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Asia Industrial

Gases Association

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Oxygen Ignition Mechanisms and Industry Incidents 氧氣點火機制及工業意外

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劉忠良先生現職擔任亞東工業氣體(股)公司安全,衛生暨環保資深協理. 主要負責亞東氣體安全衛生環保相關事項之系統管理及督導,風險管理及工業 稽核.

劉忠良亦曾經管理過亞東氣體操作運轉,專案及設備安裝…等等業務.

劉忠良先生畢業於中原大學機械系,工業安全技師高考合格並具有法 液空集團電子事業安全衛生及風險管理國際專家之資格.

Henry LIU is currently ALFE Health, Safety and Environment senior Director, responsible for HSE activities supervision and management, Risk Management and Industrial Audit.

He had previously led and supervised ALFE Industrial Operation and Project Implementation Department.

Henry graduated from Chung Yuan University with major in Mechanical Engineering. He holds the Taiwan Industrial Safety Professional Engineer Certification and is also an AL Group International expert in electronic business safety and risk management.

1. Temperature effect 溫度效應

• Temperature of oxygen systems 氧氣系統之溫度

Most oxygen systems operate at nearly atmospheric temperature. If an oxygen system operates at a higher temperature, an ignition is more likely to occur 大多數氧氣系統均操作於大氣溫度,若操作於高溫將有可能被點燃.

• Auto Ignition temperature of materials 材料之自燃溫度

- The Auto Ignition Temperature (AIT) is the temperature at which a product begins to burn when placed in an oxygen atmosphere at 120 bar 自然溫度是將材料置於120bar之氧氣中開始燃燒之溫度.
- Characteristics of non metallic materials: see Excel file 非金屬材料之特性: 請叁考Excel file
- When the AIT of a product is too low, the product is not considered compatible for oxygen service as it can easily burn



若產品之自然溫度太低,因爲非常容易燃燒,所以不適合用於氧氣操作服務

- Use only products which are compatible with oxygen 只使用與氧氣匹配之材料
- When replacing a gasket, an O-ring, never change its type 勿隨意更換墊片及O型環



