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Design and Safety Considerations on the Gas Supply Side

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Albany NY**

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Semiconductor Wafer Manufacturing

Safety on the Gas Supply Side



- Venting Residual Gas from Gas Cabinets and Pressure Relief Lines
- “Leaker” Cabinets and Valve Manifold Boxes (“VMBs”)
- Exhaust of Gas Cabinets

These areas are often overlooked when doing the facility design



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Semiconductor Wafer Manufacturing Hazardous Process Gases

Common classes of hazardous gases include:

- **Toxics:** e.g. AsH_3 , PH_3 , H_2Se , NH_3
- **Pyrophorics:** SiH_4 , B_2H_6 , GeH_4 , ...
- **Corrosives:** HCl , Cl_2 , HBr , BF_3 , F_2 , ...
- (Many gases pose more than one risk – e.g. PH_3 is both toxic and pyrophoric).



Semiconductor Wafer Manufacturing

Hazardous Process Gases



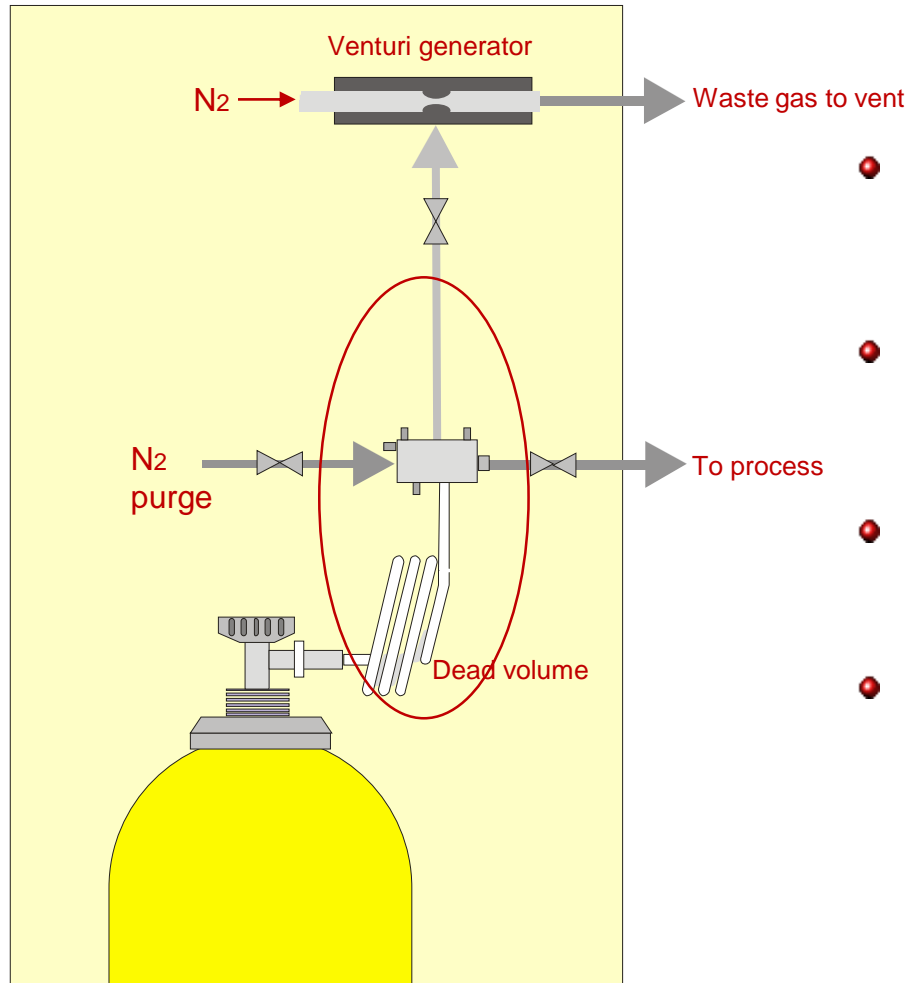
- Silicon Semiconductor Fabs
 - Large installations of corrosives and pyrophorics
 - Smaller amounts of Toxics

- Compound Semiconductor Fabs
 - Larger quantities of AsH_3 , PH_3 cylinders used for Epi Growth
 - Organometallic liquid precursors (bubblers)

