TestConX 2025

ADVANCED CO_2 SPRAY TECHNOLOGIES AND THEIR EFFECTIVENESS FOR IC SOCKET CLEANING APPLICATIONS

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Introduction

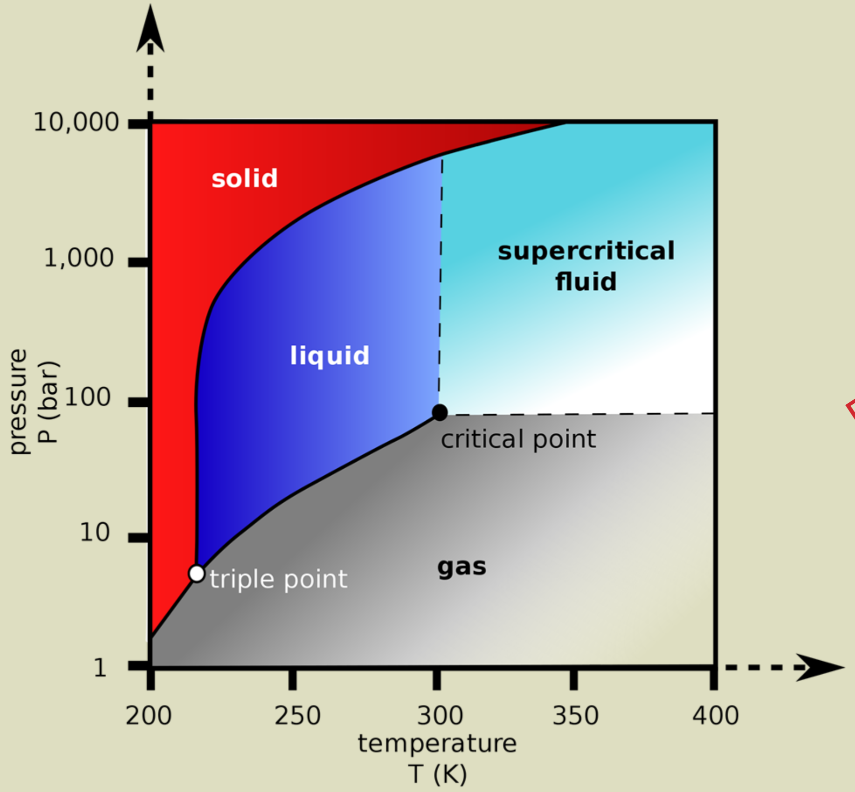
Background

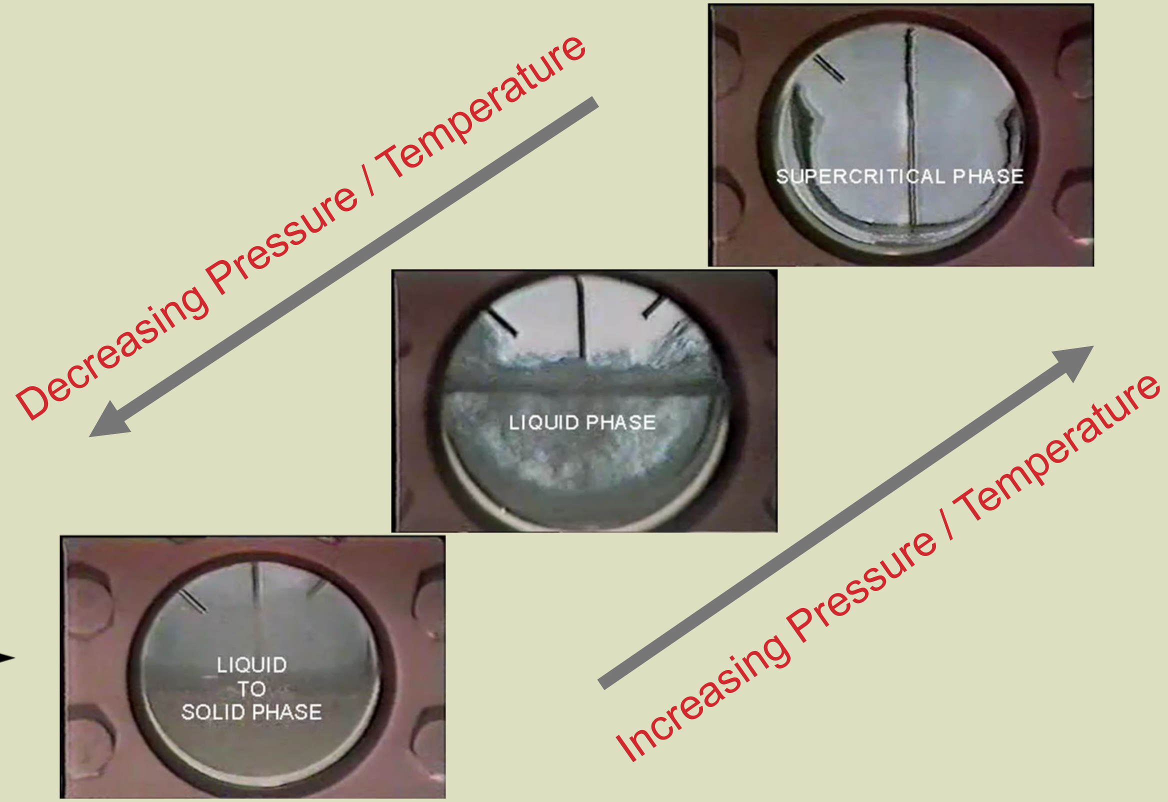
- CO_2 spray is utilized for a variety of cleaning challenges in many industries.
- Key spray characteristics:
  - Particle size distribution
  - Particle momentum
  - Spray temperature
  - Spray chemistry modification
- Nozzle configurations can be used to achieve the spray characteristics.

Presentation Outline

- CO_2 spray technology
  - CO_2 spray physics
  - How does CO_2 spray clean?
- CO_2 spray nozzles
- CO_2 spray cleaning applications
  - Electronic circuit cards
  - Optical sensor cleaning
  - Integrated circuit (IC) socket cleaning
- Operating cost estimate
- Summary