AIT of plastic materials

NI 396														
Symbol	name	P lastic or E lastomer	PRODUCTS NAMES	SPONTANEOUS IGNITION TEMPERATURE	HEAT OF COMBUSTION cal/g	OXYGEN INDEX	CHEMICAL COMPATIBILITY						Limits of	Hardness
							Data from	Oxygen	Nitrogen	Nitrous oxide	Fluorine and HF	Carbon dioxide	Temperature °C	shore
PTFE	polytetrafluoroethylene	Р	Teflon - Hostaflon - Neoflon (*)	450 - 500 °C	1526	95-100	CTE tests	С	С	С	C if P<1 bar and ambiant	C but permeation	-200/+260	50/56 D
PCTFE	polytrifluoromonochloroethyl ene	Р	Kel'F - Voltalef - Dyneon	420 °C	1476-2300	95-100	CTE tests	С	С	С	C if P<1 bar and ambiant	С	2	80 D
ETFE	ethylene tetrafluoro-ethylene	Р	Tefzel	245°C	3514	30	STP 1395 p98						150	
PVDF	polyvinylidene fluoride	Р	Kynar	268-294°C	3277-3533	39-44	various	С	С				-10/+150	80 D
FFKM	perfluoroelastomere	E	Kalrez	350 - 380°C	1565-2090	100	various	С	С		type 4079 = C		-50/200 - 316?	60-90 A
FPM ou FKM	fluoroelastomere	E	Viton	290 - 350 °C	1963-3600	22-80	CTE tests + STP 1454 p25	С	С	NC		NC	-50/+200	60-90 A
PEI	polyetherimide	Р	Ultem 1000	440 °C		47	CTE tests	С		increase in weight : + 9% - reduction in hardness 10%		С	-50/+170	90 D
PPS	polyphenylene sulfide	Р	Ryton	438 °C	6853	46	various						-30/+220	90 D
PMMA	polymethylmethacrylate	Р	Plexiglas	430°C	6000	15-21,5	PrEN 13159 + STP 1454 p25							
PSU	polysulfone	Р	Ultrason S2000	404 °C		30-51	various						-100/+160	74 D
PES	polyethersulfone	Р	Victrex 4100	398 °C	7521	38	CTE tests	С		reduction in hardness (6%)		reduction in hardness (7 %)	-10/+180	82 D
PI	polyimide	Р	Vespel SP 1 - Kinel	350 °C	5970-7610	36-65	various						?/260	
PAI	polyamide-imide	P	Torlon 4203	324 °C		44-52	CTE tests	C		C		C	-196 ?/+230	88 D
PEEK	polyetheretherketone	Р	PEEK 450 G	338 °C	7775	35	CTE tests	reduction in hardness (10%)		С		С	-65/+250	88 D
PC	polycarbonate	P	Makrolon	300-315°C	?	22,5-44	PrEN 13159							
NBR	nitrile rubber	E		173-310°C	5400-8500	17-22	PrEN 13159 + STP 1454 p25							
MQ	silicone - polysiloxane	E	Silicone	270 - 325 °C	4155	21-45	CTE tests + STP 1454 p25	C usually	С	С		C but permeation	-70/+200	30-80A
PUR	polyurethane	E/P	Vulkollan - Urethanne	181-246 °C	6510	26-29	CTE tests	С	С	С		С	-50/+90	75/95 A 51/69 D
TPE or TEEE	thermoplastic polyester elastomer	E/P	Hytrel - Lomod	da	ta depending on type			С					data depending on type	30/82D
EPDM	ethylene propylene	E		159 - 220 °C	9220-11300	17-26	various	С	С	С		С	-40/+120	40/90 A
РОМ	polyacetal - polyoxyméthylène	Р	Delrin	200-210°C	?	14.2	PrEN 13159							
PA 6-6	polyamide	Р	Nylon / Zytel	200 - 220 °C 250 - 300°C	7500-8842	19-30	CTE tests	С	С	C risk of swelling for		C but plastifiants ???	-65/100	74/83 D
CR	chloroprene - neoprene rubber	E		175-190°C	3000-9000	17-26,3	PrEN 13159 + STP 1454 p25							
PE	polyethylene	Р	numerous	181°C	11100	17,5-30,2	various							
PP	polypropylene	Р	numerous	150-160°C	11000	17,4-29,2	PrEN 13159							
РРО	polyphénylène oxyde	Р	Noryl			22-33	STP 1454 p25							
ABS	Acrylonitrile Butadiène Styrène	Р				16-18	STP 1454 p25							

(*) Italic red, non suitable for "breathable

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C : compatible

use"

NC : not compatible



2. Adiabatic compression effect: combustion of a flexible hose 絕熱壓縮效應:使軟管燃燒



- When opening a valve, the gas downstream (if contained in a closed space) is quickly compressed. An almost adiabatic compression is created and heats the gas (like in a pump used to inflate tires) 開高壓鋼瓶閥太快,下游之閥若是關閉將會產生類似絕熱壓縮,氣體將會 快速增溫.(類似使用幫浦將輪胎充氣)
- For a circuit passing from 1bar to 200bar, the temperature theoretically reached can be as great as 1000°C 從1bar加壓至 200bar, 溫度將可能高於1000°C
- This temperature is above the AIT of all plastic materials 高於所有非金屬材料之自燃溫度.
 - Always open valves slowly 慢慢開閥
 - Use validated flexible hoses 使用認證合格之軟管
 - Use validated high pressure oxygen equipment 使用認證合格之高壓氧設備

3. Adiabatic compression effect: explosion of a pressure gauge 絕熱壓縮效應: 壓力表爆炸





 The block on the picture comprises a connection to the cylinder valve, a pressure gauge and a small flow valve

照片內包含與鋼瓶閥連接之壓力表及小流速閥

• This block is used to check the pressure and analyse the gas in cylinders. It is fixed on the cylinder valve

用來檢查鋼瓶壓力及分析氣體,是固定於鋼瓶閥上.