Removal of Purge Gases during Cylinder Change



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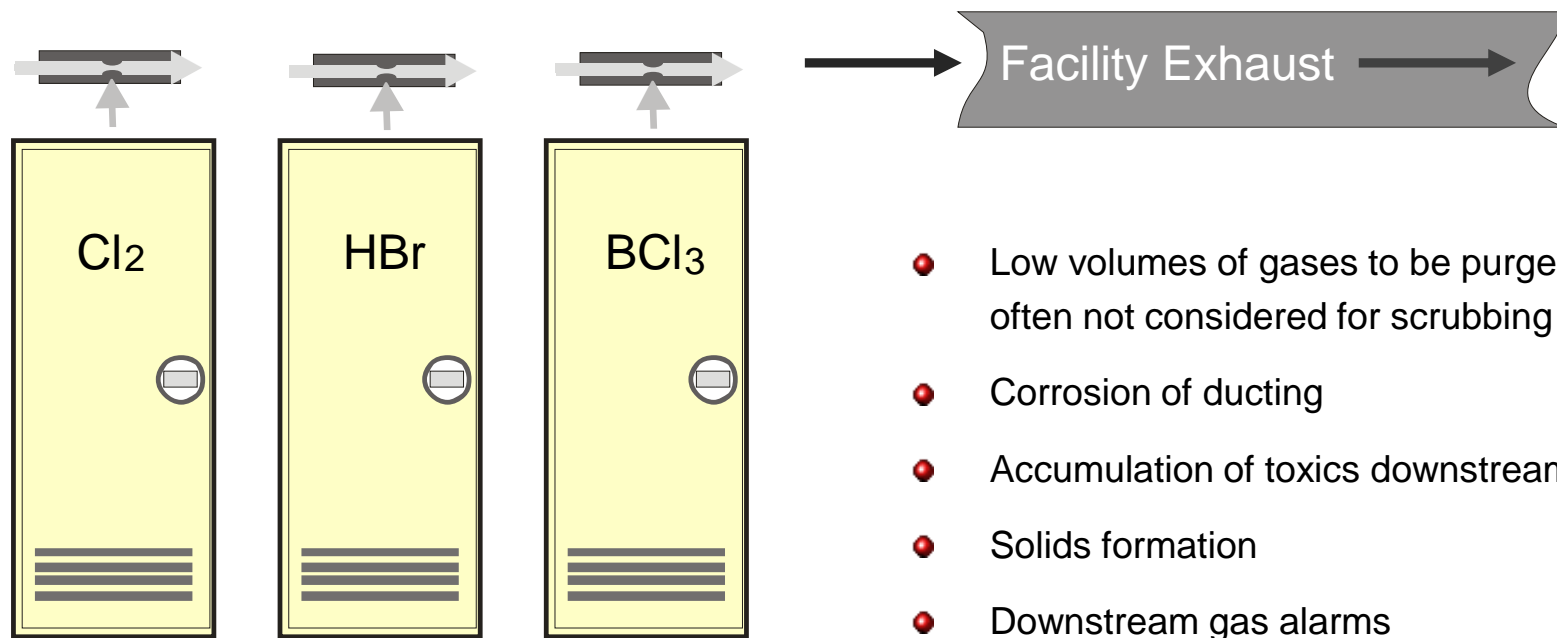
- As part of the cylinder-change operation, the gas supply panel must be purged free of any remaining process gases.
- In addition to safety considerations, this procedure is also necessary to ensure the purity of the gas supply.
- Vent Purge Cycle: Dead volume of residual gas is repeatedly diluted by N_2 pressurization
- Each step evacuated via venturi vacuum generator



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Gas Cabinet Vent Purge **Vent to Atmosphere- No scrubber!**

Venturi vacuum generators

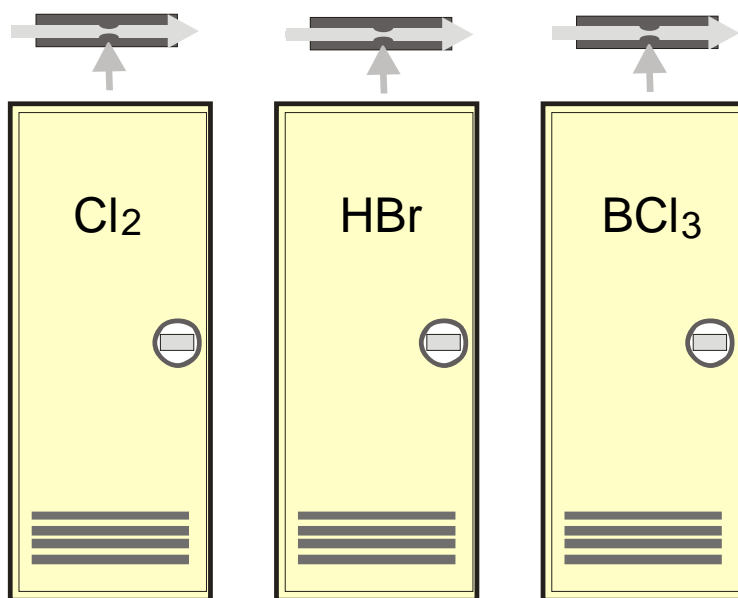




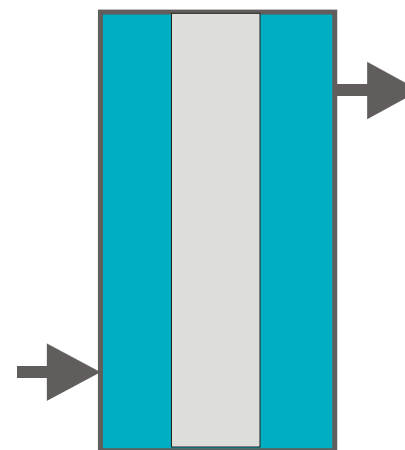
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Gas Cabinet Vent Purge Combined Gas Cabinets - PoU scrubbers

- Gases usually grouped by category
- Typically, cylinder change-outs do not coincide
- Dedicated, downstream scrubber most suitable when additional pressure relief valves or rupture discs are connected

