

산업세정연구회 세미나

에어로졸 건식세정기술 현황
및 연구개발 동향(1)

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중앙대학교 화학공학과

김선근

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- 에어로졸 세정의 전망

에어로졸 *Aerosol*:

- 기체 속에 부유하는 액체 또는 고체 입자들

에어로졸 세정

에어로졸의 *impact*에 의한 오염물질의 제거

Particles, Films

에어로졸 세정의 분류

- Cryogenic aerosol snow cleaning
 - Dry ice snow
 - Argon snow
- Cryogenic pellet cleaning
 - Dry ice pellet
 - Ice pellet
- Electrohydrodynamic aerosol cleaning
 - Microcluster beam

세정 이론

Adhesive forces

Van der Waals force
Electrostatic force
Liquid bridge force

$$\propto d$$

Detachment forces

Gravitational, vibrational
and centrifugal forces

$$\propto d^2$$

Air current force

$$\propto d^3$$

$$\frac{\text{Detachment force}}{\text{Adhesive force}} \propto \frac{d^2 \text{ or } d^3}{d} \propto d \text{ or } d^2$$

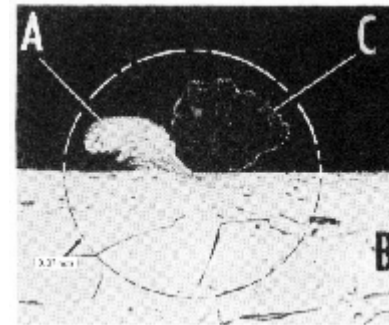
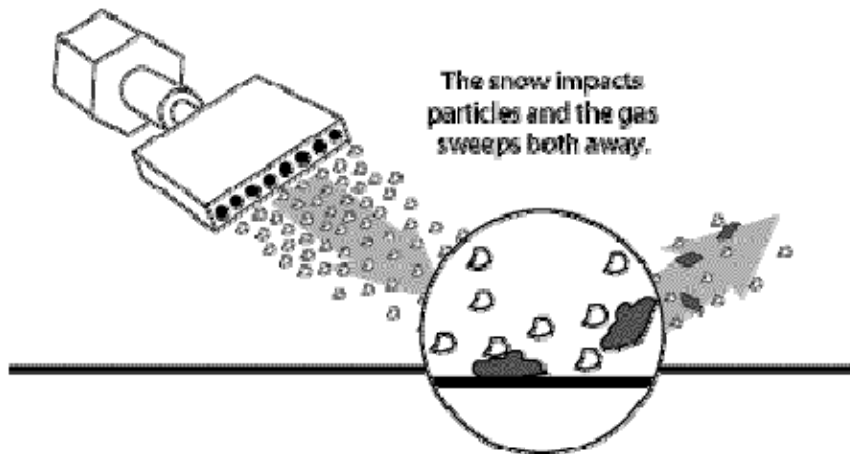
As particle size decreases, it becomes more difficult to remove particles from surfaces

극저온 세정 원리

Cryogenic Aerosol:

Ice particles, solid CO₂ particles, solid argon particles
- Snow(~micron) and pellets(~mm)

Impact 후 승화 – 잔사를 남기지 않음



극저온 세정 특징



- 제거된 오염물이외에는 추가 폐기물이 없음
- 헹굼이나 건조 공정이 불필요
- 기판에 손상없음
- 세정속도 향상
- *Online and in-line* 세정 가능
- Nontoxic, non-pollutant, nonflammable, inexpensive

