2023 Mary Kay O'Connor Safety & Risk Conference

Safe and Sustainable Energy Transition

Making Safety Second Nature

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TEES

Mary Kay O'Connor Process Safety Center

Texas A&M Engineering Experiment Station

Process Safety Culture in Research Centers; Road Map Toward Enhancement

Hesham Alsubait

Abstract:
A recent in-depth internal analysis-2019 / and 2020 SMS (Safety Management system-PSM) internal review has revealed several HSE improvement opportunities namely around:

- The level of engagement and commitment of employees to HSE,
- The need to enhance HSE core competencies,
- The need to focus on pro-active risk discovery and mitigation,
- The need to enhance the current SMSs/OEs audit mechanism and
- Increasing the ownership by all of our SMS.

Despite substantial improvement in HSE overall performance between 2019 and 2020 led by STTF team, recent incidents and near-misses have generated a sense of urgency to steeply increase risk management effectiveness across the Dept.
As part of Major Safety Goals established in the Safety Annual Letter for 2021, Strengthen of Safety Culture has been targeted by implementing a series of activities and communications across the department to reinforce our unmistakable commitment to safety and excellence.
This has resulted in deciding to form a Safety Enhancement Culture Committee sponsored by Head of the Organization.

Application of Inherently Safe Principles to Projects

Tim Hoff

Abstract:
Projects, especially large capital projects, often increase the residual risk profile of an operating plant through the addition or modification of equipment and processes. Management of those new risks is normally achieved through hazard identification and subsequent application of administrative or engineered safeguards. Maintaining those risks at an acceptable level over the life of a facility requires maintenance of those safeguards through mechanical integrity programs, training and procedures, and appropriate management of change. In reality, the best way to manage risk in a new operation is to never create it, instead applying Inherently Safe Principles during the project phase, which serve to reduce risk by the removal or reduction of the hazard instead of controlling the hazard. By properly applying these principles in the early stages of a project's timeline, operational risks can be eliminated or greatly reduced and, as an additional benefit, total project costs can likely be reduced through elimination of project scope. Application of Inherently Safe Principles can also reduce operating costs through elimination of installed safeguards and their associated life cycle maintenance costs.

Threshold Quantity for Process Safety Metrics for Special / Coded Chemicals

Hema Divya Katna

Abstract:
An essential element in improving the process safety program is to identify existing process safety performance to improve future performance. Based on CCPS Process Safety Metrics [1] and API-754 [2] [3], a company can develop the process safety metric system. The guidance provided is not exhaustive and especially leaves interpretation of determining threshold quantities for chemical compounds with ambiguity due to the material complexities in a multi-product plant. Furthermore, the standards are US-centric and more guidance is needed for companies who want to implement it in a global scale. CCPS Process Safety Metrics suggests that without proper grouping of various compounds used in an organization, lagging process metrics becomes futile. Lagging metrics are important to identify the performance of process safety in an organization. The major step involved in implementation of lagging metrics are grouping the compounds based on its physical and chemical properties to define its threshold quantities. In recent days, many companies in India are adopting process safety metrics. The difficulty faced by these companies are grouping the materials and assigning the correct threshold quantities. Most of these companies use coded chemicals and introduce at least 50 new compounds in 2-3 months of time frame. This article provides the procedure/ workflow to classify the compounds and associated threshold quantities for those compounds whose class of the compound is not mentioned by Supplier.

PSM Boundaries in the Semiconductor Industry

Mike Stone

Abstract:
For years, PSM has been the standard to containing highly hazardous chemicals within their intended containment. These standards provide a guideline for how to create and maintain a program with the ultimate goal of keeping employees safe. As industry grew, the need for more robust chemical safety programs grew as well. PSM was developed for these chemical and petrochemical industries. So, what about the comparatively new Semiconductor Industry? While this industry does use PSM chemicals, they are mostly used in below threshold quantities. The chemicals that are over TQ are few and dispersed quickly. This paper will go in depth into the boundaries of the PSM program and how to maintain this program specifically in the Semiconductor Industry.

Bridging Gaps in Process Safety for the Offshore Energy Transition, the Work of the Gulf Research Program

Hallie Graham/James Pettigrew

The United States' energy transition will transform energy production across the country. From a shift away from traditional oil and gas towards renewables, budding energy sources, and technologies such as hydrogen and carbon capture and storage. Although the energy transition will see less reliance on oil and gas, lessons learned from the oil and gas industry can inform a safe and sustainable transition.

Within the National Academies of Science, Engineering, and Medicine the Gulf Research Program (GRP) and the Gulf Offshore Energy Safety Board (GOES Board) are focused on understanding the impacts of the energy transition within the Gulf of Mexico region. The GOES Board, within the GRP, serves as a bridge between stakeholders in the offshore energy sector and aims to develop and implement programs that promote safety in offshore energy practices.

Since its founding in 2013, the GRP has coordinated four funding opportunities in the area of safer offshore energy systems. This has resulted in over 20 research opportunities were academia and the energy industry have worked together to reduce risk and increase safer operations. The GRP has also funded 130 early career research fellows, including 11 in offshore energy safety. Since 2021 the GOES Board has organized two serious gaming workshops bringing together over 75 stakeholders in the Gulf of Mexico region, including one workshop focused on investigating the impacts of the energy transition within the Gulf of Mexico. In this presentation, we will review the key findings of the workshop including insights on what is yet to come with the energy transition and ideas on how to leverage opportunities and mitigate negative consequences. We will highlight how our fellows and grants are tackling process safety research in the energy transition. And we will review the findings from the National Academy of Sciences' (NAS) consensus report on systemic risk in offshore oil & gas and how we are taking these lessons learned into the energy transition.

Swiss Cheese – Why the Holes Line Up?