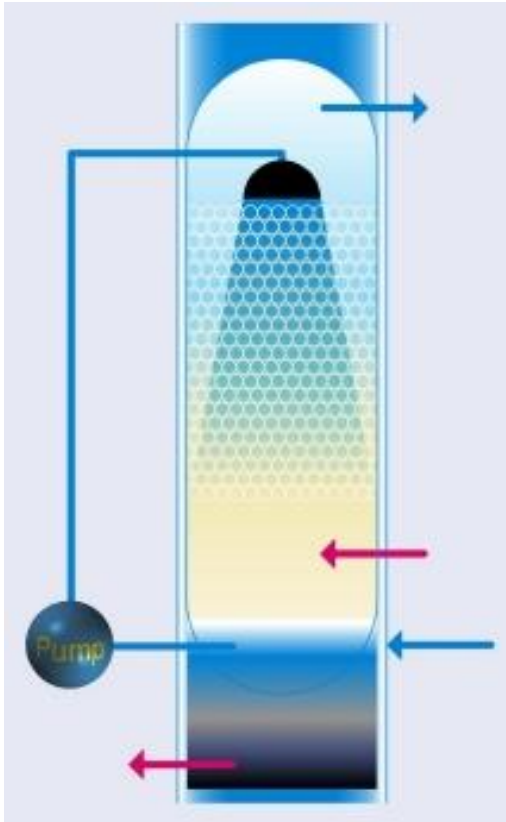


Gasroom scrubber



Gas Cabinet Vent Purge Scrubbing Technologies

Wet Scrubber



Description

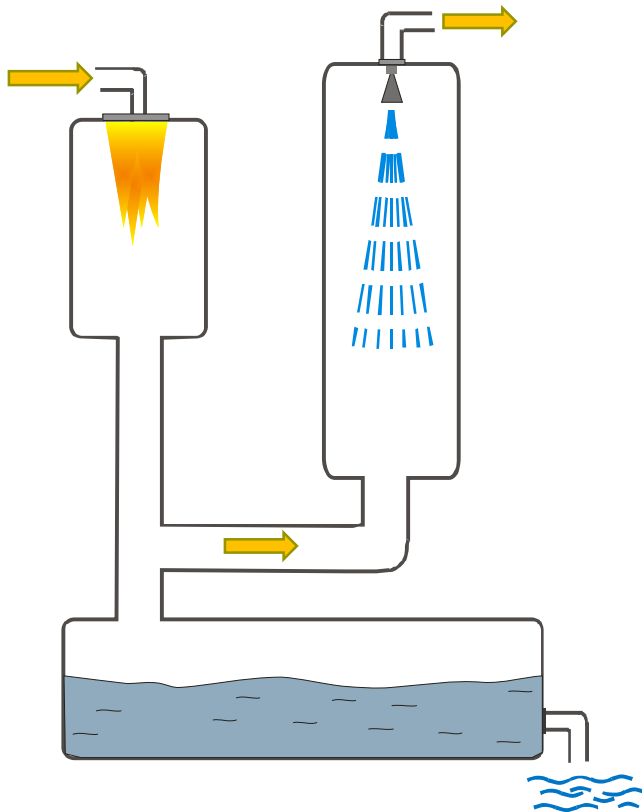
- Not typically used as point-of-use scrubber in gas rooms, usually “end-of-pipe”
- Where used as PoU in gas room, must be kept up-and-running for intermittent vent purges

Gas Cabinet Vent Purge Scrubbing Technologies

Thermal and Burn-Wet Scrubbers



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Description

- Exhaust gases first combusted using fuel /air flame or heated surface, followed by:
- Downstream wet-scrubbing of gaseous and solid by-products
- Efficient removal of hydride gases
- Oversized for Vent Purge application
- Needs to be started-up or kept running (facilities costs!)
- Heat generation

Gas Cabinet Vent Purge Scrubbing Technologies

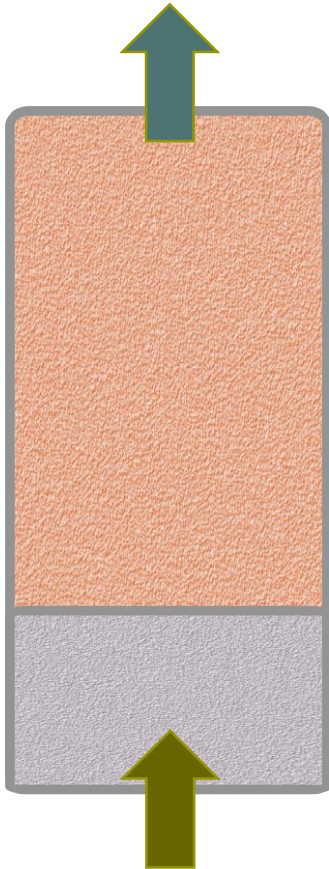
Dry Bed Chemisorption



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Description

- Waste hydrides react with chemisorber media to form solid by-products
- Breakthrough of gas can be monitored by gas sensor
- Temperature of column can be monitored
- On-Demand use only - economical
- Passive design – will function during facilities outage
- Minimal exposure to toxic by-products
- Requires logistics for off-site waste disposal
- Not cost-competitive with activated carbon or wet scrubbing