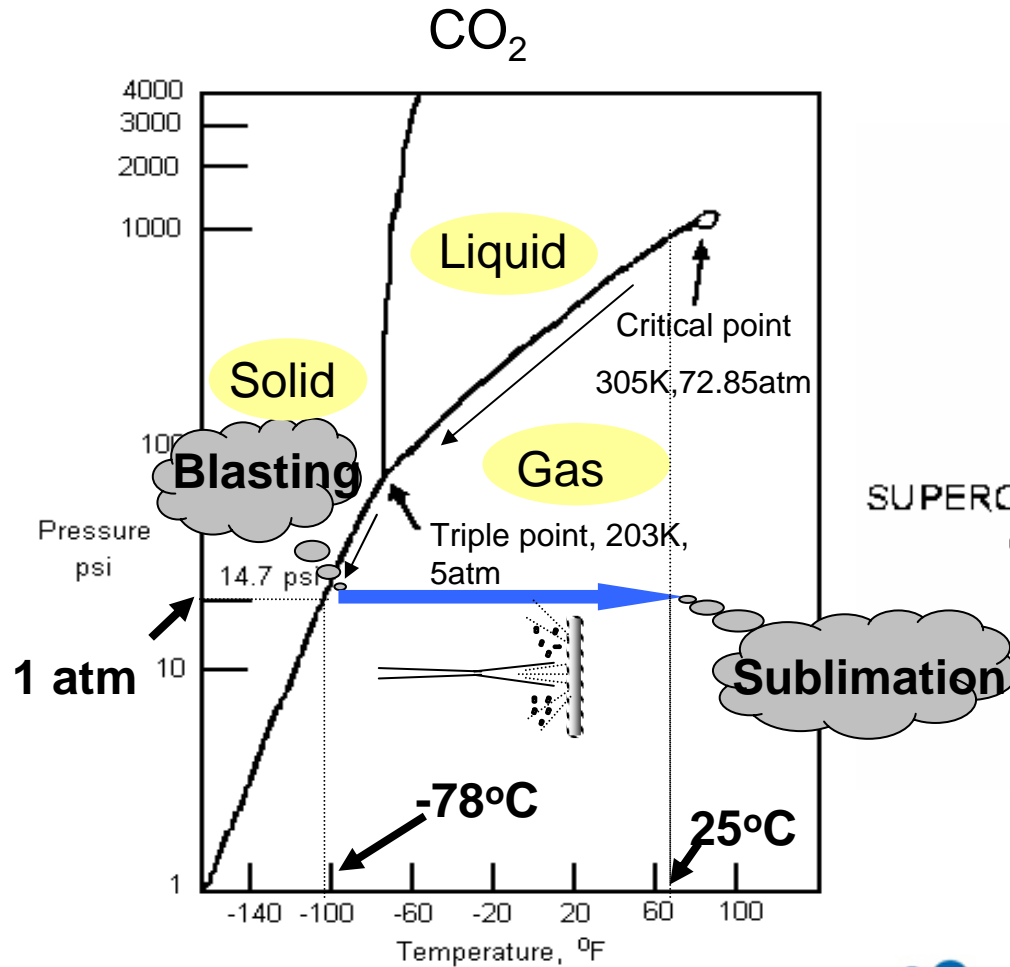


- Momentum 전달
- 용매효과 – film 제거
- 열영동 효과(Thermophoretic effect)
- Freeze/Fracture effect – film 제거
- 승화 입자의 부피팽창

- 입자 flux
- 입자크기/밀도/경도
- 운반기체의 종류/유량
- 노즐 설계
- 분사각도 및 거리
- 전후 압력차
- 오염종류
- 기관종류

Dry Ice Snow Cleaning

Thermodynamics of Aerosol Formation



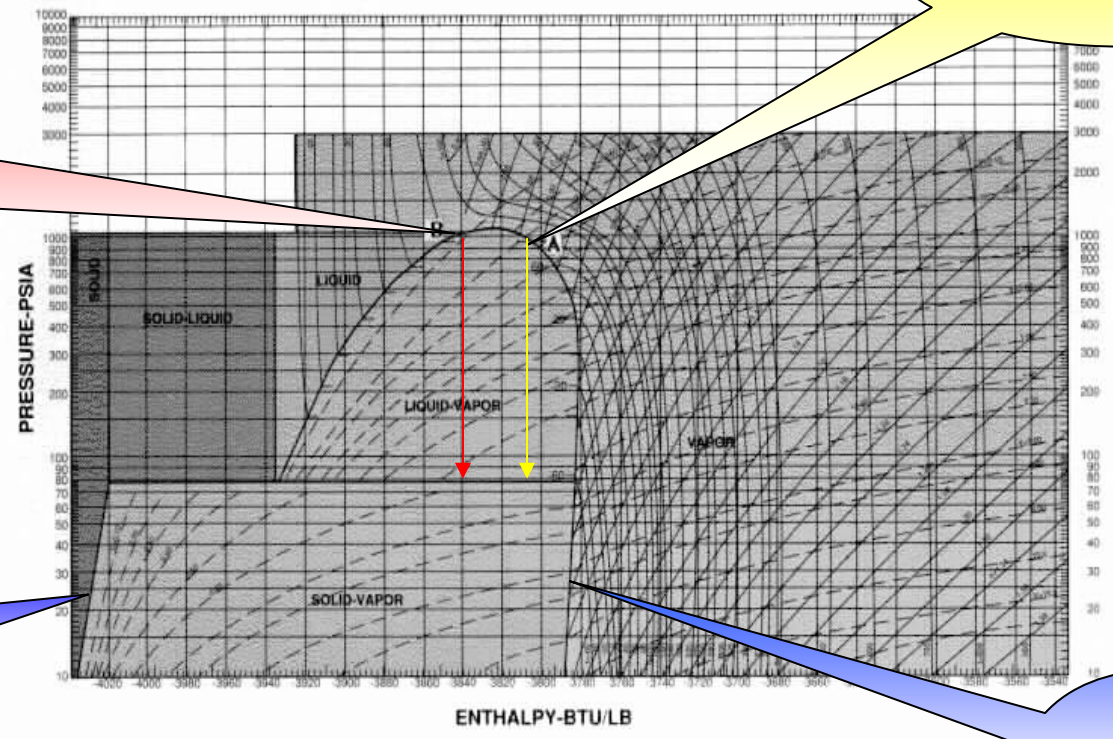
Properties of CO₂

<u>PHYSICAL PROPERTIES</u>	<u>QUANTITY</u>	<u>UNITS</u>
CHEMICAL FORMULA	CO ₂	
MOLECULAR WEIGHT	44.01	g/mole
SOLID STATE DENSITY	1.6	g/ml
GAS STATE DENSITY	0.002-0.2	g/ml
LIQUID STATE DENSITY	0.7 - 1.2	g/ml
SUPERCRITICAL STATE DENSITY	0.4 - 1.2	g/ml
CRITICAL TEMPERATURE	305	K
CRITICAL PRESSURE	72.85	atm
CRITICAL DENSITY	0.468	g/ml
T.P. TEMPERATURE	203	K
T.P. PRESSURE	5	atm