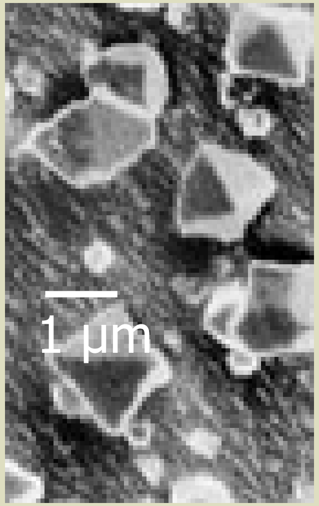
Different CO_2 Phases





Solid CO_2 Particle Characteristics

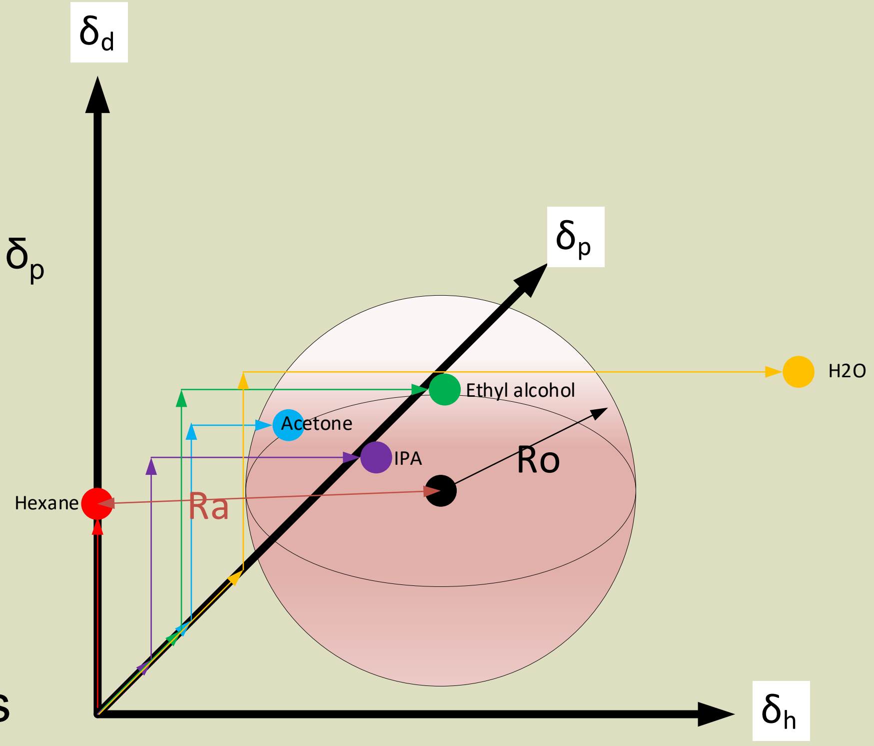
- Impact Phenomenon
  - Ablation and phase change (solid→gas, solid→liquid→gas)
- Co-Solvency
  - Modified with liquids, solids, vapor-phase additives
- Density
  - 1.6 g/cm3
- Hardness
  - <2 Hm (ex: 1 – talc, 2.5 - fingernail, 3 – calcite, 5.5 – glass, 7 – quartz, 9 – aluminum oxide).
- Particle Size
  - < 0.5 microns to > 500 microns, range adjustable (coarse/fine)
- Impact Stress
  - up to 130 Mpa (18,850 psi), pressure/particle size/distance dependent



Solubility Characteristics of Liquid CO_2 (LCO_2)

<u>Hansen's Solubility Parameter (HSP)</u>

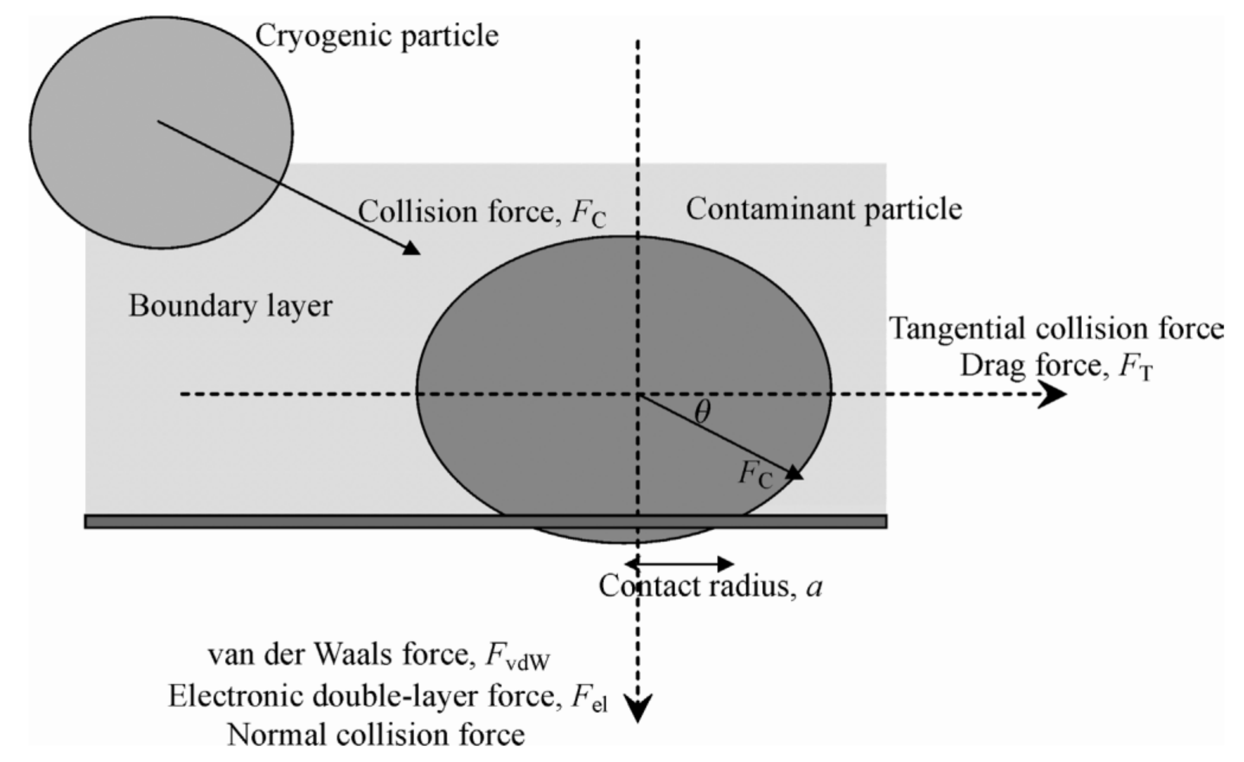
- Combines three forces important to solubility evaluation:
  - Dispersive/non-polar energy - δ_d
  - Polar (dipole-dipole/dipole-induced dipole) energy - δ_p
  - Hydrogen Bonding energy – δ_h
  - Total HSP
- Solvent / Solute solubility evaluated by comparing relative HSPs
  - 'Like / Similar' HSPs ➔ soluble
  - 'Un-Like / Dis-Similar' HSPs ➔ insoluble
- Similar HSP values to many standard solvents



How Does CO_2 Spray Remove Particles?