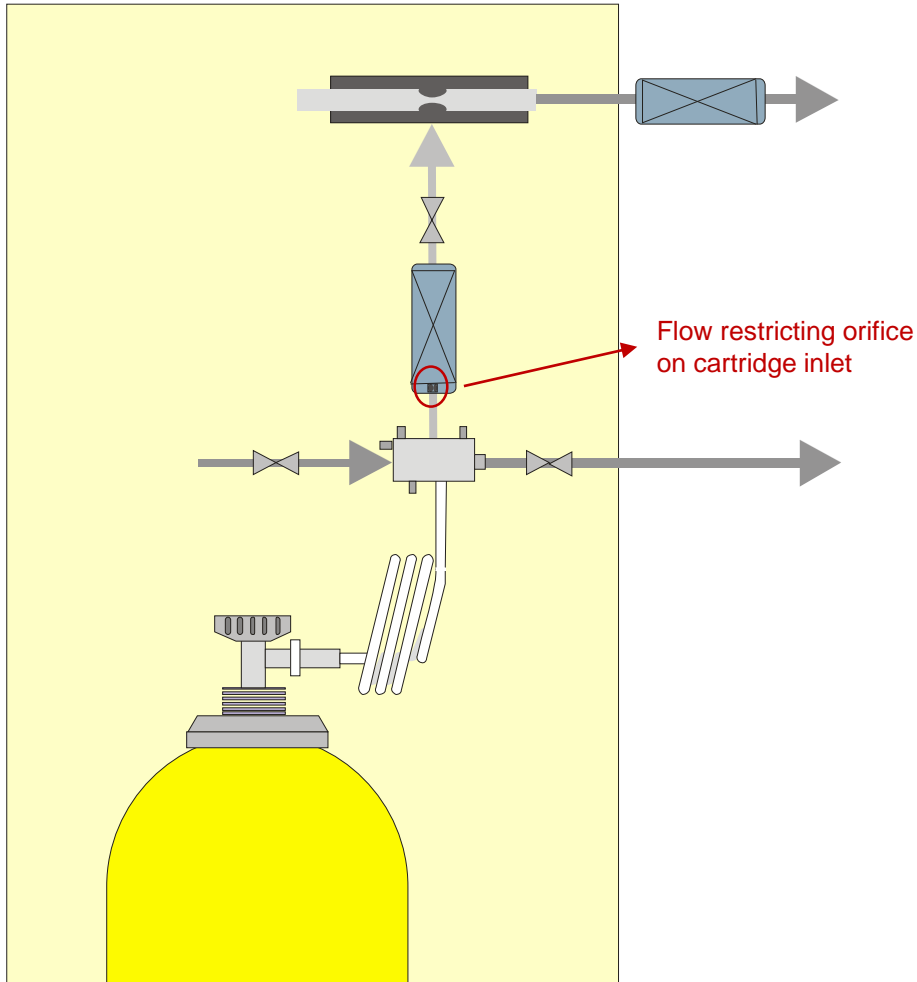


Removal of Hazardous Gases During Purging of Vent Lines

At-Source Removal within cabinet – Scrubber cartridges



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- One scrubber cartridge per gas cabinet
- Can be on suction side of vacuum generator – typically with flow restrictor
- Alternatively, can be placed in outlet of Venturi generator (not supported/ recommended by CS CLEAN SOLUTIONS)

Removal of Hazardous Gases During Purging of Vent Lines

At-Source Removal within cabinet – Scrubber cartridges



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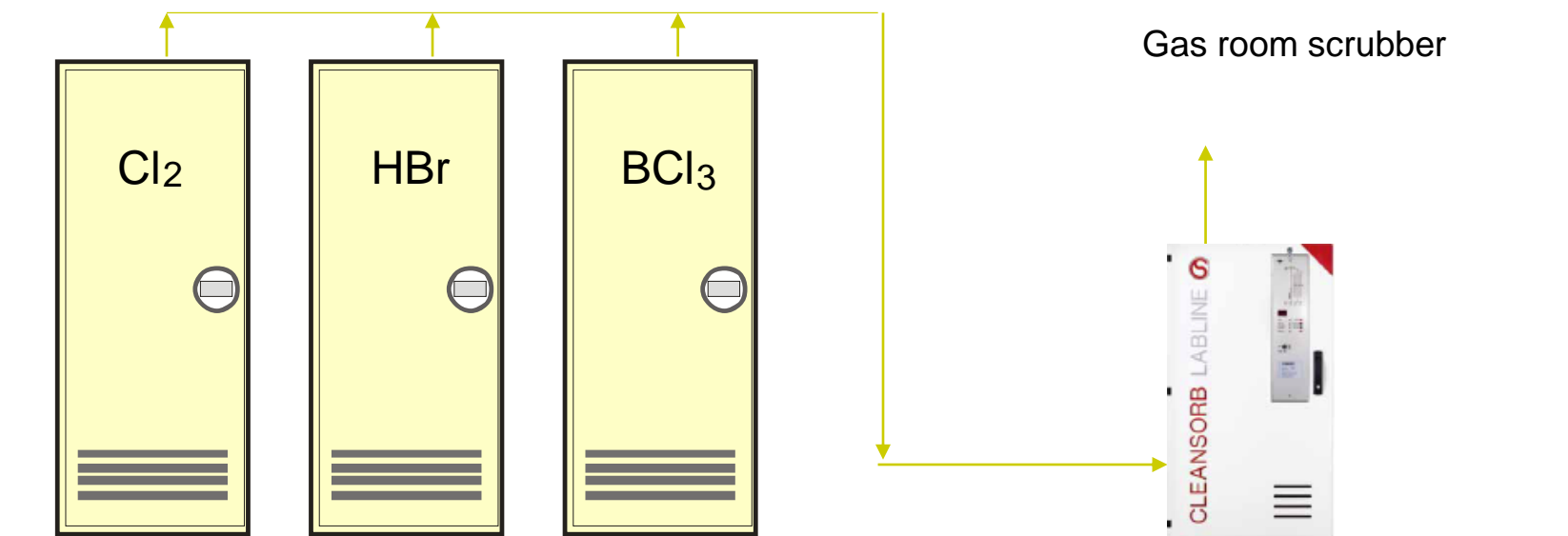
- At-source removal of residual gas
- Efficient scrubbing of undiluted gas
- No mixing of incompatible gases
- Saves floor space, saves external pipework
- Requires integration by cabinet manufacturer
- Check-valve at outlet to prevent back-diffusion of air (hydride gases)
- Can be more costly than downstream scrubber, if many cabinets



