出國報告（出國類別：開會）

赴美國丹佛參加美國腐蝕工程師協會 (AMPP) 論文發表及年會 (AMPP Annual Conference + Expo 2023)

服務機關：台灣中油股份有限公司
煉製事業部桃園煉油廠
姓名職稱：陳紹綺 課長
派赴國家：美國
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2023.04.18 (二版)

目錄

摘要

職原於 2021 年投稿腐蝕相關論文(題目：Pressure Vessel Thickness Monitoring and Analyzing Using Linear Regression and Control Chart)至美國腐蝕工程師協會(舊稱 NACE，現稱 AMPP)，當時已接獲該協會通知邀請 2022 年至美國發表該篇論文，惟上述計畫當時經與廠內主管討論，考量當時疫情不確定因素而取消前往；而 2022 年收到該協會再次邀約 2023 年前往美國丹佛舉辦之年會(AMPP Annual Conference+ Expo 2023)發表論文並進行簡報，考量國內、外當時疫情情勢漸為趨緩，職經與廠內主管討論後決定再次投稿並參加上述 2023 年 3 月於美國丹佛舉辦之年會，參加腐蝕相關研討及論文簡報發表。

壹、目的

投稿之論文主要係以統計分析方法，建議使用者可建立一具有代表性且適當的模組用來監控及分析壓力容器的腐蝕減薄狀況以確保其機械完整性。論文內容基於一煉油廠中上千座壓力容器數十年的檢查資料紀錄，分享基於統計學理的線性迴歸 (Linear Regression) 降低檢測過程中無可避免的誤差，並以此合理推估設備腐蝕速率；並為確保檢查資料品質，統計品管工具如管制圖 (Control Chart) 可用來監控、確認設備超音波測厚檢查資料的有效性。

期望透過該論文發表，可強化國內職安單位對於本廠現行超音波厚度量測方法之可信度，並透過參與國際腐蝕專業研討會過程中吸取國外經驗，作為日後腐蝕管理之參考。

貳、過程

一、撰寫論文及簡報製作

論文撰寫過程中需註冊 AMPP 的會員，並於撰寫全程參考其技術手冊 (AMPP Technical Program Manual) 相關規定，而後上傳其論文投稿系統。論文撰寫各階段依序為摘要(Abstract)、草稿(Draft)以及定稿論文(Final Paper)，需依研討會主席(Chair)指正之意見進行多次修改，直至在時限內被接受(Approved)，被接受的論文才會通知可準備後續簡報(Presentation)，簡報製作亦需遵循技術手冊格式規定且經審核接受，方可於年會中發表。職定稿之論文檔案詳如附件一，定稿並於研討會中發表之簡報檔案詳如附件二。

二、行程安排

此次公務出國行程，原則上遵照公司核定之出國行程表辦理，簡要彙整如表一。

表一、公出行程表簡述

日期	公出行程
2023.03.17(五)	台灣時間 17:20 由桃園機場飛往 Los Angeles，抵達當地時間為 2023.03.17(五) 15:50，入境住宿一晚，隔天轉機前往 Denver。
2023.03.18(六)	Los Angeles 當地時間 11:35 飛往 Denver，抵達當地時間 14:54，下飛機後轉當地輕軌後直接步行前往研討會現場早鳥報到。
2023.03.19(日)	AMPP 研討會第一天，參與研討會。

2023.03.20(一)	AMPP 研討會第二天，參與研討會。
2023.03.21(二)	AMPP 研討會第三天，論文發表簡報並參與研討會。
2023.03.22(三)	AMPP 研討會第四天，參與研討會。
2023.03.23(四)	AMPP 研討會第五天，參與研討會。
2023.03.24(五)	Denver 當地時間 15:40 飛往 Los Angeles，抵達當地時間為 2023.03.24(五) 17:09，在機場內等候轉機。
2023.03.25(六)	Los Angeles 當地時間 00:50 飛往桃園機場，抵達台灣當地時間 2023.03.26(日) 05:45。

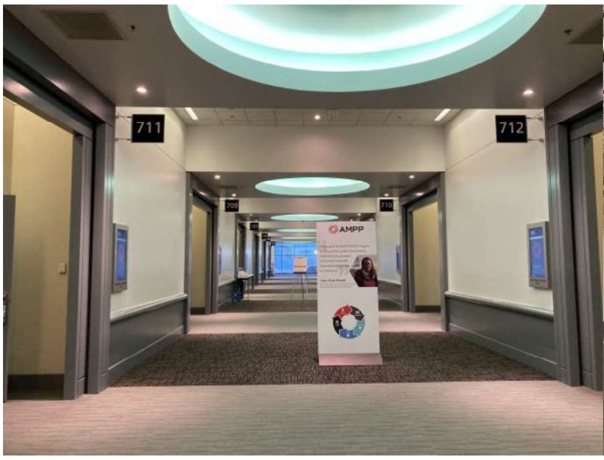
三、參與研討會及論文簡報發表

研討會場舉辦在丹佛市中心 Colorado Convention Center，五天的腐蝕研討會中，各個會議(Session)舉辦在整個場館 B1、1F、2F 各個會場，其會場外觀及內部一景如下圖一～四所示，該協會同時也提供手機應用程式 app － “AMPPAnnual” 供使用，使用該 app 可追蹤各個研討議題的時段及會議室地點，並可於參與後給予評價回饋，如圖五、六。

圖一、研討會場外觀

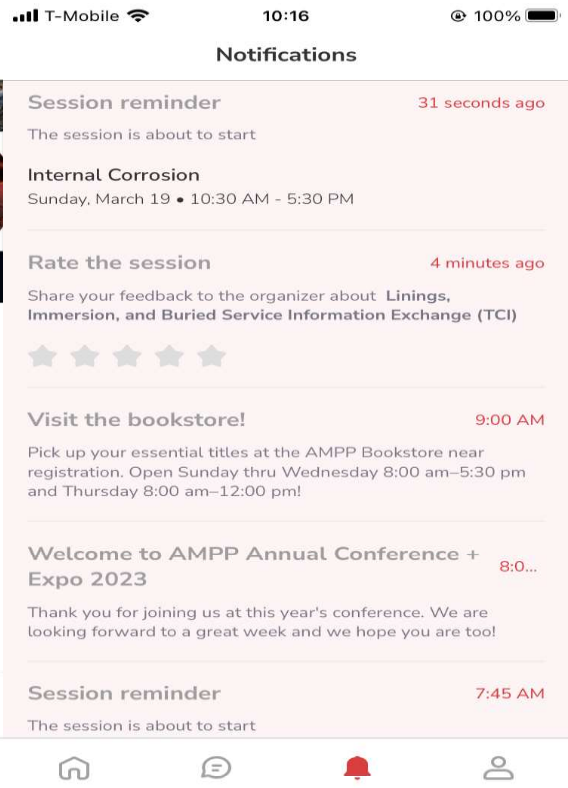
圖二、研討會場內部_1

圖三、研討會場內部_2



圖四、研討會場內部_3

圖五、AMPP 年會專用手機 app_1



圖六、AMPP 年會專用手機 app_2

(一)、研討會

為期五天的研討會中，在 Colorado Convention Center 會場內同時間、不同會議室舉辦不同研討議題，在有限的時間內只能取捨選擇與公司產業類別、議題有相關聯之研討會議選擇參加，過程中使用 app 篩選出行程表清單詳如附件三。下述將職參與之研討會議分成以下類別進行討論介紹：專題討論會、工作坊、規範修正研討、技術交流會、以及其餘相關聚會。

1、專題討論會 (Symposia)

專題討論會為各領域論文簡報發表，每個人約有 25 分鐘，包括 5 分鐘的問答時間 (Q&A session)。以下表格化呈現五天研討會中，職參加的專題討論會：

2023.03.19(日)	Internal Corrosion
	Digital Asset Transformation: Application of Data Science and Analytics for Corrosion Management
2023.03.20(一)	Gaseous Hydrogen Embrittlement
	Corrosion Under Insulation
	Environmental Assisted Cracking Day1
	Facility Integrity Day1
2023.03.21(二)	Corrosion Management
2023.03.22(三)	Refining Industry Corrosion

	Pipeline Integrity Day1
2023.03.23(四)	Direct Assessment
	High Temperature Materials and Corrosion

AMPP 就每場專題討論會指派主席(Chair)進行主導該會議並指導論文寫作，各個專題討論會開放世界各地的人投稿，只要投稿內容能被主席依照 AMPP 技術手冊(Technical Program Manual)審查其內容並終其被接受，將可至年會研討會以簡報的方式發表論文，未來也有機會在 AMPP Conference Papers 網頁上供有興趣人士購買下載。

職參與上述各個研討會議，過程中接受來自世界各地不同的人發表並分享其研究成果，讓業界可以了解現今世界腐蝕相關議題的趨勢作法並互相交流學習。以下綜合分類成以下三個類別進行心得分享：

(1)、腐蝕劣化案例專題研討

在內部腐蝕(Internal Corrosion)專題討論中，其中一篇論文：Analysis Of Internal Corrosion Data In Relation To ILI Results 文中使用統計分析工具進行腐蝕試片(Corrosion Coupon)之裝設與長途管線線上檢查腐蝕資料(ILI Corrosion Rate Data)進行專題研究比對。該簡報結論指出長途管線腐蝕試片腐蝕率與整體長途管線腐蝕率資料分析無明顯相關性，顯示出長途管線若使用腐蝕試片進行監控管理之點位選擇重要性，至於該論文研究樣本是否充足足以支持其論點則有待商榷。

在環境引發破裂(Environmental Assisted Cracking，EAC)專題討論中，其中一篇論文：Hydrogen Embrittlement Susceptibility In Corrosion Resistant Material For Fasteners 文中對於 Alloy 625 Grade1 各種熱處理狀況、Alloy 716、Strain Hardened Austenitic Material 進行實驗，也包括是否在陰極防蝕的條件下進行測試，並帶出結論上述合金材質之螺栓在陰極防蝕的情況下對於氫脆裂的抗性(Resistance)有著不同程度的差異，說明不確定材質之適用性時先進行相關試驗之必要。

在長途管線完整性(Pipeline Integrity)專題討論中，其中一篇論文：Finding The Smoking Gun: Lesson Learned From An HDD Coatings Failure (Coating Application Aren’t As Simple As They Appear)介紹一失效案例，在其新製鋼管進行水平導向鑽掘(Horizontal Directional Drilling，HDD)前進行鋼管外部塗層保護，接著進行 103%降伏強度(Yielding Strength)的耐壓試驗後過一陣子發現塗層表面裂紋，隨後進行塗層破損分析確認因其中間塗層使用之抗磨耗塗層(Abrasion Resistant Coating，ARO)經驗證確認不適延展，在壓力過高之耐壓試驗後致使該塗層產生表面裂紋，也由此分享案例了解到長途管線塗層工程所需考量的多項層面。

在長途管線直接評估法(Direct Assessment)專題討論中，其中一篇論文：Case Studies In ECDA and SCCDA 簡報中介紹依照 NACE SP0502 - Pipeline External Corrosion Direct Assessment Methodology 規範專案實施長途管線外部腐蝕直接評估(External Corrosion Direct Assessment，ECDA)以及應力腐蝕龜裂直接評估(Stress Corrosion Cracking Direct Assessment，SCCDA)，講者提到依據 NACE 規範應選擇最有可能造成腐蝕之區域條件包括不當陰極防蝕條件區段、腐蝕性較高之土壤區段等進一步篩選出擬進行直接評估之管

段並進行規範所述之 4 個階段的管線 ECDA 及 SCCDA 評估：

1. 預評估 (Pre-Assessment)，主要目的為資料蒐集。
2. 間接檢查 (Indirect Inspection)，其手段方法包括陰極防蝕、緊密電位、雙電極法、地形及土壤條件等。
3. 直接檢測 (Direct Examination)，確認最有可能發生之腐蝕區域其實際狀況。
4. 後評估 (Post-Assessment)，對於檢測結果進行管線狀況評斷。

作者介紹 2 個案例分享藉由上述規範所定流程進行管線 ECDA 及 SCCDA 結果皆正常，以此評斷研究之案例長途地下管線外部完整性。

在高溫材料及腐蝕(High Temperature Materials and Corrosion)專題討論中，其中一篇論文 Metallurgical Investigation of Hydrogen Reformer Tube Rupture – A Case Study 介紹一氫氣重組爐管的破損案例分析，該設備基本資料如下：

建造日期：1977 年

材質:：ASTM A297-HP15Nb (26Cr-35Ni)

管徑：4”

操作時間：18 年

操作溫度：810-850˚C

操作壓力：2.2 – 2.4 MPa (22.43 – 24.47 kg/cm^2)

管壁厚度：0.55” (13.97mm)

破損區段為輻射區，其破損原因經分析確認為高溫潛變造成，也提到破損區段有管徑增加的現象，故可考慮以量測爐管圓周確認其潛變傷害狀況。另一篇論文 Creep Life Assessment of Grade T91 Superheater Tubes Using Creep Void Density And Hardness Measurements – Case Studies 同樣為高溫潛變之破損案例分享，其爐管材質為 ASTM A213 Gr. T91 (9Cr – 1Mo)，因業主無安裝線上溫度偵測，故以氧化層公式估算其操作表面溫度可能高達 575˚C，破損之爐管甚至有局部鼓脹(Bulge)情形。破損分析手法包括以洛氏硬度測試確認遠離破損處的爐管硬度約 95 HRB，而破損處明顯變軟僅有 77 HRB。上述案例分享，可做為加熱爐管可靠度及檢測方法選用之參考。

(2)、腐蝕相關管理

在數位資產轉化(Digital Asset Transformation: Application of Data Science and Analytics for Corrosion Management)專題討論中，議題包括使用先進非破壞檢測技術陣列式渦電流(Eddy Current Array，ECA) 對於壓力容器、管線等檢測的應用、將大量資料建置儀表板(Dashboard) 以有效視覺化管理各種防蝕對策(Corrosion Barrier Management，CBM)、將電磁超音波檢測技術結合有限元素分析進行油槽底板腐蝕率資料庫分析等。現今腐蝕業界在資料數位化的應用，有些做法相當新穎如腐蝕檢測相關資訊儀表板化以利決策者進行正面決策，如能對公司有幫助，未來將考量引進相關作法以利腐蝕管理。

在設施完整性(Facility Integrity)專題討論中，其中一篇論文：Asset Life Extension Through Deployment Of Corrosion And Inspection Technologies: Corrosion Monitoring vs Condition Monitoring 文中對於設備及管線之狀況監控分成腐蝕監控(Corrosion Monitoring)及狀況監控(Condition Monitoring)；腐蝕監控係指安裝腐蝕試片、腐蝕探針等了解內容物

腐蝕性狀況之主動作為，而狀況監控則係指如各種檢測手段包括超音波測厚去確認是否有腐蝕現象的發生，簡報中說明兩種方式互相搭配使用可加強了解確認設備及管線對於腐蝕減薄之掌握程度。

在腐蝕管理(Corrosion Management)專題討論中，除了職發表之論文簡報於另一章節介紹外，也聆聽了幾個腐蝕管理相關議題論文介紹。其中一則論文簡報：The Importance Of Leadership In Corrosion Management Corrosion Management，點出領導(Leading)與管理(Managing)的差異。領導係藉由自身做起，進而讓周邊人們有著正向改變；管理則是在有限的資源限制下執行、落實已制定之計畫。講者為一腐蝕風險管理公司的創始人，簡報說明有效的腐蝕管理，需要從正面有效的領導做起。另一則論文：A Novel Internal Corrosion Risk Management Methodology For Relief Lines，簡報中介紹該公司建置量化失效分數(Likelihood of Failure)管理安全閥滯留區管段，不同滯留管段依其內容物(Service: HP Wet Gas or History of Leak or Repair, LP Wet Gas, Crude Service, or Dry Gas)、管線配置(Configuration: Stagnation Potential, or Self-draining)或是管線設計(Design: Bare CS or Defective Coating, Downstream PSV, or Coated or CRA) 給予不同的評分，進行安全閥滯留區管段風險管理並擬訂檢查計畫。此種作法與 API 570 及 RBI 等作法仍需考量內容物洩漏後果(Consequence)有所不同，因世界各地人事時地物皆有所差異造成不同的風險管控方法，只要為證實有效且合乎當地法規，工程實務及腐蝕管控有著因地制宜的作法；另一則論文：The Implementation Of A Corrosion Management System (CMS) In An Operating Gold Mine 介紹該公司引用 ISO 9223 進行腐蝕地圖(Corrosion Map)進行腐蝕管控，也是一個因地制宜的腐蝕管理實例。

(3)、基於腐蝕機制學理進行實驗或實務驗證

在氫脆裂(Gaseous Hydrogen Embrittlement)專題討論中，其中一篇論文：Stress Cracking And Fatigue Resistance of Seamless Pipes For Hydrogen Storage And Transport Applications 文中提到作者依據 ASME B31.12 - Hydrogen Piping and Pipelines 進行充氫 (Pressurized Hydrogen) 環境之鋼材疲勞裂紋成長速率實驗。該實驗結論提到氫氣與材料不連續處(Dislocation)的反應成為氫引發破裂的關鍵因素，同時環境相對溼度(Relative Humidity)造成的影響也不可輕忽。

在保溫層下腐蝕(Corrosion Under Insulation，CUI)專題討論中，其中一篇論文：Thermal & Moisture Cycling Impacts On The Corrosion Behavior Of Carbon Steel Under Contacting And Contact-Free Insulation 文中作者依據 ASTM G189-07 進行保溫層下腐蝕相關實驗模擬，證實溫度和濕度的反覆(Cycling)明顯加劇 CUI 腐蝕速率；也藉由實驗證實選用適當設計、材質之保溫材料，即使有溫度、濕度反覆作用，將能有效降低 CUI 腐蝕速率。職也聆聽相關論文發表如使用脈衝式渦電流(Pulsed Eddy Current，PEC)進行保溫支撐環處 CUI 檢查有效性之研究、透過數位資料評估管線 CUI 腐蝕趨勢等，這些廠商及業界的做法，將列入公司日後管理保溫層下腐蝕之參考。

在煉油工業腐蝕(Refining Industry Corrosion)專題討論中，其中一篇論文：Mechanistic Insights into Refining Sulfidation Corrosion 先從高溫硫化的反應機制及其腐蝕動力學理(Kinetics of Sulfidation Corrosion)介紹該腐蝕機制腐蝕率分成三個階段：1. Nonlinear 2.