• When the valve is opened, the pressure gauge catches fire

壓力表於開啓後著火

- The stainless steel filter burns 不銹鋼過濾器燃燒
 - Open cylinder valves slowly 慢慢開閥
- Use a gauge for oxygen service 使用適合氧氣使用之壓力表
- Use a filter in copper or nickel alloys 過濾器使用銅或鎳合金
- Keep the whole system clean 保持系統潔淨





4. Particle impact effect: fire in an elbow 粒子衝擊效應: 彎管著火

- At the commissioning of a plant, when introducing oxygen in the piping, a jet fire occurred 試車期間,將氧氣導入管路時發生噴射 火焰.
- The main damages were apparent at an elbow
 - 主要損傷位於彎管
- The incident was caused by particles remaining in the pipeline after welding
 金林見田奈旭校後豫砚之顧時洗法式
 - 意外是因爲焊接後殘留之顆粒造成.
- An ignition occurred in the elbow, burning the stainless steel 顆粒衝擊彎管產生燃燒而將不鏽鋼燒 毀.



 A procedure for cleaning the system from all contaminants and particles must be implemented before introducing oxygen 清除所有汙染物及顆粒之清潔程序於系 統導入氧氣前必須完成.



5. Flow friction effect: fire at filling using a quick connector 流體摩擦效應: 灌充快速接頭著火



- A leak occurs at end of filling 灌充完後發生洩露
- The quick connector catches fire 快速接頭著火
- Velocity of gas is sound velocity and creates a friction on the damaged gasket 氣體洩漏速度爲音速並於損傷之墊片產生摩擦
- The damaged gasket catches fire 墊片著火
 - Avoid leaks避免洩漏
 - Keep gaskets in good condition 保持墊片完整
 - More generally: Never dismount a flange of an oxygen circuit under pressure 於壓力下切勿拆氧氣接頭



6. Impact and contamination effects 撞擊與汙染的效應

- A cylinder falls and hits the valve of another cylinder made of aluminium
 - 一支鋼瓶傾倒並撞擊另一鋁製鋼瓶的閥
- This last cylinder ruptures 鋼瓶破裂了
- Its valve burns 閥燒毀了
- The aluminium burns 鋁材質鋼瓶燃燒起來
- The cause of the accident is the combination of a shock on a full oxygen cylinder and the presence of non compatible grease in the parallel thread of the cylinder valve

此事故的原因是充滿氧氣的鋼瓶被撞擊及鋼瓶閥 螺紋平面上存在的油脂所共同造成的

- No grease on valve threads 禁止油脂在瓶閥的螺紋上
- Avoid parallel threads for aluminium cylinders in GOX 避冤氣態氧氣銘瓶使用平行的螺紋
- Avoid shocks on oxygen equipment 避免撞擊氧氣設備







7. Electrical energy: static electricity, electrical continuity 電氣能量:靜電,電位之連續性

- A cylinder exploded while being rolled to homogenize its oxygen rich mixture 當滾動鋼瓶以混合富氧的混合氣鋼瓶時,這鋼瓶爆炸了。
- The cylinder was not corroded internally 這鋼瓶內部並未被侵蝕。
- It was discovered that it was equipped with a dip tube in a plastic material 我門發現鋼瓶內部裝有塑化材質的浸入管.
- It is assumed that an electrostatic spark started the violent combustion of the dip tube in the 200 bar oxygen mixture leading to the explosion of the cylinder (friction of the dip tube on the cylinder wall might also be a possible cause of the ignition) 靜電的火花引起了浸入管dip tube 在 200 Bar 的氧氣混合氣鋼瓶內猛烈地燃燒,進而導致鋼瓶的爆炸(dip tube在 鋼瓶內的摩擦也可能是引起燃燒的原因)
 - No dip tube in a plastic material 禁止使用塑化材質的浸入管
 - For O2 and mixtures, use dip tubes in copper or Nickel alloys 針對氧氣及其混合氣,使用銅製或鎳合金的dip tube
 - Mark cylinders equipped with a dip tube 標示鋼瓶內有dip tube
 - Ensure electrical continuity between all parts of an equipment containing O2 or O2 mixture 確認在含有氧或氧混合氣的設備內所有零件間的電力的連續性

