Pressure Safety

Health, Safety & Environment Department

Course Content

Part I
- Basic Pressure Concepts
- General and Specific Hazards associated with High Pressure Systems

Part II
- Hazards Control Principles / Safety Precautions
- Statutory Requirements

Part III
- Safety with Compressed Gas Cylinders

Part IV
- Specific Pressure Systems

Cryogenic Gas Containers

Oxy-flame Welding

Boilers/Pressure vessels

Autoclaves

Hydraulic System

Vacuum apparatus

Part I

Basic Concepts

- What is pressure?
- How do we measure pressure?

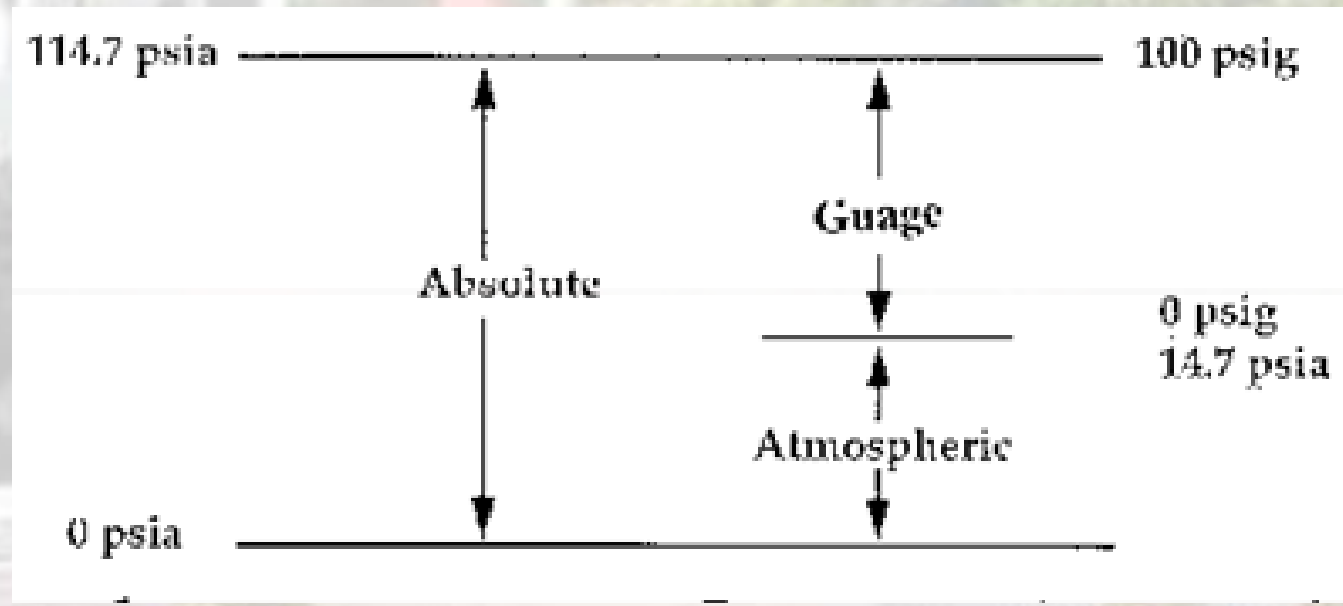
Pressure = Force/Area

Force = Pressure x Area

Pressure Terminology

- Atmospheric Pressure
- Gauge Pressure
- Absolute Pressure = **Atmospheric + Gauge Pressure**