Linear 3. Parabolic，而影響腐蝕情況屬於哪一階段則主要與各種因子包括濃度(Concentration)、時間(Duration)以及溫度(Temperature)有關。該簡報介紹藉由現場置放腐蝕試片(Corrosion Coupon)於製程管線中試驗不同腐蝕試片對於上述因子參數變動時造成腐蝕改變透過電子顯微鏡(SEM)進行 EDS 元素分析、X 光繞射分析等方法分析各個腐蝕試片其腐蝕生成物，確認該區段流體中上述因子對腐蝕率的反應性，進而製表比對簡報一開始介紹的腐蝕率所屬階段進行歸類，以得到機械學理(Mechanistic)驗證，而後進一步制定操作完整性視窗(IOW)進行該區製程管線高溫硫化腐蝕風險管理。上述作法為驗證各種腐蝕因子對於腐蝕率的反應性進行實驗，結合腐蝕學理比對實驗資料後續進而制訂操作完整性視窗，就科學的角度相當令人信服。另一則論文 Practical Consideration For The Assessment of HTHA Risk 則為基於高溫氫攻擊建置製程主要參數包括操作時間、溫度、氫分壓、退火條件、承受應力、碳活性(Carbon Activity)以及檢查條件如頻率及方法等，進而制定高溫氫攻擊量化後所屬之風險區間進行不同風險管控作法，以利決策者決定是否達汰換標準或檢查監控，後續同樣制定 IOW 進行腐蝕風險管控。

2、工作坊 (Workshop)

工作坊為專家對於腐蝕相關議題進行教學簡報，職參與的 Coating 101 Workshop 從各種塗層(Coating)相關基礎知識開始介紹，進一步介紹如何確保有品質的塗層腐蝕防護系統包括以下六個層面：

1. 設計 (Design)
2. 塗層 (Paint)
3. 規範 (Specification)
4. 承攬商 (Contractor)
5. 檢查 (Inspection)
6. 修護 (Maintenance)

簡報中同時也提到上述工程規範須具有可理解性(Understandable)以及可實施性(Enforceable)的重要，且規範需要明確具體(Specific)避免過於通則敘述(General)，才能有效管理承攬商。

3、規範修正研討 (Standards)

在 AMPP 年會中，部分會議場合也召集了規範制定委員會(Standard Committee，SC)成員進行已發布或尚未發布之 AMPP/NACE 出版之工程規範進行審閱並開放旁聽。職旁聽的 SC 研討會議包括 SC 10 - Asset Integrity Management、SC 15 - Pipelines and Tanks、SC 08 - Metallic Material Selection and Testing 以及 SC 20 - Internal Corrosion Management。旁聽討論的工程規範包括：

1. NACE SP0207 - Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines
2. NACE SP0106 - Control of Internal Corrosion in Steel Pipelines and Piping Systems
3. NACE TR1F192, no.24010 - Use of Corrosion Resistant Alloys in Oilfield Environments

過程中了解到 AMPP 討論、制訂規範過程具有開放、專業、嚴謹等特性，個別會

議一開始介紹審視該規範的成員組織，並將規範細部條文檢視負責人員表格化追蹤進度，接著共同討論規範條文是否有改進的空間，任何新增或修正都將有紀錄可循，同時也強調規範中任何專業條文都需要有專業文件支持、佐證其相關敘述。

研討過程中也有人提出意見：為什麼部分條文不寫得簡易容易實行，讓大家生活好過點呢？主持人表示：我們制訂工程規範不是為了讓生活過得簡單，而是為了制定高標準的工程準則(We make standard, not to make life easier, but to set high engineering standard criteria.)。這段對話讓遵循、使用工程規範的人有所共鳴感觸。

4、技術交流會 (Technical Communities of Interest，TCI)

AMPP 成立了各種技術交流組職(TCI)，不同領域的 TCI 定期/不定期分享該特定領域相關知識、經驗、資訊讓成員能共同參與討論，除了網路線上分享資訊外，也透過如此次 AMPP 年會的機會場合，讓世界上相關腐蝕領域的人可以就專業討論上共襄盛舉。這次職抽空參加的 TCI 包括：Linings, Immersion, and Buried Service Information Exchange、CUI and Passive Fire Protection、Data Analytics Information Exchange、Oil and Gas Materials Selections and Metallurgy information exchange 以及 Oil and Gas Petroleum Refining and Gas Processing information Exchange (downstream)，其中又以最後一場石化業界的經驗技術交流最為熱絡，現場有上百人參加討論。即使人群眾多，會議一開始還是每個人傳接麥克風進行簡短自我介紹，足以得知參與會議的人員包括來自各知名企業機構如 ExxonMobil、ASME、Chevron、Shell 等公司。以下就 Oil and Gas Petroleum Refining and Gas Processing information Exchange (downstream)幾個議題進行介紹。

會議流程係依煉製工場製程單元進行案例分享，該 TCI 主持人引領會員事前已準備好的資料進行簡報，並就製程單元領域分成如下逐一討論：

1. Crude Distillation/Vacuum Unit
2. Conversion Unit
    2.1 Hydrocracking Unit/Hydrodesulfurization/Hydrotreating Unit
    2.2 FCC Unit
    2.3 CRU, all regen modes
    2.4 Alkylation Unit (H_2SO_4, HF)
    2.5 DCU, FCU
3 Supporting Unit
    3.1 Hydrogen Plants
    3.2 LER
3.3 Amine Treater/ Gas Processing
    3.4 Sour Water Stripper
    3.5 Sulfur Plant/ Tail Gas Unit
4. Other Processing Unit
    4.1 ISO
    4.2 Polymerization Unit
    4.3 Lube Extraction/ Dewaxing Unit

該技術交流會過程中，職參與學習三個討論議題：

1. Crude Overhead System Failure
2. CCR Heater Tube Failure
3. Alkylation Unit IOW for Caustic (NaOH/KOH) Strength (rather than choosing pH)

上述第一個議題為蒸餾工場塔頂系統管線滯留區腐蝕減薄案例分享，第二項為觸媒重組工場因壓縮機跳車進料中斷，而加熱爐火焰第一時間未關斷持續燃燒，三日後開放爐內檢查確認爐管已明顯結焦並部分鼓脹，經適用性評估後汰換了約 17 隻爐管。最後一項為烷化工場的技術交流討論，引用 API 751 規範指出控管工場潛在腐蝕狀態所需建置的 IOW 包括鹼液強度(Caustic Strength)，然而酸鹼值(pH)的控管對於腐蝕性的影響經證實無明顯作用。講者也說明強調 IOW 為控管製程工場的重要手段，但選用有效、適用之參數才能達到腐蝕控管的目的。

期間參與另一場 TCI 為 Data Analytics Information Exchange，其中一個簡報 Streamlining Insights To Actions: An Evolution of Managing Oilfield Chemistry Data 講者說明如何將數位化資料(Digitalized Data)轉換成具有實質意義的洞見(Insight)，進而做成決策(Act)。簡報中點出規模較大的企業進行數位化資料的一個困境：資料/資訊多元豐富(Diversity Rich)，但是資料/資訊連結性不足(Connectivity Poor)。大公司中各單位往往各自將所需資料數位化卻無法有效整合共享，導致組織員工作業重工等資源浪費；決策者如果在有限的工時內得到的是整合、分析後有意義之視覺化資訊，將更有可能做出對組織有利的正向決策，也說明將原始資料(Raw Data)進行整理成格式化資料(Formatted Data)，再精確分析、整理成有用的資訊報告、報表或儀表板資訊的重要性。講者同時也提醒一個觀念：資料/資訊的彈性(Flexibility)，必須考量每個人以不同的方式、角度吸收資訊；同樣一份文件資訊，操作部門、技術部門、檢查部門將以不同的角度去看待與吸收。

講者最後將其所介紹之組織內部資料數位化傳遞概念簡化成如下流程：

1. 資料來源 (Data Source)
2. 風險分析 (Risk Calculation)
3. 分析後之視覺化資料呈現與資訊吸收 (Consumption/Visualization)
4. 決策者採取行動 (Action)

而上述之行動可包括主動電子郵件提醒(Email Notification)、自動化工作流程(Automotive Workflow)或是使用者採取引發工作流程(User Triggered Workflow)等。

以上概念或許有點抽象模糊，回歸到此技術研討會：Data Analytics Information Exchange 以及該簡報標題：Streamlining Insights To Actions，在這每天與時間競賽的數位化時代，數位化資料應該簡化彙整(Streamlining)成可供決策者有利正面判斷之視覺化資訊(Visualization)，以利使用者將資訊轉換成洞見(Insight)進而採取對組織正面且有利之行動(Action)，方可進行有效且有效率的腐蝕及風險管控。

5、其餘相關聚會

(1)、專業證書持有人進修討論 (AMPP Certified Card Holders)

AMPP 平時於世界各地有舉行一些課程及證照測驗，而如取得相關資格證書依規定如屆期前需換證，則需在期間內持續進修取得被協會認可之專業進修時數(Professional

Development Hours，PDH)方可換證。這次年會也於特定時段開放相關課程供人進修換取 PDH，因職於幾年前受訓及考試通過取得 NACE Corrosion Technologist 及 Cathodic Protection Technician 資格(如圖七、八)且證照將於今年屆期，故順道參與相關進修課程。

其中與陰極防蝕相關課程中，介紹 Effect Of Decoupler On CP Potential Measurement，簡報中介紹去耦電路器(Decoupler) 安裝在長途管線絕緣法蘭附近，提供以下三個重要功能：

1. 在絕緣法蘭跨接處提供突波保護(Surge Protection)
2. 讓陰極防蝕系統與接地系統進行有效隔絕
3. 防止交流電壓干擾

講者介紹該電子元件安裝之功能性及重要性，供地下管線陰極防蝕使用業者參考。

圖七、Corrosion Technologist 證書

圖八、Cathodic Protection Technician 證書

(2)、主題演講 (Keynote Speech)

這次的年會主題演講邀請到 Terry Bradshaw 美式職業足球 (National Football League，NFL)傳奇球星，過往贏得 4 次超級盃(Super Bowl)冠軍、其中兩次獲選超級盃最有價值球員等殊榮。整個主題演講現場熱鬧非凡(如圖九、十)，會議室聚集了上千人潮。雖然 AMPP 年會為材料及腐蝕相關，明顯與 Terry Bradshaw 傳奇美式足球球星形象不一致，但短短一小時多 Terry Bradshaw 幽默詼諧的演說並與觀眾互動讓現場氣氛充滿歡樂，也讓人感受到這名偉大的成功人士 Terry Bradshaw 演說中教導人們樂觀進取的人生觀，不限定於特定領域與專業，值得學習讓人敬佩。

圖九、主題演講_1　　　　　　　　　　　圖十、主題演講_2

(二)、論文發表

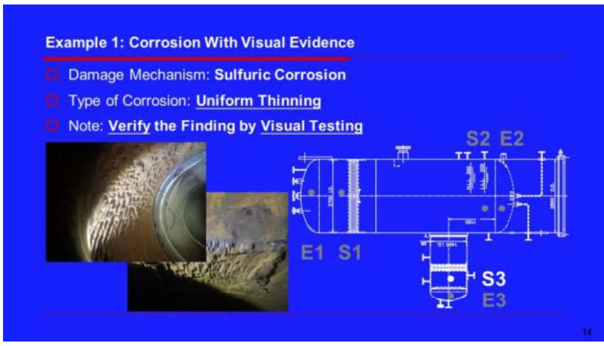
誠如上述介紹，職這次投稿於腐蝕管理的專題討論會，論文 Pressure Vessel Thickness Monitoring and Analyzing Using Linear Regression and Control Chart 主要係基於統計學理對於壓力容器厚度量測資料以迴歸分析決定其誤差最小之腐蝕率，稱之為線性迴歸腐蝕率(Linear Regression Corrosion Rate，LRCR)；並基於統計理論建置厚度量測品質管控上下界線：管制上限(Upper Control Limit，UCL)以及管制下限(Lower Control Limit，LCL)。

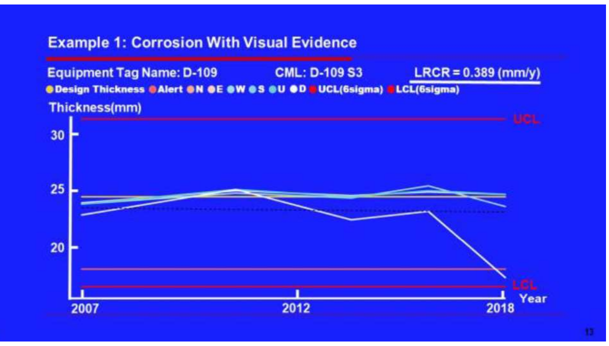
簡報中舉出三個實務案例：

1. 目視檢查可確認之腐蝕減薄 (Corrosion With Visual Evidence)，如圖十一、十二。
2. 目視檢查難以確認之腐蝕減薄 (Corrosion Without Visual Evidence)，如圖十三、十四。
3. 局部腐蝕減薄 (Localized Corrosion)，如圖十五、十六。

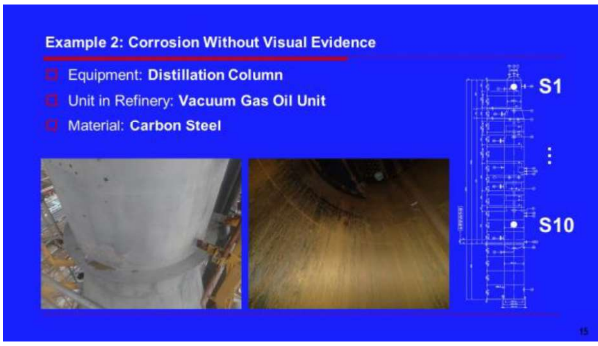
完整簡報檔案如附件二，當日 25 分鐘的簡報時間包括 5 分鐘的與會者提問順利結束，因簡報過程禁止拍攝錄影，僅於簡報前觀眾等待及主席介紹時拍攝照片如圖十七。整個過程非常感謝 AMPP 腐蝕管理主席 Mr. Brian Burgess 自投稿以來，期間提供不間斷地協助與鼓勵，當日演講完也在 Mr. Brian Burgess 同意下合影留作紀念如圖十八。

