut butter, use the sunflower seed butter and/or fluorescent powder.
- With a partner, take **photos** of your dirty coupons with the UV lights.



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Cleaning and Damage Thresholds

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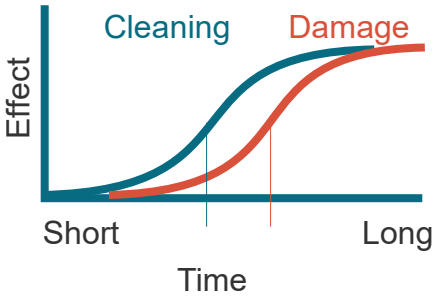
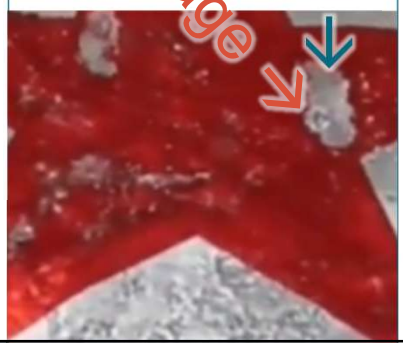
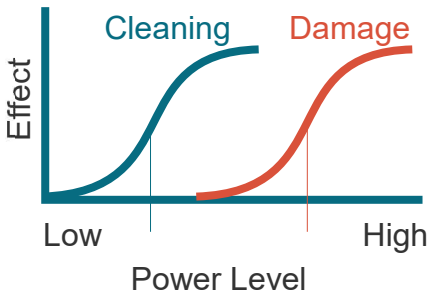
Cleaning vs Time



You want to determine the cleaning and damage time thresholds



Cleaning vs Power Level



You want to determine the cleaning and damage power levels

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A bad situation…

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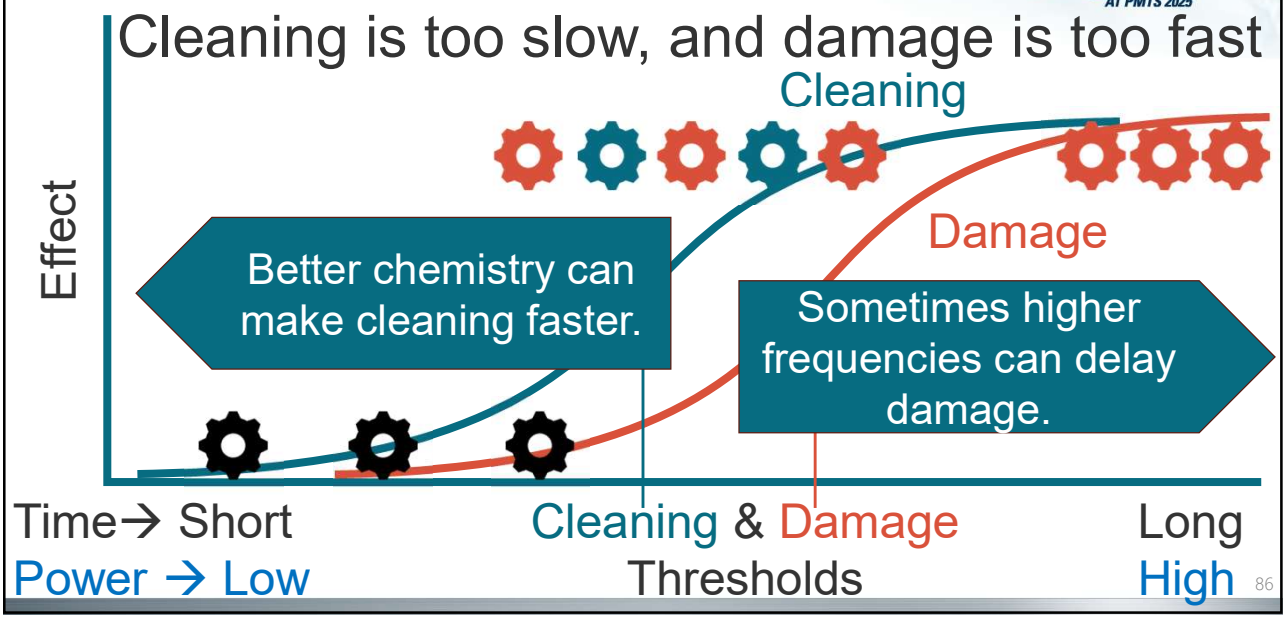
Cleaning is too slow, and damage is too fast