Dry Ice Snow Cleaning

Two stage cooling

Carbon Dioxide Pressure-Enthalpy Diagram



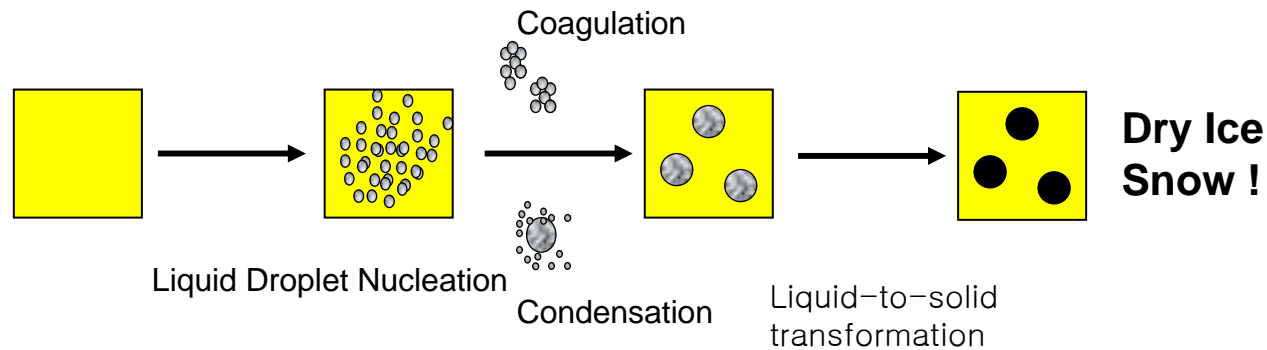
Liquid
Higher snow
conversion

Gas
Less contaminant

Solid

Gas

From Gaseous CO₂



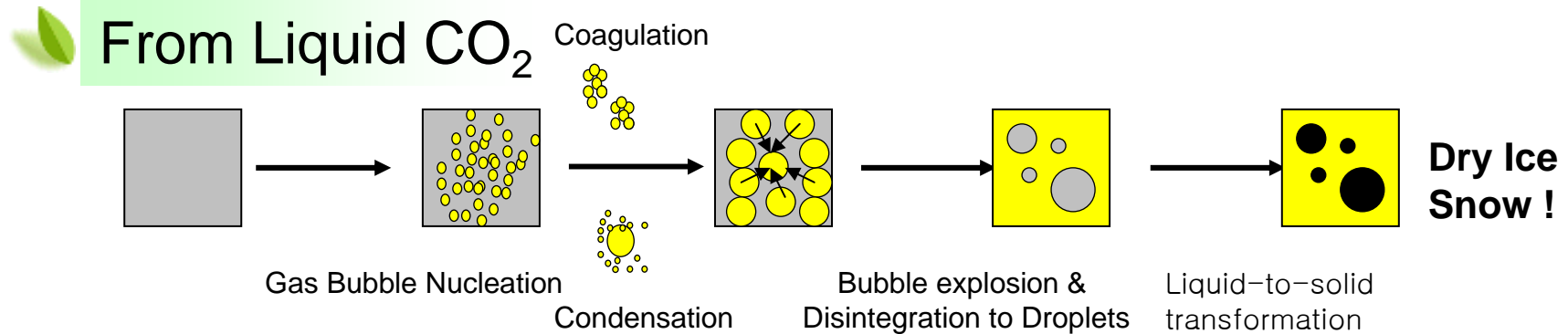
~Several micrometers

~8% yield

Buildup process

균일 핵생성 (homogeneous nucleation)

불균일 핵생성 (heterogeneous nucleation)