圖十一、目視檢查可確認之腐蝕減薄_1　　圖十二、目視檢查可確認之腐蝕減薄_2

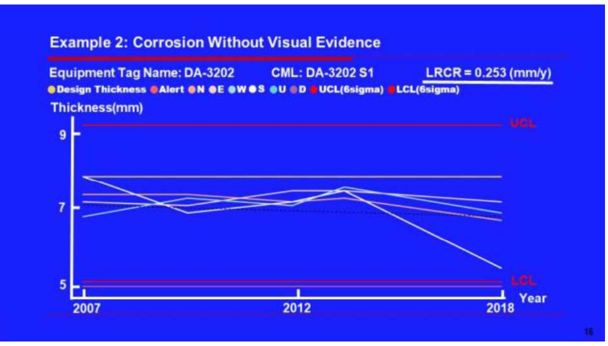




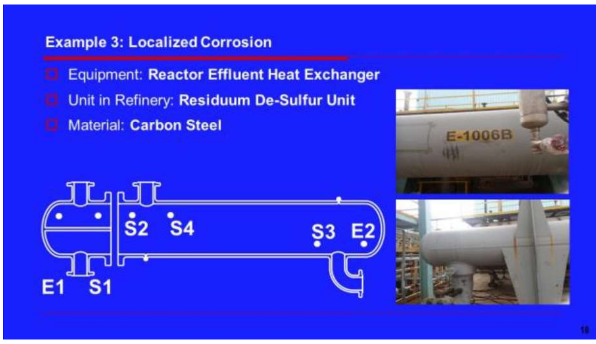
圖十三、目視檢查難以確認之腐蝕減薄_1



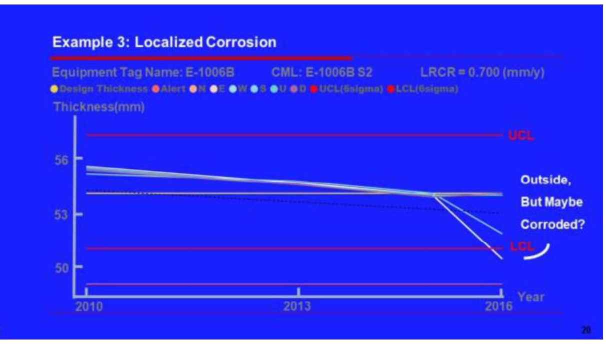
圖十四、目視檢查難以確認之腐蝕減薄_2



圖十五、局部腐蝕減薄_1



圖十六、局部腐蝕減薄_2



圖十七、準備進行演講前主席介紹

圖十八、與 Mr. Brian Burgess 合影

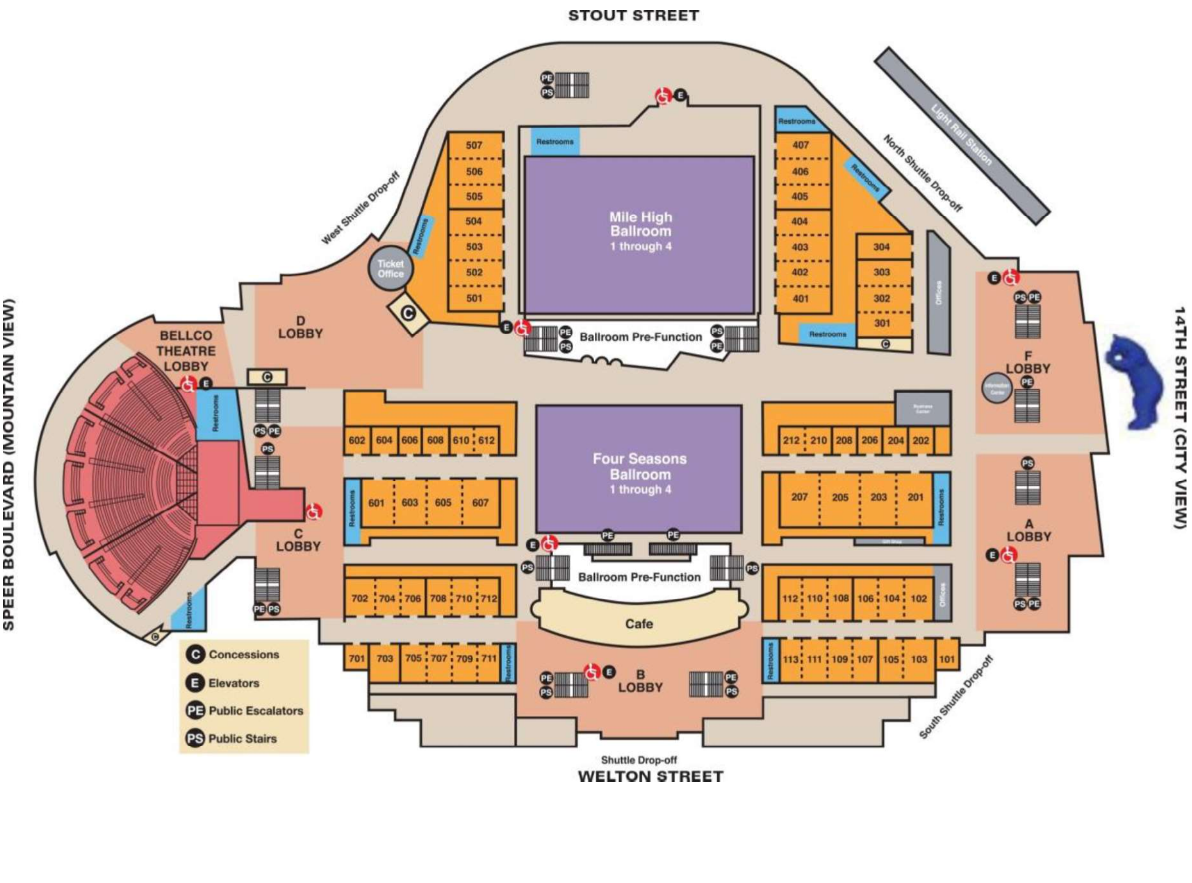
(三)、觀察與學習

此次 2023 年 AMPP 年會舉辦在 Colorado Convention Center，整個場館大小約 50,000 m^2，場館內各個會議室於不同時段持續進行不同研討議題，藉由會場平面配置圖(如圖十九) 能感受到整體規劃及動線安排得宜的重要性。主辦單位為了讓五天的研討會參與人員可以有效率地安排並順利參與相關會議，藉由手機 app 功能及現場適當指標指引得以實現。

除了研討會議外，場館一樓有報到註冊區及圖書展覽區，二樓主要為腐蝕相關儀器、材料廠商的展覽會場如圖二十、二十一。二樓現場上百間廠商進行展覽介紹，也藉機觀摩美國當今防蝕相關儀器、材料技術發展。職在聽取一保溫材廠商介紹該公司專利材料對於抑止保溫層下腐蝕具有不錯的效果後，索取型錄將相關資訊帶回公司，待日後與相關單位研究討論。

因為全程進出會場出入口及會議室需由現場保全或工作人員確認是否具有資格身分，研討會中需全程需配戴人員掛牌以利他人識別確認，掛牌上有人員姓名、職稱、公司等資訊，也有 QR Code 可供他人掃描加入聯絡資訊。在幾個會議場合中，透過識別對方的身分有一些對話交流，過程中遇到曾經來過高雄進行塗層防蝕教學課程的塗層防蝕專家(Protective Coating Specialist) Mr. Phil，交談甚歡。Mr. Phil 為 AMPP 資深會員，在聊天過程也建議 AMPP 未來可以考慮來台灣對於煉製腐蝕課程(Corrosion Control In the Refining Industry)開班授課，為期五天的課程目前在國際上其他地區包括中東、美洲等偶有實體課程或線上課程(Virtual Course)可供學習。Mr. Phil 表示這是不錯的意見，目前 AMPP 會不定期在台灣舉行之證照課程主要為防蝕塗層以及陰極防蝕，開班時仍有上課最低人數考量，未來如有機會將考量拓展 AMPP 在台灣其餘腐蝕相關領域課程。

圖十九、Colorado Convention Center 會場平面配置圖



圖二十、AMPP 年會圖書展覽販賣　　　圖二十一、AMPP 年會廠商展覽區

參、具體成效

參加為期五天的研討會，或許難以達成立竿見影的成效，煉油廠整體腐蝕管控仍需仰賴長年經營的公司文化來帶動。美國腐蝕工程師協會為國際上頗具知名度的機構，該機構發表許多具公信力之工程規範及專業課程，帶給全球各個產業腐蝕防治相關議題莫大幫助；職有幸參加如此盛大的國際研討會，希望能帶給公司以下兩點正向作用：

1. 適時了解並學習國際上腐蝕管控科技趨勢、思維及相關經驗與作為，並將所學資訊帶回公司與同仁分享，期盼能對於公司腐蝕管控有所幫助。

2. 透過國際專業研討會議中發表簡報，增加中油商標在國際上的曝光率，以期拓展公司能見度。

肆、心得與建議

感謝公司長官鼓勵支持職參與此次 AMPP 論文投稿以及研討會，整個過程學習收穫滿滿，也深刻了解到自我所學不足，期許未來持續成長。以下就此次學習經驗整理成如下幾項心得：

1. 國內煉油產業以中油、台塑為主體，相關腐蝕經驗分享、交流、參考及學習除了網路上相關資訊外，若不跨出國界，則實務經驗直接交流僅限於兩間公司。雖然腐蝕管控有著因地制宜的適當作法，適時了解並學習國際上腐蝕管控科技趨勢、思維及相關經驗與作為，應能對公司以及整體產業有所幫助。

2. 超音波厚度檢查如同任何實驗、量測技術，基本上存在不可避免的誤差，故透過超音波檢查之設備厚度趨勢難免有上下波動的情形。如同學生時期進行牛頓運動定律或是虎克定律等實驗結果，理論上都應為完美線性關係；而腐蝕率等於厚度變化值除以時間(Corrosion Rate = ΔThickness / Time) 也應為完美線性關係，惟儀器量測存在不可避免之誤差因素致使數據浮動。參考美國品質學會(America Society of Quality，ASQ)出版之品質工程師手冊(The Certified Quality Engineer Handbook)，量測資料可透過統計學方法包括迴歸分析(Regression Analysis)使誤差最小化；並依據量測資料標準差、取樣數量等建

置管制圖(Control Chart)確認資料浮動是否合乎基於統計學理之品質界線。職發表於AMPP 論文中提到使用超音波厚度量測技術決定設備腐蝕率，可基於統計學理將腐蝕率誤差最小化並監控檢查品質，期許成為國際上認可具有科學依據且實務可行之作法。

3. 研討會中學習到一些現今國際上業界對於腐蝕控管的思維及作法，如使用主動腐蝕監控(Corrosion Monitoring)包括腐蝕試片、腐蝕探針、操作完整性視窗 IOW 等應用，以及被動式狀況監控(Condition Monitoring)方法如各種非破壞檢測技術。不同主、被動監控方法互相搭配並以學術理論為基礎，更能掌握腐蝕實際情況。而在科技成熟的時代，跨部門數位資料如何有效整合、分析成有用資訊，以迅速提供決策者做成正向決策，也是腐蝕控管重要的一環。研討會中一些簡報介紹不錯的腐蝕案例分享及管理作法，未來也將與相關部門分享討論；然而腐蝕管控仍需考量不同人事時地物，採取因地制宜的作法，以有效管理腐蝕造成的風險危害。

Pressure Vessel Thickness Monitoring and Analyzing Using Linear Regression and Control Chart

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ABSTRACT

In API 510, it offers two ways for corrosion rate determination, one is using" point-to-point" method, in which long-term and short-term corrosion rates can be compared so that the corrosion rate which best reflects the current process can be chosen.[1]

The other way is "statistical analysis method", in which owner can establish a representative and suitable model to monitor and analyze pressure vessel corrosiveness behavior in order to maintain its mechanical integrity. This paper, based on the experience of thousands of pressure vessels, will present the model using linear regression which has been used successfully to monitor corrosion rate. And to maintain the quality of thickness measurements, statistical approaches like control chart have been applied effectively to reduce inspection errors.

Key words: API 510, pressure vessel thickness, corrosion rate, linear regression, control chart

INTRODUCTION

Metal loss due to corrosion is a universal phenomenon in refineries which could in turn cause leakage or explosion if not well monitored. There are several units in a refinery such as crude distillation unit, hydro-processing unit, acid alkylation unit, etc. In each unit, there are hundreds of pressure vessels which have different potential damage mechanisms.[2] Hence, it's critical to establish an effective and efficient way to monitor thickness changing behavior.[3]

Considering two facts that:
1. Most pressure vessels' surface area in refinery is over 10 ft^2, some are even over 100 ft^2.
2. Traditional thickness monitoring ultrasonic testing (UT) probe's diameter is about 1 inch or smaller.

The concept of these 2 facts results in relative dimension between whole pressure vessel's surface area and thickness monitoring location (TML) is immense as shown in (Figure 1).

Figure 1: Size of thickness monitoring relative to Surface area of pressure vessel

Therefore, to use ultrasonic thickness measurement (UTM) as a tool to determine the mechanical condition of pressure vessel is similar to sampling.

Although there are some thickness monitoring techniques such as thickness scanning or radiography profile, it's not economically feasible to apply these techniques to every pressure vessel. Instead of fixing "exactly" same locations to monitor thickness of specified point, "approximately" same location to monitor thickness changing behavior would be a better option in a broad sense.

Given that there are several factors such as measurement location variation, equipment calibration, operator's skill can contribute to errors, thickness measurement results are inevitably inconsistent, which means thickness values could increase/decrease even though the pressure vessel does not suffer any thickness change. To reduce these errors in order to obtain quality inspection result and monitor thickness change due to corrosion effectively; statistical approaches, i.e. linear regression and control chart can be applied.

CORROSION RATE DETERMINATION BY LINEAR REGRESSION

Definition of corrosion rate is metal loss during the reference time period. But for each pressure vessel, it's impossible to find the specific location that provides the most representative corrosion rate of that pressure vessel. The primary considerations for determination of pressure vessel condition are effective (quality) and efficient (timely) monitoring. It's beneficial to use statistical tools such as linear regression to determine representative corrosion rate for each part of pressure vessel with minimal error.
A simple linear regression model can be shown as below:

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i$$

in which: β_0 is intercept, β_1 represents slope, ε_i means errors.[4]

Once point estimates (thickness measurement data) are obtained, a regression line can be fit as below:

$$y_i = b_0 + b_1 x_i$$

In which: b_0 is the intercept of the line, b_1 represents the slope of the line.
If x-axis is assigned as time of thickness measuring (unit: year), y-axis as thickness measurement value (unit: mil), then b_1 means corrosion rate for linear regression modeling, which is identified as Linear Regression Corrosion Rate, LRCR. Then the formula for LRCR is:

$$\text{Linear Regression Corrosion Rate (LRCR)} = b1 = \frac{S_{xy}}{S_{xx}} \text{ (unit: mpy)}$$

Where

$$S_{xy} = \sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y}) = \sum_{i=1}^{n} x_i y_i - \frac{(\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{n}$$

$$S_{xx} = \sum_{i=1}^{n}(x_i - \overline{x})^2 = \sum_{i=1}^{n} x_i^2 - \frac{(\sum_{i=1}^{n} x_i)^2}{n}$$

in which: S_{xy} is sum of the product of the difference between x its means and the difference between y and its mean. S_{xx} is sum of the squares of the difference between each x and the mean x value.
$\bar{x}$ is sample mean of x. $\bar{y}$ is sample mean of y.

Since linear regression is based on theory of minimizing the error of squares, a corrosion rate value for each part of pressure vessel with minimal error can be achieved.

QUALITY THICKNESS MEASUREMENT USING CONTROL CHART

Because of inherent variability for UTM for pressure vessel, it's important to be aware of the quality of thickness measurement. There are several kinds of control chart have been applied in industry to ensure the quality does not deviate from its intension. The control chart will be discussed in this paper is $\overline{x}$ control chart with standard deviation.

Suppose there are **n** thickness measurement values at specified thickness monitoring location per inspection time. If thickness measurements of each part of shell were taken according to its orientation: north, west, south, east, then n=4.

Sample standard deviation (s_i) of thickness measurement for each year:

$$s_i = \sqrt{\frac{\sum_{j=1}^{n}(x_{ij} - \overline{x})^2}{n-1}}$$

Suppose there are **m** sets of inspection data in years, then average standard deviation of thickness measurement ($\overline{s}$) would be:

$$\overline{s} = \frac{\sum_{i=1}^{m} s_i}{m}$$

Then the upper control limit (UCL) and lower control limit (LCL) on control chart are:

$$UCL = \bar{x} + C \times \bar{s}$$
$$LCL = \bar{x} - C \times \bar{s}$$

In which: $\bar{x}$ is average thickness, C is a constant according to specifications such as 6-sigma rule applied in the following examples, or based on the sampling size (n) in (Table 1).[5]

THICKNESS MONITORING USING CONTROL CHART AND LRCR

Accordingly, the control chart for thickness measurement and LRCR can be integrated into a chart like (Figure 2) below:

Figure 2: Control Chart with Linear Regression Corrosion Rate and Other Information

In which ① is linear regression corrosion rate (mpy, mm/yr), ② is upper control limit (UCL), ③ is lower control limit (LCL). It is helpful to add other related information including pressure vessel tag name, design thickness, minimum required thickness to the thickness control chart of pressure vessel in order to show relevant information.

A control chart is a statistical tool for monitoring changes or trends in the quality characteristics of interest, which, in this case, is thickness measurement on pressure vessel. Data within validity control limits suggests its quality is acceptable. Only when the quality of thickness measurement data over years is acceptable can corrosion rate values be considered reliable. Otherwise, it may suggest unacceptable quality of thickness measurement or metal corrosion is occurring.

Table 1
Typical Constant C for Control Chart

n	Constant
2	2.659
3	1.954
4	1.628
5	1.427
6	1.287
7	1.182
8	1.099
9	1.032
10	0.975

EXAMPLE 1: CORROSION WITH VISUAL EVIDENCE

In this example, a case of sulfuric acid corrosion identified by spot UTM in a sulfuric acid alkylation unit is shown. An acid wash coalescer called as D-109 has been monitored for thickness change over a number of years. To effectively monitor each section of the pressure vessel, appropriate TMLs need to be assigned to each part of vessel. In this case, 6 TMLs were assigned to D-109 (S1, S2, S3, E1, E2, and E3) as (Figure 3).