Atmospheric Pressure
= 1 atmosphere
= 1 bar
= 14.5 psia
= 100 kPa abs

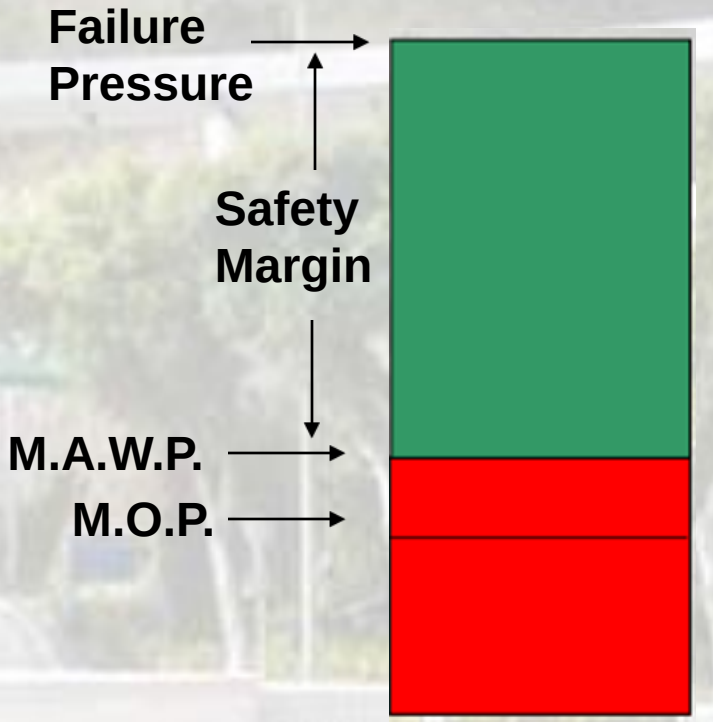


Pressure Terminology

- **M.A.W.P.** （Maximum allowable working pressure）
  → Relief Device Setting
- **M.O.P.**（Maximum Operating pressure）
  → 10% - 20% below M.A.W.P.

Safety Factor = Failure Pressure / M.A.W.P.

→ Manned Area = 4
→ Remote Area = less than 4
(with management approval)



General Gas Law

Relationship of :

Pressure - Temperature – Volume

The equation :

$(PV)/T = \text{Constant}$ $(P1V1)/T1 = (P2V2)/T2$

Real Life Situation 1

- A 10 ft3 cylinder of dry nitrogen is received from a vendor. The temperature of the nitrogen is 25 deg. C. and the pressure within the cylinder is 2250 psig.
- An employee inadvertently stores the cylinder too close to a radiator so that within 8 hours the nitrogen is heated to 80 deg. C.
- What is the pressure build-up within the cylinder?

Calculation:

P1=2250+15=2265psia
V1=V2=constant T1=25+273=298K
T2=80+273=353K
P2=(2265)(353)/(298) =2683psia= 418 psi increase

Real Life Situation 2

If the nitrogen cylinder leaks and the nitrogen is released to the atmosphere, what volume will the released gas occupy?

Calculation:

P1=2265 psia V1=10 ft3
T1=T2=constant P2=15 psia
V2=(2265)(10)/(15) = 1,510 ft3 = 151 times expansion

High Pressure Hazards

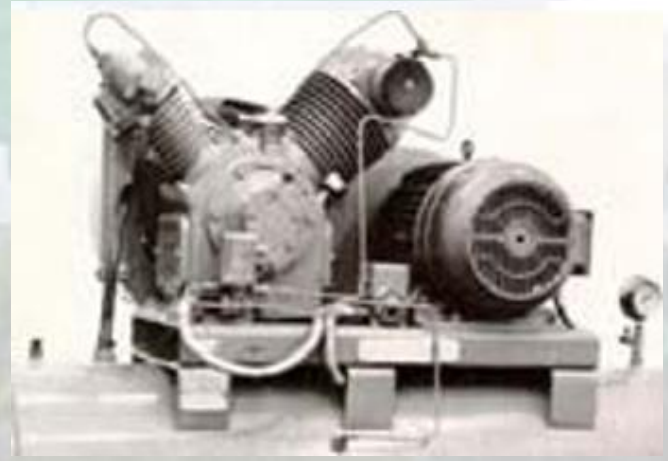
General Hazards vs. Specific Hazards

-Common to all pressure systems

-Caused by over-pressurization

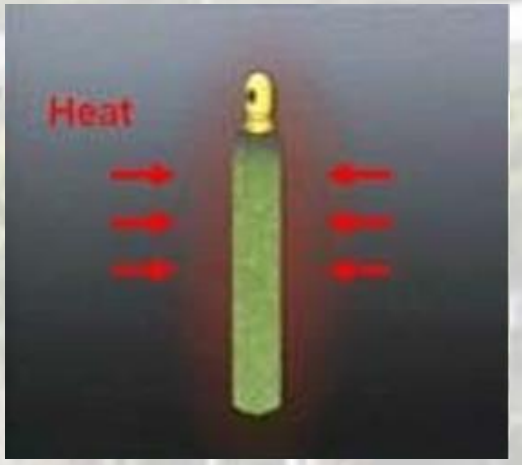
High Pressure Hazards

Over-pressurization may occur under any of these circumstances:



Compressing air /gas by a compressing device, e.g. compressor, pump.

Pressurizing container from a “high pressure” source



Heating air/ gas / liquid in a closed container

High Pressure Hazards

- Blast Effect
  -Shock wave caused by
  -Release of stored energy

- Fragmentation Effect
  Case Scenario
  The cooling coil of an a/c system exploded when being pressurized.

A piece of copper tube was blown off and stabbed a technician to death.


眼科醫院冷氣系統爆炸
銅管飛脫插死一技工

-Impact
-Copper pipes can fly out like a spear

Stored Energy

What is stored energy?

- When a gas or liquid is compressed into a container, energy is stored.
- When the container fails, the stored energy will be released, and (depending on the mode of failure) may create devastating shock waves, causing injuries and damages of varying degrees.
- Stored energies in compressed gases are much greater than compressed liquids.