~Several tens of micrometers

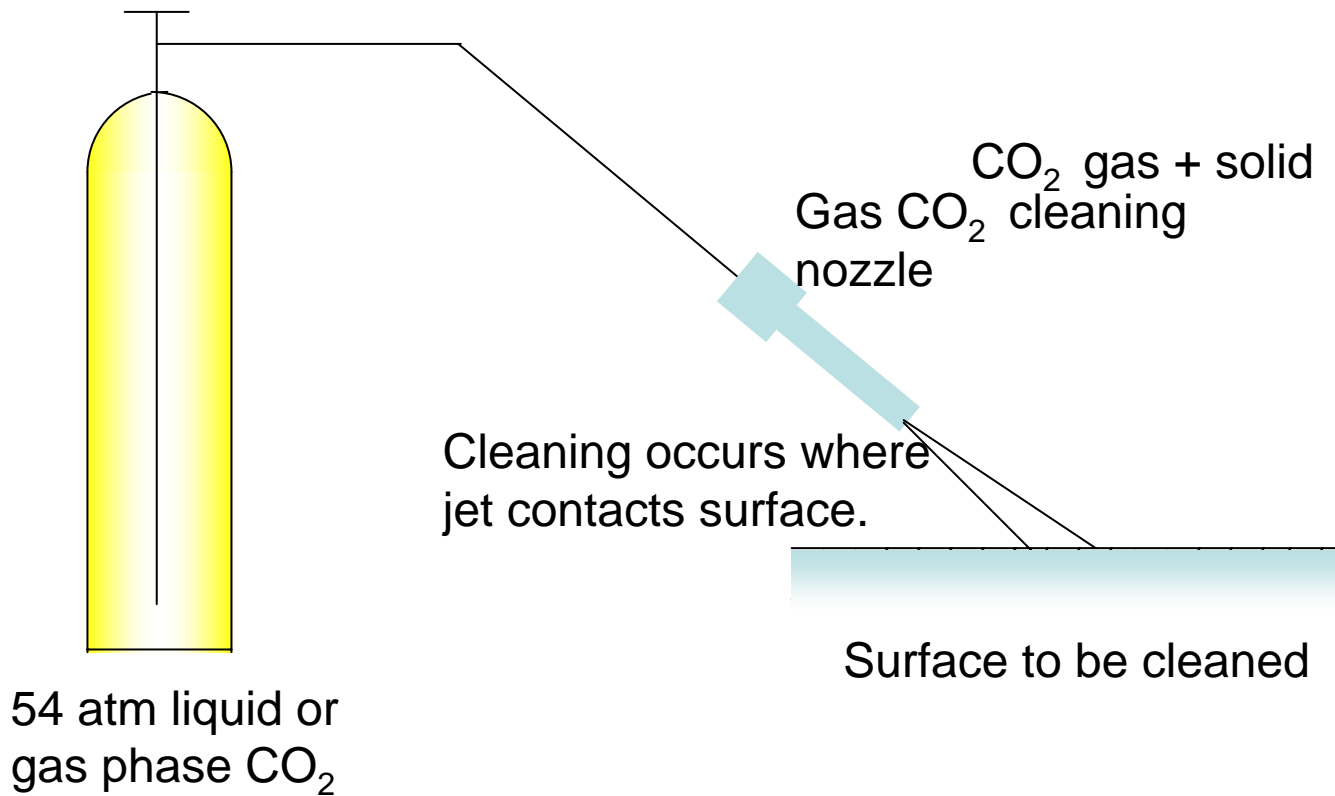
~45% yield

Breakdown process

- Explosive shattering of liquid jet

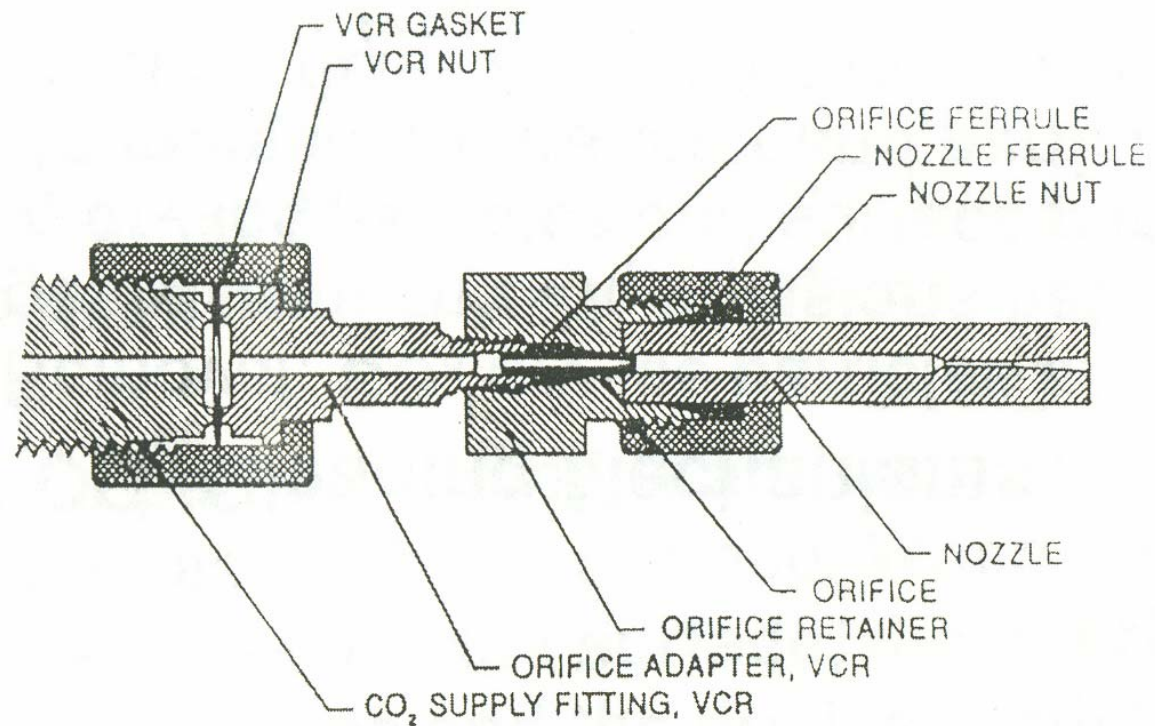
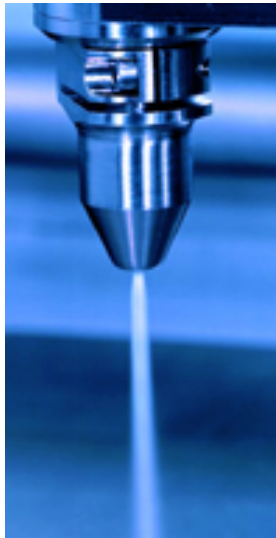
Dry Ice Snow Cleaning