Rajender Dahiya

Abstract:
Swiss cheese model is one of the commonly used tool to demonstrate how management system's weaknesses causes holes in the safeguards and make them ineffective or compromise the integrity. The incident occurs when the multiple safeguard's holes line up. The size of the holes corresponds to the level of weaknesses in the management systems.
Piling of multiple safeguards is not the solution. Maintaining the integrity of fewer safeguards is the right way. The priority should be to eliminate rather than to prevent the lineup.
There are numerous causes and opportunities to identify and fix these holes proactively. Each cause gives multiple signals which are either ignored or not recognized or not addressed.
In this paper author explains the following with examples.

1. Why and how the holes in a Swiss Cheese Model lineup – most common causes?
2. Why do we fail to recognize until an incident occurs?
3. What are the best practices and proactive approaches to recognize the weaknesses in the management systems before the holes lineup and incident hits?

The author in his current role as a senior risk control engineer performs audits and inspections of a variety of high hazard industries including refineries, chemicals, petrochemicals, oil terminals, etc. In this paper, he will share real life scenarios and examples by explaining why the efficacy of management programs, employee competency, and process safety culture play a vital role.

The presentation will be concluded by sharing the strategies on how to recognize the management system gaps and apply best practices to maintain the integrity of safety critical equipment to prevent process incidents.
Keywords: safeguard's integrity, Swiss Cheese, management system causes, risk management

Fire Behaviour of Acetonitrile by Cone Calorimeter

Gianmaria Pio

Abstract:
The introduction of innovative solutions for the electrification of the energy supply chain on a large scale is promoting the use of storage solutions based on batteries. This trend is posing new challenges from a safety point of view. Indeed, the presence of liquid organic solvents in batteries can result in additional accidental scenarios (e.g., runaway reactions or fires). In this framework, a complete understanding of the physical-chemical behaviour in the case of exposition to a heat source is paramount to assess the overall sustainability of alternative solutions.

This work presents experimental and numerical analyses devoted to the evaluation of the liquid-vapour behaviour of acetonitrile, which has been recently introduced in fast-charging electrochemical devices. In particular, bench scale tests were performed employing an in-house procedure based on the standard cone calorimeter test. The presented
modifications are necessary to make the experimental system suitable for the complete characterization of liquid systems. Either tests in the presence or absence of ignition were conducted to quantify the mass evolution along with the time. The comparison of the resulting evaporation rate and the mass burning rate allowed for the assessment of the different contributions of thermal and kinetic aspects. The produced vapours and the exhaust gas have been analysed together with the evolution in time of the heat generation rate in the case of ignition tests.

The collected data were compared and discussed against numerical estimations based on different approaches. Operative conditions representative of the analysed scenarios were identified and implemented at this stage. At first, the overall reactivity of the investigated species and the composition of the exhaust gas resulting from a mono-dimensional geometry were assessed through detailed kinetic mechanisms. More specifically, the laminar burning velocity and the gas-phase composition were assessed. Therefore, a more detailed geometry mimicking the adopted experimental system was implemented and analysed utilizing computational fluid dynamics. The heat release rate and flame temperature distribution were estimated at this stage. Results were also discussed in view of data available in the current literature.

The combination of different approaches, either experimental- or numerical-based, provides a comprehensive and robust set of technical data suitable for the comparison of safety performances of alternative solutions for energy storage systems.

You have a “safeguard(s)” in place; Sounds promising, but have you tested it?

Harigopal Attal

Abstract:
Risk Management is an integral part of everyday life…
“The biggest risk is not taking any risk. In a world that is changing quickly, the only strategy that is guaranteed to fail is not taking risks,” said Mark Zuckerberg.

In other words, life and risk are the two sides of the same coin, and you cannot escape them. Whether you like it or not, life is a series of events and trade-offs, with challenges from birth to death. You are

considered successful if you navigate and manage the risk adequately. Managing the risk adequately, be it in adverse life situations or at work in an industrial situation, fundamental concepts are the same, and it implies that identifying adequate safeguards corresponding to the risk is a crucial step.

Applying Process Hazard Analysis (PHA) techniques is a widespread practice in the Risk Management process to reduce the risk to a tolerable level. One of the critical features of these varied techniques (HAZID, HAZOP, What-If, etc.) is to identify an adequate "safeguard(s)" corresponding to the level of risk in the avoidance of significant catastrophes be it Oil and Gas, Petrochemical, Chemical, Pharmaceutical, Power or any other industry.

Looking at any major or minor incident report, you will find the causal and root cause of any incident is centered around failing to properly appreciate the role of an adequate safeguard which could be Plant (physically engineered controls), Process (practices and procedures), and People (competency and training). However, the root cause of any incidence is a lack of understanding and application of the nuances of Risk Management techniques at the organization's various levels that yield a potentially undesirable situation.

Suppose your goal is to improve Process Safety culture and are concerned about preventing incidents; the focal point of any organization's Process Safety and Occupational Safety initiatives should be centered around the "SAFEGUARD." Other terms, such as independent Protection Layer (IPL) and Barriers, denote a safeguard.

This paper will explore what safeguards are and why they are needed, the hierarchy of safeguards, the criteria for validation, why safeguards fail, the nuances in understanding and applying safeguards, how to audit safeguards, and how to address safeguards in any incident investigation. Keywords: Process Safety Competency, Auditing, Safeguard

Dynamic Risk Assessment of Liquid Carryover in Oil and Gas Separator Based on Condition-Monitoring Data

Abdullah Alsulieman

Abstract:
Risk assessment models in Oil and Gas (O&G) industry has begun to transform from time-static models like fault tree, event tree or bowtie to dynamic risk assessment (DRA) models, as the latter are able to better capture the real time-dependent risk behavior of safety barriers. Currently, most existing works on DRA in O&G industry mainly rely on event-driven data such as failures or accident data from similar systems for risk updating. These data can be collected only when accidents or near-misses have occurred, which limits the prediction capability of the DRA model. To address this drawback, a DRA model is developed in this paper that uses condition-monitoring data for risk updating. A significant advantage of using condition-monitoring data is that the risk can be updated before accidents or failures occur, giving the operation team more time to take preventive actions.