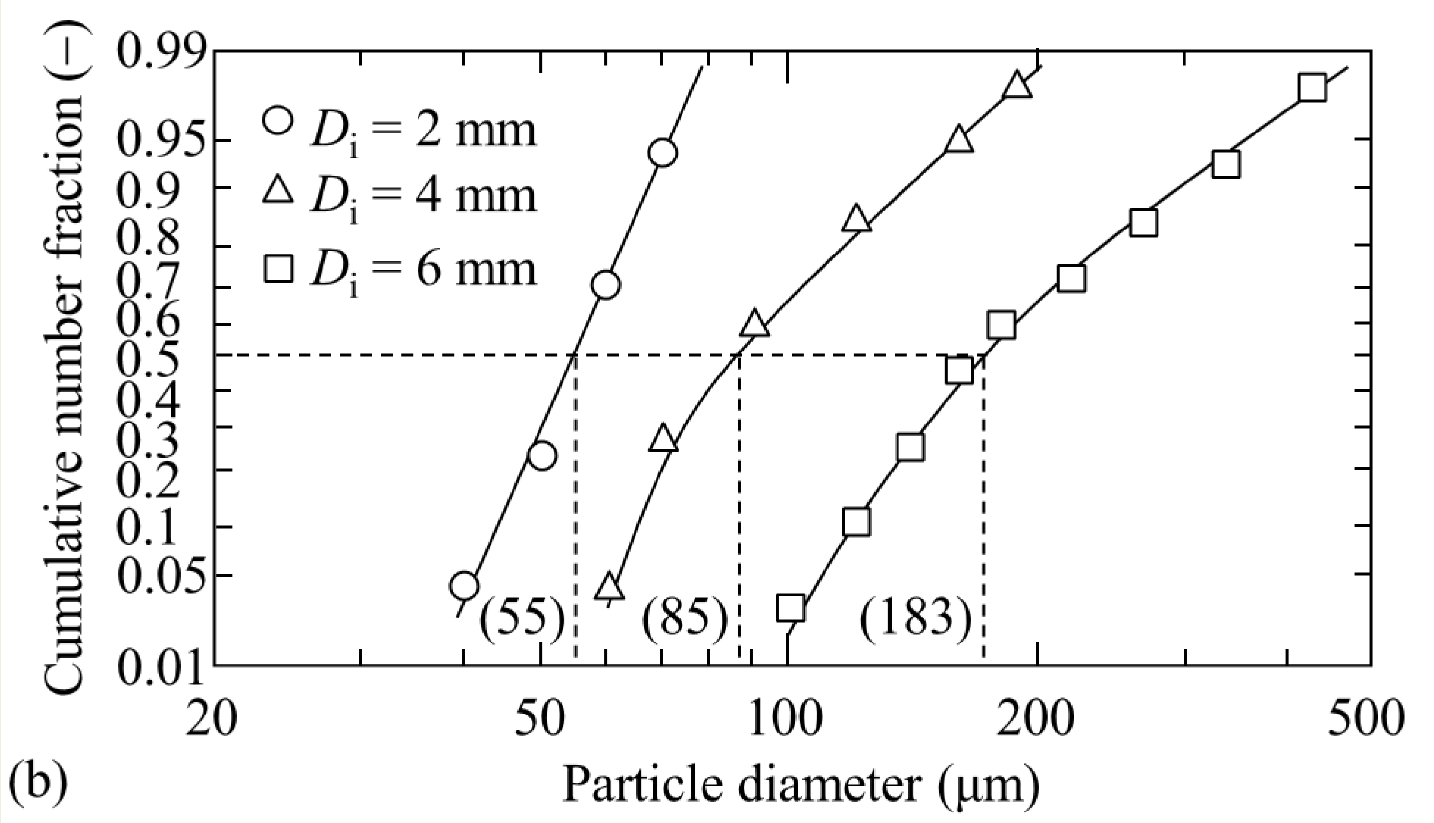
- Particles removed by momentum exchange:
- Particles removed when:

$F_{cleaning} > F_{adhesion}$



Ref: Souvik Banerjee & Andrea Campbell (2005) Principles and mechanisms of sub-micrometer particle removal by CO2 cryogenic technique, Journal of Adhesion Science and Technology, 19:9, 739-751.

Size of CO_2 Particles Leaving Nozzle

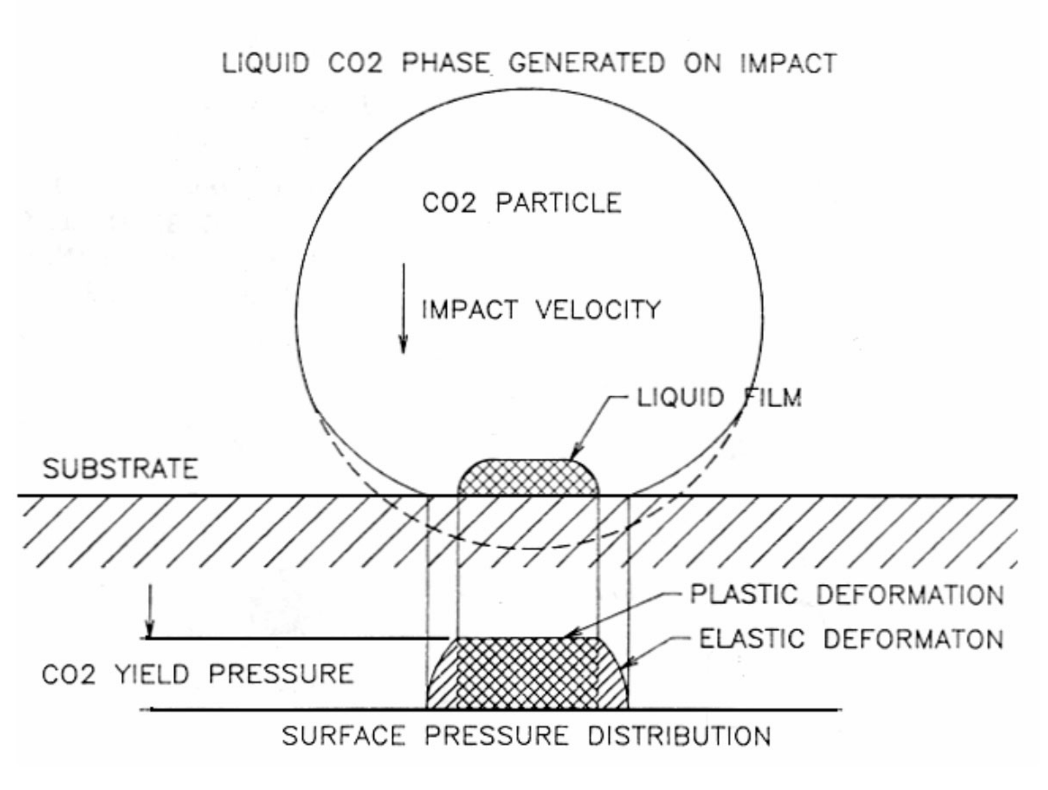


Ref: Liu, Yi-Hung ...[et al]. Agglomeration process of dry ice particles produced by expanding liquid carbon dioxide. Advanced Powder Technology 2010, 21(6): 652-657