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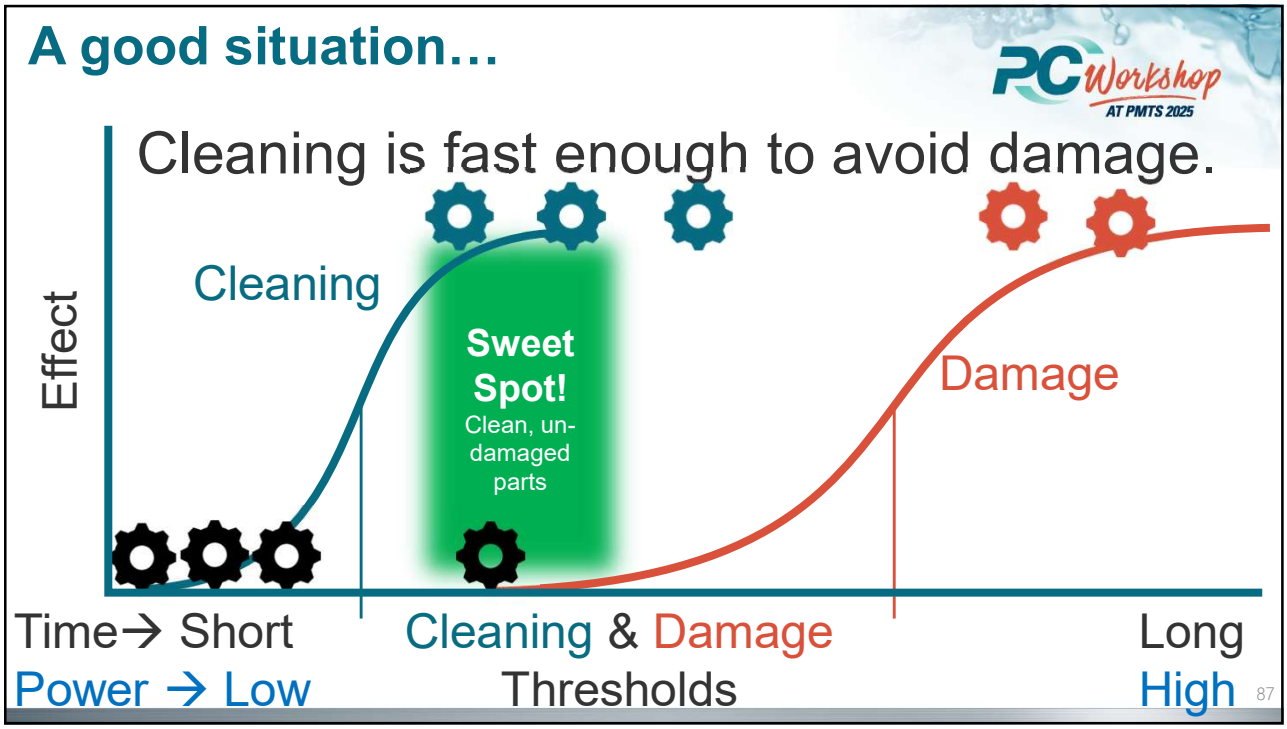