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Gas Cabinet Vent Purge Combined Gas Cabinets - POU scrubbers

- Gases usually grouped by category
- Typically, cylinder change-outs do not coincide
- Dedicated scrubber downstream of multiple vacuum venturis for a number fo gas cabinets – same/similar similar or different gases



Hazardous Gases Stored Under Pressure

The Risk of Accidental Release



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: **DANGER! Toxic, flammable liquefied gas** . Immediately evacuate all personnel from danger area. Do not approach area without self-contained breathing apparatus and protective clothing. If cylinders are leaking, reduce toxic vapors with water spray or fog. Reverse flow into cylinder may cause rupture. (See section 16.) Shut off flow if without risk. Ventilate area or move cylinder to a well-ventilated area.

- Excerpt from Safety Data Sheet for toxic gas – Emergency Release Measures

Hazardous Gases Stored Under Pressure

The Risk of Accidental Release

- Hazardous release from gas cylinders poses a very serious threat to environment and safety, owing to the quantity of pressurized gas which is usually concentrated.
- Gas Leakages are known to have occurred:
 - During transport of cylinders to the factory (leaky valves, etc)
 - During storage of fresh and “empty” cylinders
 - Due to improper connection of fresh cylinder in gas cabinet
 - Due to component failure, e.g. rupture of pressure regulator diaphragm
 - Due to operator error.



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Hazardous Gases Stored Under Pressure

The Risk of Accidental Release



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- Direct toxic hazard to factory personnel
- Toxic risk to facility neighborhood
- Spreading of fires in exhaust ducting
- Risk to factory and machinery (e.g. corrosion)
- Risk to manufacturing uptime
- Factory insurance/ liability
- EPA violations
- Workforce morale
- Good community relations/ corporate image



Hazardous Gases Stored Under Pressure

The Risk of Accidental Release



Regulatory Considerations

- Requirements vary somewhat from state to state in the US
- Based on International Fire Code (IFC) state edition
- Toxic vs Highly Toxic Gases ie Arsine (AsH_3)
- Consult with your local Engineering team and Fire Marshall for specific interpretation

HIGHLY TOXIC. A material which produces a lethal dose or lethal concentration which falls within any of the following categories:

1. A chemical that has a median lethal dose (LD 50) of 50 milligrams or less per kilogram of body weight when administered orally to albino rats weighing between 200 and 300 grams each.
2. A chemical that has a median lethal dose (LD 50) of 200 milligrams or less per kilogram of body weight when administered by continuous contact for 24 hours (or less if death occurs within 24 hours) with the bare skin of albino rabbits weighing between 2 and 3 kilograms each.
- 3 . A chemical that has a median lethal concentration (LC 50) in air of 200 parts per million by volume or less of gas or vapor, or 2 milligrams per liter or less of mist, fume or dust, when administered by continuous inhalation for one hour (or less if death occurs within 1 hour) to albino rats weighing between 200 and 300 grams each.

Hazardous Gases Stored Under Pressure

The Risk of Accidental Release



Regulatory Considerations

- Section 3704 “Highly toxic and toxic” Compressed gases of the IFC outlines requirements for storage of these materials.
- For highly toxic compounds, treatment systems are required unless containment systems are provided.
- The containment system must be able to tolerate the resulting pressure once the containment is in pressure equilibrium with the leaking cylinder.
- For treatment systems the solution must be able to handle the maximum rate of release and be able to abate the content of the largest cylinder.
- Treatment systems must be able to reduce the concentration of the HPM to below $\frac{1}{2}$ the IDLH value. In some cases, the local authorities have requested a concentration of $\frac{1}{4}$ the IDLH value.
- *The safety regulations in many countries require companies storing or using hazardous gases to carry out a risk assessment and adopt preventative measures in accordance with “Best Available Technology”*