8. Kindling chain effect 引火鏈效應

- The AIT of metals is greater than 1300°C 金屬的AIT 是高於 1300°C
 - So, it is much more difficult to start a combustion with metals only 所以,這是更不容易讓金屬開始燃燒
 - An adiabatic compression is not sufficient to start burning metals
 絕熱壓縮並不足以使金屬開始燃燒
- Plastics have a low AIT, but don't easily dissipate heat 塑化材質的AIT較低, 但並不容易使熱能散失.
- The combustion of plastics can create enough localized heat to reach a temperature at which metals begin to burn

塑化材質的燃燒可以在小範圍內製造足夠的熱能來達到金屬燃燒時需要的溫度

- The combustion of metals depends on the metal and on the oxygen pressure 金屬的燃燒是依靠金屬及氧氣的壓力
- Metals may propagate a combustion initiated by plastic materials, grease, oil, dust, rust or other contaminants 金屬增殖性的燃燒可以由塑化物質, 脂肪, 油, 粉塵, 鐵銹或其他可燃物開始
- This effect of promoted ignition is called the kindling chain 這助長燃燒的效應稱為引火鏈效應
 - Stopping the kindling chain effect can only be done by design and material selection 阻止引火鏈效應的發生只能靠設計及材質的選擇
 - Use only oxygen validated equipment 使用只有氧氣適用的設備
 - Use oxygen validated spare parts from the equipment supplier使用設備供應商 處取得的氧氣適用的備品零件



9. Concentration effect: fire on a LOX trailer: 濃度效應:液態氧氣槽車火災



- A leak occurs on the feed line of the pump 洩漏發生在充填幫浦上的管路
- A fire occurs on the electrical box located in the trailer's rear gas cabinet 火災發生在槽車尾端後面的氣 體操作盤面上的電箱
- The tanker burns completely 槽體完全被燒毀
- Analyze the accident report 分析事故報告
- Find causes of the incident

找出事故之基本原因



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- The tanker burns completely 槽體完全被燒毀
- Driver must stay close to the tanker during filling to be able to immediately stop the pump 在充填時司機必須待在槽體附近以便能立即停止幫浦運作
- When possible shut-off the pump and LOX valves of the trailer and of the customer storage

有機會時去停止幫浦運轉, 關閉槽車上液態氧氣閥及客戶端儲存槽

• Do proper maintenance of LOX pumps to avoid leaks 適當的執行液態氧氣幫浦維護作業以避免洩漏發生



10. Concentration effect: fire of a homecare delivery van:

濃度效應:居家醫療運輸車的火災

- A homecare delivery van carrying medical liquid oxygen cylinders catches fire on a highway, blocking road traffic during several hours 一台裝載著液態醫療氧氣鋼瓶的居家醫 療廂型貨車在高速公路上著火了,阻礙了數小時的道路交通.
- The driver suffers burns to the scalp, a cylinder explodes, pin index values are expulsed on small cylinders 司機的頭皮遭到燒傷,一支鋼瓶爆炸,小鋼瓶上有指針的閥也炸飛.
- An oxygen enriched atmosphere is created in the van and material impregnated with oxygen ignites due to a spark or a flame 廂型貨車內形成了富氧環境,物質因爲火花或是火焰及氧氣而被點燃.
- A LOX cylinder had a liquid leak which had not been fixed 一個液態氧氣鋼瓶有液體洩漏而未被修復
- The driver was smoking in the cab 司機在駕駛座上抽菸
- No smoking in presence of oxygen 禁止吸煙
- Use dedicated ventilated vehicles 使用特定的通風運輸工具
- Segregate LOX and GOX containers