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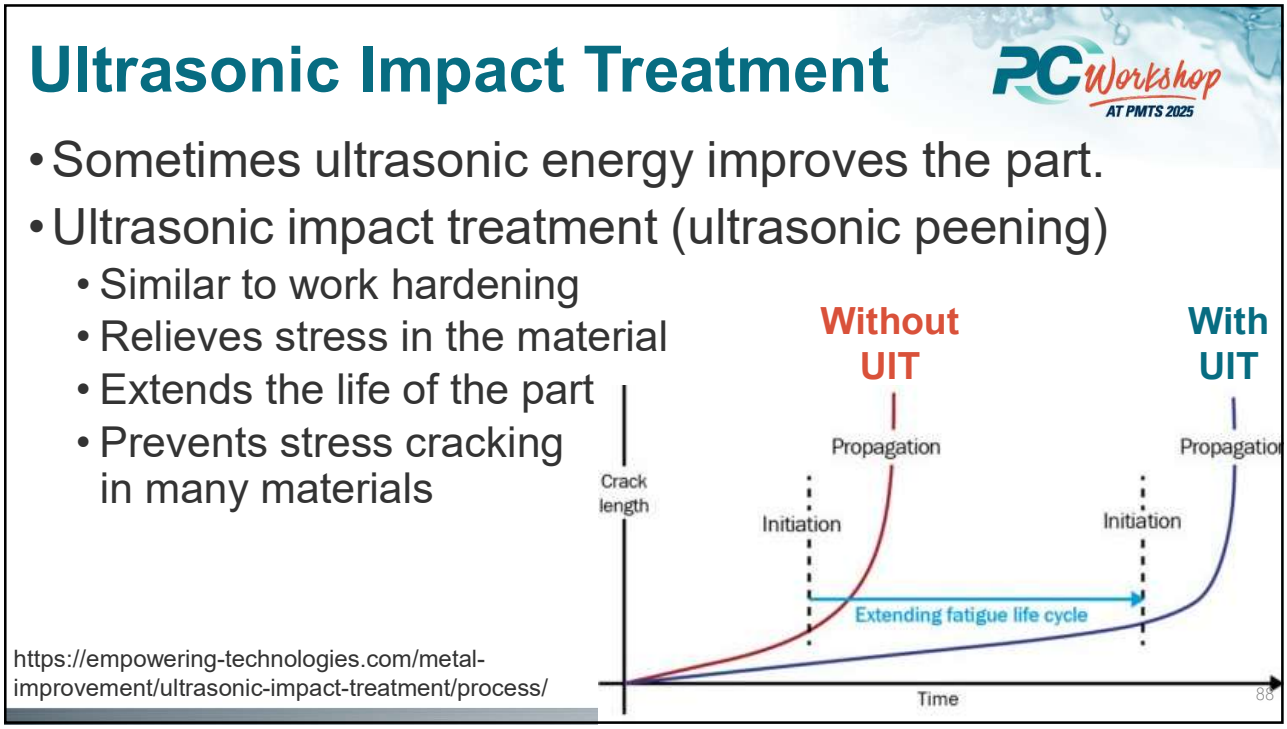

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Measuring Sonic Energy

Qualitative Methods
- Foil erosion
- Graphite tests
- Ceramic rings
- Sonic vials

Quantitative Methods
- Sonoluminescence
- Hydrophones

https://www.ondacorp.com/

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Activity
Ultrasonic cleaning of soiled coupons

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Ultrasonic Cleaning of the Coupons

- Wearing gloves and glasses…
- Make a part fixture for your coupons.
- Place the soiled coupons on the edge of the tank.
- Sonicate for 1 minute and inspect.
- With a friend, take UV **after photos** with your phone.
- Save the coupons for inspection with contact angle.

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Slooooow Cavitation

(Slow when compared to ultrasonic cavitation)

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Ways to Create Cavitation

- Ultrasonic Cavitation
  - Cavities form in the troughs between pressure waves.
- Boiling liquids create cavities
- Vacuum can create cavities
  - Boiling liquids at low temperature
  - **Best cleaning method for BLIND HOLES**
  - Industrial names for this
    - Cyclic Nucleation Process (cNP)
    - Vacuum Cycle Nucleation (VCN)
  - Our name: cyclic Vacuum Cavitation Cleaning (VCC)