Hazardous Gases Stored Under Pressure

Accidental Release of Gas: Methods of Emergency Abatement



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- None
 - Dilution is the solution to pollution

- Facility (End of Line) Water Scrubber

- Media Based Scrubber Vessel
 - Carbon Media
 - Chemisorption Media

Hazardous Gases Stored Under Pressure

The Risk of Accidental Release



OPTION 1 – DILUTION

- Advantages
 - No Capital and Operating Cost
- Disadvantages
 - Provides no protection for personnel, plant and environment
- Many customers rely on Restrictive Flow Orifices (RFO)

Hazardous Gases Stored Under Pressure

The Risk of Accidental Release



Restrictive Flow Orifices

Example: Phosphine cylinder @ 594 psig/ 42.8 atm.

Orifice Size	mm	0.254	0.356	0.508	0.762	1.016
	inches	0.010	0.014	0.020	0.030	0.040
Flowrate	sccm	22393	42751	88216	196789	339291
	scf/h	47	91	187	417	719

With 0.02 inch RFO: 88 slm PH3 !

Accidental Release of Gas: Methods of Emergency Abatement

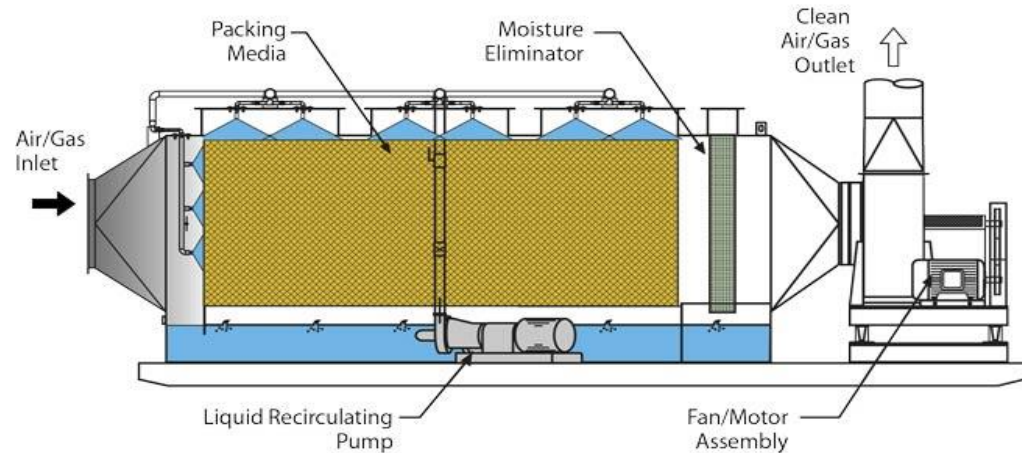
Facility Water Scrubber



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Rooftop Location



Accidental Release of Gas: Methods of Emergency Abatement

Facility Water Scrubber



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- Standard installation on most fab roof-tops
- No additional costs

- Unlikely to be effective for all types of gas chemistries
- Probably not capable of handling high-flow release during emergency release scenario
- Centralized installation – risk of fire, toxic leak, corrosion in duct systems
- Maintenance and service, though rarely needed

Accidental Release of Gas: Methods of Emergency Abatement

Carbon-Based Adsorption (Physisorption) Scrubbers



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- Advantages
 - Lower cost
 - Can treat a variety of gases
- Disadvantages
 - Temperature excursions possible
 - Flammable media in presence of oxidizer