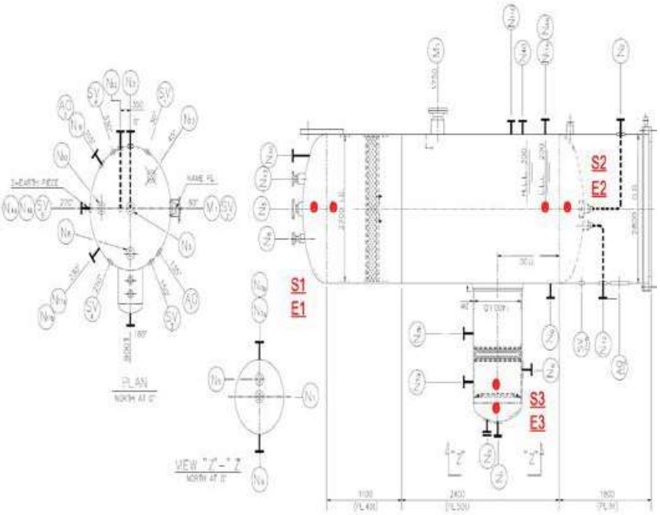

Figure 3: Thickness Monitoring Location for D-109

Figure 4: External Appearance @ D-109 S3

From the control chart of D-109 (Figure 5), all of these thickness measurements are within specified control boundary, which means the quality of these measurements should not to be an issue. But the thickness measurement value at S3 changes rapidly and the LRCR equals to 15.315 mpy (0.389 mm/yr) which is noteworthy. The external appearance at D-109 S3 is acceptable shown as (Figure 4). Then, the internal condition was examined shown as (Figure 6).

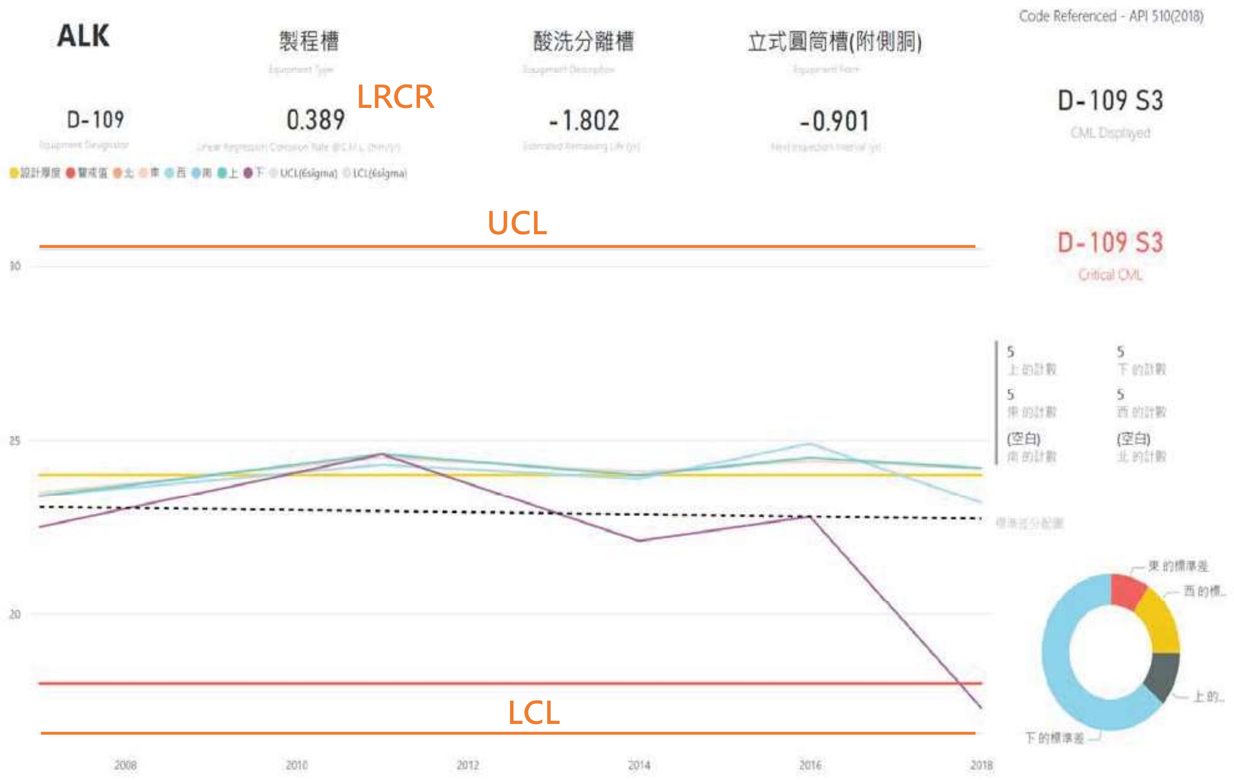

Figure 5: Control Chart for D-109 S3

Figure 6: Internal Corrosion Pattern @ D-109 S3

The inside of D-109 S3 has suffered some corrosion problem shown as (Figure 6). Consider its operating condition (sulfuric acid), material used (carbon steel) and corrosion pattern, the damage mechanism of this case was concluded as sulfuric acid corrosion. For severe corrosion problem like this example, the frequency of thickness measurement and locations to be thickness monitored should be established with caution.

EXAMPLE 2: CORROSION WITHOUT VISUAL EVIDENCE

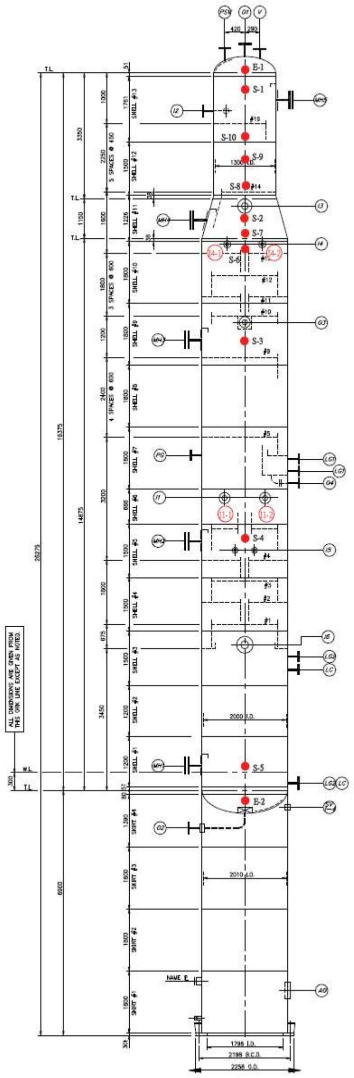

Figure 7: Thickness Monitoring Location for DA-3202

In this example, a distillation column DA-3202 in a Vacuum Gas Oil unit in a refinery has been found to have a general corrosion problem without significant visual evidence. The main function of DA-3202 is to separate naphtha, light product, and heavy product. Considering this tall column with differing operating condition throughout its height, there are 10 TMLs assigned, each with 4 orientations on its shell shown as (Figure 7).

The thickness values at S1 location (near the top of the column) decreased distinctly in recent year shown as (Figure 8), LRCR at S1 amounts to 9.961 mpy (0.253 mm/yr), and the thickness measurement trend changes but still within control chart boundaries, which suggests the quality of measurement is acceptable.

Even though the external appearance and internal condition at S1 location is acceptable shown as (Figure 10), there are some potential corrosion mechanisms caused by light substances such as hydrochloric acid corrosion which could result in general corrosion. Therefore, an advanced inspection method was decided to be applied: phased array ultrasonic testing (PAUT) scanning at this location to determine the thickness distribution condition over this area.

The probe of PAUT can excite more than ten ultrasonic testing signals simultaneously, using PAUT will be helpful to collect thickness distribution over certain area of pressure vessel efficiently with suitable encoder equipped.

The PAUT inspection result at DA-3202 S1 is shown as (Figure 9), the thickness of the shell varies with height, some areas with approximately 0.08 inch (2.0 mm) remaining thickness were observed. The PAUT inspection report validates the concern of corrosion at S1, and demonstrates that the spot UTM could be an effective thickness monitoring tool for pressure vessel once the monitoring location, inspection frequency, and quality systems were established appropriately.

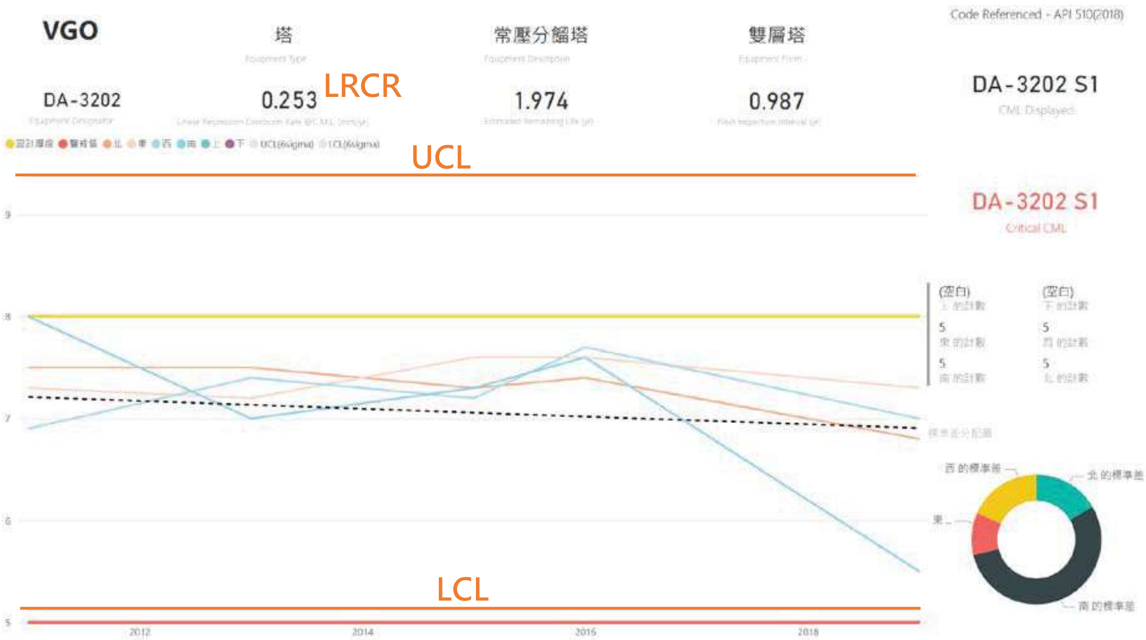

Figure 8: Control Chart for DA-3202 S1

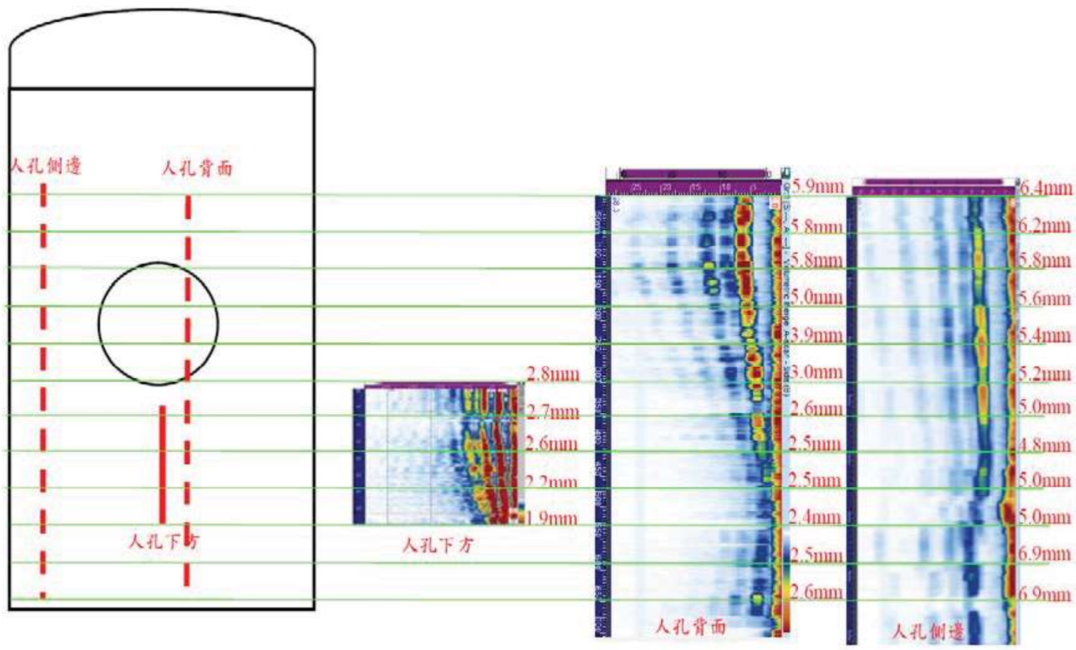

Figure 9: PAUT signals @ DA-3202 S1

The lesson learned from this example: even if the external and internal appearance of pressure vessel looks normal, once the conditions of corrosion reaction (material used, environment, operating conditions, etc.) have been met, general corrosion still could be a potential problem which can result in smooth appearance that is hard to be identified visually.

In order to identify corrosion problem with unnoticeable pattern, appropriate and sufficient TMLs need to be established, and applying suitable inspection technique with sufficient frequency thereafter.

Since it is not economically feasible to apply advanced non-destructive testing (NDT) technique such as PAUT to every pressure vessel, spot UTM can be an inspection option to screen for this kind of corrosion problem.

If decreased thickness value was found by spot UTM with reliable quality (with qualified examiner, suitable inspection procedure, and with control chart), other applicable NDT methods or direct visual testing can be applied to validate the finding of UTM.

Figure 10: External and Internal Appearance @ DA-3202 S1

EXAMPLE 3: LOCALIZED CORROSION

A localized corrosion case in which spot UTM were applied as thickness monitoring tool is introduced in this example. A reactor effluent heat exchanger with tag name E-1006B in a Residuum Desulfurization Unit in a refinery experienced localized metal loss identified by UTM. In a desulfurization process, in order to decrease sulfur dioxide production and absorb hydrogen sulfide in process stream, there is ammonia added into effluent stream.

Aggressive metal thinning may occur due to the presence of sour water with corrosion/erosion characteristic and high velocity. Most of the time, it corroded locally at areas with fluid direction changes or high turbulence. For pressure vessels that have potential damage mechanism with aggressive and localized corrosion, extreme caution must be given to select appropriate locations to be thickness monitored.

Accordingly, pressure vessel with tag name E-1006B has been monitored for thickness change behavior over years with spot UTM whose location were carefully chosen by potential fluid direction change area. The control chart for E-1006B is shown as (Figure 11). Abrupt changes thickness measurement readings were observed and in the control chart LRCR as high as 27.559 mpy (0.700

mm/yr). As thickness values were below the lower control limit, meaning the situation was significant, additional steps should be taken to confirm the abnormal condition.

An additional check was made by direct visual testing inside this heat exchanger, a portion of corroded area was found shown as (Figure 12).

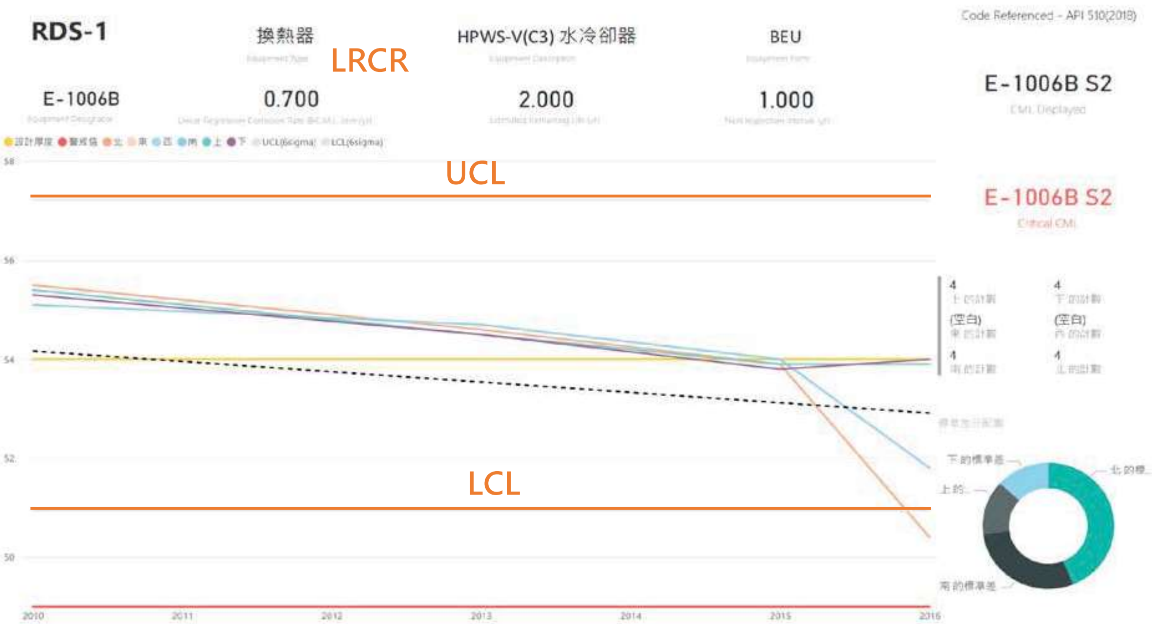

Figure 11: Control Chart for E-1006B S2

Figure 12: Localized corrosion @ E-1006B S2

In this example, if the thickness values are beyond control limit in control chart, based on the operating condition and material used for the target pressure vessel, actual metal loss due to corrosion may be experienced.

Although the thickness values obtained may be in error due to the factors previously discussed, additional confirmation should be obtained using other inspection methods, such as, visual testing or advanced NDT techniques.

Although it is not easy to identify localized corrosion problem on pressure vessel with spot UTM, using careful corrosion analysis, considering potential damage mechanism(s), geometry of equipment, material of construction, etc., it is possible to set proper TMLs on those pressure vessels to allow use of spot UTM to monitor for localized corrosion.