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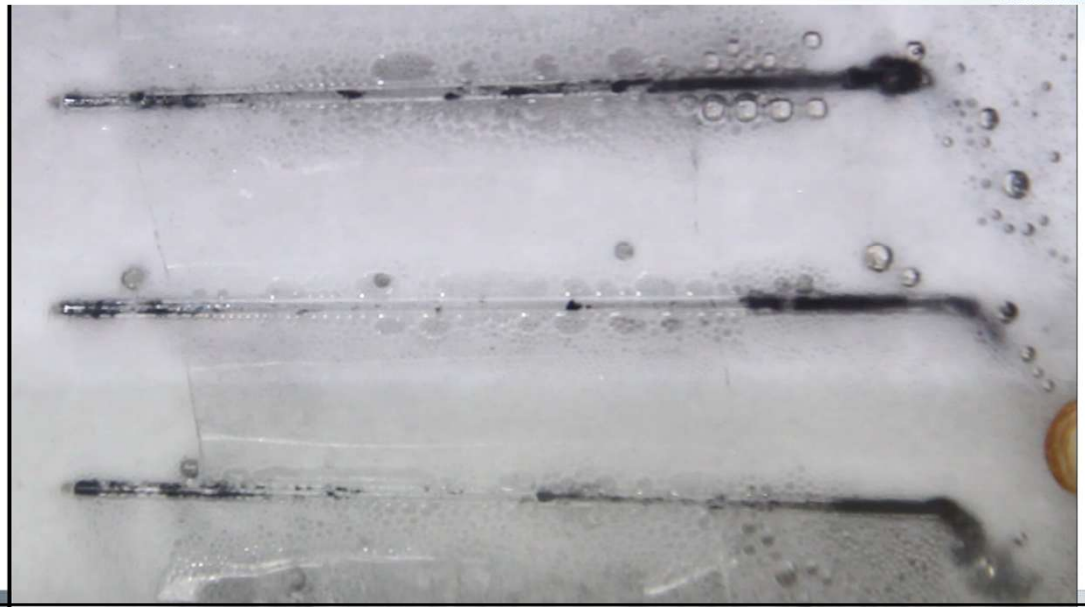
Cyclic Vacuum Cavitation Cleaning



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We will do this ourselves…

- Syringe cyclic vacuum cavitation cleaning (VCC) method.

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VCC on a Ring Coated in Peanut Butter

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Activity
Vacuum cavitation cleaning

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Syringe Cleaning Samples

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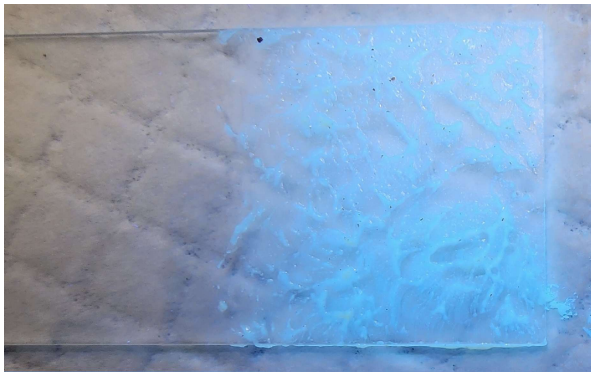
1. Smear a very little amount of peanut butter on the frosted area of a microscope slide.

Take a UV “BEFORE” Photo



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Syringe Cleaning Setup

1. Pull the plunger out of your syringe.
2. Place a lightly soiled microscope slide inside.
3. Get the plunger seated inside cylinder.
4. Gently push until the plunger touches the slide.
5. Draw up some cleaner.
6. DON'T PULL THE PLUNGER ALL THE WAY OUT.
7. Turn tip up and expel the air into a paper towel.
8. Repeat steps 5-7 until no air is inside.
9. Place the cap on the tip.

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Vacuum Cavitation Cleaning

- Create cavitation by pulling on the plunger. **DO NOT PULL IT ALL THE WAY OUT.**
- Cycle the cavitations 20 or 30 times.
- Open cap and expel cleaner back into tank.
- To save time, we are not rinsing.
- With a friend, take UV **after photos**.

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Quantitative cleanliness verification with Contact Angle

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Contact Angle

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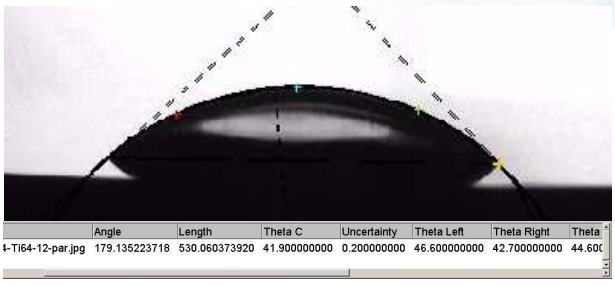
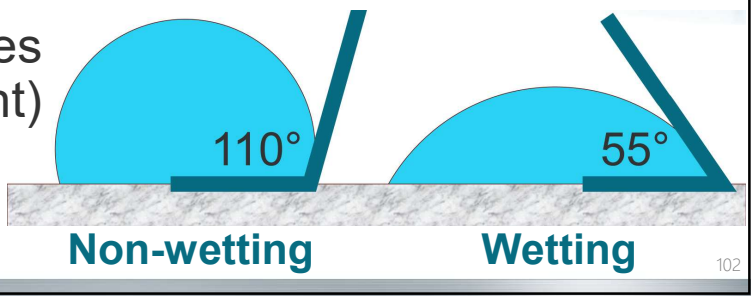
- Simple technique to estimate surface quality
- Rapid
- Can be quantified
- Can be automated
- Subject to interferences (eg. residual surfactant)