Stored Energy Calculations

Stored Energy for Gas

- ***A function of Volume and Rupture Pressure***
- **$E_{gas}=[P1V/(r-1)]\,[1-(P2/P1)^{(r-1/r)}]$**

Egas : stored energy of gas in Joules
P1 : container pressure in MPa
P2 : atmospheric pressure = 0.1 MPa
V : volume of container in ml
r : 1.41for N_2, H_2, O_2 and air; 1.66 for He

(Reference from US DOE Pressure Safety Guidelines)

Stored Energy Calculations

Work Example for Compressed Gas:

- Calculate the Stored Energy of a 280 liters cylinder containing nitrogen which fails at 41 Mpa (approx. 6000psig).

  V = 280 l
  P1 = 41 MPa P2 = 0.1 MPa
  By applying the Equation
  Stored Energy = 23.6 MJ

Stored Energy Calculations

Stored Energy for Liquid

- **$E_{liq} = 1/2 (P1^2 V/B)$**

Eliq : stored energy for liquid in ft.lb.

x 1.356 = joules

V : volume of container in in3
B : liquid bulk modulus
water = 300,000 psi Oil = 225,000 psi

Effect of Energy Release

- Result in shock wave when stored energy is released.
- Magnitude of shock waves/over-pressure is a function of:
  -Stored energy
  -Distance from pressure container (free air blast)
  -Size and configuration of room in which the pressure container is located

Specific Pressure Hazards

Loss of Containment of Hazardous Content

Specific Pressure Hazards

Whipping of Hoses/Lines (Dislocation)

Reactive forces at nozzles caused by fluid moving out.

If forces large enough, they can cause the nozzle and the hose to move or whip.

Case Example
Flexible hose of pneumatic breaker detached. The hose whipped Violently and struck the worker

Specific Pressure Hazards

Ejecting Liquid (Hydraulic system)

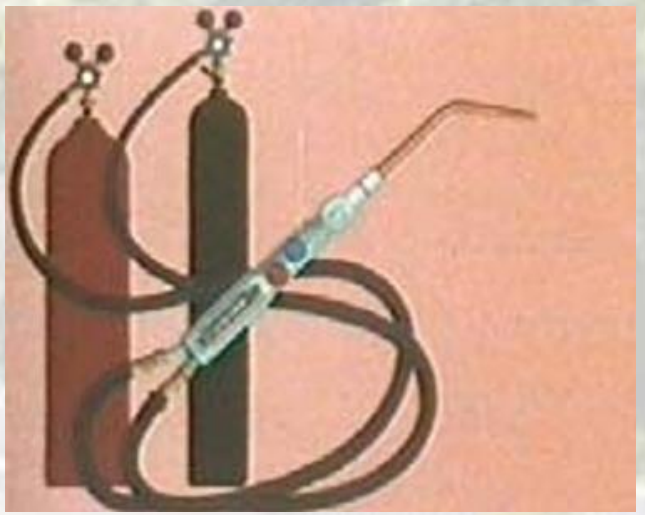
High velocity liquid stream can cut like a sharp knife.


吊臂脫壓力喉「油箭」亂射
過路汽車毀窗傷司機

<u>Case Example</u>
The hydraulic drum of a crane-truck leaked while lifting a load. Hydraulic fluid ejected out and hit the windscreen of a passing-by vehicle. The windscreen of the vehicle was shattered as a result.

Specific Pressure Hazards

Flashback (flammable gas cylinders)
- Flame burns into the cylinder



Hazards at Low Pressure

- We don’t need a high pressure to cause a serious accident
- We should also be aware of the possible hazards inherent in relatively low-pressure systems

Hazards at Low Pressure

Case Example

A garage mechanic used compressed air from an air receiver to drive diesel oil out of a drum. The drum bursted and hit him on the head. He was seriously injured.

What went wrong in this incident ??

Hazards at Low Pressure

Calculation of Force:

Total Force = Pressure x Surface Area

Total area of end plate:

1.52x3.14 = 7.065 ft2 = 1017 in2

Total Force at end plate:

PA = 100x 1017= 101700= 45 tons.