Caution should be taken when using prior experience alone to choose appropriate location for monitoring.

CONCLUSIONS

On the foundation of regression analysis and control chart, corrosion rate for each portion of pressure vessels in refinery with minimalized error can be obtained, and quality thickness measurement can be achieved based on statistical theory. Supported by examples above, here are some conclusions as below:

(1) Even though the values of ultrasonic thickness measurement for pressure vessel vary due to unavoidable inherent factors, corrosion rate for each portion of pressure vessels can be obtained with minimal error through the application of regression analysis.

(2) In order to have quality inspection data, control chart can be applied to monitor the quality of ultrasonic thickness measurement data over time. Once the data are enclosed by control chart boundaries, inspection data could be deemed as effective even if the values fluctuate.

(3) It is possible that spot ultrasonic thickness measurement can be used to monitor thickness changes behavior for pressure vessels effectively as long as thickness monitoring locations were chosen appropriately. Once suspected areas of corrosion were found, some advanced inspection methods with higher reliability such as PAUT or direct visual testing could be applied to demonstrate the findings.

(4) The discussion and examples in this paper are for thickness monitoring for pressure vessels due to corrosion for thinning only. Pressure vessels could suffer other potential damage mechanisms that cannot detected by ultrasonic thickness measurement such as stress corrosion cracking, fatigue cracking and high temperature creep, etc. For those damage mechanisms, other suitable NDT or analytical methods should be used.

ACKNOWLEDGEMENTS

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REFERENCES

1. API 510 (latest revision), “Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration” (Washington, DC: API)

2. API 571 (latest revision), “Damage Mechanisms Affecting Fixed Equipment in the Refining Industry” (Washington, DC: API)

3. API 572 (latest revision), “Inspection Practices for Pressure Vessels” (Washington, DC: API)

4. S. Burke and R. Silvestrini, “The Certified Quality Engineer Handbook”, 4^{th} ed. (Milwaukee, Wisconsin, 2017), p.398-p.402.

5. S. Burke and R. Silvestrini, “The Certified Quality Engineer Handbook”, 4^{th} ed. (Milwaukee, Wisconsin, 2017), p.526.

Pressure Vessel Thickness Monitoring and Analyzing Using Linear Regression and Control Chart

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2023.03.21

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1

Outline

- Introduction
- Corrosion Rate Determination By Linear Regression
- Quality Thickness Measurement Using Control Chart
- Thickness Monitoring Using Control Chart and LRCR
- Example 1: Corrosion With Visual Evidence
- Example 2: Corrosion Without Visual Evidence
- Example 3: Localized Corrosion
- Poor Thickness Measurement Examples
- Conclusion

2

Introduction

- Ultrasonic Thickness Measurement on Pressure Vessel
- Probe is small. Surface area is large.

Similar to SAMPLING

3

Introduction

- FACTs:

1. Factors (measurement location variation, equipment calibration, operator's skill, etc.) cause Errors.

2. Ultrasonic Thickness Measurement (UTM) increase/decrease even though the pressure vessel does not suffer any thickness change.

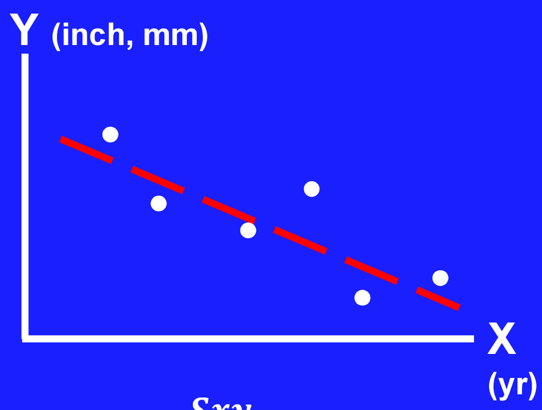
- QUESTIONs:

1. How to get <u>Corrosion Rate with Minimal Errors</u>?

2. How to get <u>Quality Inspection Data</u>?

4

Corrosion Rate Determination By Linear Regression



- **A Simple Linear Regression Model:**

yi = β0 + β1xi + εi (β0: intercept, β1: slope, εi: errors)

- **With Points Estimates (i.e., UTM):**

yi = b0 + b1xi (b0: intercept, b1: slope)

- **Linear Regression Corrosion Rate (LRCR)**

Sxy = $\sum_{i=1}^{n} xiyi$ - $\frac{(\sum_{i=1}^{n} xi)(\sum_{i=1}^{n} yi)}{n}$

Sxx = $\sum_{i=1}^{n} xi^2$ - $\frac{(\sum_{i=1}^{n} xi)^2}{n}$

LRCR = b1 = slope = $\frac{Sxy}{Sxx}$

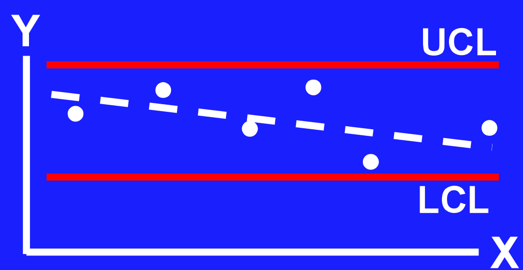
Based On "**Theory Of Minimizing The Error of Squares**"

5

Quality Thickness Measurement Using Control Chart

- With **N measurements** at **Thickness Monitoring Location (TMLs):**

Sample Standard Deviation = **si =** $\sqrt{\frac{\sum_{j=1}^{n}(xij - \bar{x})^2}{n-1}}$



- With **M sets of inspection data** over years:

Average Standard Deviation of UTMs = $\bar{s}$ = $\frac{\sum_{i=1}^{m} Si}{m}$

- Then **Upper Control Limit (UCL)** and **Lower Control Limit (LCL):**

UCL = $\bar{x}$ + C x $\bar{s}$; LCL = $\bar{x}$ - C x $\bar{s}$

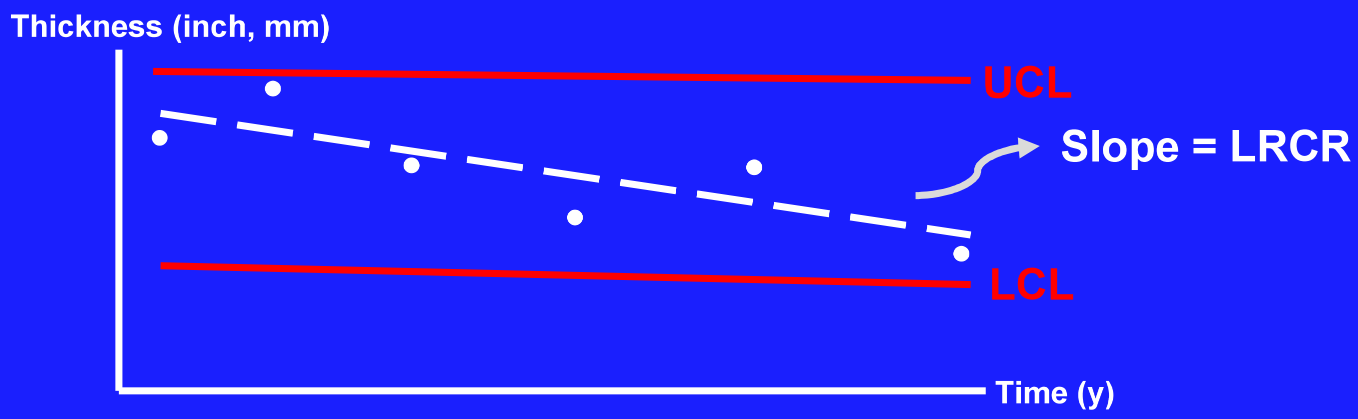
($\bar{x}$: average thickness, C: constant based on sampling size or other spec.**)**

- With data above, **Control Chart for UTM** can be established to **Monitor the Quality of Inspection.**

6

Thickness Monitoring Using Control Chart and LRCR

- LRCR : Corrosion Rate determined with Minimal Error
- Control Chart for UTM : Monitoring the Quality of Inspection



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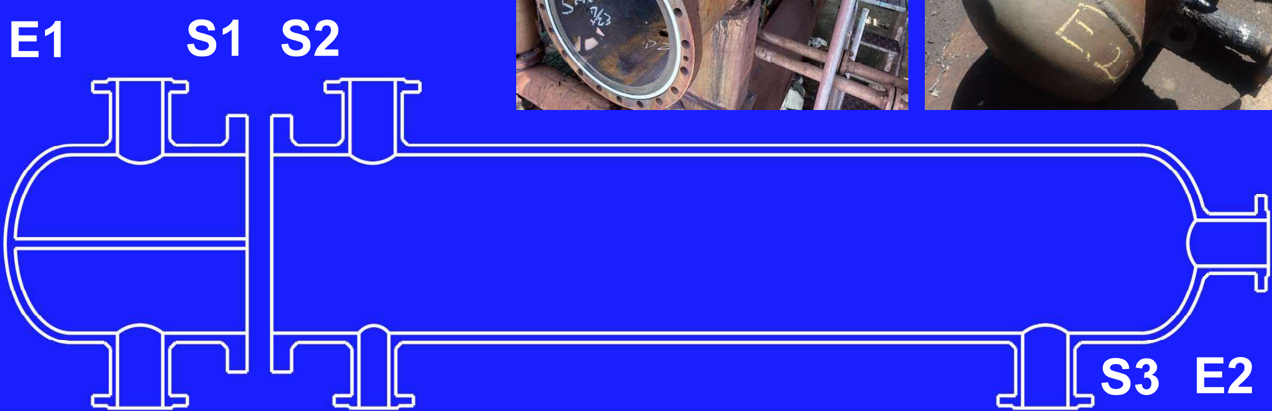
Thickness Monitoring Using Control Chart and LRCR

- Set Appropriate TMLs
- Thickness Monitoring
- Statistical Tools



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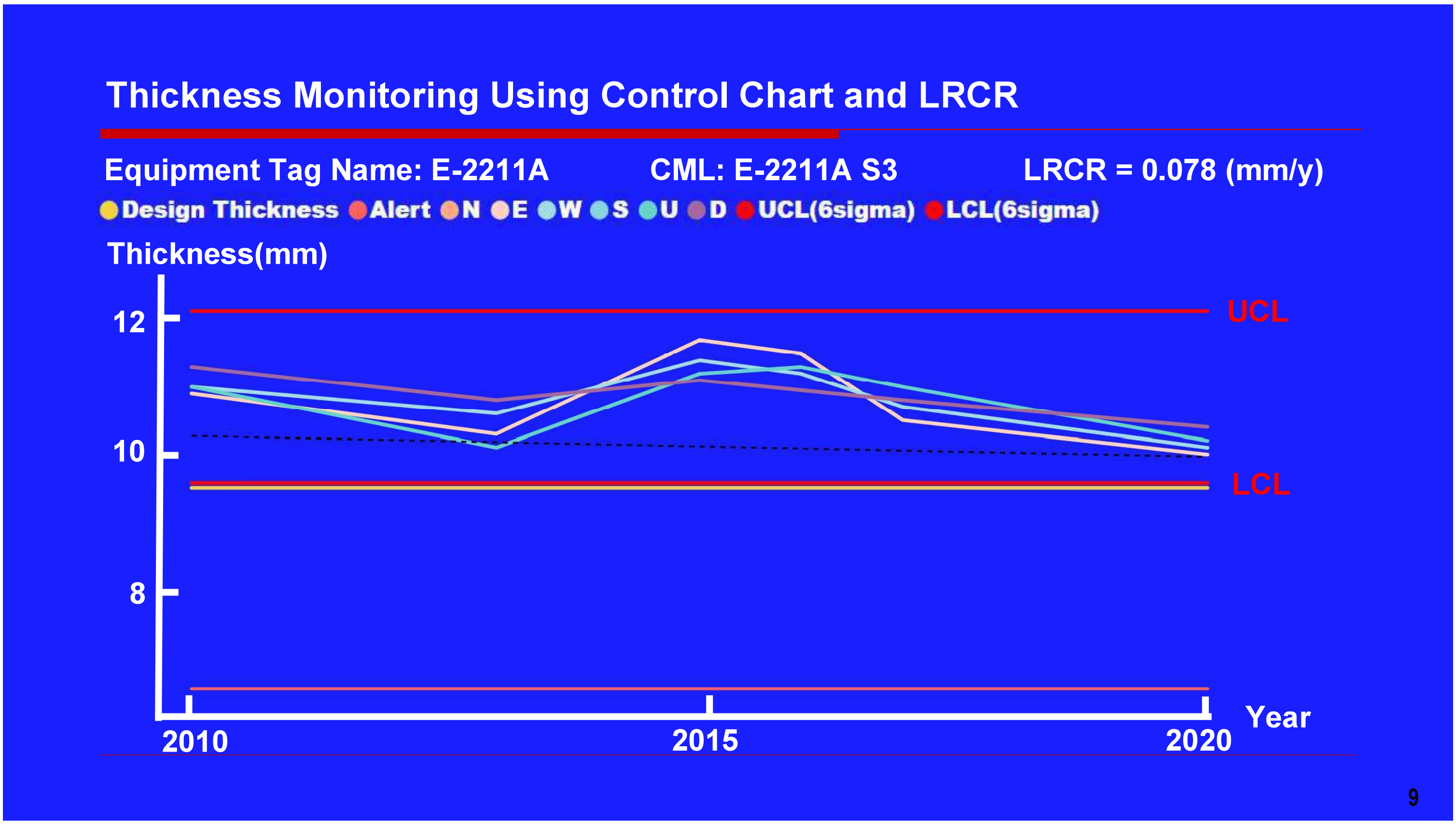
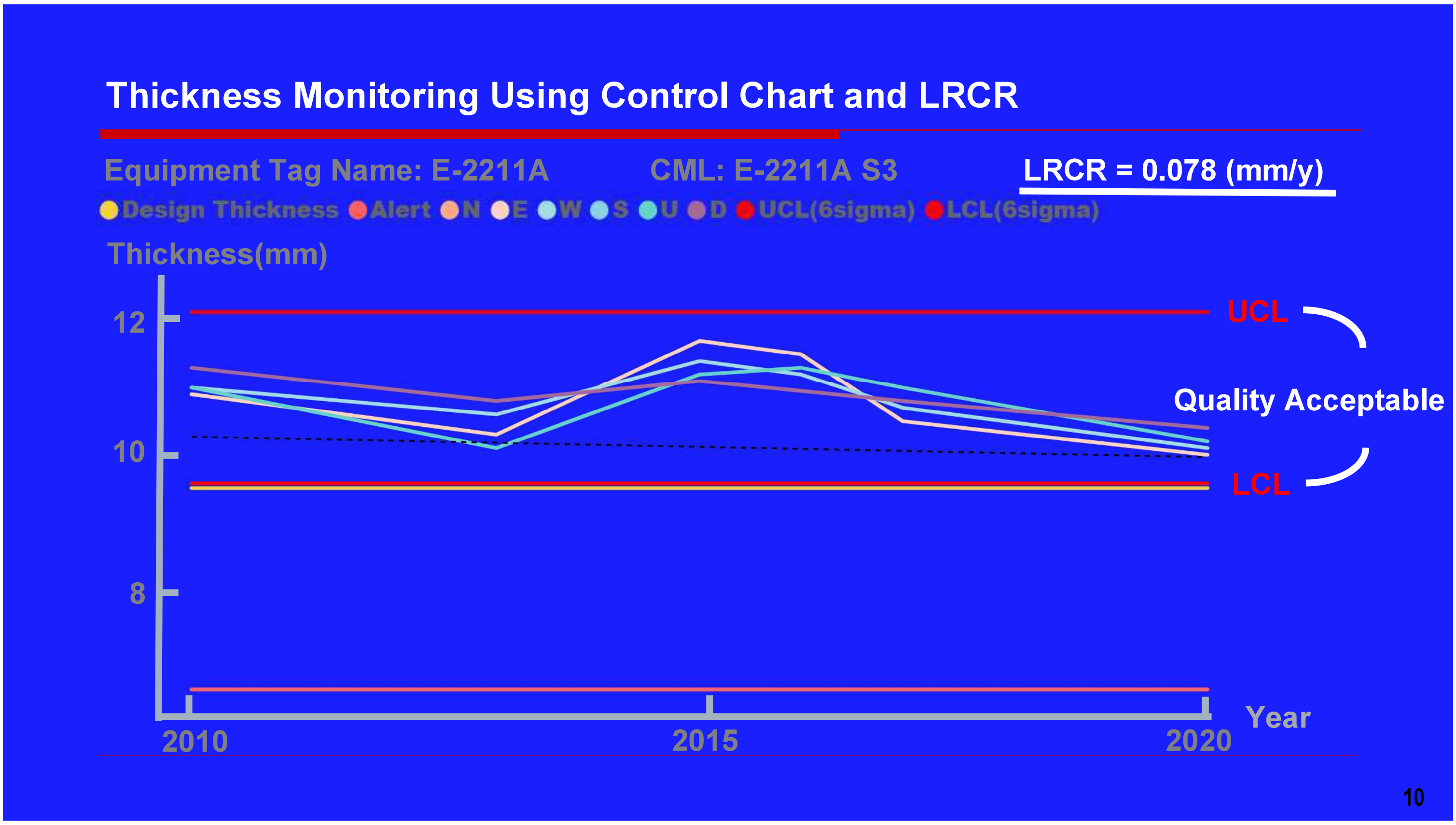