Adhesive Removal - Video

Removing Non-Particulate Organic Residues

- Non-Particulate Organic Residues:
  - Oils
  - Thin films
  - Fingerprints
- Residues solubilized by chemistry:
  - CO_2 particles change upon impact
  - Solid -> Liquid -> Gas
  - Liquid CO_2
    - "Hexane-Like" chemistry:
    - HSP: 9 –18 $MPa^{0.5}$



Ref: King, JW et al.; Ablation and Sorptive Removal of Films and Particles from Surfaces Using Carbon Dioxide

Fingerprint Removal from Optical Surface - Video

Solvent – Solute Solubility

- Occurs when solvent – solute are similar
  - ‘Like dissolves like’
- Strategy for ‘chemical’ cleaning
  - Match solubilities of solvent to contaminant.
- Need the chemistry of the contaminant

LCO2 generated from impact from CO2 particles

CO2 (T,P)	δ_d Dispersion	δ_p Polar	δ_h Hydrogen bonding	δ_T Total
CO2 - TP @ 0.41 Mpa, -56C	16.6	5.4	6.7	18.7
CO2 - Sat @ 1.1 Mpa, -40C	15.6	5.2	6.3	17.6
CO2 - Sat @ 2 Mpa, -20C	14.1	5.0	5.9	16.1
CO2 - Sat @ 3.5 Mpa, 0C	12.3	4.7	5.5	14.3
CO2 - C.L. @ 5 Mpa, 0C	12.6	4.8	5.5	14.5
CO2 - Sat @ 4 Mpa, 6C	11.7	4.6	5.3	13.6
CO2 - Sat @ 4.5 Mpa, 11C	11.1	4.5	5.2	13.1
CO2 - Sat @ 5 Mpa, 14C	10.6	4.5	5.0	12.6
CO2 - Sat @ 5.5 Mpa, 18C	10.0	4.4	4.9	12.0
CO2 - Sat @ 6 Mpa, 22C	9.4	4.2	4.8	11.4
CO2 - C.L. @ 6.5 MPA, 0C	12.8	4.8	5.5	14.7
CO2 - S.C. @ 20.6 Mpa, 60C	9.1	4.2	4.5	11.0
CO2 - S.C. @ 20.9 Mpa, 50C	10.1	4.4	4.7	12.0

Saturated fatty acids

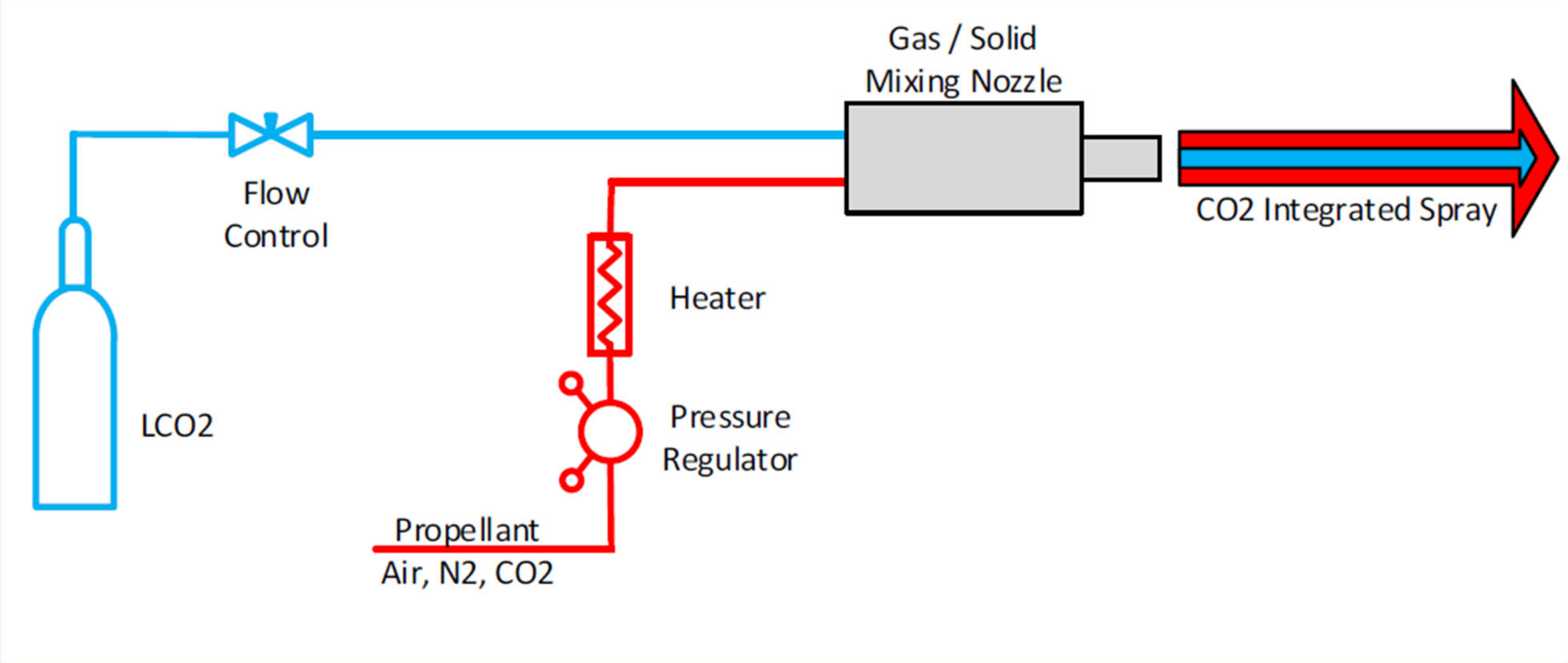
Carbon number	δ_d	δ_p	δ_h	δ_t
4:0	16.0	6.5	12.9	21.6
5:0	16.0	6.0	11.9	20.8
6:0	16.1	5.5	11.1	20.3
7:0	16.1	5.2	10.3	19.8
8:0	16.1	5.1	9.5	19.4
9:0	16.2	4.4	8.7	18.9
10:0	16.2	4.2	8.3	18.7
11:0	16.2	4.1	[illegible]	18.5
12:0	16.2	[illegible]	7.4	18.3
13:0	[illegible]	3.6	6.8	18.0
14:0	16.3	3.4	6.6	17.9
15:0	16.3	3.3	6.3	17.8
16:0	16.3	3.4	6.0	17.7
17:0	16.3	3.0	5.6	17.5
18:0	16.3	3.3	5.5	17.5
19:0	16.3	2.8	5.2	17.3
20:0	16.3	2.9	5.0	17.3
21:0	16.3	2.6	4.7	17.2
22:0	16.3	2.5	4.6	17.1
23:0	16.3	2.5	4.5	17.1
24:0	16.2	2.6	4.3	17.0
25:0	16.3	2.3	4.0	16.9