隔離液態氧氣與氣態氧氣產品

• Fix leaks 修復洩漏處





11. Inventory effect: fire on large size compressors and stations: 存量效應:大型壓縮機及基地火災

- Examples of fires on a large size oxygen compressor and a let down station 安裝於平台上之大型氧氣壓縮機火災案例
- Damages are important, but limited inside barriers 嚴重的損壞,但侷限於防火防爆遮蔽區內
- Molten metal is projected around 鎔解的金屬散佈四處





 Never go inside barriers during operation (oxygen flow or pressure)

本姆作時 紹不進入防火防爆渡薪

在操作時,絕不進入防火防爆遮蔽 區內(氧氣流體或壓力)

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12. Contamination effect: solvents for cleaning 汗染效應: 清潔用 的溶劑



- When oxygen was introduced in the installation for the first time, ignition and serious burns on equipment occurred and the flexible hose ruptured 當氧氣第一次引入安裝的設備時,設備著火並嚴重 的燒毀及軟管破裂了
- Cleaning had been performed using a solvent, which was vented with nitrogen 有使用溶劑清潔過設備並以氮氣吹淨。
- Some degreasing agent was left in the piping and ignited at the first oxygen valve opening 在開啓第一個氧氣閥時,某些除油劑被留下來在管 路中引起了燃燒。



- Use only components already cleaned for oxygen service 只使用已經被清潔可供氧氣供應系統使用的零組件.
- If cleaning in place cannot be avoided, use only solvents approved for Oxygen service cleaning or water based cleaning agents

如果適當的清潔不可以避免,只使用被核准用於氧氣供應系統的溶劑或 是以水爲基礎的清潔劑

• Procedure for cleaning in place an oxygen system must be validated 清潔氧氣供應系統的程序必須被驗證

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13. Contamination effect: Ignition during maintenance of an oxygen cylinder 汗染的影響: 在維護氧氣鋼瓶時燃燒



- A metallic brush ignited during maintenance of the cylinder thread 在修整鋼瓶螺牙時,金屬刷燃燒了
- The cylinder is used in oxygen service and oxygen remained in the cylinder at atmospheric pressure

這鋼瓶是充填氧氣的,並且在大氣 壓力下鋼瓶內部仍存有氧氣

- Brush was contaminated with grease
 刷子上有油脂
- Make sure that the cylinder has been vented 確認鋼瓶已經被排空了
 Install a protection of the operator 裝設操作員的防護設備



14. Contamination effect: Explosion of the reboiler condenser of an ASU 汙染效應: 空氣分離設備內之再沸冷凝器爆炸



- C_nH_m accumulated in the reboiler condenser 碳氫化合物累積在再沸冷凝器
- They burned in presence of oxygen (LOX and GOX) 當氧氣存在時便開始燃燒(LOX and GOX)
- Aluminium of the reboiler condenser also burned 鋁製再沸冷凝器同時燃燒
- The column containing the reboiler condenser burst as well as the cold box
 承載安裝再沸冷凝器之冷箱也同時爆裂

• Make sure that the reboiler condenser operates according to the manufacturer's instruction 依再沸冷凝器製造商之指示操作