Part II

Hazards Control Principles
Safety Measures
Statutory Requirements

Control Principles

- **Engineering Controls** ← Preferred first choice
- **Administrative Controls** ← To ensure appropriate engineering controls are in place and to supplement areas not addressed by engineering controls
- **Statutory Controls**
- **Codes and Standards**

Determined by Risk Assessments

Engineering Controls

- **Adequate design/construction/ materials**
- **Safety devices**
- **Barrier/ Enclosure/ Segregation**

Engineering Controls

- **Adequate design/construction/ materials**

  -Documents to certify design and construction process are up to safety standard

  -A legal requirement for pressure vessels to be certified

- **Safety devices**

  -Pressure relief devices

  -Pressure sensing and control devices

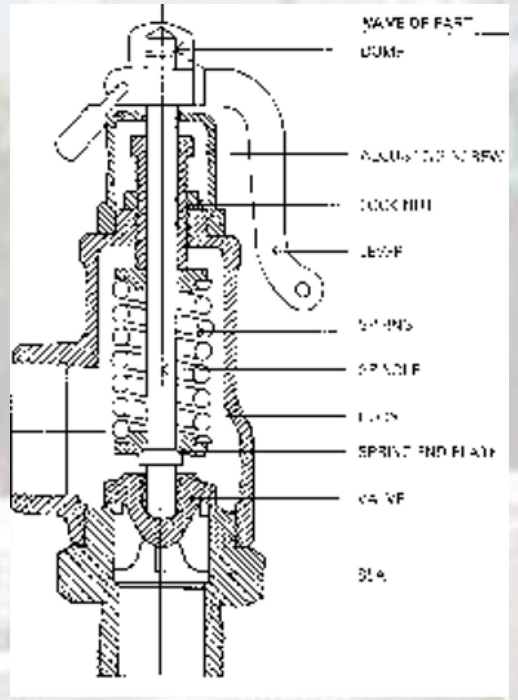
  - Temperature sensing and control devices

- **Barrier/ Enclosure/ Segregation**

Types of Pressure Relief Devices

Spring loaded pressure relief valve

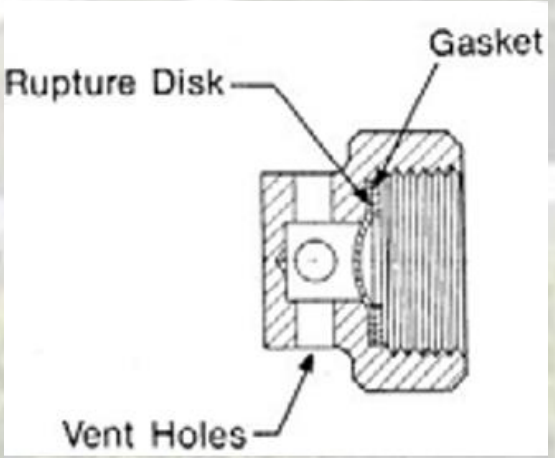
- pressure adjustable
- can be tested



Rupture Disc:

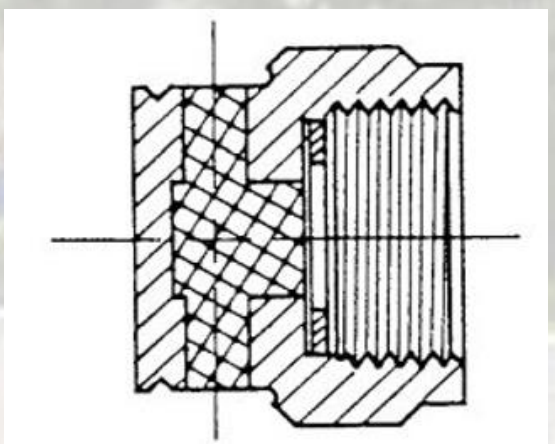
-Fixed pressure setting only

-Non-destructive test not feasible



Fusible Plug:

-The fusible plug will melt (e.g. in a fire) at a specific high temperature to release the pressure inside the system



Spring loaded pressure relief valve

Can only be set by an Appointed Examiner

The Pressure Relief Valve should be sealed by the Approved Examiner after setting has been made.

Administrative Controls

- **Risk assessments**
- **Operation Safety Plan (OSP)**
- **Safety Rules and Procedures**
- **Maintenance and Repairs**

Risk Assessment

The following factors have to be considered in risk assessment:

- **<u>Hazards of Pressure</u>**
  -Size of container and Pressure range
  -Stored energy
  -Shock wave to be generated when the system fails

- **<u>Hazardous nature of Contents</u>**
  -Temperature
  -Exposure (People etc.)

- Is the system remote?
- Is it manned?
- How many people will be exposed?