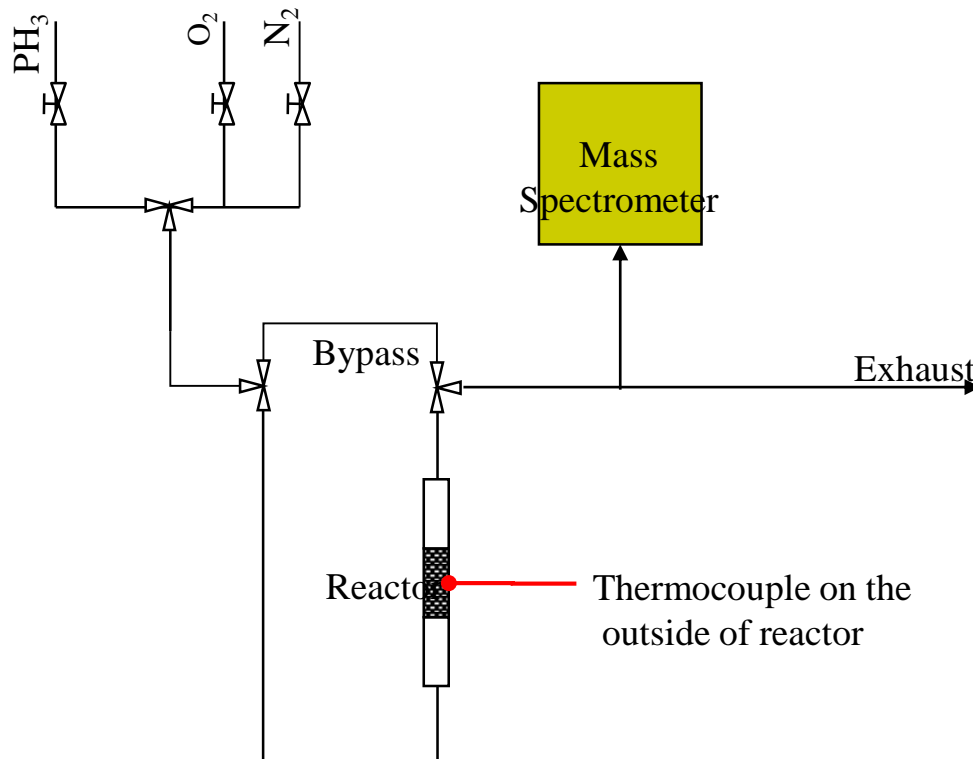


Accidental Release of Gas: Methods of Emergency Abatement

Carbon-Based Adsorption (Physisorption) Scrubbers

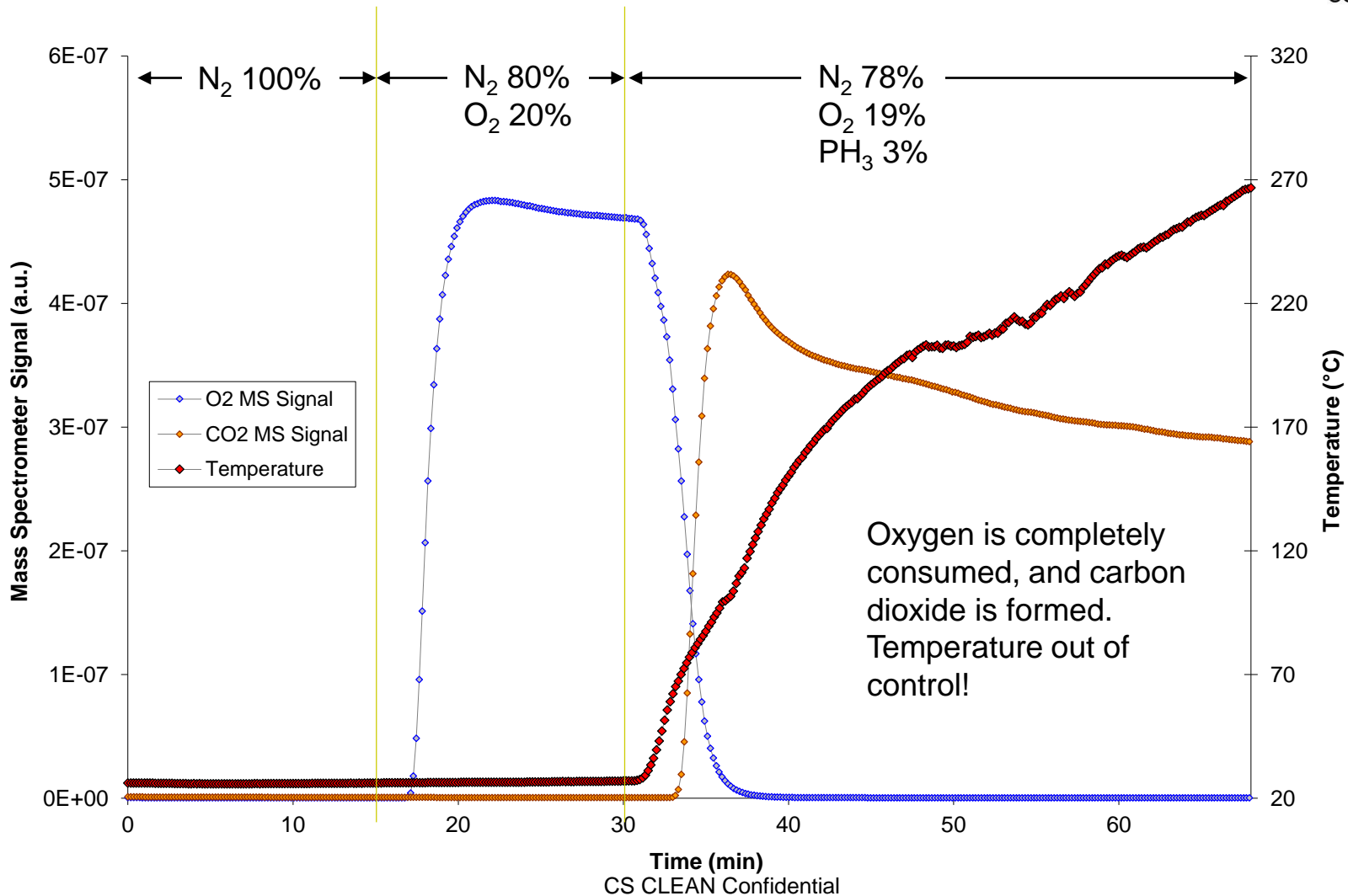


Laboratory simulation of phosphine release



Carbon-Based Adsorption (Physisorption) Scrubbers

Laboratory simulation of phosphine release



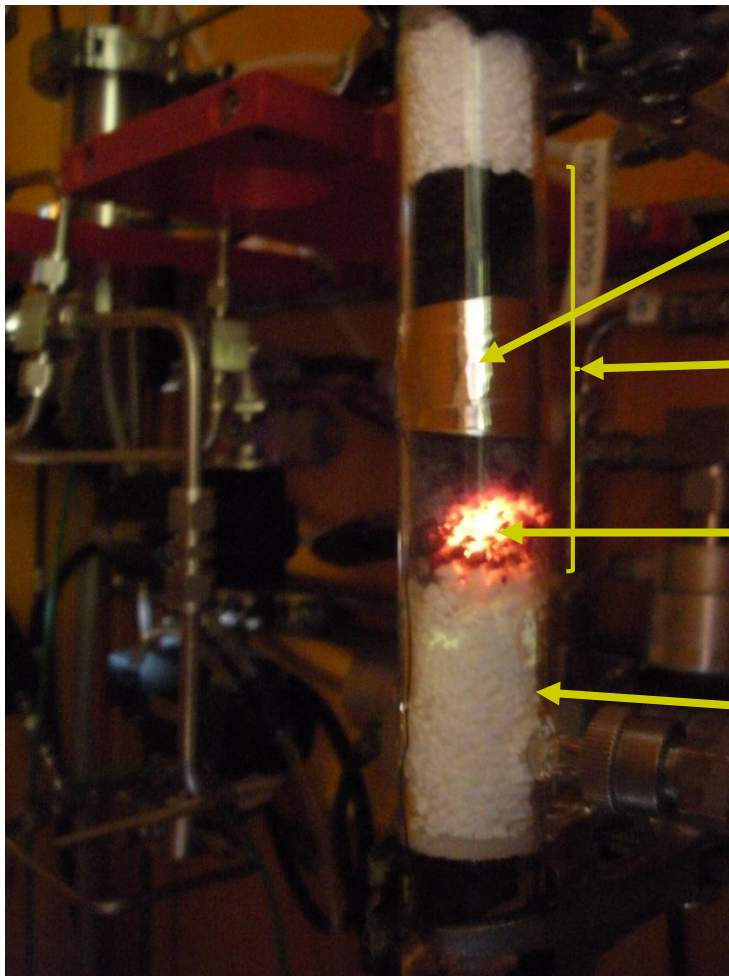
Oxygen is completely consumed, and carbon dioxide is formed. Temperature out of control!

Carbon-Based Adsorption (Physisorption) Scrubbers

Ignition of Carbon



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Thermocouple behind adhesive tape

Active carbon bed

Burning active carbon zone

Inert bed support

Carbon-Based Adsorption (Physisorption) Scrubbers

Ignition of Carbon



- In the emergency case of a valve rupture the flow of phosphine carries enough energy to ignite the active carbon bed.
- The active carbon will only stop burning if the flow of air is shut off completely.
- Temperatures in excess of 1000°C are to be expected.

Containment of Uncontrolled Gas Leaks

Dry Bed (Chemisorber) Emergency Absorber



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Features:

- High air extract flowrates, protection of multiple gas cabinets
- Scrubbing capacity for full gas cylinder and high airflows
- No electrical connections
- Typical 5 years service life between absorber refills
- Replenishment with fresh absorber on customer site
- Gases and filling media depend on customer activity:



**AsH₃, BF₃, Br₂, Cl₂, ClF₃, COCl₂,
F₂, HCl, HF, HBr, H₂S, H₂Se, HCN,
NH₃, N₂H₄, PH₃, SO₂**

Containment of Uncontrolled Gas Leaks

Emergency Absorbers– Installation Examples



- In this photo: CP1000SF model