Unsaturated fatty acids

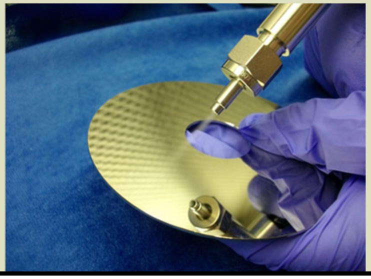
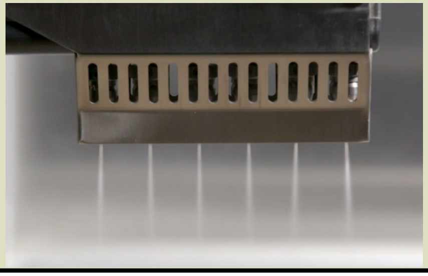
Carbon number	δ_d	δ_p	δ_h	δ_t
16:1	16.5	3.4	6.4	18.0
16:3	17.1	3.2	7.2	18.8
18:1	16.5	3.1	5.7	17.7
18:2	16.8	3.1	6.2	18.2
18:3	17.0	3.2	6.5	18.5
18:4	17.3	2.9	6.8	18.8
20:1	16.6	2.6	5.3	17.6
20:2	16.8	2.6	5.7	17.9
20:3	17.0	3.2	6.5	18.5
20:4	17.2	2.8	6.5	18.6
20:5	17.4	2.9	6.7	18.9
21:5	17.4	2.6	6.3	18.7
22:1	16.5	2.7	4.8	17.4
22:4	17.2	2.4	6.0	18.4
22:5	17.4	2.5	6.2	18.6
22:6	17.6	2.5	6.6	19.0
24:1	16.5	2.3	4.5	17.3
24:4	17.1	2.4	5.5	18.1
24:6	17.5	2.3	6.0	18.6
Hydroxy fatty acids				
18:0 12OH	16.4	4.5	8.6	19.1

Ref: Anaid De La Peña-Gil & Jorge F. Toro-Vazquez & Michael A. Rogers (2016); Simplifying Hansen Solubility Parameters for Complex Edible Fats and Oils; Food Biophysics DOI 10.1007/s11483-016-9440-9

Basic CO_2 Spray Cleaning System Setup

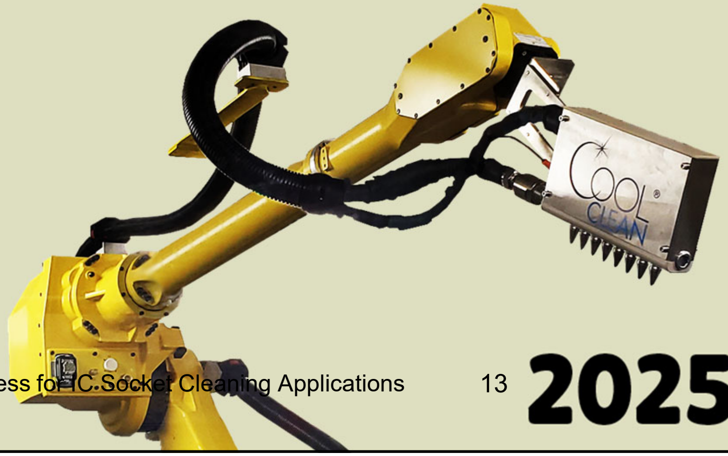


CO_2 Spray Nozzle Offerings

Coaxial – Short-range	High Energy	Coanda – Long-range
		
• 'Standard' Spray Configuration • 'Soft' to 'Moderate' Impact • Working distance 10 – 25 mm	• High Energy Nozzle (HEN) • Very high momentum particles • Working Distance: 25 – 250 mm	• Large high momentum particles • Induces ambience into cleaning jet • Working Distance: 50 – 300 mm

Wide Angle

- Fine particle spray width – 50 mm
- Very fine spray
- Working Distance: 25 - 50 mm

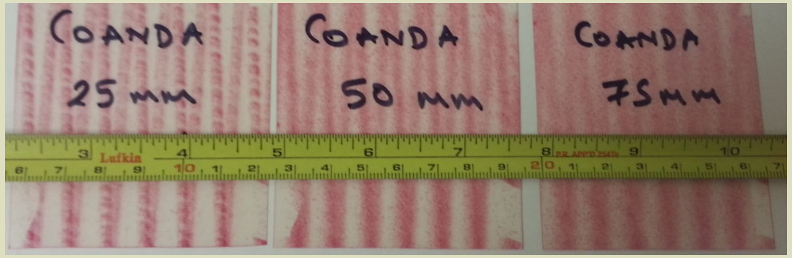


Identify CO_2 Spray Pattern / Impact Energy

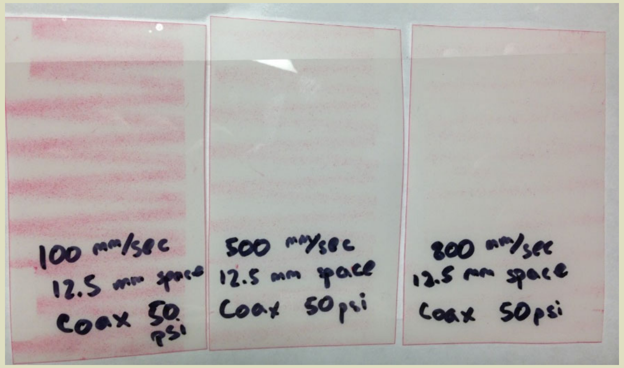
- Two methods used to assess effectiveness of spray for a given application.
  - Aluminum Foil Test
    - Pebbling method used a lot in ultrasonic cleaning →
  - Fuji-Film Pressure Paper
- Both methods are effective to determine:
  - Size of the spray pattern
  - Energy available for cleaning