15. Contamination effect: cryogenic pump fire

汙染效應: 低溫幫浦火災





- The pumps were not continuously cooled down 幫浦未被持續地冷卻
- The mechanical seal had been changed several times 機械用的密封墊被更換了數次
- Small parts of burnt mesh are found in the pump after the fire
 - 火災後於幫浦內發現燃燒後的小部分篩網.
- Stainless steel mesh particles were found in the mechanical seal, which caught fire 在密封墊處發現引起火災的不鏽鋼篩網顆粒。
- The filter with stainless steel mesh was wrongly installed with the cone downstream 這不鏽鋼篩 網的過濾器以圓椎體向下游的方式安裝錯誤
- New filter mesh shall be in copper or nickel alloy whatever the pressure 不管在哪種壓力 下新過濾器篩網應是銅製的或鎳合金
- Narrow part of filter cone is first exposed to the upstream gas flow 圓錐體過濾器的錐形部 分應朝向上流安裝。





16. Velocity and flow friction effects: Ignition of ball valve 速度及流動摩擦效應:引燃球閥



- Ball valve located on a copper pipe at 150 bar, diameter 25 mm
 - 球閥銜接於一內有 150 bar氣體, 直徑 25 mm之銅管.
- Sealing gasket disappeared 密封墊片不見了
- The stainless steel ball valve is partially burnt 不銹鋼球閥部分燒燬
- The valve body is also burnt 閥體同時燒燬
- The operator is slightly burnt on his hands 操作人員稍爲灼傷雙手



- Limit use of manual ball valves:
 手動球閥之操作限制:
- pressure limit: 25 bar壓力限制: 25 bar
- diameter limit: ND 50 mm管徑限制: ND 50mm





17. Mechanical friction effect: pump running without liquid (dry running) 機械摩擦效應: 幫浦在沒有液體下運轉(乾式運轉)



- The pump trips due to high temperature 幫浦因為高溫跳脫
- The operator restarts the pump, by-passing the safety. 操作員重新開啓幫浦, 並規避安全裝置
- The pump catches fire 幫浦著火
- The cause of the fire is the friction of certain internal moving parts in the pump due to the absence of liquid in it
 - 起火的原因是內部幾個因爲沒有的液體在裡面的 活動零件的摩擦.
- These parts are progressively heated and catch fire 這些零件逐漸增加的熱能引起了火災
 - A cryogenic pump must be cooled down before start 低溫幫浦在啓動前必須被冷卻
 - Never run a pump without liquid 決不在沒有液體的況下運轉幫浦
 - Don't by-pass temperature safeties
 不能規避溫度安全設置



18. Mechanical friction effect: dismounting of an oxygen cylinder valve under pressure 機械摩擦效應: 壓力下拆除氧氣鋼瓶閥



- Analyze the accident report 分析意外報告
- List the facts and the possible causes 列下事實及可能原因
- Perform a root cause analysis 基本原因分析

- In a retesting plant, the valve could not be opened by the unqualified operator 不能由非操作人員拆瓶閥
- The valve was dismounted without checking that the cylinder was empty 拆閥前未確認鋼瓶是否已放空.
- The operator was burnt by burning metal and died a few hours later
 - 操作人員被燃燒之金屬燒傷並於幾小時後死亡

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18. Mechanical friction effect: dismounting of an oxygen cylinder valve under pressure 機械摩擦效應:壓力下拆除氧氣鋼瓶閥

- In a retesting plant, the valve could not be opened by the unqualified operator 不能由非操作人員拆瓶閥
- The valve was dismounted without checking that the cylinder was empty 閥拆除前未確認鋼瓶是空的
- The operator was burnt by burning metal and died a few hours later 操作員被燃燒的金屬燒傷並於幾個小時後死亡
- More than 3 kg of aluminium burnt 超過三公斤的鋁被燃燒掉



- Before dismounting a cylinder valve, check that the valve is open by trying to introduce gas into the cylinder and checking that it flows out 在拆除鋼瓶閥前,藉由引導氣體進 入鋼瓶並確認氣體是流出的來確認閥是開啓的
- If not, put the cylinder aside so that it follows a specific and adapted treatment and inform the manager 不然,將 這鋼瓶放到一旁,以便於遵循特定及適當的處置並通知主管

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Thank you

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