	Angle	Length	Theta C	Uncertainty	Theta Left	Theta Right	Theta
t-Ti64-12-par.jpg	179.135223718	530.060373920	41.900000000	0.200000000	46.600000000	42.700000000	44.60



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Demonstration
Automated Contact Angle Measurement Device

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Contact angle measurement

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- Contact angle is very sensitive to contamination.
- Water wets polar surfaces like metal oxide surfaces
- Water beads on non-polar surfaces
  - Small water drops adopt a spherical shape, which allows the determination of the contact angle.
  - Standards exist for you to calibrate your imaging equipment and your measurement technique.

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Activity
Measure the contact angle on your cleaned coupons

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Contact angle measurement on your coupons

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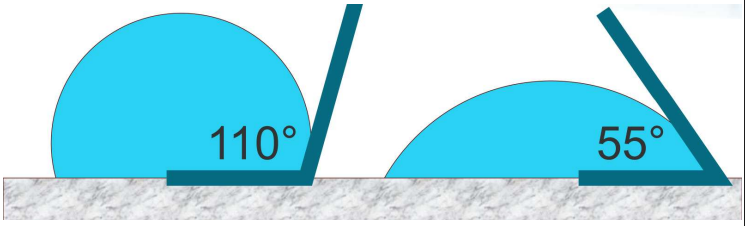
- Use the pipette to deposit a $10\mu L$ drop on your witness coupon
- See if you can determine if it is **wetting (< 90°)** or **non-wetting (> 90°)**
- Your phone camera can get closer than your eye



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Demonstration: Results
Aqueous Cleaners and Biology Critters in my bath

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Initial Photo

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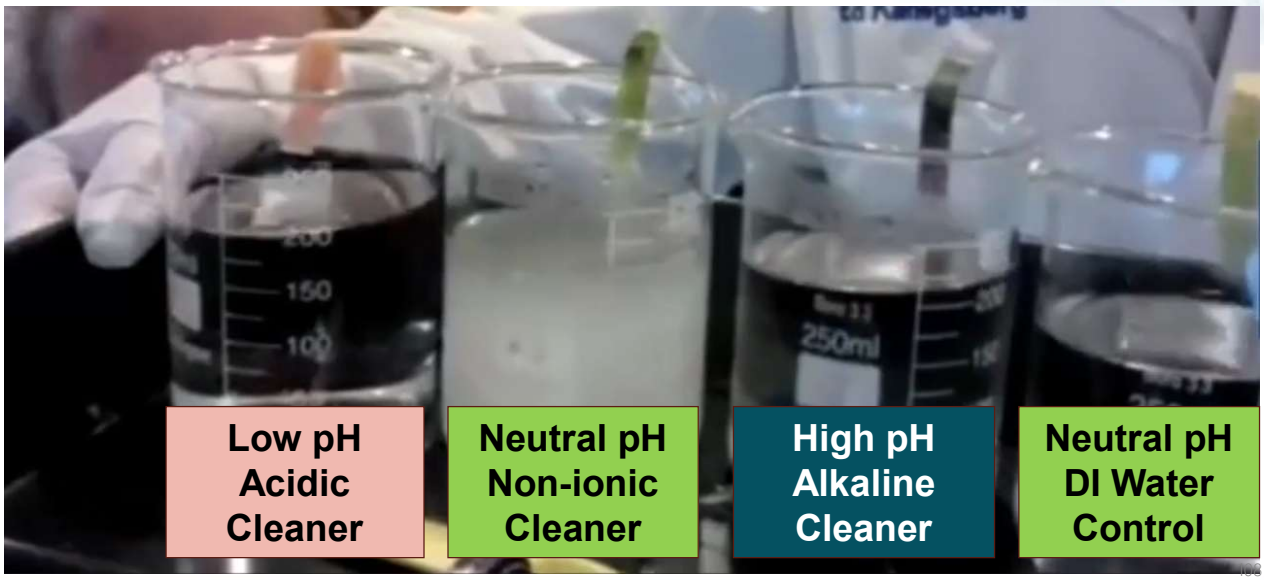