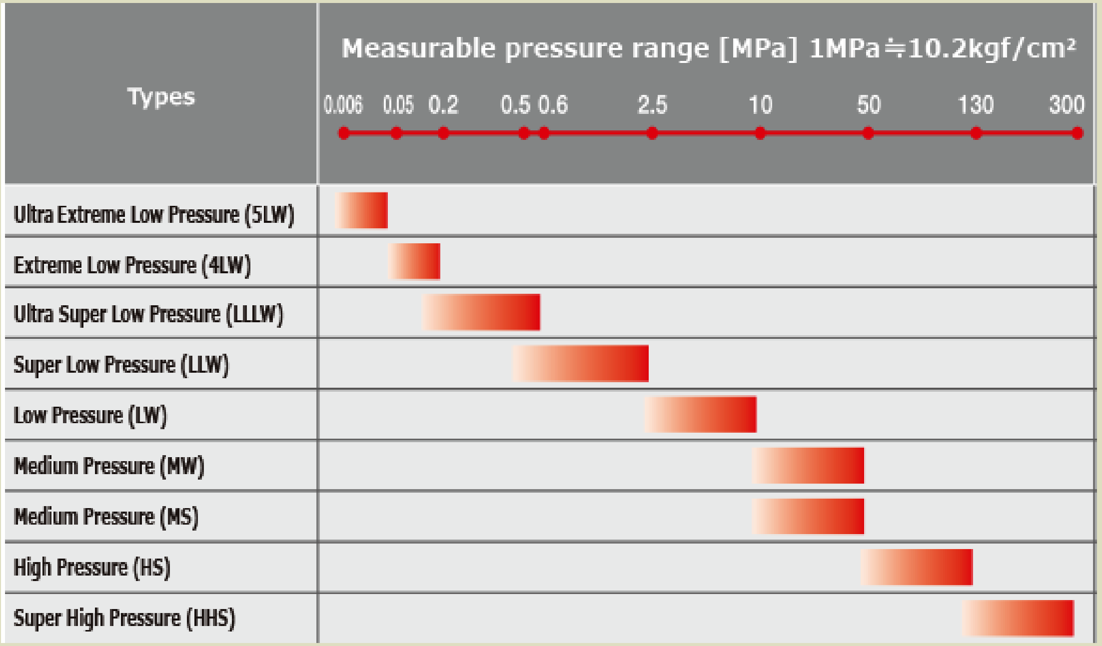
Pressure Paper Spray Nozzle Impact

Coanda



Coaxial





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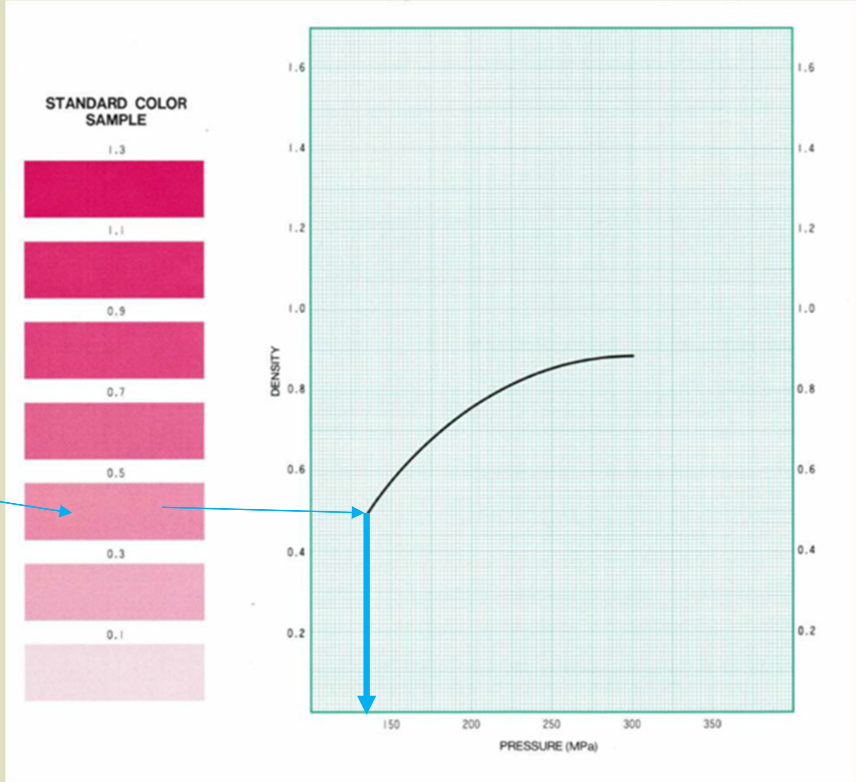
Spray Nozzle Impact Characteristics: HEN

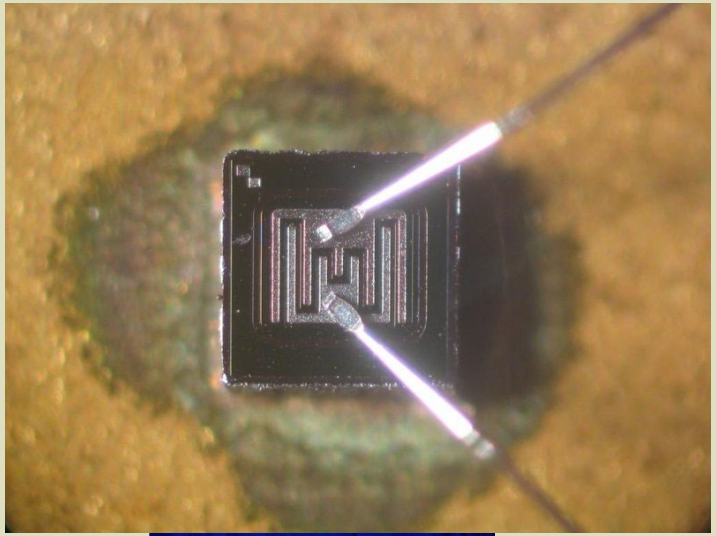
Spray width
(5.6 mm)

Spray impact stress
(130 Mpa)



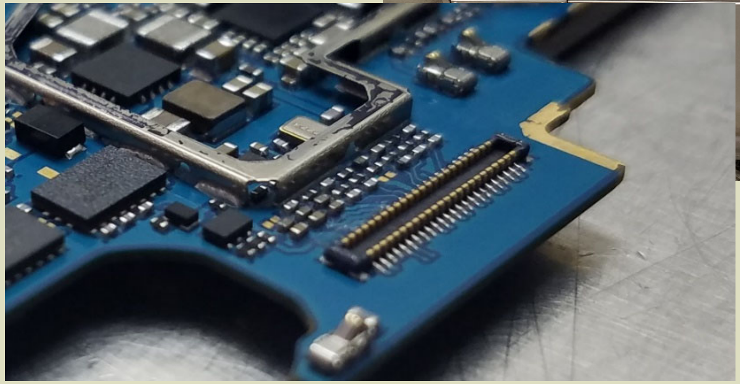
Automated In-Line Circuit Card Cleaning System

- Requirement:
  - Achieve equivalent or better cleaning method electronic circuit card pockets
  - No damage to fine wires
  - Cleaning system must accept customer specified feed trays
- Previous cleaning methods: IPA/Q-tip, tape cleaning