Thickness Monitoring Using Control Chart and LRCR
Equipment Tag Name: E-2211A
CML: E-2211A S3
LRCR = 0.078 (mm/y)
Design Thickness Alert N E W S U D UCL(6sigma) LCL(6sigma)
Thickness(mm)
12
10
8
UCL
LCL
2010
2015
2020
Year
9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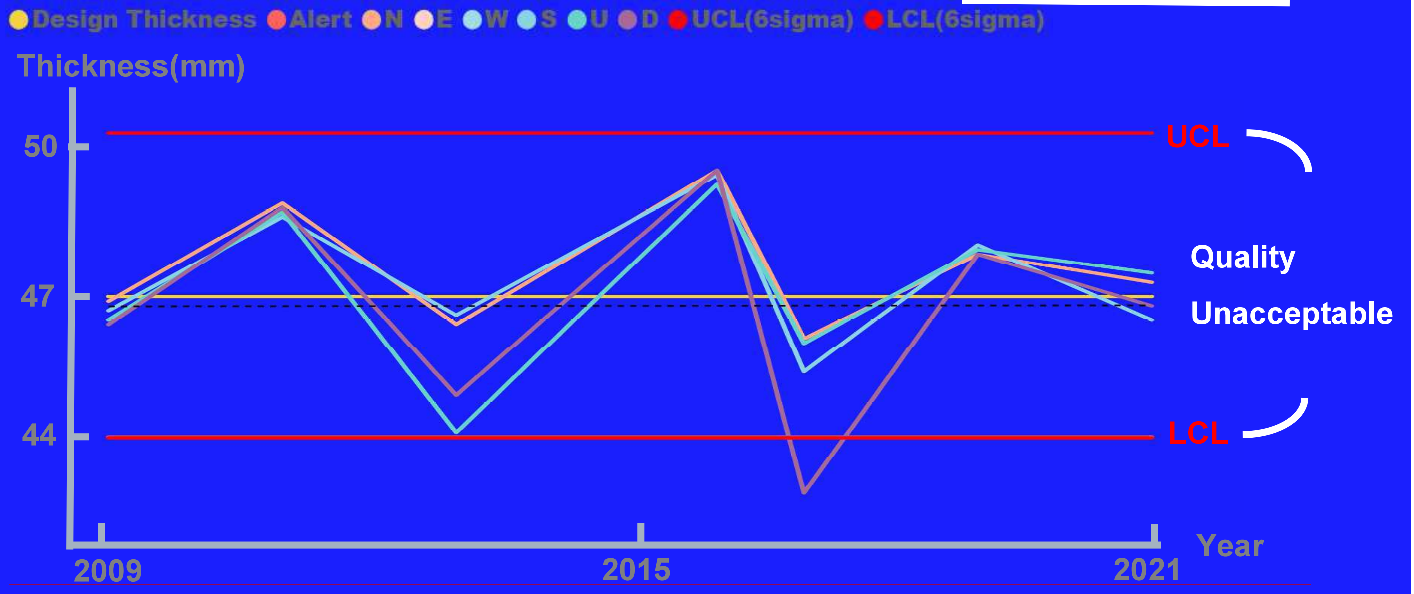
Thickness(mm)
12
10
8
UCL
Quality Acceptable
LCL
2010
2015
2020
Year
10

Thickness Monitoring Using Control Chart and LRCR

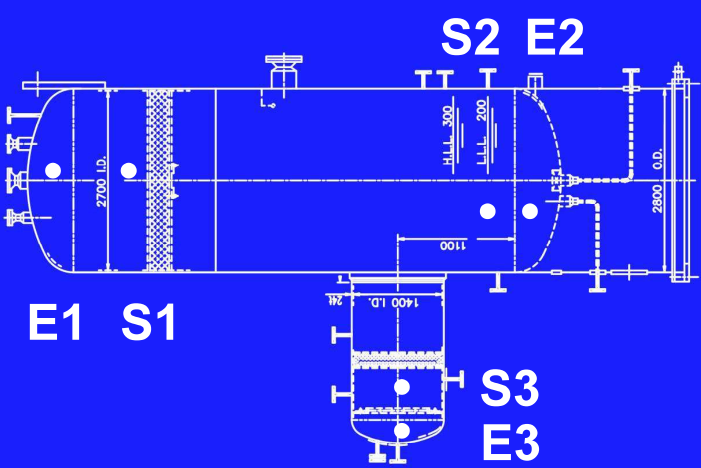
Equipment Tag Name: C-4102C-3C   CML: C-4102C-3C E2   LRCR = 0.000 (mm/y)



11

Example 1: Corrosion With Visual Evidence

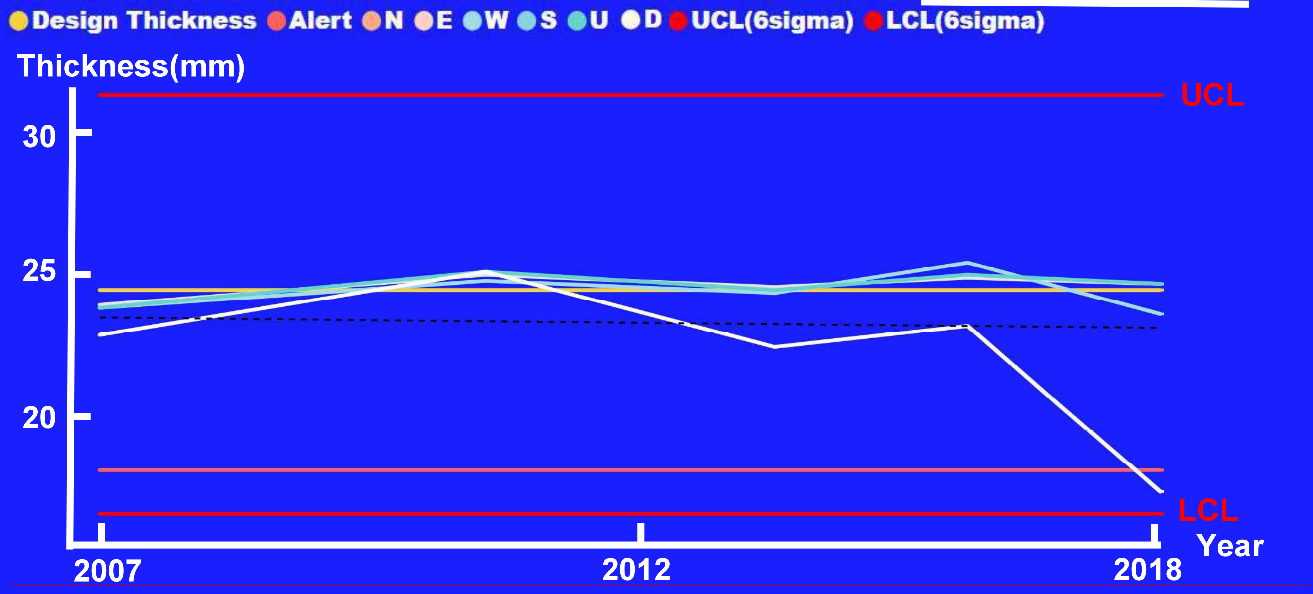
- Equipment: **Acid Wash Coalescer**
- Unit in Refinery: **Sulfuric Acid Alkylation Unit**
- Material: **Carbon Steel**



12

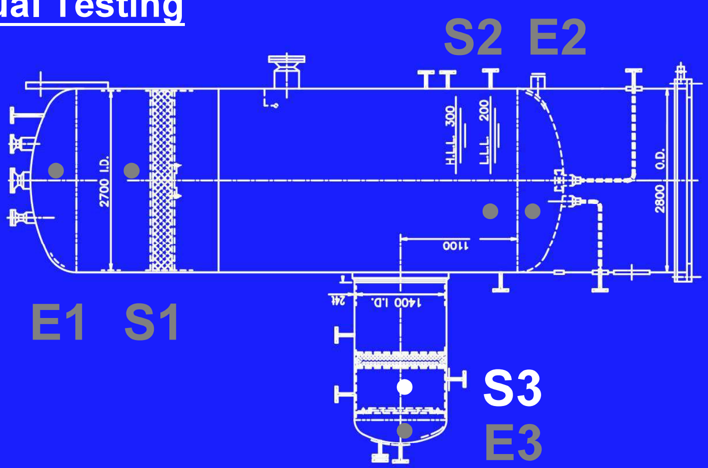
Example 1: Corrosion With Visual Evidence

Equipment Tag Name: D-109 **CML: D-109 S3** **LRCR = 0.389 (mm/y)**



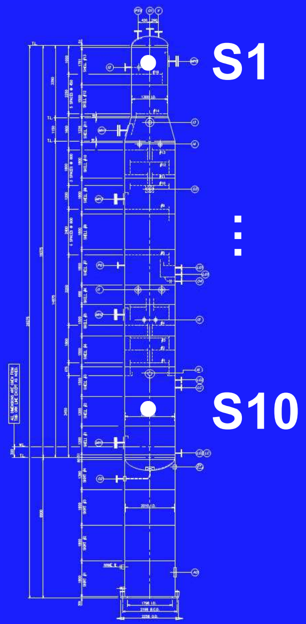
Example 1: Corrosion With Visual Evidence

- Damage Mechanism: **Sulfuric Corrosion**
- Type of Corrosion: **Uniform Thinning**
- Note: **Verify the Finding by Visual Testing**



Example 2: Corrosion Without Visual Evidence

- Equipment: **Distillation Column**
- Unit in Refinery: **Vacuum Gas Oil Unit**
- Material: **Carbon Steel**



15

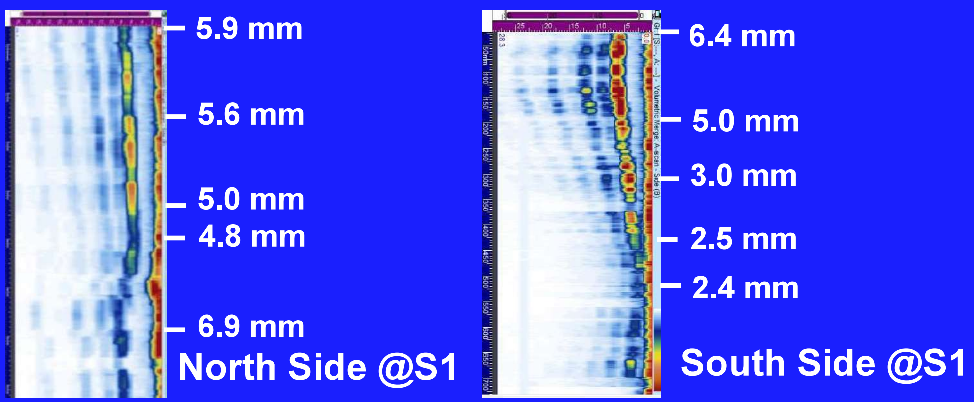
Example 2: Corrosion Without Visual Evidence

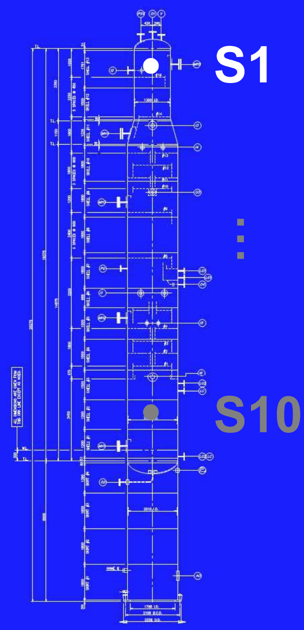
Equipment Tag Name: DA-3202 **CML: DA-3202 S1** **LRCR = 0.253 (mm/y)**

16

Example 2: Corrosion Without Visual Evidence

- Damage Mechanism: **Hydrochloric Acid Corrosion**
- Type of Corrosion: **Uniform Thinning**
- Note: **Verify the Finding by other Advanced NDE**



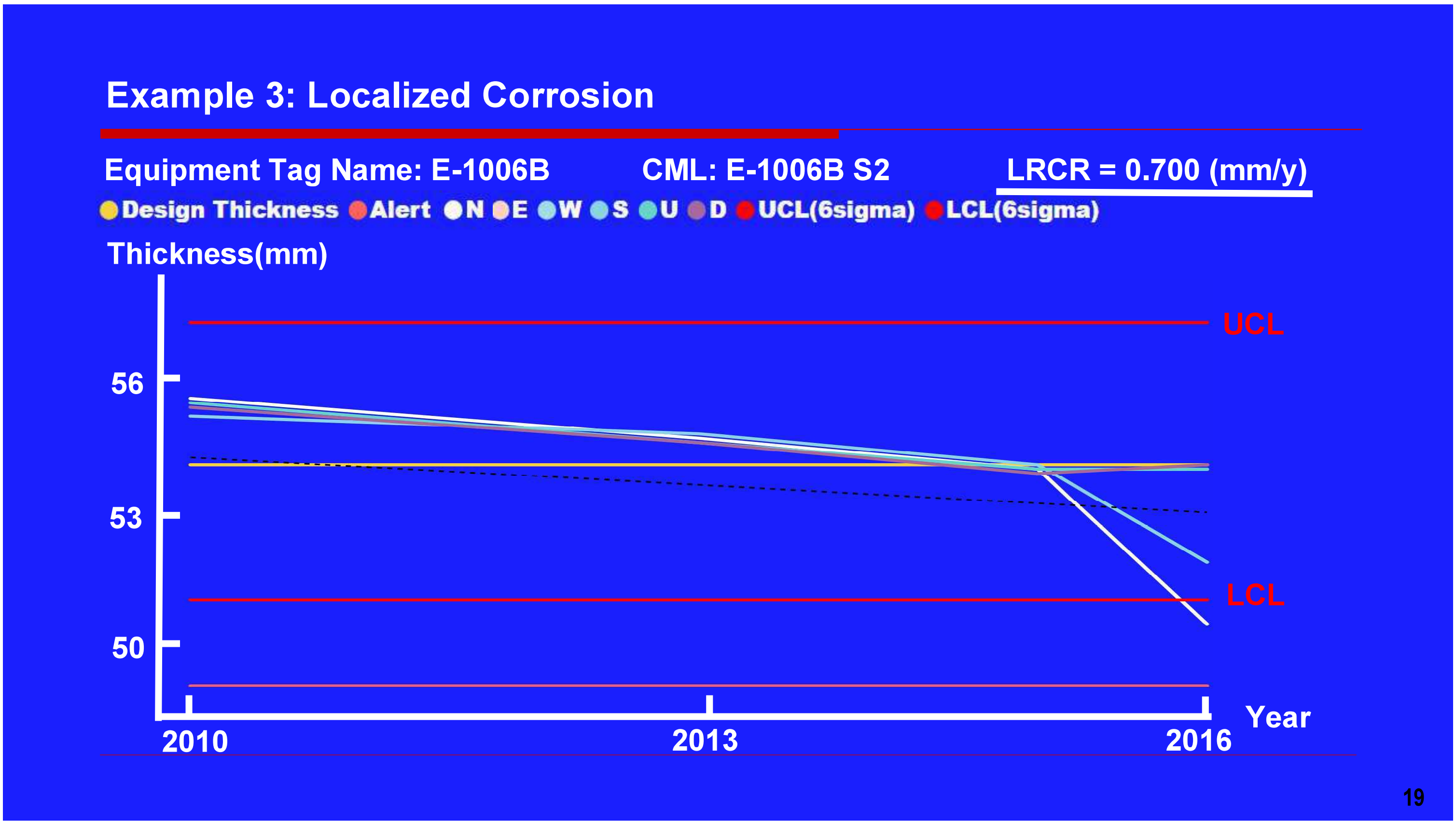


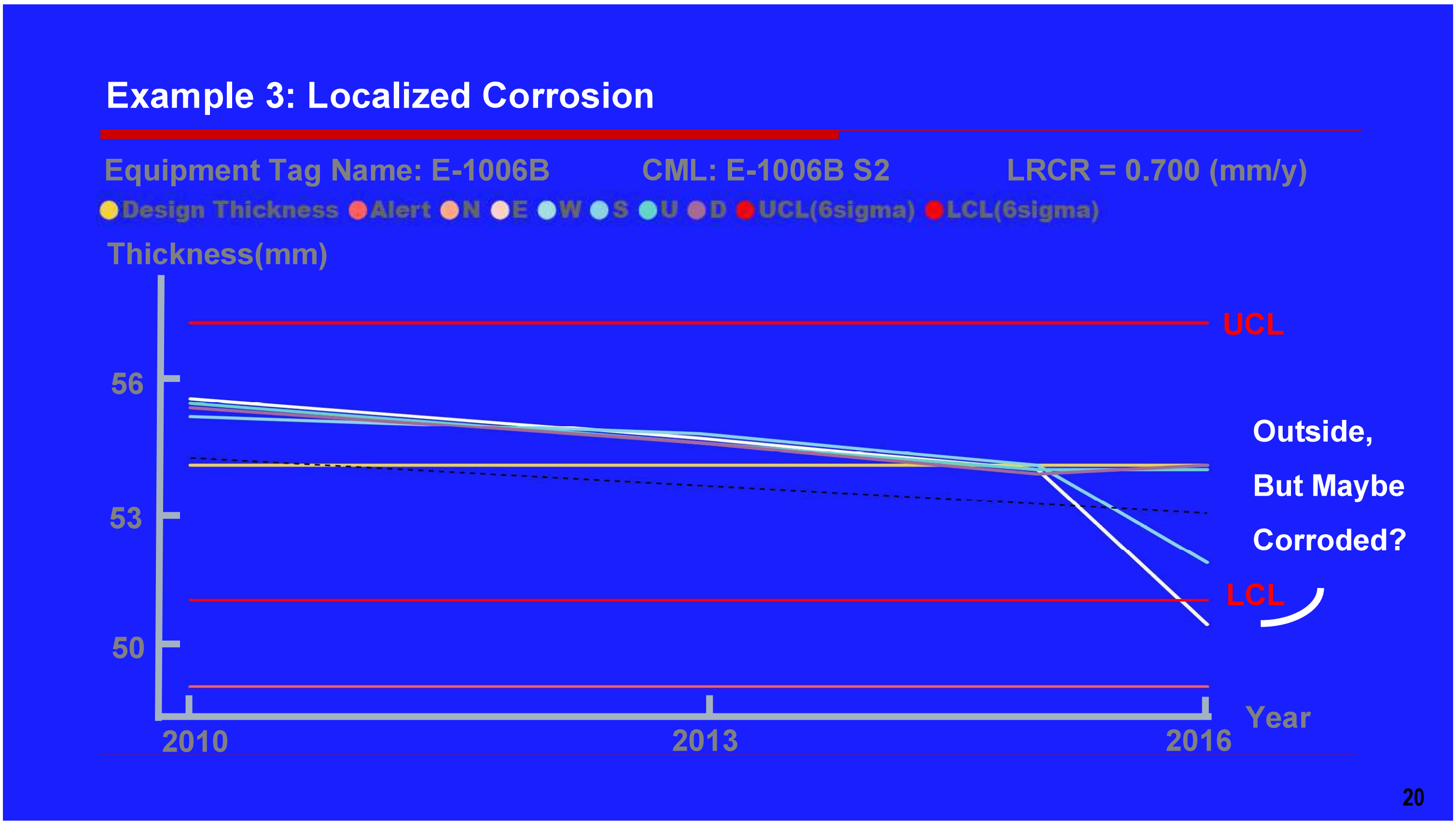
17

Example 3: Localized Corrosion

- Equipment: **Reactor Effluent Heat Exchanger**
- Unit in Refinery: **Residuum De-Sulfur Unit**
- Material: **Carbon Steel**