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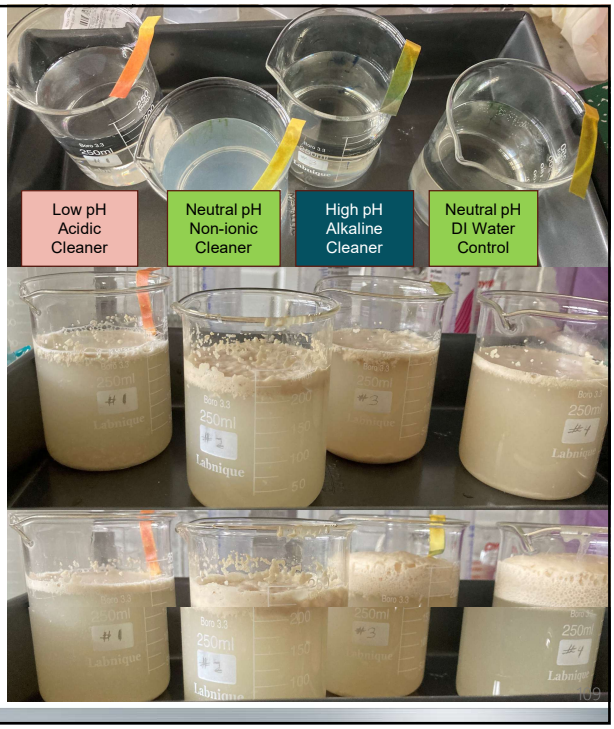
Yeast growing test

Sugar added to all beakers

After 15 minutes →

After 35 minutes →



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Protein and tiny critter removal

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- Enzyme cleaning
  - Breaks up & inactivates the protein
  - Do you remove it?
- Disinfection
  - There can be acceptable killing, but the dirt may still remain
  - A part can be sterile, but not necessarily clean
  - You can't disinfect or sterilize without cleaning
- Dead dirt is still dirt
  - Even after terminal sterilization

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Minimizing critters in the cleaning process bath

- Know your process
  - Soils
    - Variety
    - Variability
    - Soil loading
  - Product
- Have a plan, involve the techs
  - Observation
  - Ongoing maintenance
  - **Scheduled change-out of cleaning agent**
  - Cleaning the cleaning equipment
    - Including the **plumbing & process lines**

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Sending your soils to the lab
Chromatography
Spectroscopy
Mass Spectrometry

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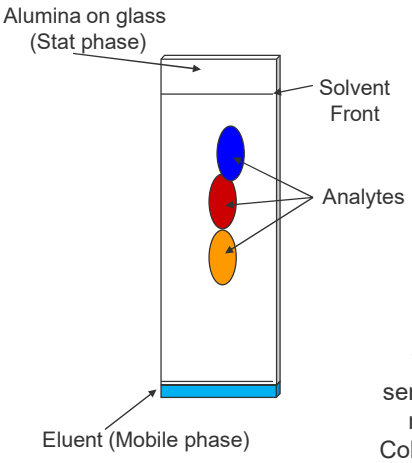
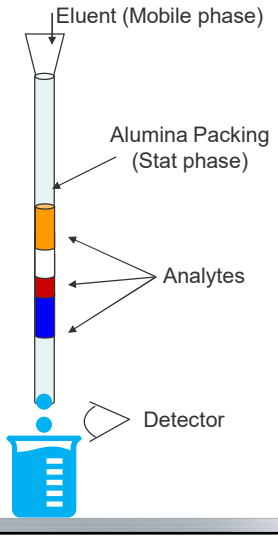
Chromatography as Sample Prep

- Thin-Layer Chromatography (TLC)



- Column (Prep) Chromatography



TLC is fine for very sensitive techniques like mass spectrometry. Column LC is needed for larger amounts of analyte.