The developed approach comprises of an offline and an online phase. In the offline phase, a conventional risk assessment is performed based on fault tree models to calculate the risks at the beginning of the operation. Through the offline analysis, we can also identify the most critical safety barriers by examining their contribution to the risk indexes. Critical safety barriers are selected for condition-monitoring. In the online phase, the condition-monitoring data are used to update the reliability of the safety barriers in real-time based on a sequential Markov Chain Monte Carlo (MCMC)

algorithm using a Bayesian framework. The updated reliabilities of the safety barriers are, then, used in the offline risk assessment model for a DRA.

The developed approach is applied for a DRA of liquid carryover from an oil and gas separator to downstream equipment, using real-time data from the separator's safety barriers. The results show that the developed method provides a more accurate representation of the system's performance, enabling early detection of potential failures and reducing uncertainty in risk estimates. The proposed DRA model demonstrated its effectiveness in predicting failures of safety barriers in real-time, giving operational teams ample opportunity to take corrective action. This leads to improved decision-making in the O&G industry, enabling timely response to changes in risk levels. The use of condition-monitoring data enhances the accuracy of risk estimations, representing a crucial advance in DRA applications in the O&G sector.

Detection & Mitigation of Hydrogen Releases

Jesse Brumbaugh

Abstract:
As the share of green energy continues to increase worldwide, the demand for hydrogen is projected to grow rapidly. Production rates in 2022 of nearly 100 mT (Executive summary – Global Hydrogen Review 2022 – Analysis - IEA) are expected to triple to 300 mT by 2030 (Hydrogen production worldwide 2030 | Statista). With such a large growth rate, many new players are entering the hydrogen production market. Hydrogen vapors are especially hazardous due to their high reactivity and low minimum ignition energy. A great need therefore exists for process safety knowledge sharing that is focused on hydrogen safety at such facilities.

Hydrogen behaves very differently from other materials. While hydrogen vapors are known to rapidly rise due to its very low molecular weight, liquefied hydrogen (LH2) has a unique characteristic known as superfluidity. While in the liquid phase, superfluids have zero viscosity and are therefore able to flow without any loss of kinetic energy. Cryogenic liquids are also known to stay low to the ground including just after evaporating, meaning a flammable vapor cloud from a LH2 release can travel a far distance even though it does not form a liquid pool.

Hydrogen safety is evolving rapidly. The International Society of Automation is revising ISA 84.00.07 to include a new section specifically discussing hydrogen. In addition, several software vendors have specifically focused on more accurately modeling the properties and consequences of hydrogen releases.

A selection of case studies will be shared in which hypothetical indoor and outdoor liquid and vapor hydrogen releases from new hydrogen facilities were evaluated. The case study selection will include an analysis of selection and placement of gas and flame detectors for hydrogen releases and a review of potential hazard preventions and mitigations.

Process Safety of hydrogen filling station in the Czech Republic

Vojtech Jankuj

Abstract:
Hydrogen is the most promising choice as an alternative and the cleanest known energy source. Main advantage is in the hydrogen lifecycle and various option of production, storage, transportation/distribution and a multiple hydrogen application. Hydrogen strategies and national policies aim to a progress of the hydrogen usage and supporting carbon free/neutral society. One of the most usable application seems to be hydrogen mobility with a fuel cell electric vehicle which produce only water and warm air without any harmful tailpipe emissions. However, infrastructure and green hydrogen production are still insufficient. In the recent years the number of refuelling stations is newly installed not only in the Czech Republic. Since the hydrogen is perceived as an explosive's gas, it is very important steadily increasing of social acceptance.

For this purpose, it is necessary to set up the process safety and the risk management before the installation and avoid the risk of leakage and possible explosion or major accident. This study aimed to perform a quantitative risk assessment of hydrogen refuelling station, where hydrogen will be produced, stored, distributed and used. The potential hazards and related risks connected to hydrogen lifecycle and the most significant scenarios that pose the greatest risk to the physical surrounding was employed and evaluated. The main assessed activity that will affect safety is production technology and hydrogen storage, including the pipeline and the stand for filling. These activities are given the necessary attention in the risk analysis and assessment. The following scenario, continuous leakage of hydrogen from a high-pressure vessel, dispersion to the surrounding area, and possible ignition which should lead to fire or explosion, was evaluated in detail.

According to the results, the risk in the hydrogen filling station considered is socially acceptable. Within the risk analysis, safety measures were adequately evaluated and they appeared to be sufficient given the results of the presented risk analysis. Nevertheless, the hydrogen filling station should require additional safety measures such as detachable couplings, detection sensors or emergency shutdown systems, which are required for risk acceptance.

10,000 lbs of Hydrogen - A Process Safety Perspective on Hydrogen Based Fuels and H2Hubs

Michael Snakard

Abstract:
In 2003 a hydrogen fuel initiative was unveiled to reverse America's growing dependence on foreign oil. However, the idea of establishing a hydrogen-based fuel economy only recently became feasible with legislation that has provided billions of dollars and other incentives to support clean hydrogen and the creation of a network of Hydrogen Hubs (H2Hubs). This is the first step in the creation of a national network of clean hydrogen producers and customers. This initiative to facilitate a clean hydrogen economy involves development of hydrogen hubs across the county, the proliferation of hydrogen fuel cells, and the integration of hydrogen into existing fuel systems, either as a fuel by itself, or as an addition to a carbon-based fuel, such as natural gas. Each part of this hydrogen economy comes with a unique set of hazards and risk which will need careful consideration to facilitate safe operations.

This paper looks at the process safety challenges of managing hydrogen hazards and risks within H2Hubs and fuel cells as well as exploring process safety implications associated with the addition of hydrogen into natural gas, and other fuel supply networks.