- Installed on roof of factory which manufactures LED (light emitting diodes)
- 4 x cylinders: **NH₃ (ammonia)**
- Air extract to be handled: 2000 m³/h
- Designed to remove 25 kg NH₃ during an emergency release situation

Containment of Uncontrolled Gas Leaks

Emergency Absorbers– Installation Examples



- In this photo: CP500SF model
- Installed outdoors at rear of gas cylinder bunker
- 2 x cylinders: **ClF₃ (chlorine trifluoride)**
- Air extract to be handled: 800 m³/h
- Chlorine trifluoride is highly oxidizing as well as highly toxic. It is used for cleaning chemical vapor deposition chambers in semiconductor manufacturing

Containment of Uncontrolled Gas Leaks

Emergency Absorbers— Installation Examples



- In this photo: CP500SF model
- Hooked up to 2 gas cabinets:
- **B₂H₆ + PH₃**
- Air extract to be handled: 1700 m³/h (980 cfm)
- Can scrub full contents of gas cylinder
- Installed on facility roof
- Lifetime: 5 years between refilling if no emergency absorption of toxic gas

Containment of Uncontrolled Gas Leaks

Emergency Absorbers– Installation Examples



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- In this photo: CP1000SF model
- Gas cabinets: **AsH₃** and **PH₃**
- Can handle airflow of 3600 m³/h (2120 cfm)
- Can scrub full contents of gas cylinder
- Installed since 2001
- Lifetime: 5 years between refilling if no emergency absorption of toxic gas

SUMMARY



- Gas delivery systems have somewhat different requirements than point of use abatement systems
- Work with your Engineering, EHS and Consultants/ Professional Engineering teams to do a proper risk assessment
- Be safe in everything you do



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THANK YOU

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