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Demo: Thin Layer Chromatography

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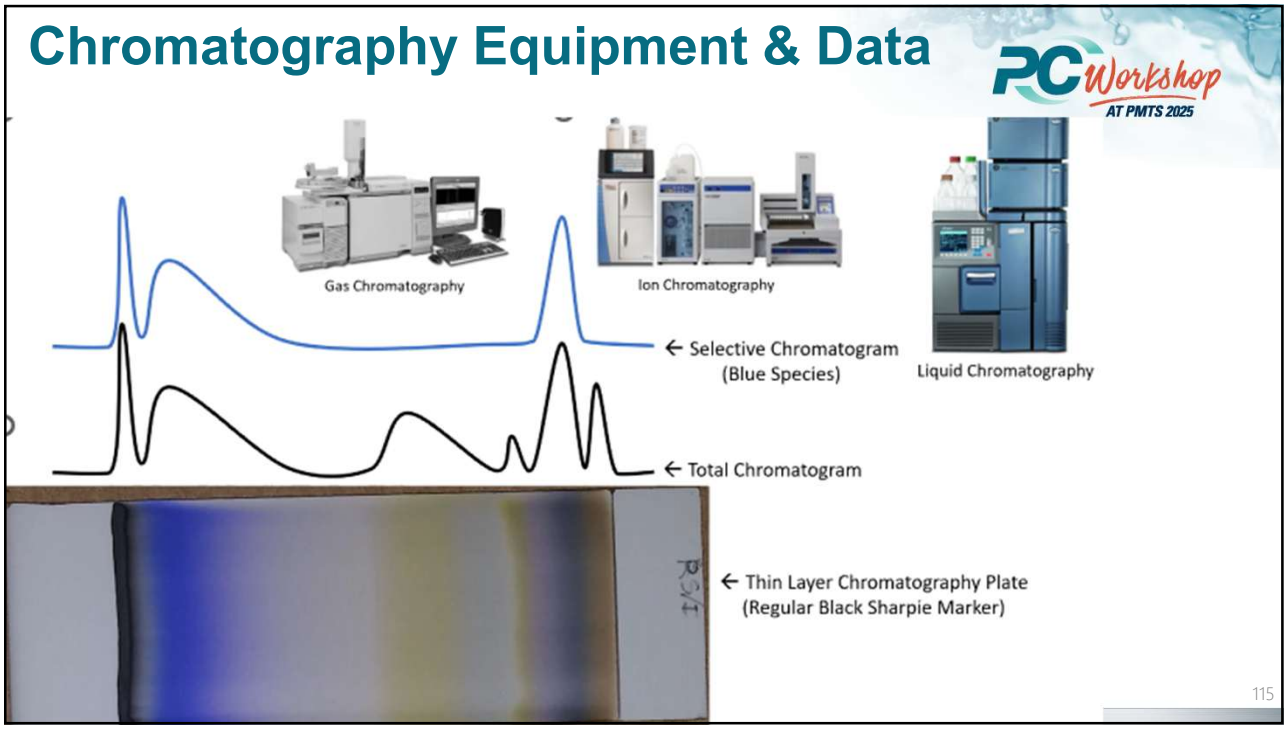

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Don't go it alone

- You need a cleaning **team**
- Not enough $$$ for a team?
  - Find the time and $$$
  - Get input from the interested/impacted people

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Do NOT roll your eyes at me!!! A team is a good thing

- Cleaning process team
  - An effective team saves time
  - Essential: Upper management support and involvement
  - Essential: Buy-in, support from assemblers, techs, operators
- Begin with the end in mind – how clean is clean enough?
- Communicate
- Coordinate!

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What's a team? – it depends

- MUST HAVE MANAGEMENT SUPPORT
- Must be a person in charge
  - Who is it? You?
  - Level of authority
    - Set up meetings
    - Get signoff from key players
    - Even if it's a report with recommendations
- How does the team function?
  - Dozens of meetings with scores of people
  - Meetings with few key players
    - Not you alone!
  - Emails, texts to "Loop in" concerned parties

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Move the team forward

- Communicate
- Must avoid
  - Endless meetings
  - People nodd their heads politely
  - Ask for more studies
  - Won't commit
  - No progress
- Must have mechanisms to move forward
  - Are there show-stoppers?
  - Time frame
  - Milestones
  - If people "kvetch" – ask why
  - Set-up "sign-off" sheet

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Don't compromise!