Integration of Psychological Safety into the Chemical Process Industry

Osama Alghamdi

Abstract:
This study aims to explore the integration of psychological safety in the chemical process industry and its potential influence on safety performance and incident prevention. The analysis of existing regulations, along with two major incidents, suggested that psychological safety is significant in preventing major incidents and enhancing safety performance. The study indicated that the current safety regulations could use some improvement to provide comprehensive guidance for industry leaders on how to develop, sustain, and measure psychological safety in the workplace. The study also developed a high-level model for organizations in this industry to start integrating psychological safety. The model was applied in a real-world scenario to prove its validity and applicability. Despite some limitations, the study has contributed to understanding the significance of psychological safety in the chemical process industry and offered recommendations for future research.

Applying Machine Learning and Keyword Analysis for Efficient Incident Reporting and Risk Management

Yuexin Liu

Abstract:
Many companies maintain incident databases, where severe incidents are analyzed in detail to prevent recurrence, while minor incidents are often stored without further evaluation. However, incidents with lesser consequences, especially common incidents, may lack necessary details or may be inconsistently recorded for understanding the root causes accurately. The aim of this research proposal is to develop a digitalized system using machine learning and keyword analysis that enables efficient incident reporting and generates risk matrices, trend reports, prevention and mitigation strategies, and leading indicators for each incident report. During this research project, we will analyze the incident reports to build a customized library that includes labels for machine learning, keywords from the incident database, and a list of statements for accurately describing incidents. The labels and keywords will be logically matched to the statements, and the output results will be programmed to align with the company's safety guidelines, standard operating procedures, and asset management systems. The proposed methodology will be applied to incident report case studies to showcase its effectiveness. The outputs will include a risk matrix, trend analysis, prevention and mitigation strategies, and leading indicators that can be used by workers and companies to increase hazard awareness and improve safety performance. By leveraging machine learning and keyword analysis, the proposed system aims to enhance the accuracy and efficiency of incident reporting and analysis, and provide valuable insights for proactive risk management and safety improvement.

The outcomes of this research project have the potential to significantly impact the field of process safety and risk management by providing a digitalized system that can enable more accurate and efficient incident reporting and analysis. By leveraging machine learning and keyword analysis, and providing data-driven recommendations for risk management, we can unlock valuable insights from incident data that may be missed with traditional approaches, the generated outputs, such as risk matrix, trend analysis, prevention and mitigation strategies, and leading indicators, can support decision-making and proactive risk management efforts in companies, also provide actionable information for preventing and mitigating incidents in the future.

Major accident scenarios caused by pipeline failure due to earthquakes

Valerio Cozzani

Technological infrastructure and transport systems can be damaged by earthquake impact. If these systems carry hazardous substances, the derived Natech scenarios may lead to severe major accidents including fires, explosions, and toxic releases. Fixed installations handling hazardous substances such as chemical and process plants are often the only sources considered in risk analysis procedures, where the Natech scenario is modelled as a point source scenario. However, also pipelines, widely used for the long-range bulk transport of hazardous substances as oil, natural gas and flammable/toxic chemicals, may undergo severe Natech accidents.

In the present study, a Natech Quantitative Risk Assessment (QRA) methodology addressing Natech events triggered by earthquakes causing pipeline failures was developed. The assessment of pipeline failure probability is carried out through the application of specific pipeline vulnerability models. The consequences of the Natech events are assessed considering several possible different end-point scenarios (as jet fire, pool fire, etc.) and the risk is evaluated considering both potential damages to people and to the environment along the route of the pipeline. Two different case studies are discussed, evidencing the importance of risk due to Natech scenarios involving pipelines and the potentiality of the developed methodology to support Natech risk management and mitigation along the route of pipelines carrying hazardous substances.

COMPUTATIONAL MODELLING OF BURNING VELOCITY OF GASES VENTED BY LI-ION BATTERIES

Savio Vianna

Abstract:
Due to the effects of climate change, the implementation of alternative and renewable sources of energy has grown over the last decade. Solar and eolic energy have been strong contenders for the number one spot for their lack of solid waste. However, in this present time, the market is led by lithium-ion batteries (LIBs) for their high energy density, low weight, and lower discharge cycles compared to other batteries. In the last few years LIBs have been associated with explosion incidents, this is due to a process called thermal runaway that can be triggered by a plethora of technical factors associated with overheating. During this process, exothermic decomposition reactions start to occur inside the solid electrolyte interphase (SEI) adding to the highly volatile nature of lithium and rising the pressure and temperature even more. It reaches a certain point that the battery releases all of the heat that has been building up inside, ejecting toxic and flammable gases that have been the cause of the aforementioned incidents. The objective of this research is to obtain a new correlation for the laminar burning velocity of the vented gases by failed LIBs to further understand the propagation of these flames through the use of computational fluid dynamics and open-source code STOKES. Parameters such as pressure distribution, flame front position and velocity are evaluated and compared to pre-existing experimental data.

Footprint of uncertainty (FOU) in the context of Bow-tie risk tool using fuzzy logic

Savio Vianna

Abstract:
The Bow-tie method, as a qualitative risk analysis tool, is characterized by its clarity in visualizing the relationship between causes, barriers, and consequences. Many studies have proposed ways to quantify the frequencies of event occurrences and control measure failures, turning the qualitative method into a quantitative one. However, the model results may be limited by uncertainty which arises from subjective evaluations and incomplete or unreliable data sources. To address this issue, some studies have proposed the use of fuzzy sets and rule-based inference systems to map specialists' knowledge onto rules. Nevertheless, the traditional fuzzy approach does not consider the uncertainty associated with the assignment of linguistic variables' fuzzy membership functions. The interval fuzzy type 2 addresses this issue by introducing the concept of the footprint of uncertainty (FOU), which improves the integration of uncertainties into the model. In this paper, we developed two fuzzy systems, one for the traditional type 1 and another for the interval type 2. These systems describe the relationships between events and barriers with the objective of obtaining the frequencies of consequences in a baseline scenario in the oil and gas industry. The scenario and consequences were specified in greater detail in the paper. A global sensitivity analysis was conducted to compare the robustness of the results obtained using the two approaches. The aim of this work is to compare the performance and reliability of the two approaches and identify the most effective method for risk analysis in this context.