세정장치

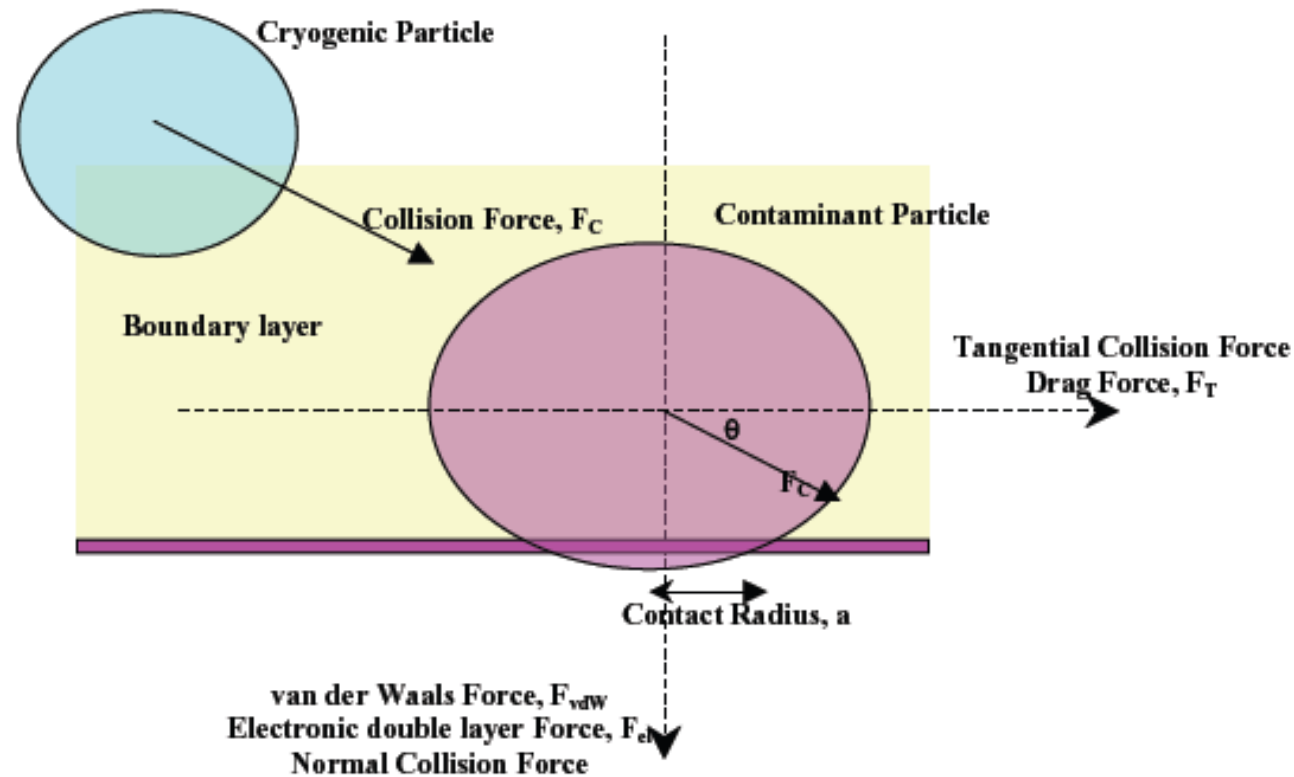


Dry Ice Snow Cleaning

노즐



Tangential force (Removal) vs. Vertical force (Adhesion)





Characteristic time

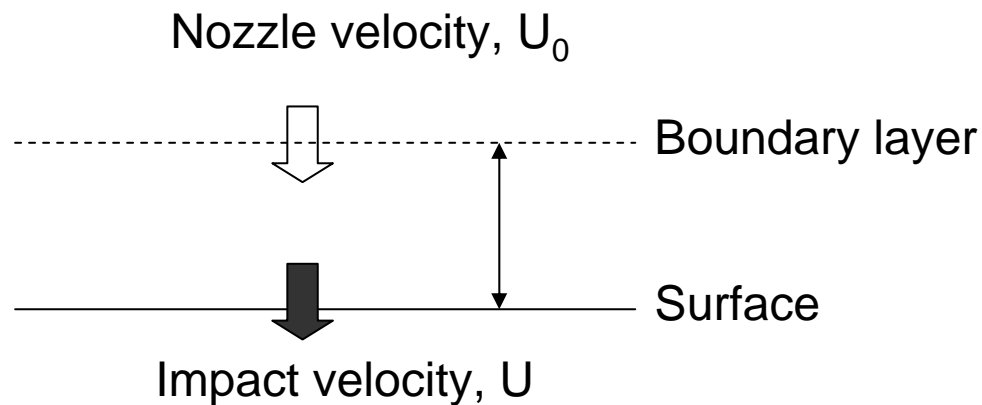
$$\tau = \frac{d_p^2 \rho_p C_c}{18\mu}$$