Risk Assessment

Control Measures:

-Ensure adequate design/ materials/ construction
-Check documents / calculations
-Arrange certification by competent examiners
-Install appropriate pressure relief valves
-Pressure/ temperature control devices
-Install enclosure/ shielding
-Limit no. of people exposed and distance
-Establish safety procedures/arrangements

Common Safety Requirements for Installing Pressure Vessels

- Markings displayed showing max. allowable working pressure
- Protected against overpressure by appropriate safety relief valves and pressure control sensors.
- Connected piping should be installed with due consideration of expansion and contraction effects on the vessels and piping, and to reduce nozzle connection stresses.
- Component properly supported to ensure that the weight is uniformly distributed to prevent bearing stress & avoid local yielding or cracking.
- Adequate clearance from ground to minimize corrosion from moisture
- Adequate clearance around the pressure vessel for inspection maintenance and repairs
- All welded seams should be accessible for external inspections
- Access openings, inspection holes, gauges, markings and safety valves should be accessible at all times
- Suitable access platforms for inspections and maintenance should be provided as necessary

Part III

Safety with Compressed Gas Cylinders
Safety with Cryogenic Gas Containers
Safety with Oxy-flame Welding

Compressed Gas Safety

How Gases are Stored Inside Cylinders

- **Compressed**
  -about 2000 psi
- **Liquefied**
  -LPG
  -Cryogens
- **Dissolved**
  -Acetylene

Hazards Associated with Gas Cylinders

- **Rupture of cylinder due to overpressure**
  -rise in temperature
- **Cylinder valve knocked off**
  -Cylinder valve ejected like a missile.
- **Leakage of gas/ hazardous content**
- **Contamination**
  -incompatible gases
  -grease and oil mixed with oxygen
- **Using the wrong type of gas**
- **Tipping**
- **Flashback**

The Cylinder

- Regular inspection
- Marking
- Labeling -- type of gas
  《气瓶安全技术规程》（TSG 23-2021）
- Colours
  《气瓶颜色标志》（GB/T 7144-2016）
- Status Tag

表 9-1　气瓶定期检验周期

气瓶品种		介质、环境		检验周期(年)
钢质无缝气瓶、钢质焊接气瓶(不含液化石油气钢瓶、液化二甲醚钢瓶)、铝合金无缝气瓶		腐蚀性气体、海水等腐蚀性环境		2
		氮、六氟化硫、四氟甲烷及惰性气体		5
		纯度大于或者等于 99.999%的高纯气体(气瓶内表面经防腐蚀处理且内表面粗糙度达到 *Ra*0.4 以上)	剧毒	5
			其他	8
		混合气体		按混合气体中检验周期最短的气体特性确定(微量组分除外)
		其他气体		3
液化石油气钢瓶、液化二甲醚钢瓶	民用	液化石油气、液化二甲醚		4
	车用			5
车用压缩天然气瓶		压缩天然气、氢气、空气、氧气		3
车用氢气气瓶				
气体储运用纤维缠绕气瓶				
呼吸器用复合气瓶				
低温绝热气瓶(含车用气瓶)		液氧、液氮、液氩、液化二氧化碳、液化氧化亚氮、液化天然气		3
溶解乙炔气瓶		溶解乙炔		3

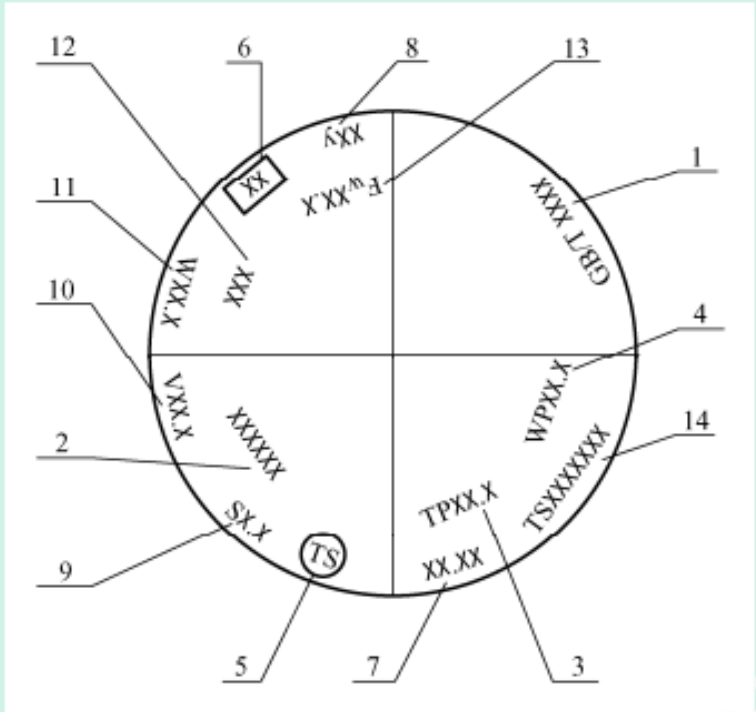


图 D-3　气瓶制造钢印的项目和排列

表 D-1　气瓶制造钢印标志的项目和含义(注 D-3、注 D-4)

编号	钢印项目(例)	含义
1	GB/T ××××	产品标准号(注 D-5，下同)
2	××××××	气瓶编号
3	TP××.×	水压试验压力，MPa
4	WP××.×	公称工作压力，MPa
5	TS	监检标记
6	××	制造单位代号
7	××.××	制造日期

表 D-1(续)

编号	钢印项目(例)	含义
8	××y	设计使用年限，y
9	S××.×	瓶体设计壁厚，mm
10	V××.×	实际容积，L
11	W××.×	实际重量，kg
12	×××	充装气体名称或者化学分子式
13	Fw××.×	液化气体最大充装量，kg
14	TS××××××	气瓶制造许可证编号

注 D-3：溶解乙炔气瓶及焊接绝热气瓶除外。

Status Tag
Full?
In-use?
Empty?