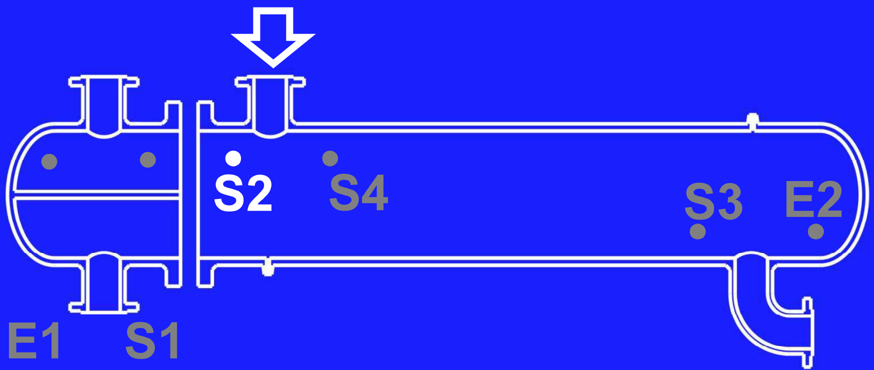
18


Example 3: Localized Corrosion
Equipment Tag Name: E-1006B
CML: E-1006B S2
LRCR = 0.700 (mm/y)
Design Thickness
Alert
N
E
W
S
U
D
UCL(6sigma)
LCL(6sigma)
Thickness(mm)
56
53
50
UCL
LCL
Year
2010
2013
2016
19


Example 3: Localized Corrosion
Equipment Tag Name: E-1006B
CML: E-1006B S2
LRCR = 0.700 (mm/y)
Design Thickness
Alert
N
E
W
S
U
D
UCL(6sigma)
LCL(6sigma)
Thickness(mm)
56
53
50
UCL
Outside,
But Maybe
Corroded?
LCL
Year
2010
2013
2016
20

Example 3: Localized Corrosion

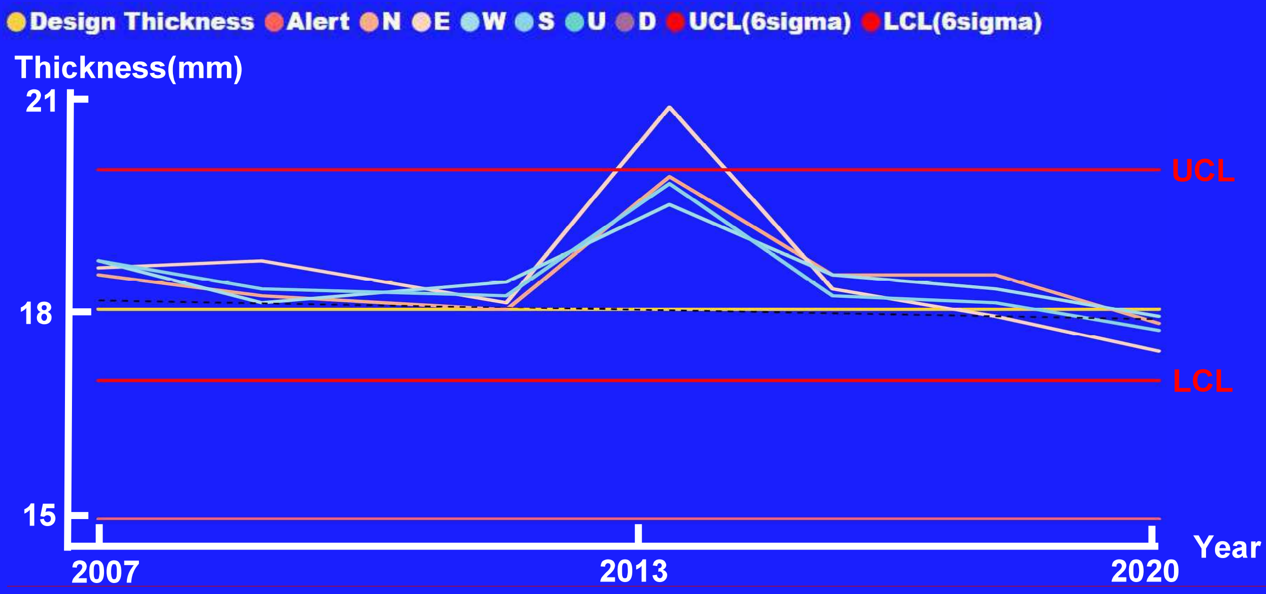
- Damage Mechanism: **Sour Water Corrosion/Erosion**
- Type of Corrosion: **Localized Thinning**
- Note: **Chose TMLs Carefully with Localized Case**



21

Poor Thickness Measurement Examples - Abnormality

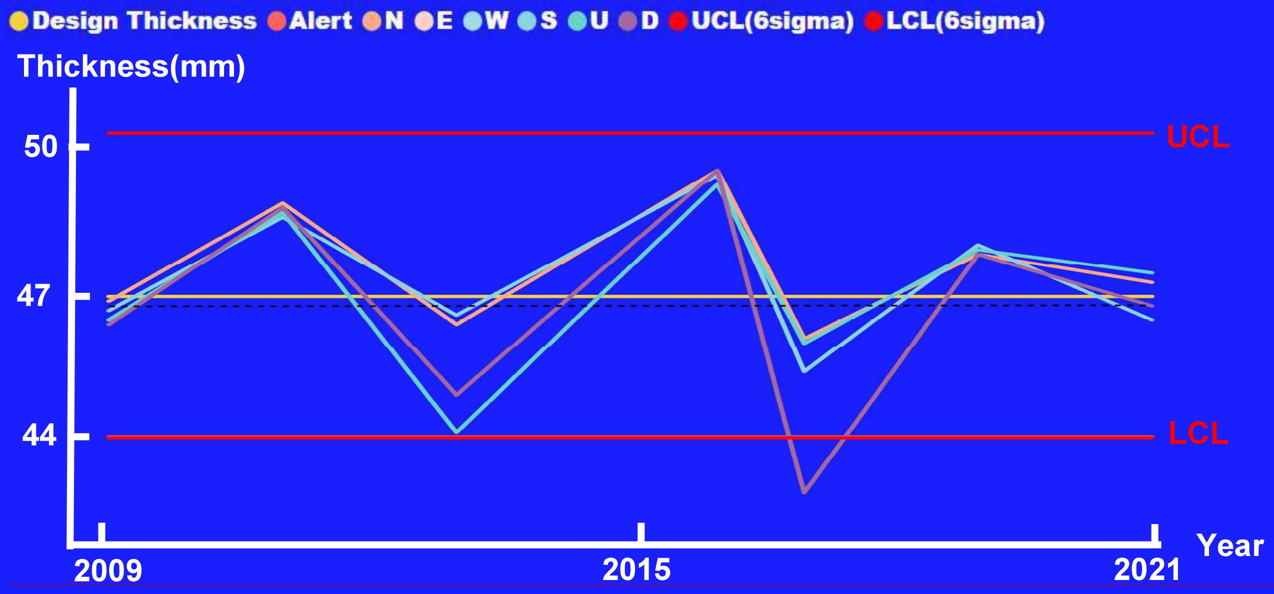
Equipment Tag Name: D-7330 CML: D-7330 S1 LRCR = 0.076 (mm/y)



22

Poor Thickness Measurement Examples - Over Fluctuation

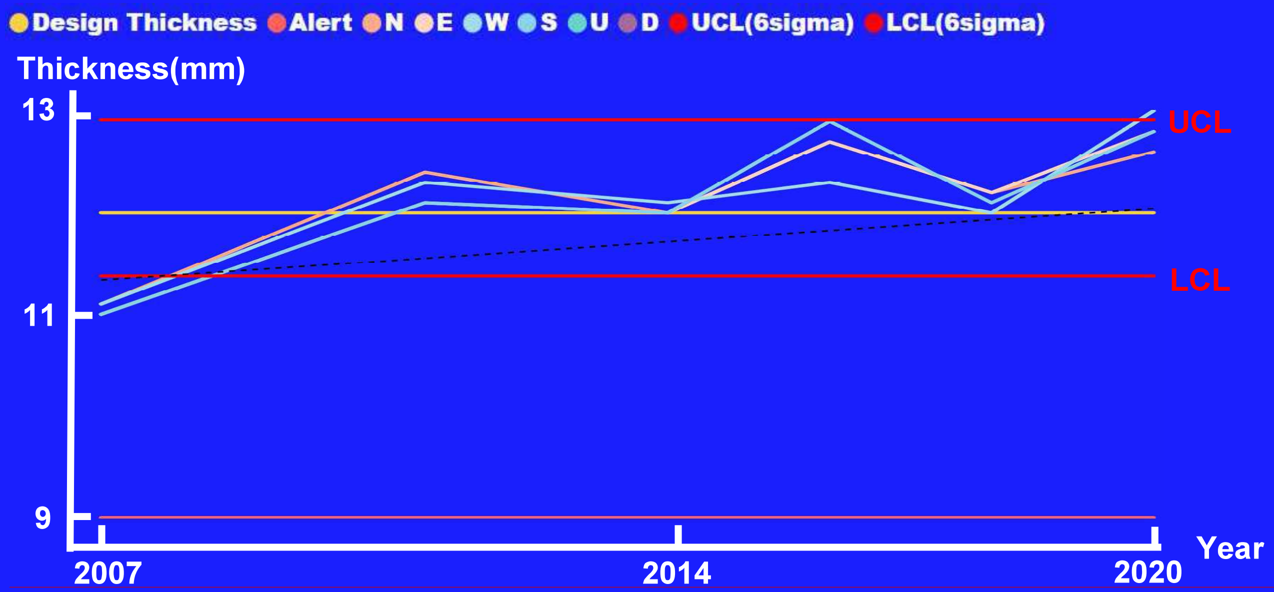
Equipment Tag Name: C-4102C-3C CML: C-4102C-3C E2 LRCR = 0.000 (mm/y)



23

Poor Thickness Measurement Examples - Increasing Thickness

Equipment Tag Name: V-402 CML: V-402 S5 LRCR = 0.000 (mm/y)



24

Conclusion

- Corrosion Rate for each portion of pressure vessels can be obtained with Minimal Error through the application of Regression Analysis.
- Control Chart can be applied to monitor the Quality of Inspection.
- Spot UTM could be used to monitor thickness changes behavior for pressure vessels effectively as long as TMLs were chosen appropriately.
- Other damage mechanisms that cannot be detected by UTM such as stress corrosion cracking, fatigue cracking and high temperature creep and so on. For those kinds of damage mechanism, other suitable NDT or analysis methods should be considered.

25

26

附件三 參加之研討會議清單

My schedule

Sunday, March 19, 2023

8:00 AM
12:00 PM

MR0175/ISO 15156 Maintenance Panel

Room 104 & 106

ISO

8:00 AM
10:00 AM

Linings, Immersion, and Buried Service Information Exchange (TCI)

Room 407

Technical

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

8:00 AM
12:00 PM

Coatings 101 Workshop

Presented by Charles Brown, Mike Basse, and Chris Farschon, Greenman-Pedersen, Inc., This workshop for thos...

Room 401 & 402

Workshop

CB **Charles Brown**
GPI

CF **Christopher Farschon**
GPI

Coatings

10:30 AM
5:30 PM

Internal Corrosion

Chair: Mohsen Achour, Vice Chair: Moavin Islam | This symposium will be discussing Internal Corrosion Mechanism...

Room 705 & 707

Symposia

MA **Mohsen Achour**
ConocoPhillips Company

MI **Moavin Islam**
CORROSION FORENSICS LLC

Science of Corrosion | Science of Corrosion

1:00 PM
4:30 PM

Digital Asset Transformation: Application of Data Science and Analytics for Corrosion Management

Chair: Mustafa Kara, Vice Chair: Jason Moral | This symposium features technical papers on new development...

Room 710 & 712

Symposia

MK **Mustafa Kara**
Chevron Technology Center

Corrosion Monitoring and Control

3:00 PM
5:00 PM

Corrosion Under Insulation and Passive Fire Protection Information Exchange (TCI)

Room 407

Technical

Coatings

3:10 PM
3:35 PM

C2023-18785 Real Time Sour Water Corrosion Prediction For Fluid Catalytic Cracking Overhead System

Hui Li, Pierre Constantineau, Cady Zhuang, Yan Hong Hou - Crude feeds often contain contaminants such as sulfur an...

Room 710 & 712

Symposia

HL **Hui Li**
Honeywell Process Solutions

Corrosion Monitoring and Control

5:30 PM
7:00 PM

Opening Reception

Four Seasons 3 & 4

Networking

Monday, March 20, 2023

8:00 AM
12:00 PM

High Temperature Applications

Chair: Rajeev Gupta, Vice Chair: David Shifler | This RIP symposium is seeking abstracts that cover recent advance...

Room 709 & 711

RIP

RG **Rajeev Gupta**

Science of Corrosion | Science of Corrosion

8:00 AM
5:00 PM

SC 10 - Asset Integrity Management

Room 103 & 105

Standards

Science of Corrosion | Science of Corrosion

8:00 AM
+ 3 days

SC 15 - Pipelines & Tanks

Mar 20, 2023 8:00 AM to Mar 23, 2023 5:00 PM

Room 104 & 106

Standards

Oil and Gas Pipelines | Oil and Gas Pipelines | Oil and Gas Pipelines

8:00 AM
2:00 PM

Corrosion Resistant Alloy Development and Applications

Chair: Narasi Sridhar, Vice Chair: Vinay Deodeshmukh | This symposium is focused on the development of corrosion...

Room 507

Symposia

NS **Narasi Sridhar**

VD **Vinay Deodeshmukh**
Haynes International, Inc.

Science of Corrosion | Science of Corrosion

8:00 AM
3:30 PM

Environmental Assisted Cracking (EAC) - Day 1

Chair: Gaoxiang Wu, Vice Chair: Fei Tang | This symposium is seeking technical papers related to understanding various...

Room 710 & 712

Symposia

GW **Gaoxiang Wu**
ExxonMobil Research & Engineering Company

FT **Fei Tang**
DNV

Science of Corrosion | Science of Corrosion

8:00 AM
11:00 AM

Gaseous Hydrogen Embrittlement

Chair: Marco De Marco, Vice Chair: Marco Palombo | This symposium features technical papers on the study of the...

Room 601

Symposia

MDM **Marco De Marco**
Istituto Italiano Saldatura

MP **Marco Palombo**
Istituto Italiano Saldatura

Materials Selection and Design | Materials Selection and Design
Materials Selection and Design | Materials Selection and Design

8:00 AM
11:00 AM

Corrosion Under Insulation

Chair: Ahmad Raza Khan Rana, Vice Chair: George Jarjoura | This symposium includes technical papers on CUI (corrosio...