d_p : Diameter of cryogenic particles

ρ_p : Density of cryogenic particles

μ : Viscosity of CO₂ gas

C_c : Cunningham correction factor

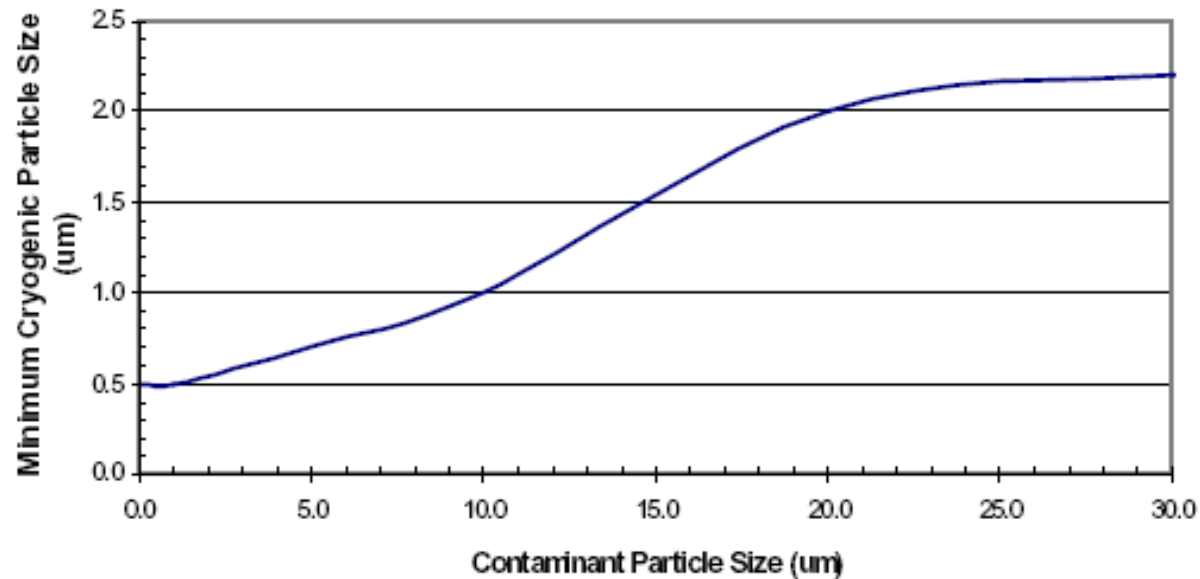


$$U = U_0 \left(1 - \frac{\delta}{U_0 \tau} \right)$$



극저온 입자의 크기 vs. 오염입자의 크기

Assuming $\delta = 0.63U_0\tau$ and $U_0 = 40\text{m/s}$



Dry Ice Snow Cleaning *세정원리*

용매 효과

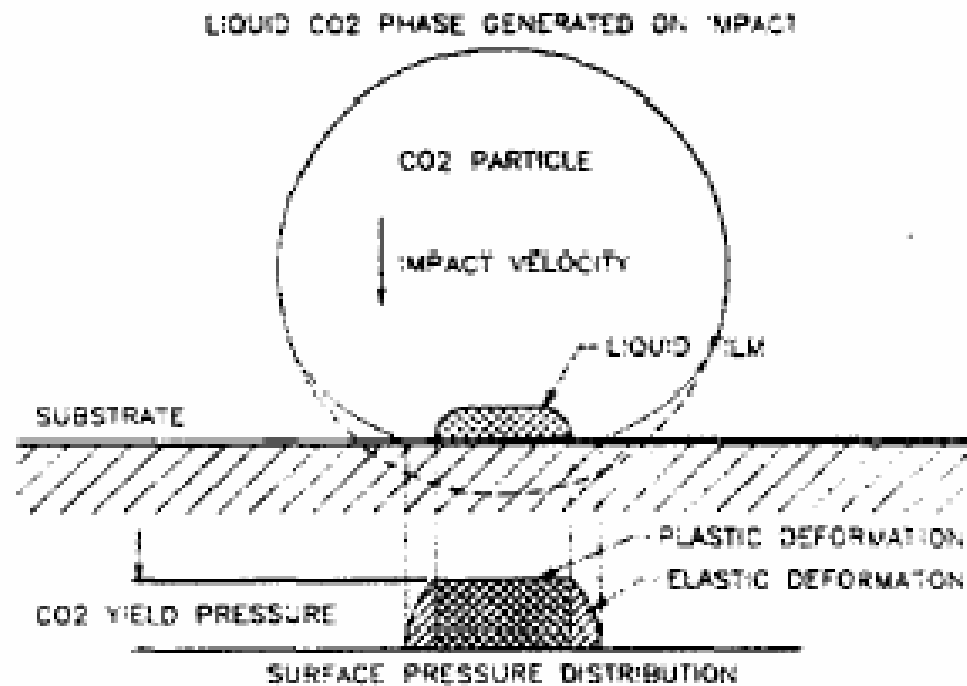
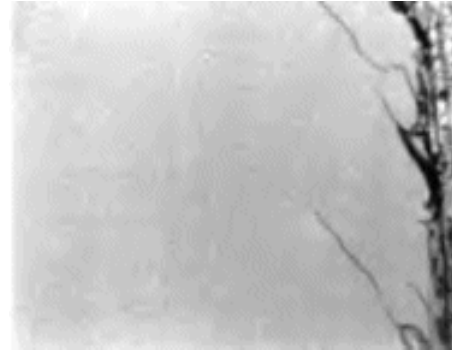
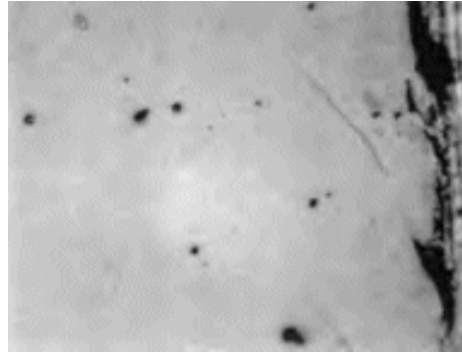
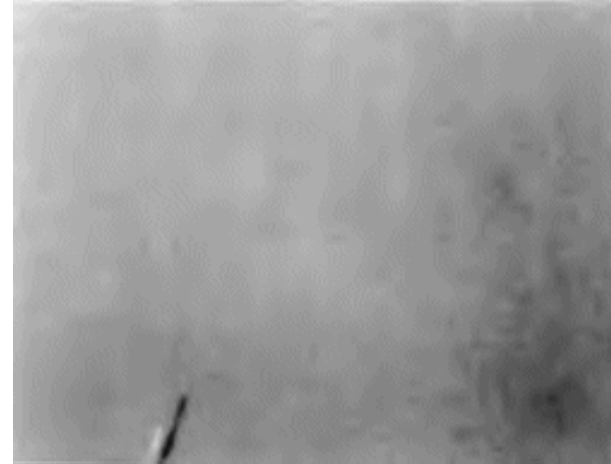
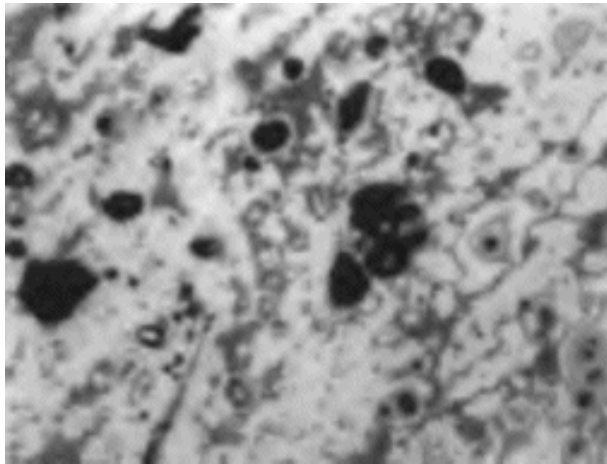