General Safety Practice

- Storage
- Transportation
- Operation (Use)
- Inspection / Maintenance and Care

《气瓶搬运、装卸、储存和使用安全规定》（GB/T 34525-2017）

Storing Gas Cylinders

Common Precautions:

- Stored in cool, dry and well-ventilated places
- Returned to DG stores when not used
- Kept from sources of ignition and excessive heat
- Stored upright and secured from falling by chains and straps
- Not placed where objects may strike or fall on them
- Not placed where emergency escape will be impeded
- Incompatible gases not stored together
- Properly labeled to indicate content
- Empty cylinders should be marked and separated from full ones.

Transporting Gas Cylinders

General Precautions:

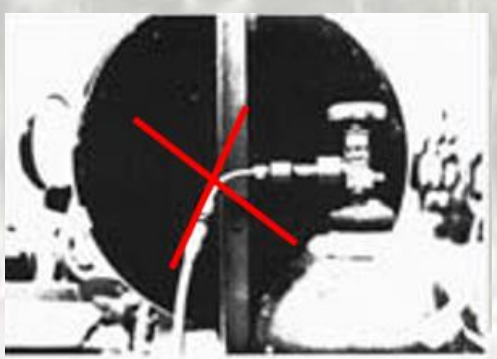
- Always shut off the valve before moving
- Do not drag, roll or slide cylinders
- Use proper trolleys or carts for transporting cylinders for long distances
- When moved by crane, hoist or forklift, cylinders must be securely placed inside a cradle or platform and securely tied with chains or ropes
- Cylinder valves should be protected with caps (if provided) during transportation
- Never drop a cylinder or permit cylinders to strike each other violently
- Wear proper personal protective equipment (e.g. gloves, safety shoes) when moving cylinders

Use of Gas Cylinders

- Before Use
- During Use
- After Use
- Inspections, Maintenance & Care

Before Using Cylinder

- Never accept or use a leaking cylinder
- Check the label to make sure the gas is the one you want
- Do not rely only on the colour of cylinder, if in doubt-ask
- Never use gas without label of type of gas
- Know the "material safety data" of gas you use
- Check to ensure the regulator and pressure gauges are of the proper types. CYLINDERS MUST NOT BE USED WITHOUT AN APPROPRIATE REGULATOR
- Check to ensure hoses/ tubes are appropriate types of sufficient pressure ratings and securely connected
- Never force fit regulators or fittings to cylinders



Before Using Cylinder

- Do not force open cylinder valve. Return cylinder if valve cannot be opened by turning hand wheel or using valve key
- Gases must never be mixed inside cylinder
- "Reverse flow check valves" and "flashback arresters" must be fitted for each gas cylinder whenever an oxidizer and a flammable gas are used
- Never strike an electric arc or direct a flame at a cylinder, or make a cylinder as part of an electric circuit

Flashback Arresters

After Using Gas Cylinder

- Close cylinder valves when not in active use
- The gas in the bottle should not be used up, excess pressure should be left.
  香港科技大学（广州）《实验室气瓶安全管理规定》
- Close cylinder valves for empty cylinders to prevent contamination
- Empty cylinders should be labeled

Inspections/ Maintenance & Care

- Inspect gas cylinders regularly for obvious signs of defects, deep rusting or leakage
- NEVER use a flame for testing leaks. Use proper leak test solution
- Cylinders, cylinder valves, couplings, regulators, hoses and apparatus must be kept free of oily or greasy substances. THIS IS IMPORTANT ESPECIALLY FOR OXYGEN. Not observing this may result in EXPLOSION

Clean grease from hands

Regulators and Pressure Gauges

- Use only the right type of regulators and gauges. They are not interchangeable for certain types of gases (graduated to at least one and a half times MAWP)
- Regulators and Gauges for other gas cylinders must not be used interchangeably with oxygen cylinders.
- Store and handle regulators and fittings carefully to avoid contamination with oil and grease.
- Fittings and tubings which contain copper must not be used for acetylene gas cylinders.