Study on the consequences of hazardous gas releases from buried pipelines

Ola Srour

Abstract:
Underground gas leaks can quickly escalate to pose a threat on the population, environment, and properties. The intensity of the leak is reflected in the soil morphology on the ground, which can remain intact in case of gas migration, present an uplift when the gas flow fluidizes the subsurface soil layer, or be completely displaced forming a crater. These underground phenomena affect the gas dispersion into the atmosphere and hence should be considered for an accurate consequence modelling. A review of the state-of-the-art indicated a lack of a comprehensive study that describes the whole spectrum of the underground phenomena. This work aims to fill this gap through laboratory scale tests using a tomography tool to assess the transient soil behavior upon gas injection. In parallel, a computational model is suggested to present a valid characterization of the physical process. Preliminary results of the described approach are presented.

Understanding Microbial Corrosion using Density Functional Theory

Mohammad Asif

Abstract:

Corrosion of metal is associated with complex thermodynamic changes, in which molecules are running through physical and chemical transformations at the same time. Density functional theory (DFT) based on quantum chemical calculation provides robust ways to understand complex problems such as corrosion. The DFT not only provides the mechanism of adsorption of species on the metal but can also help in developing new corrosion inhibitors. This work aims to capture inhibition characteristic of arginine (an amino acid) found in most of the protein rich food. Our purpose in this work is to get theoretical understanding of potential uses of food waste for developing corrosion resistant coating. The DFT can be implies to calculate intrinsic properties of arginine such as highest occupied molecular orbital energy (E_{HOMO}), lowest unoccupied molecular orbital energy (E_{LUMO}), electronegativity, and electrophilicity.

Physics-informed deep learning applied to steady-state methane dispersion

Savio Vianna

Abstract:
The calculation of gas dispersion is relevant for many applications in process safety. Although the gas flow can be described by the set of Navier-Stokes equations, the numerical solution is demanding as far as the computational time is concerned. The solution also requires a closure model for the turbulence problem. We address these issues by developing a physics-informed neural network (PINN) that considers the underlying physics of the problem by means of the Navier-Stokes that are embedded in the architecture of the neural network. An in house CFD (Computational Fluid Dynamics) code is used to generate the dataset. We show that the physics-informed deep learning is robust to low quantity of the dataset. It is also generating quick solutions for gas dispersion problems what is a feature of interest when compared with the long time required to perform CFD calculations.

Comparative analysis of the methodologies for the evaluation of the gas generation rate for gas generating chemical systems under runaway conditions

Luc Vechot

Abstract:
The design of emergency relief systems (ERS) as one of the last protection barriers against the explosion of vessel/reactor containing reactive systems under runaway conditions requires the understanding of the evaluation of the gas/vapor production rate, the phase of the vented material and the corresponding flow capacity at the vessel maximum allowable working pressure. For chemical system which produce gas as a product of the runaway reaction the evaluation of the gas production rate is usually performed using pseudo adiabatic calorimetry where a sample of the chemical system is taken to runaway condition in a closed or open cell. The temperature and pressure profile resulting from the experiment is used to assess the gas generation rate using the ideal the gas law. While this approach is largely used, there is still significant concern and a lack of consensus as per the choice of the most adequate experimental conditions to use, namely closed versus open cell (to a containment vessel), and the overall capability of the approach to accurately provide an evaluation of the gas generation rate under runaway conditions.

The work presented in this paper aims to evaluate the current approach for the evaluation of the gas generation rate for gas generating system under runaway condition and the potential impact on emergency relief size. A model capable of simulating the runaway reaction in a cylindrical vertical reactor vessel was used to predict the temperature and pressure profiles and composition of the liquid and vapor phase during a runaway of the decomposition of di-tert-butyl peroxide in toluene solvent (a gas generating system), in closed vessel, opened vessels and vessels in venting conditions. The model couples' rigorous thermodynamics to determine the state of the fluid within the vessel, the composition of the vapor and liquid phase of the reactor, the decomposition reaction kinetics and heat transfer to the vessel walls and the surroundings for vessel. The gas generation rates rigorously calculated by the model were compared to the gas generation rate evaluated using the above described approach. The results are discussed to demonstrate that the sole reliance on temperatures and pressure (and the ideal gas law) to evaluate the gas generation rate may not properly represent the actual gas generation rate and impact the subsequent vent size calculation. Additionally, a series of simulations of runaway's reactions under venting conditions for different ERS sizes was performed and the results used to discuss the limitations of closed and open cell calorimetric data to evaluate the gas generation in a reactor vessel under venting conditions.

Understanding the Reactivity and Dynamics of Hybrid-Mixture Explosions at Large Scales

Lorenz Boeck

Abstract:
Reactive mixtures of flammable gases with combustible dusts and oxidizer, commonly referred to as hybrid mixtures, pose severe explosion hazards in industries such as mining, power generation, pharmaceutical, agriculture and food, and other manufacturing. Developing risk assessment methods and explosion prevention/protection solutions requires knowledge of explosion sensitivity and severity parameters for these mixtures, and an understanding of explosion dynamics at realistic industrial scales. This work presents the results of hybrid-mixture explosion experiments conducted at large scale using an 8-m^3 vessel and discusses reactivity parameters including maximum explosion pressure, deflagration index, and turbulent burning velocity. Novel insight is gained on the effect of mixture composition on these parameters and the overall explosion dynamics.