Figure Removal of organic contaminants by solid-state carbon dioxide per the theory of liquid-phase solvency.

Dry Ice Snow Cleaning Applications



Removal of submicron particles deposited on silicon wafer



Removal of grease residue(organic films) deposited on silicon wafer

Dry Ice Snow Cleaning Applications

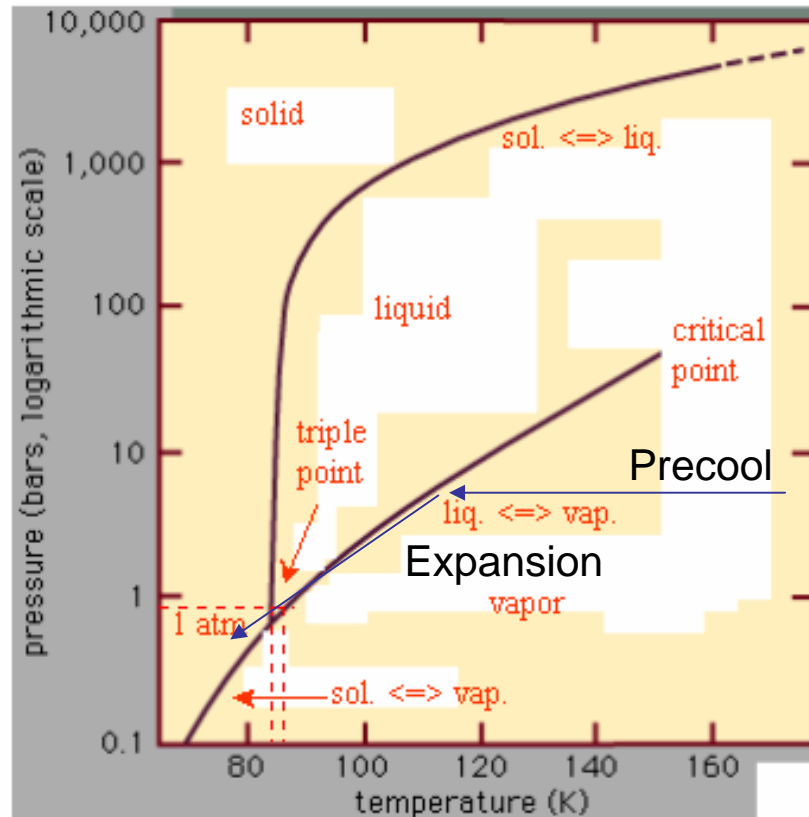
- Optics
- Laser interferometers and mirrors
- Silicon wafers
- Ceramics
- Flat panel Display substrates
- Printed circuit board
- Read/write head
- Medical products
- Semiconductor instrument
- Gyroscopes and microvalving