Connecting & Operating Regulators

Safety With Cryogens

Cryogenic Liquids

- Liquefied gases stored inside containers at extremely low temperatures

- Gases commonly found in liquid form include:
  -Nitrogen
  -Oxygen
  -Helium
  -Argon
  -Carbon Dioxide

Physical Characteristics

Extremely low temperature
High Expansion Ratios

Cryogens	Boiling Points ^{o}C	Expansion Ratio
Carbon Dioxide	-78	553:1
Oxygen	-183	860:1
Argon	-185	847:1
Nitrogen	-196	696:1
Hydrogen	-253	851:1
Helium	-269	757:1

Cryogenic Hazards

- Potential pressure buildup
- Cold burns
- Oxygen deficiency
- Oxygen enrichment
- Fire/ Explosion
- Back injury

Preventing Cold Burn

- **Wear appropriate attire and PPE**
  -Wear cuffless trousers over boots
  -Face shield / Goggles
  -Thermal Insulated (loose fitting) gloves
  -No sneakers
- **Handle with care**

Treatment on Cold Burn

- Un-tight covering clothing
- Do not rub frozen parts
- Wash with warm (not hot) water
- Cover frozen parts with dry sterile dressing.
- No alcohol or cigarette for patient
- Send patient for medical attention as soon as possible

Preventing Asphyxiation

- Cryogens flash to very large gas quantities and will displace air

- Good ventilation
- Avoid low places, confined spaces, air intakes
- Oxygen monitoring as required

Oxy-Acetylene Welding Safety

General Hazards & Precautions

Hazards

- Fire and Explosion
- Flashback

Precautions:

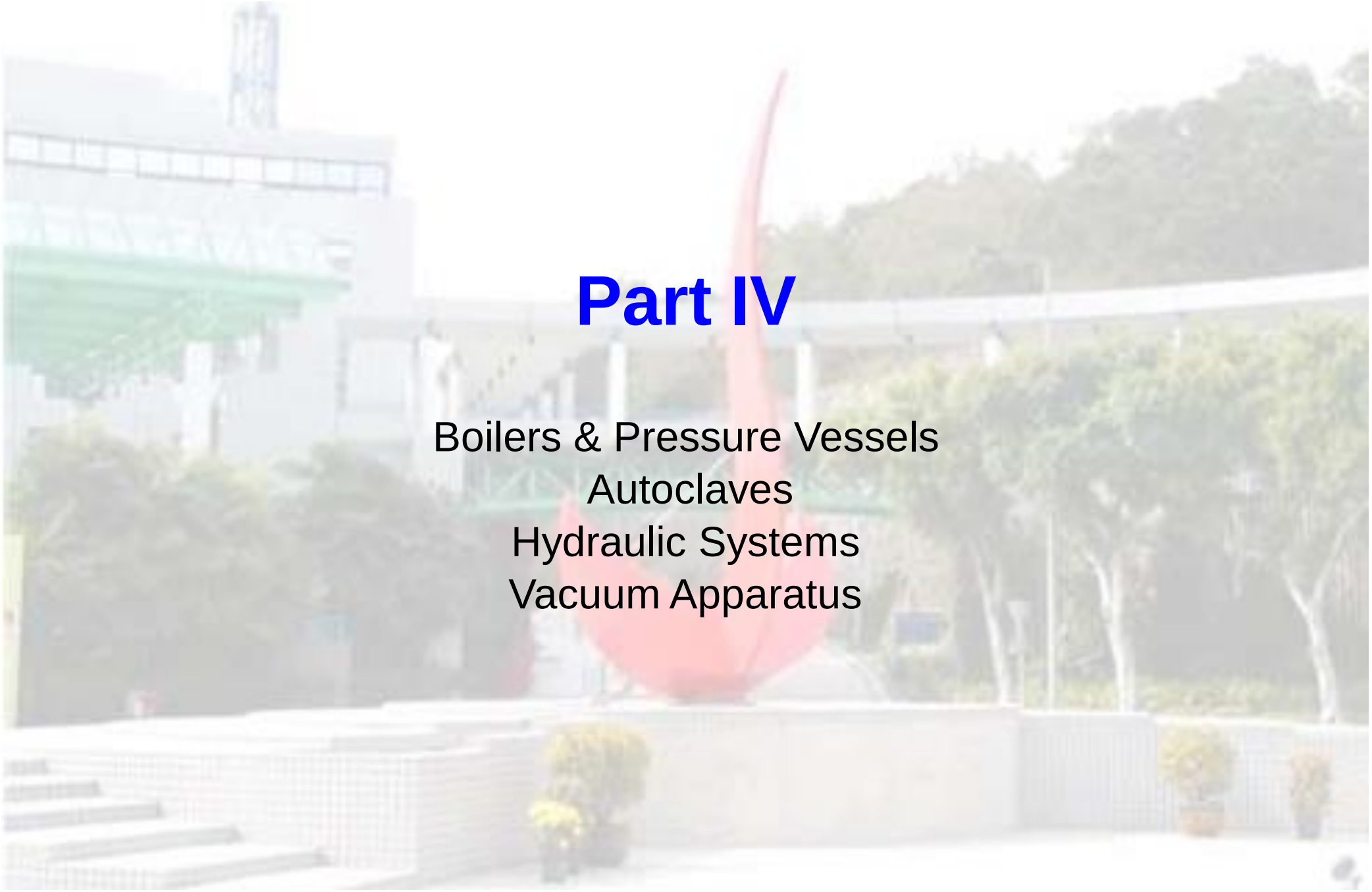
- Cylinders must be kept upright, especially for acetylene cylinder
- Fittings and piping containing copper must not be used for acetylene gas cylinder to prevent formation of explosive compounds
- Gaseous acetylene under pressure may decompose with explosive force.
- Install flashback arresters at the outlets of the acetylene and oxygen cylinders