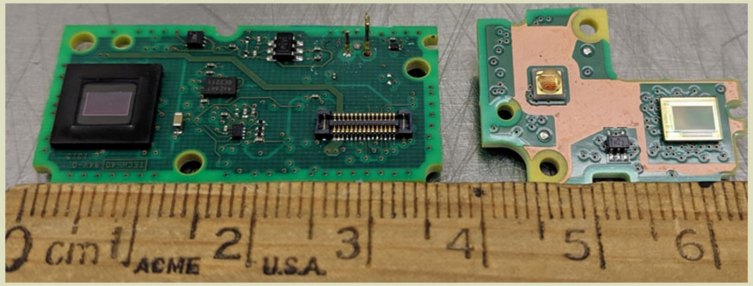
Cell Phone Board Cleaning System

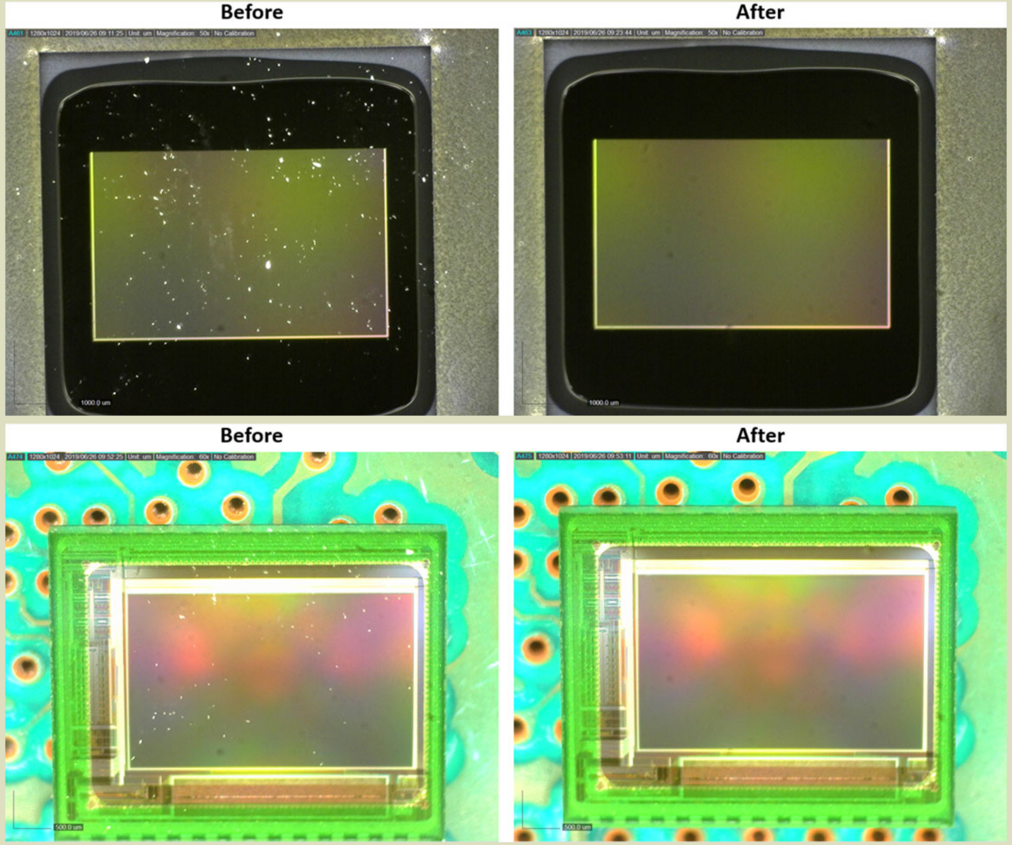
- Cleaning Challenge:
  - Remove contamination from cell phone circuit board:
    - Water Residue, Salts, Debris
- Solution:
  - Automated CO_2 Spray Cleaning system
  - Auto Feed System
  - Four (4) HEN Nozzles
  - 1000 boards cleaned per week



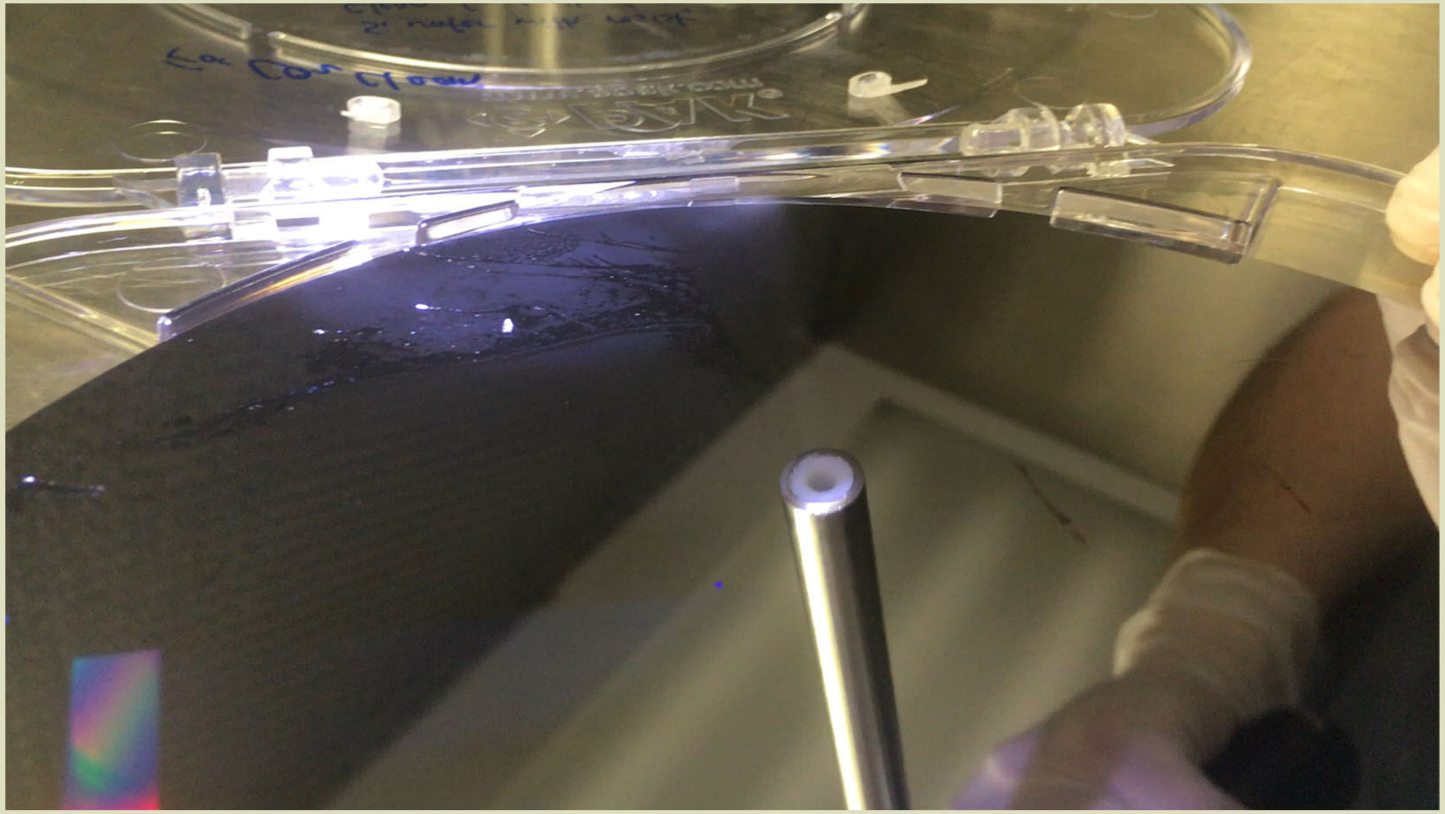
Cleaning Printed Circuit Board (PCB) with Optical Sensor