Room 403 & 404

Symposia

ARK Ahmad Raza Khan Rana

GJ George Jarjoura

Oil and Gas Production | Oil and Gas Production

10:35 AM
11:00 AM

C2023-18871 Preventing Corrosion Under Insulation In Piping – Trends After Evaluating Digital Data From Thousands Of Piping Circuits

Ana Benz, Eddie Sanchez, Eric Sjerve, Katherine Jonsson, Michael Townsend, Michael Nichols - Insulation provides a...

Room 403 & 404

Symposia

AB Ana Benz

GJ George Jarjoura

ARK Ahmad Raza Khan Rana

Oil and Gas Production | Oil and Gas Production

1:00 PM
3:30 PM

Coating Failure Investigations - Finding the Cause

Presented by Valerie Sherbondy and Rick Huntley, KTA-Tator, Inc.It is not supposed to happen, but sometimes...

Room 401 & 402

Workshop

VS **Valerie Sherbondy**
KTA-Tator Inc

RH **Rick Huntley**
KTA-Tator Inc

Coatings

1:00 PM
1:25 PM

C2023-18763 Hydrogen Embrittlement Susceptibility In Corrosion Resistant Materials For Fasteners

Hans Husby, Gisle Rørvik, Inge Kulbotten - In this work, the HE resistance of several seawater corrosion resistant...

Room 710 & 712

Symposia

HH **Hans Husby**

Science of Corrosion | Science of Corrosion

3:00 PM
3:25 PM

C2023-19279 Asset Life Extension Through Deployment Of Corrosion And Inspection Technologies: Corrosion Monitoring Vs. Condition Monitoring

Rakan Alshebel, Faisal Al-Mutahhar, Ayman Alabdullatif - With the new development in the fields of corrosion and...

Four Seasons 4

Symposia

AJ **Alyn Jenkins**
Schlumberger

MS **Michael Snow**
Enbridge Pipelines, Inc.

Oil and Gas Production | Oil and Gas Production

3:10 PM
3:35 PM

C2023-19397 Material Selection And Process Control In Tail Gas Treating Unit (TGTU)

Ameer Hamza, Rakan Samman - The material of construction made of carbon steel are seriously getting...

Room 709 & 711

Symposia

AH **Ameer Hamza**
Yanbu Aramco Sinopec Refining Company (YASREF)

BG **Barinder Ghai**
Alleima

SLM **Sandra Le Manchet**
ArcelorMittal - Industeel USA LLC

Materials Selection and Design | Materials Selection and Design

3:30 PM
4:30 PM

Keynote with Hall of Fame Quarterback and TV Personality Terry Bradshaw

"Why not you're best?" The Association for Materials Protection and Performance (AMPP) is proud to announce...

Four Seasons 1 & 2

Other

5:00 PM
8:00 PM

Exhibit Hall Grand Opening

Exhibit Hall

Exhibit Hall

7:00 PM
10:00 PM

EAPA Seminar: Intelligent Corrosion Control

Presented by Bei Gu, AMPP | With staggering and increasing corrosion losses globally, stronger, smarter yet...

Forum

Corrosion Monitoring and Control

Tuesday, March 21, 2023

8:00 AM
12:00 PM

SC 13 - Corrosion Monitoring & Measurement

Room 107 & 109

Standards

Science of Corrosion
Science of Corrosion
Science of Corrosion

8:00 AM
9:00 AM

TC 10 Pipelines and Tanks Technical Committee

Room 111 & 113

Technical

Pipelines, Tanks, and Underground Systems

8:00 AM
5:00 PM

Oil & Gas Petroleum Refining and Gas Processing Information Exchange (TCI)

Room 605 & 607

Technical

Oil and Gas Production

10:00 AM
5:30 PM

Environmentally Assisted Cracking and Hydrogen Embrittlement – Day 1

Chair: Brendy Rincon Troconis, Vice Chair: Jenifer Locke | This RIP session includes presentations that focus on all aspects...

Room 710 & 712

RIP

BRT

Brendy Rincon Troconis
University of Texas at San Antonio

Science of Corrosion Science of Corrosion

10:00 AM
2:30 PM

Corrosion Management

Chair: Brian Burgess, Vice Chair: Robin Tems | This symposium is seeking recent technical papers on recent...

Room 705 & 707

Symposia

BB

Brian Burgess
Brian Burgess, Consultant

RT

Robin Tems
Hollybeach Corrosion Management

Transportation Transportation

10:00 AM
5:30 PM

Sweet and Sour Corrosion - Day 1

Chair: Krista Heidersbach, Vice Chair: Carmen Fonseca | This symposium features technical papers on corrosion related...

Room 601

Symposia

KH **Krista Heidersbach**
Phillips 66

CF **Carmen Fonseca**
BP Exploration & Production Operating Co. Ltd

Oil and Gas Production | Oil and Gas Production | Oil and Gas Production

10:10 AM
10:35 AM

C2023-18821 Pressure Vessel Thickness Monitoring And Analyzing Using Linear Regression And Control Chart

Shao-Chi Chen, Cheng Hsuan Hsieh - In API 510, it offers two ways for corrosion rate determination, one is using...

Room 705 & 707

Symposia

RT **Robin Tems**
Hollybeach Corrosion Management

BB **Brian Burgess**
Brian Burgess, Consultant

SC **Shao-Chi Chen**
CPC Corporation/Refining Business Division

Transportation | Transportation

11:25 AM
11:50 AM

C2023-19477 The Importance Of Leadership In Corrosion Management

Zoe Coull, Noelia Diaz, Muan Wei - Leadership accountability and involvement is vital to the success of a...

Room 705 & 707

Symposia

ZC **Zoe Coull**

BB **Brian Burgess**
Brian Burgess, Consultant

RT **Robin Tems**
Hollybeach Corrosion Management

Transportation Transportation

1:50 PM
2:15 PM

C2023-19385 The Implementation Of A Corrosion Management System (CMS) In An Operating Gold Mine – Lessons Learned

Muan Wei, Noelia Diaz, Zoe Coull - It is known that corrosion has significant impacts on all types of assets with respect t...

Room 705 & 707

Symposia

MW **Muan Wei**

BB **Brian Burgess**
Brian Burgess, Consultant

RT **Robin Tems**
Hollybeach Corrosion Management

Transportation
Transportation

Wednesday, March 22, 2023

8:00 AM
5:00 PM

SC 08 - Metallic Material Selection & Testing - Day 1

Room 111 & 113

Standards

Materials Selection and Design
Materials Selection and Design

8:00 AM
12:00 PM

Beyond the Standard: Leadership Behaviors that Drive Results

Co-chaired by Stephanie Biagiotti, Xcel Energy; Kailey Dharam, Dairyland; and Kelsey May, MESAPresented by:...

Room 601

Forum

BC **Bob Chalker**

KM **Kelsey May**

KD **Kailey Dharam**

MT **Michael Tachick**

SB **Stephanie Biagiotti**

CB **Clay Brelsford**
Bass Engineering

JB **Jarret Brelsford**
Bass Engineering

8:00 AM
1:30 PM

Mechanisms of Localized Corrosion

Chair: Helmuth Sarmiento Klapper, Vice Chair: Angeire Huggins-Gonzalez | This symposium features technical...

Room 709 & 711

Symposia

HSK

Helmuth Sarmiento Klapper
Baker Hughes INTEQ

Science of Corrosion

Science of Corrosion

8:00 AM
5:00 PM

Pipeline Integrity - Day 1

Chair: Matthew Ellinger, Vice Chair: Tod Barker | This symposium will feature technical papers on all aspects of...

Room 605 & 607

Symposia

ME

Matthew Ellinger
DNV

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

8:00 AM
3:30 PM

Recent Experiences With Austenitic and Duplex Stainless Steels

Chair: Nicole Kinsman, Vice Chair: Lena Wegrelius | This symposium is seeking technical papers on recent...

Room 507

Symposia

NK **Nicole Kinsman**

LW **Lena Wegrelius**

Science of Corrosion | Science of Corrosion

8:00 AM
12:00 PM

Refining Industry Corrosion

Chair: Joe Yin, Vice Chair: Nathaniel Sutton | This symposium is seeking technical papers on corrosion and material issue...

Room 503 & 504

Symposia

Oil and Gas Production

8:00 AM
11:00 AM

Environmental Assisted Cracking (EAC) - Day 2

Chair: Gaoxiang Wu, Vice Chair: Fei Tang | This symposium is seeking technical papers related to understanding various...

Room 710 & 712

Symposia

GW

Gaoxiang Wu
ExxonMobil Research & Engineering Company

FT

Fei Tang
DNV

Science of Corrosion | Science of Corrosion

8:00 AM
9:00 AM

Sweet and Sour Corrosion - Day 2

Chair: Krista Heidersbach, Vice Chair: Carmen Fonseca | This symposium features technical papers on corrosion related...

Room 705 & 707

Symposia

KH

Krista Heidersbach
Phillips 66

CF

Carmen Fonseca
BP Exploration & Production Operating Co. Ltd

Oil and Gas Production | Oil and Gas Production | Oil and Gas Production

8:00 AM
9:00 AM

Data Analytics Information Exchange (TCI)

This TCI is associated with the TC 05 Corrosion Management Technical Committee.Chase Schippers,...

Room 703

Technical

8:10 AM
8:35 AM

C2023-18771 Integrity Assessment Of Carburization Damage For Refinery Fired Heater Tubes

Jeff Goldstein - A common damage mechanism for fired heater tubes in a coking service is Carburization, which if n...

Room 503 & 504

Symposia

JG

Jeff Goldstein
Quest Integrity Group, LLC

Oil and Gas Production

8:35 AM
9:00 AM

C2023-19235 Strain Hardened Austenitic Corrosion Resistant Alloys' Susceptibility To Hydrogen Induced Stress Cracking

Roy Johnsen, Atle Qvale, Hans Husby, Gisle Rørvik, Gotthard Mälzer, Xu Lu, Amrinder Dhillon - Three different strain...

Room 710 & 712

Symposia

RJ

Roy Johnsen

Science of Corrosion

Science of Corrosion

8:35 AM
9:00 AM

C2023-19067 Review Of A Refinery Boiler Tube Failure

Darrell Freeman, Mel Esmacher, David Whitt, Ryan Horsley - Each boiler design presents its own challenges to ensure...

Room 503 & 504

Symposia

DF **Darrell Freeman**

Oil and Gas Production

9:00 AM
10:00 AM

Internal Corrosion Management Program

Presented by David Velasco, Cosasco | Roundtable discussion on leading and lagging indicators of internal...

AMPPiTheater 2

Theater

DV **David Velasco**

Science of Corrosion Science of Corrosion

9:00 AM
9:25 AM

C2023-19107 Mechanistic Insights Into Refinery Sulfidation Corrosion

Ishan Patel, Gheorghe Bota, David Young - Multiple mass transport and reaction type rate processes are involved in...

Room 503 & 504

Symposia

IP **Ishan Patel**

Oil and Gas Production

10:00 AM
12:00 PM

AMPP Certified Card Holders - Cathodic Protection Updates and Industry Information

Certified card holders attend this session, earn PDHs for recertification and learn about what is new in Cathodic...

Room 701

Other

11:00 AM
11:25 AM

C2023-19187 Practical Considerations For The Assessment Of HTHA Risk

Frank Sapienza, Gerrit Buchheim, Dave Dewees, Jeremy Staats - Recent developments in HTHA models now allow...

Room 503 & 504

Symposia

FS

Frank Sapienza
Becht Engineering

Oil and Gas Production

1:00 PM
5:00 PM

SC 08 - Metallic Material Selection & Testing - Day 1 Session 2

Room 103 & 105

Standards

1:30 PM
2:30 PM

Ultrasonic Inspection for Corrosion Inspection

Presented by Jorge T. Reyna, JRSA Inspections and Brenda de la Riva, Acum | Presentation objectives as follows: 1)...

AMPPiTheater 2

Theater

Corrosion Monitoring and Control

4:00 PM
4:25 PM

C2023-19039 Practical Application Of AI To Transform Pipeline Integrity Management

Pankaj Tandon - Midstream pipeline integrity teams face continual challenges from deteriorating conditions such as...

Room 605 & 607

Symposia

PT

Pankaj Tandon

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

4:25 PM
4:50 PM

C2023-19393 Predictive Analytics And Machine Learning In Integrated External Corrosion Monitoring (IECM)

Thomas Hayden, Joseph Mazzella, Keith Parker, Christophe Baete - Integrated External Corrosion Monitoring (IECM) is...

Room 605 & 607

Symposia

TH

Thomas Hayden
Engineering Director, Inc

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

4:25 PM
4:50 PM

C2023-19580 Research Progress In Understanding Hydrogen Embrittlement Behavior Of Nickel-Based Alloys: Partitioning Of Hydrogen Among Trap Sites Depending On Processing Routes

Masoud Moshtaghi - Traditionally, nickel-based alloys have a wide range of applications in different industrial...

Room 710 & 712

RIP

Science of Corrosion Science of Corrosion

Thursday, March 23, 2023

8:00 AM
10:00 AM

Aboveground Storage Tank Bottom Cathodic Protection

Chair: Husain Al-Mahrous, Vice Chair: Zhao Wei | This symposium features technical papers on comparative stud...

Room 710 & 712

Symposia

HA **Husain Al-Mahrous**

WZ **Wei Zhao**
Zhejiang Yuxi Corrosion Control Corporation

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

8:00 AM
12:00 PM

SC 08 - Metallic Material Selection & Testing - Day 2

Room 111 & 113

Standards

Materials Selection and Design | Materials Selection and Design

8:00 AM
12:00 PM

SC 20 - Internal Corrosion Management

Room 110 & 112

Standards

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

8:00 AM
3:00 PM

High Temperature Materials and Corrosion

Chair: Bill Valerioti, Vice Chair: Bingtao Li | This symposium features technical papers for experience, testing, study, an...

Room 407

Symposia

BV **Bill Valerioti**

BL **Bingtao Li**
Haynes International, Inc.

Science of Corrosion | Science of Corrosion

8:00 AM
12:00 PM

Machine Learning for Corrosion Management

Chair: Francois Ayello, Vice Chair: Hao Chen | This symposium features technical papers on how to model...

Room 709 & 711

Symposia

FA **Francois Ayello**
DNV

HC **HAO CHEN**
Energy Transfer

Science of Corrosion Science of Corrosion

8:00 AM
10:30 AM

Recent Experiences with Nickel, Titanium, Zirconium and other Corrosion Resistant Alloys

Chair: Ralph Bäßler, Vice Chair: Ajit Mishra | This symposium covers technical papers related to the practical use and...

Room 507

Symposia

RB **Ralph Baessler**
Fed. Institute for Materials Research and Testing

AM **Ajit Mishra**
Corteva Agriscience

Science of Corrosion Science of Corrosion

9:00 AM
9:25 AM

C2023-18956 Application Of Probabilistic Model In Stress Corrosion Cracking Direct Assessment

Francois Ayello, Guanlan Liu, Thodla Ramgopal, Narasi Sridhar - Stress Corrosion Cracking Direct Assessment...

Room 506

Symposia

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

10:35 AM
11:00 AM

C2023-19231 Case Studies On ECDA And SCCDA

Vignesh Shankar - ECDA (External Corrosion Direct Assessment) and SCCDA (Stress Corrosion Cracking Direct...

Room 506

Symposia

VS

Vignesh Shankar
PureHM

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

Pipelines, Tanks, and Underground Systems

11:00 AM
11:25 AM

C2023-19289 Ultrasonic Guided Waves And Machine Learning For Corrosion Monitoring In Steel Pipes

Magnus Wangensteen, Tonni Johansen, Ali Fatemi, Erlend Viggen - In a pipe, a circumferentially travelling ultrasonic...

Room 709 & 711

Symposia

HC **HAO CHEN**
Energy Transfer

FA **Francois Ayello**
DNV

MW **Magnus Wangensteen**

Science of Corrosion | Science of Corrosion

1:00 PM
3:00 PM

Oil & Gas Materials Selection & Metallurgy Information Exchange (TCI)

Room 111 & 113

Technical

Oil and Gas Production

1:00 PM
3:30 PM

TC 11 Materials Technical Committee

Room 603

Technical

Materials Selection and Design

1:00 PM
1:25 PM

C2023-18930 Metallurgical Investigation Of Hydrogen Reformer Tube Rupture – A Case Study

Eissa Al-Zahrani, Sayee Raghunathan - A catalyst tube for Hydrogen reformer at one of the refiners was observed...

Room 407

Symposia

BV **Bill Valerioti**

BL **Bingtao Li**
Haynes International, Inc.

Science of Corrosion Science of Corrosion

1:50 PM
2:15 PM

C2023-19366 Creep Life Assessment Of Grade T91 Superheater Tubes Using Creep Void Density And Hardness Measurements – Case Studies

Ewa Labuda, Emory Hull, Robert Bartholomew - This paper discusses the results of failure examinations of Grade T91...

Room 407

Symposia

EL **Ewa Labuda**

BL **Bingtao Li**
Haynes International, Inc.

BV **Bill Valerioti**

Science of Corrosion Science of Corrosion

3:00 PM
5:00 PM

Oil & Gas Materials Selection & Metallurgy Test Methods Learnings Information Exchange (TCI)

Room 111 & 113

Technical

Oil and Gas Production

Oil and Gas Production