Experimental results show how the hybrid-mixture composition significantly affects explosion dynamics, and demonstrate that conventional reactivity parameters, especially the deflagration index *K*, are inadequate to fully capture these effects. In particular, if *K* alone were used to specify reactivity, it would identify mixtures with low dust concentrations and near-stoichiometric gas concentrations as the most reactive mixtures, which would pose the most severe explosion hazards. Examinations of the entire explosion process, however, reveal that these mixtures are not universally more reactive. In fact, they show consistently lower turbulent burning velocities than pure gas mixtures during the early combustion process, a critical time where protection systems typically activate and mitigate an explosion. It is only at late times where combustion rates exceed those of pure gas mixtures, which is ultimately responsible for the higher measured deflagration indices. These results suggest that a more detailed characterization of hybrid-mixture explosion dynamics could significantly improve explosion risk assessment and the design of explosion protection systems. In particular, models used to design such

systems would greatly benefit from an accurate description of the early explosion dynamics, which is not provided by conventional reactivity parameters such as the deflagration index.

Design of a State-of-the-Art Battery Failure Experiment

James C. Thomas

Abstract:
Lithium-ion batteries (LIBs) have been widely adopted for power supply of modern electronics. However, these batteries are prone to failure via thermal runaway (TR) and pose a variety of hazards including significant energy release; production of jet flames; ejection of micro- and nano-particulates; and emission of toxic and combustible vent gasses. A state-of-the-art battery failure experiment has been designed and built at Texas A&M to evaluate these hazards for standard and new battery systems. The experiment consists of a constant-volume bomb that is optically accessible; a thermal failure initiation system; plumbing for atmospheric control and gas capture; and various diagnostics. These diagnostics include thermocouples for control, battery surface, and headspace temperature measurements; pressure transducers; open-cell voltage measurement; and optical diagnostics (e.g., high-speed video, etc.). Battery failure experiments are supplemented with post-failure analyses via complimentary techniques including gas chromatography-mass spectrometry (GC-MS), scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS), X-ray diffraction (XRD) analysis, and X-ray photoelectron spectroscopy (XPS). This paper provides an overview of the experimental design and approach, a series of representative experimental results, and a discussion of novel techniques implemented in the experiment.

Learnings from the collaboration between industry and academia to build Process Safety Competency in industry

Luc Vechot

Abstract:
Process Safety Competency is one of the elements of a healthy and efficient process safety management system. Assessing the level of process safety competency, identifying the gaps and developing programs to build robust and effective competency in an organization are challenging and remain to date one of the biggest challenges that the process industry faces.
This presentation will share the experience and the learnings of the intense collaboration between an academic institution, the Mary Kay O'Connor Process Safety Center (MKOPSC) of Texas A&M University at Qatar and a major multinational chemical manufacturing company, Saudi Basic Industries Corporation (SABIC) for the development and implementation of a comprehensive and long-term Process Safety Competency Development Program (PSCDP) for SABIC process safety engineers. The presentation will provide a description of the structure, technical contents and delivery strategies of the program. The methodology for the evaluation of the engineers' performances and progress and the use of such information for continuous improvement will be discussed. The presentation will show the results of six years of implementation of the program in 2017-2022. The impact of the program on both the individuals in their performances in process safety tasks and the overall improvement of process safety practices in the respective sites will be shared and discussed. The presentation will highlight the benefits

and challenges of the collaboration academia/industry in process safety development programs and discuss the role academia can play in helping industry tackle the challenge of competency in process safety.

IOGP Process Safety Fundamentals

Samantha Scruggs

Abstract:
The International Association of Oil & Gas Producers (IOGP) Process Safety Fundamentals (PSFs) are a set of basic principles for frontline workers, supervisors and managers that emphasize existing good practices to prevent fatalities from Process Safety Events. Between 2007 – 2017, 128 lives could potentially have been saved by following these Process Safety Fundamentals. Learn how the PSFs are used and understand the ongoing work being conducted by the IOGP the Process Safety Fundamentals Implementation Task Force.

Best Practices for Working Safely with Hydrogen: Engineering Safety Guidelines, Texas A&M University

David Breeding

Abstract:
Engineers frequently work with flammable gasses in research and in industrial operations. Hydrogen is a high risk, flammable gas that required specialized, dedicated facilities and infrastructure for safe, compliant, and successful usage. Dr. Breeding will review and discuss best practices for safe hydrogen laboratory design and operations in the Engineering and TEES research facilities at Texas A&M University, including regulations, rules, standards, and codes for compliance. This presentation addresses two sections: one for designers of facilities where hydrogen will be used and one for researchers working with hydrogen in a research laboratory setting, with applications for hydrogen safety in industrial operations.

Major accident prevention in the Czech Republic - Examples of good practice

Katerina Sikorova

Abstract:
On the basis of the European SEVESO Directive (EC, 2012) and its implementation in the Czech Republic in the form of the Act on the Prevention of Major Accidents (Collection of Laws of the Czech Republic, 2015a), the operators of objects classified in group A or B are required to prepare a risk assessment, have an emergency planning system set up and participate in regular inspections by state authorities. The issue of the prevention of major accidents concerns legal or physical business persons who use an object with a dangerous substance of selected dangerous properties. In the Czech Republic, the major accident prevention (MAP) issue concerns more than 200 industrial establishments with different

amounts of dangerous substances and different methods of handling, i.e. from smaller storages of dangerous substances, through simple chemical production to large chemical enterprises. The aim of this paper is to focus on selected areas of MAP and their tools, which are key to the proper functioning of the safety management system, namely the area of risk assessment within safety documentation, the area of emergency planning with a focus on prevention and preparedness for major accidents, and also area of regular inspections in establishments performed by the state administration.

This paper consists of an analysis of the current state and the subsequent proposal of specific recommendations for improvement or the presentation of examples of good practice based on the findings made in a working group (consisting of representatives of SEVESO experts, SEVESO authorities and SEVESO establishments) participated in the project supported by Science Research Program through the Technology Agency of the Czech Republic (No. SS02030008) titled “Environmental Research Center: Waste and Circulation Management and Environmental Safety.