- Cleaning essentials
  - Process must be effective
  - Process must not damage the product
  - Process must be reliable
- Don't meet the essentials?
  You have not solved the cleaning problem!
- Other goals
  - Safe for workers
  - Safe for environment
  - Sustainable
  - Affordable

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Achieve excellent cleaning

- Good cleaning team
  - Strong management backing
  - Correct players at the table
    - Including the techs
    - Including advisors
- Solid education/understanding
  - Cleaning options
  - What you need for your application
- Process selection plan
  - Chemicals & equipment
- Process validation plan
- YOU become the expert

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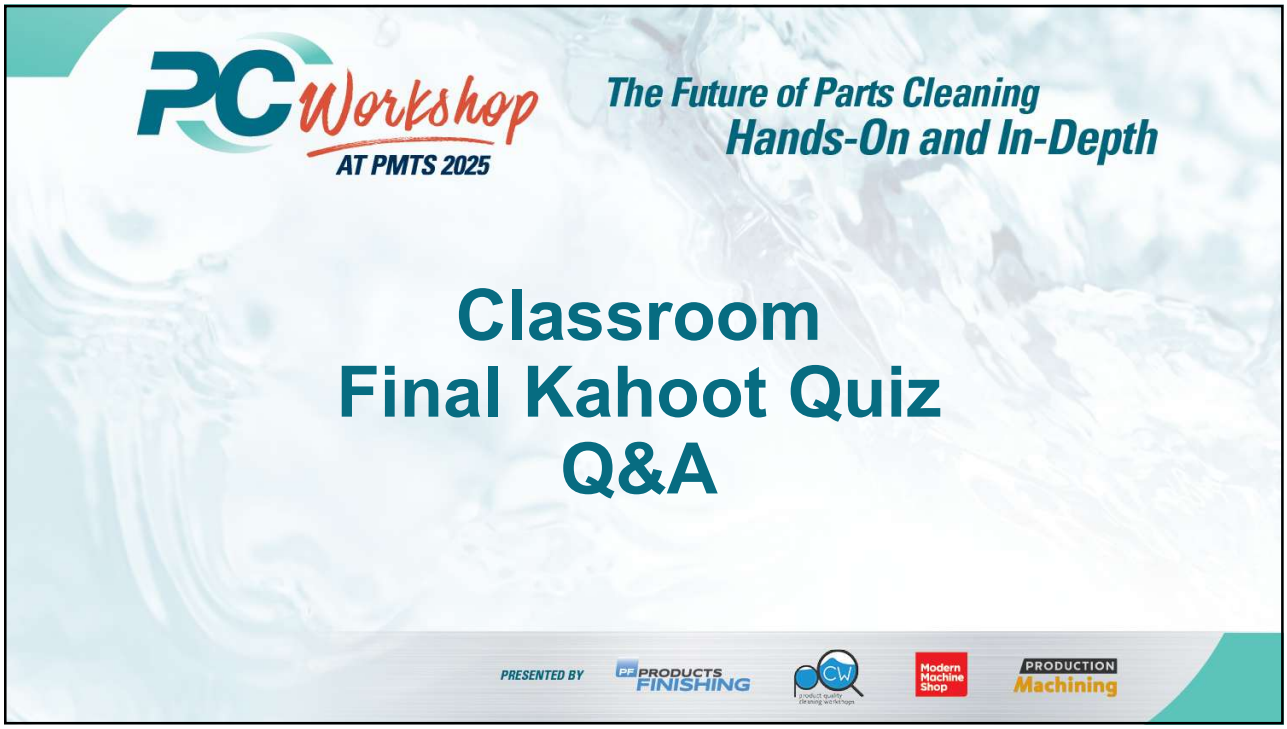

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Critical Cleaning and Surface Prep is Straightforward!

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- Remove the soil
  - Soil – matter out of place
- Without damaging
  - the product
  - the workers
  - the facility
  - the pocketbook
  - the environment

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