Safe Operating Procedure for Oxy-acetylene Welding

- Blow out cylinder valves before attaching the regulators to cylinders (for approx. 1 sec.)
- Release regulator adjusting screws before opening cylinder valves
- Stand to one side of regulator before opening cylinder valve
- Open cylinder valve SLOWLY

Safe Operating Procedure for Oxy-acetylene Welding

- Purge oxygen and acetylene gas passages individually before lighting the torch (to get rid of foreign gases and set regulator pressure while the gas is flowing)
- Light acetylene before opening the oxygen valve on the torch
- Turn on oxygen valve slowly to adjust the flame
- Never use oil on regulators, torches, fittings, or other equipment in contact with oxygen
- Make sure all hose, cylinder, and regulator attachments are tight and not leaking
- Keep heat, flame, and sparks away from hoses, regulators, tanks, and combustibles



Part IV

Boilers & Pressure Vessels
Autoclaves
Hydraulic Systems
Vacuum Apparatus

Boilers

Fossil Fuel Boiler

Steam Generator

Definition:

- Closed vessel in which steam is generated under pressure greater than atmospheric pressure

Hazards:

- High pressure
- High temperature steam

Safety Requirements:

- All boilers need to be carefully examined and certified by Appointed Examiners before use, and do the external inspection annually
  《锅炉定期检验规则》（TSG G7002-2015）
- Operated by Competent Persons
- 《锅炉使用管理规则》（TSG G5004-2014）

Air Receivers

- Any vessel for containing compressed air and which is connected with an air compressing plant

Air Receiver

Pressure Relief Device

Safety At Autoclaves

Operates at elevated Temperatures and Pressures

Specific Hazards:

- Explosive displacement of door by residual pressure when door not properly secured
- Explosion of sealed glass containers
- Scalding

Safeguards for Autoclaves

- Proper design, construction & sound materials
- Safety Devices
  -Pressure relief device
  -Interlocking devices for doors (for pressure and temperature) for higher pressure/temp. types.
  -Safety catch at door
  -Proper pressure and temperature indication device
- Suitable drains
- Warning notice and procedures
- Training of operators
- Examination and Maintenance

Hydraulic Hazards

- Shock wave of compressed liquid
- Piercing effect of high velocity leaking liquid
- Whipping of flexible hydraulic lines
- Fire hazard when hydraulic liquid with lower flash points is used
- Mechanical hazards of closing parts

Precautions for Hydraulic Hazards

- Proper design, materials and construction
- Protection of pipe lines from damage
- Fix "Hose strap" to restrain whipping motion of flexible hose when dislocation occurs
- Pressurize pipe lines and equipment in stages
- Segregate work area and post warning signs
- Frequent inspections for damages

Hose Strap

VACUUM SAFETY

- Negative Pressure
- Implosion

Vacuum Hazards

- Cuts by glass fragment
- Chemicals splash when container implodes
- Chemical injection caused by contaminated glass fragment

Precautions for Vacuum Hazards

- Use container with sufficient strength (spherical surface is stronger than flat surface)
- Avoid use of glass container if practicable
- Provide shielding for fragile containers. Fumehood can be regarded as an effective shielding (with sash lowered)
- Wear face shield and eye protection in critical situations

Remember: The larger the surface area, the larger the force to withstand

Reference

- 《中华人民共和国特种设备安全法》（2013年版）
- 《气瓶颜色标志》（GB/T 7144-2016）
- 《气瓶搬运、装卸、储存和使用安全规定》（GB/T 34525-2017）
- 《气瓶安全技术规程》（TSG 23-2021）
- 《锅炉使用管理规则》（TSG G5004-2014）
- 《锅炉定期检验规则》（TSG G7002-2015）
- 香港科技大学（广州）《实验室气瓶安全管理规定》