- Objective: remove dust and finger oil
- Solution: HEN CO_2 spray
- Cleaning time: 10 seconds
- Photo Magnification: 60x



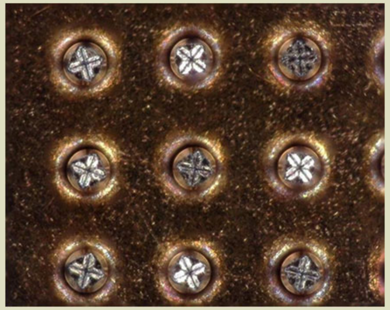


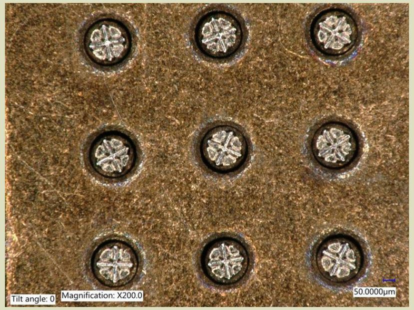
Removal of Hardened Photoresist - Video



CO_2 Spray Cleaning of IC Test Sockets

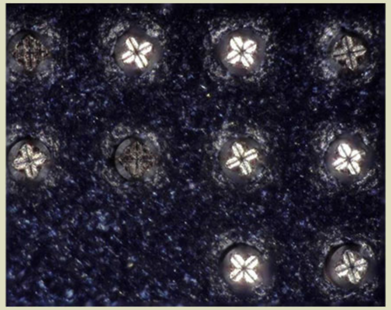
Before | After

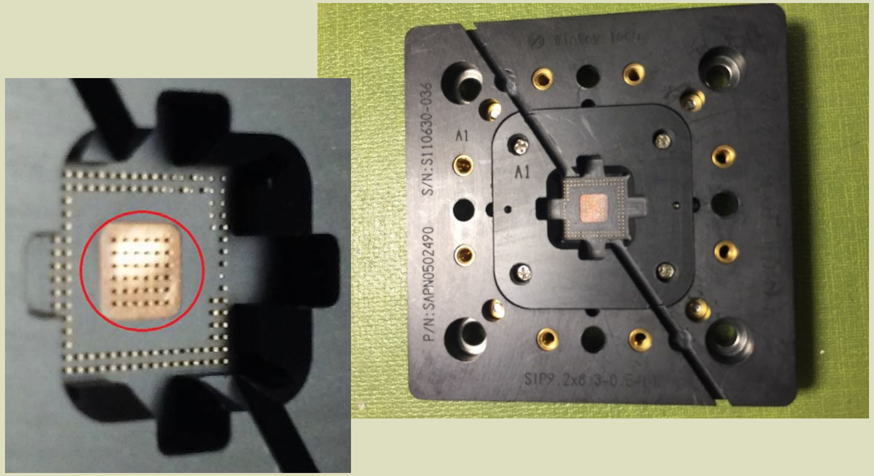




- Pins: SS coated with Ni in plastic backing
- Diameter: 0.5 -1 mm / Spacing 1 - 2 mm
- Nozzle: HEN
- Optics: Keyence Digital Microscope
  - VHX-5000 @ 200x

Before | After

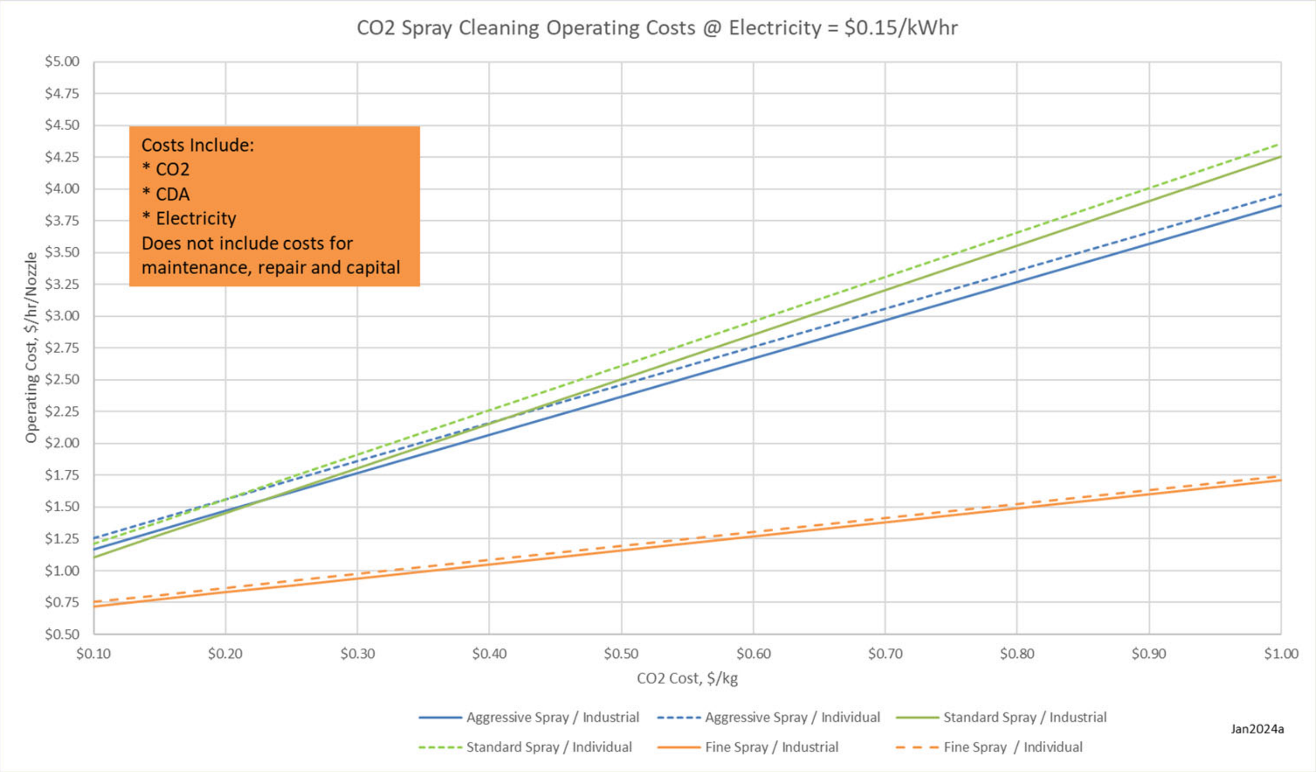




CO_2 Spray Technology Cost of Operation

Typical Costs:

- HEN Applications
  - $2-$2.50/hr./nozzle
- Coaxial/Coanda Applications
  - $1-$1.25/hr./nozzle



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