Probabilistic Assessment of Security Attacks to Offshore Oil and Gas Installations

Matteo Iaiani

Abstract:
The Offshore Oil and Gas industry plays a key role in the supply of energy in many countries. Worldwide, about a third of the oil is produced offshore and, in Europe, more than 80% of the current production of oil and gas takes place offshore. Despite their location, which makes them inherently more difficult to reach, offshore Oil and Gas installations are vulnerable to deliberate malicious attacks (security attacks) perpetrated by attackers that span from pacific protesters to hostile nation armies and terrorist organizations aimed at causing severe impacts in terms of damage and media coverage. Security attacks include both cyber intrusions to the network system managing process operations (e.g., intrusions and manipulation of the Basic Process Control System, BPCS, and the Safety Instrumented System, SIS) and physical interferences within the Physical Protection System (PPS) such as armed attacks.
As an example, in January 2006 in Nigeria, rebels attacked the Shell EA offshore oil platform and kidnapped four foreign oil workers from a support vessel anchored at the platform, causing its shutdown. The insurgents also blew up crude oil pipelines, cutting supplies to Forcados offshore export terminal.

Besides the direct outcomes of an attack in terms of casualties and loss of production, the potential for the release of large quantities of hazardous materials (e.g., crude oil and natural gas) as a result of a deliberate malicious attack, defines scenarios of damage to people, property, and the environment comparable to the outcomes of major accidents originating from safety-related causes (e.g., the well-known accidents occurred at the Piper Alpha oil platform in 1988 and at the Deepwater Horizon drilling rig in 2010).

Although the credibility of security attacks is constantly increasing, only qualitative or semi-quantitative procedures have been developed to date to address security issues in the offshore Oil and Gas industry, such as the Security Vulnerability Assessment (SVA) approach proposed by the API RP 70 and API RP 70I recommended practices.
The aim of the present study is the understanding and the modelling of the dynamics of security attacks and response strategies in offshore Oil and Gas critical infrastructures (e.g., oil and gas exploitation platforms). The proposed approach allows identifying all possible attack paths that attackers can carry

out in the facility analyzed, which is at the basis for the definition of the entire network of security events, from emergence of the threat analyzed in terms of foreseen attack scenarios, through its evolution and intervention of preventive and mitigative security measures, to attack effects in terms of process and storage equipment damage. The complete network is modelled using probabilistic approaches (e.g., Bayesian Networks, BNs).

Deep Reinforcement Learning for Cyber Security in Cyber-Physical Systems: A Comprehensive Survey

Yuexin Liu

Abstract:
With the increasing scale and complexity of Internet-connected systems, cyber-attacks have become more prevalent, posing significant threats to the security and safety of cyber-physical systems. Traditional protection mechanisms may fall short to cope with the complexity, dynamic and high-dimensional nature of cyber-attacks, requiring responsive, adaptive, and scalable solutions. Machine learning, specifically deep reinforcement learning (DRL), has emerged as a promising approach for addressing these challenges. By integrating deep learning with reinforcement learning, DRL offers the potential to effectively tackle complex, dynamic, and high-dimensional cyber defense problems. This study, we present a comprehensive survey of DRL approaches developed for cyber security in the context of process safety and security in cyberphysical system. We discuss various vital aspects, including DRL-based security methods for cyber-physical systems, autonomous intrusion detection techniques, and multi-agent DRL-based game theory simulations for defense strategies against cyber-attacks. We highlight the capabilities of DRL in addressing the unique challenges of cyber security, such as the dynamic nature of cyber-attacks, the need for adaptability to evolving threats, and the complexity of cyber-physical systems.

Furthermore, we provide extensive discussions on the current state of DRL-based cyber security research and future research directions. We emphasize the potential of emerging DRL techniques in coping with increasingly complex cyber security problems and highlight the importance of further exploration in this area. This comprehensive review aims to provide a solid foundation for researchers and practitioners interested in leveraging DRL for cyber-risk analysis in the context of process safety and security in cyberphysical systems, including the Internet of Things (IoT).

A risk-based model to detect the vulnerability of cyber breaches in the maritime industry

Mawuli Afenyo

Abstract:
Recent cyber-attacks on shipping and other maritime related companies have created the need to access the cyber readiness of the maritime industry. For a long time, the maritime industry has been the target of pirates and other malicious actors. However, a new threat of cyber-attacks is likely to be the trend in the years to come. This notwithstanding, there is a lack of a model in literature to detect cyber-attacks and their impact in a timely manner in the maritime industry. Cyber threats keep evolving and the tools also need to follow suit. Most maritime based economies are highly dependent on shipping as

well as the oil and gas industry in some cases. A disruption in shipping to the country can create a domino effect on prices of goods and services. This therefore means that there is need to develop tools that can forecast the potential impact of a cyber-attack under different scenarios in order to be fully prepared for its accompanying impact. The risk-based model developed would serve as a first point for decision makers to consult when faced with a potential cyber-attack. The model is developed based on Baye's theory which uses the conditional probability perspective. The use of the Bayesian theory for the design of the model would enable us to update the model when new information becomes available. In addition, the model would be able to use both qualitative and quantitative data as inputs. These two characteristics are very important considering the dynamic nature of maritime cyber-attacks. Finally, the model is used to evaluate a hypothetical cyber security problem in the ports of Houston and Galveston. for which the outcome is used as an input to evaluate the economic impact of an attack on the ports.