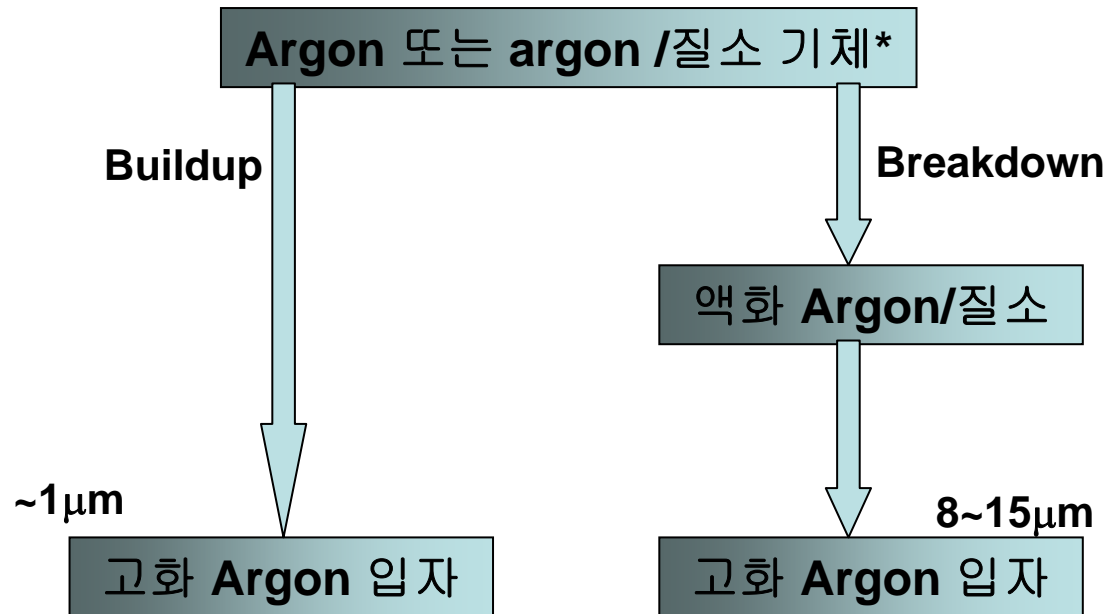
Dry Ice Snow Cleaning **Issues**

- 재오염
- 입자여과
- 수분 응축
- 정전 방전
- 기관 손상 - Thermal shock
- 원료 기체 - Consumption and purity

Argon Snow Cleaning Snow 제조

Argon 의 상평형도



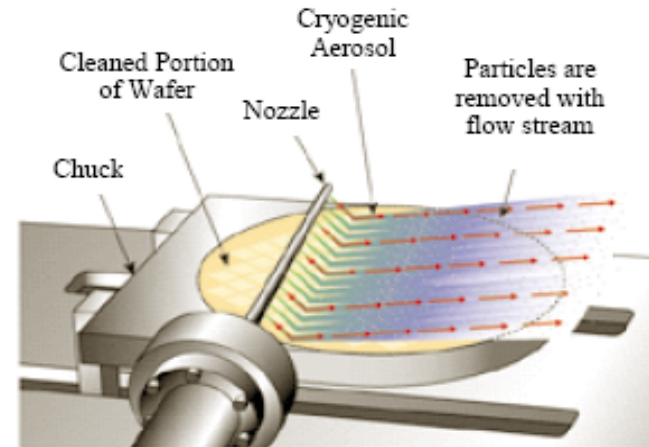
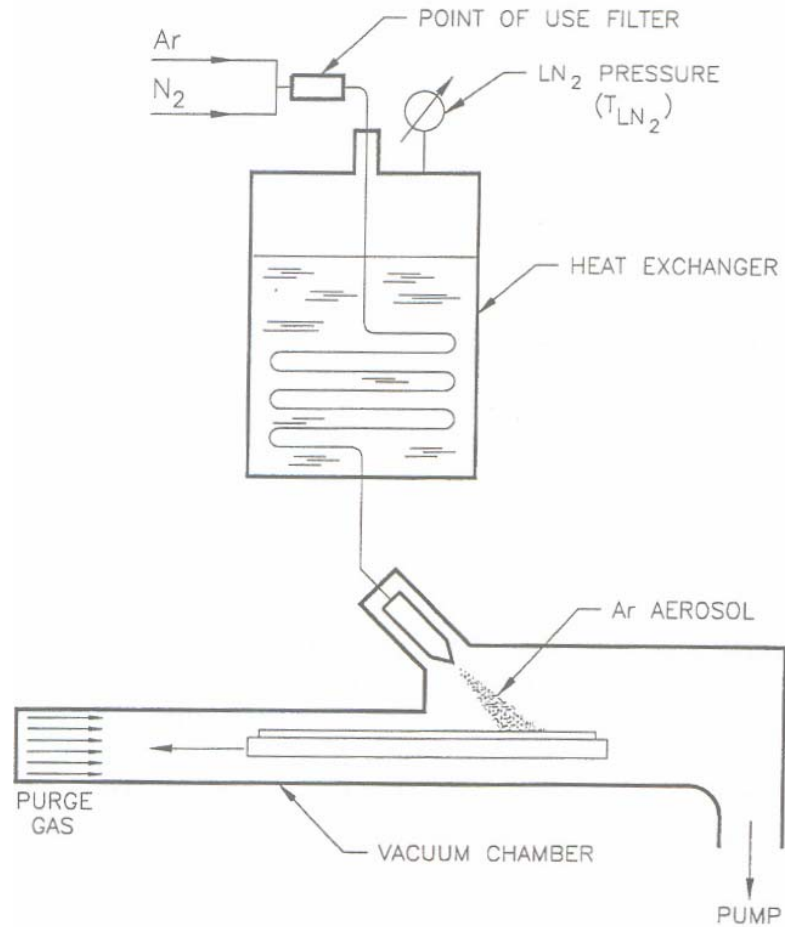


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- Joule-Thomson cooling effect 증가
- Argon 소비저감
- Argon 입자의 크기 및 모멘텀 조절

Argon Snow Cleaning

Snow 제조 및 세정장치



Argon Snow Cleaning Applications

반도체 제조 라인

Application Point	Technology Insertion	Purpose	Wet Clean Replacement
Dielectric etch	DRAM, logic	Scrap reduction	Yes
Sputter deposition	DRAM	Yield improvement	No
Gate metal silicides	DRAM	Reliability improvement	Yes
Metal etch	Advanced logic	Yield improvement	Yes
Via etch	DRAM, logic	Yield improvement	Yes
LPCVD deposition	DRAM	Yield improvement	No
Electrical probe	Logic	Yield improvement	Yes