CYBERSECURITY AND PROCESS SAFETY: A RESILIENCE BUILDING APPROACH TO RISK MANAGEMENT

Livingstone Divine Caesar

Abstract:
Cyberattacks on maritime supply chains are not only an issue of serious concern but are expected to increase in the coming years. Such gloomy prediction underscores the need to build capacity for the realization of cyber-resilient maritime supply networks. The next generation of cyberattacks will expose maritime supply chains to radical disruptions and highlights the shortcomings of existing curricula of maritime-related training establishments. Maritime organizations must construe it as a process safety issue to build functional competencies towards resilience to survive and remain competitive. There is an urgent need for content revision/overhaul to equip future graduates with holistic and futuristic skill sets. This study considers cyberattacks as a hazardous issue and proposes a process safety approach to forestall emerging threats. Since building resilience inherently hinges on intellectual capabilities, this study will unearth the specific cybersecurity skill sets lacking and what is needed to produce a cyber-resilient maritime-related workforce. Key aims of the study: (a. Review existing curricula of maritime-related establishments to identify cybersecurity-based skill/competence gaps. (b. Developing a policy framework to address the identified gaps (c. Produce a process safety-based matrix to identify critical cybersecurity learning outcomes of the maritime workforce.

Systemic Risk in US Offshore O&G: HF and HOP Challenges

Tom Sheppard

Abstract:
The National Academy of Sciences recently issued their draft report, 'Advancing Understanding of Offshore Oil and Gas Systemic Risk in the U.S. Gulf of Mexico: Current State and Safety Reforms Since the Macondo Well Deepwater Horizon Blowout (2023)'. The report reviews and evaluates a wide range of areas as potential sources of systemic risk. The sources were placed into three categories, people, human-systems integration, and systems, and then further divided into fifteen subcategories (areas). Current maturity levels were assessed and assigned to each area. On a positive note, the ratings and supporting information indicate that positive gains and progress were achieved in most areas. The

report provides insight into how this was achieved through changes in practice, industry standards, regulations, and others. On a less positive note, the report flagged several areas of concern that remain significant sources of systemic risk. The presentation focuses on the flagged areas that apply to human dependent barriers, functions, and interactions. The O&G industry is presented with the challenge of how to correct these deficiencies. The presentation explores possible steps and actions that may offer insight into a possible path forward. Correcting the recognized deficiencies may be well served by understanding the contributors to the current state. To this end, the presentation briefly examines existing practice and knowledge, technical expertise, industry standards, and historical hurdles for possible reasons and answers. The product of this effort provides essential input to the next logical question, what needs to change. The presentation briefly explores some of the possible changes and adaptations that may be needed in the industry knowledge base, expertise, tools, methodologies, standards, and regulations.

Systemic Risk in Offshore Oil and Gas in the U.S. Gulf of Mexico

S. Camille Peres, Rich Sear, Charles Williams

Abstract:
Offshore Oil and Gas is a complex business where companies invest billions of dollars in long-lived assets that produce energy resources for the nation. The industry has a long history of improvements in the management of occupational safety in its operations, but measurable improvements in process safety management have lagged.
In early 2023, The National Academy of Sciences released a report, *Advancing Understanding of Offshore Oil and Gas Systemic Risk in the U.S. Gulf of Mexico*. In this report, systemic risk, which by definition includes all aspects of design, operations, and regulation through the life cycle of offshore oil and gas facilities, was described and evaluated based on a model that disaggregates the whole into component parts. Progress in understanding and managing risk in the component pieces from a systems perspective then results in overall progress in the management and reduction of systemic risk.

The three major systems which comprise an enterprise such as oil and gas are typically referred to as people, plant, and process. In this report, they were described as the People System, the Physical System, and Human-Systems Integration. In this talk, we will look through the lens of Human-Systems Integration to broadly understand systemic risk management in offshore oil and gas and explore the current state of systemic risk management across all three major systems, the progress made over the last decade in particular, and how the risk profile might evolve into the future.

Why and How to Start A Career in Process Automation

James Beall

Abstract:
I've been involved with process instrumentation, automation and process control for over 40 years! This includes about 20 years with a chemical manufacturer and over 20 years with an automation system manufacturer. It is a very rewarding career, both personally and financially, and I highly recommend it! As an Electrical Engineer, I was initially concerned that this career is typically dominated

by Chemical Engineers. However, I soon found out that being a proficient process control engineer requires expertise in many areas. Thus, no matter what your education background, you will have to learn many more skills! So, if you are willing to learn, you can become a proficient process control professional!

There are only a few universities that teach process control theory and practice in a manner suitable for the process industries. Even fewer universities teach about process instrumentation. A process control must be knowledgeable of process instrumentation, control valve performance, process engineering, chemical engineering, process control, control system configuration and more! No one curriculum includes all of these topics! So, how does one become proficient in process control?

In my experience, the answer is to never quit learning! Though your educational background me provide you with some of the required skills, you will have to learn may other skills! There are many industrial training courses, technical conferences, books and other sources of focused training the can provide these skills. And, many process control professionals are willing to share their expertise and experience.
This presentation will share some ideas on how and why to pursue a career in process control.

Building an Engineering Data Ecosystem to Improve Instrumentation and Process Safety Records Management

Mike Antosh

Abstract:
Operating facilities count on their asset management system to be the "master" from which all other applications pull data. For most business functions, this works well while providing consistency and control to the enterprise. Still, the fundamental way data is collected, stored, and managed has led to challenges, particularly for maintenance operations. The reason for this is simple – maintenance requires accurate and reliable engineering data, and engineering data is continuously evolving.

Typically, when an asset management system is set up, a moment-in-time snapshot is pulled from the engineering platforms' document control program, and a record is established in the asset management system. This "as-built" approach fails to account for the fact that as facilities go through maintenance cycles, the engineering data changes. Yet, the asset management system data often struggles to keep up with engineering changes. As maintenance applications pull from the asset management system, the information is often obsolete, which causes delays and errors and poses unnecessary safety risks. The more experienced engineers would often bypass the asset management system's data in the maintenance application and pull data directly from the engineering systems, especially when the data in the maintenance system just did not make sense. Clearly, this is not sustainable or a best practice. The answer to this problem is not a simple fix; it requires a fundamental change in how you approach the data. It requires digital transformation and the building of an ecosystem between asset management and engineering data systems. The ecosystem needs to allow data to be updated where it was authored and routinely push fresh updates to the asset management system and maintenance applications. Updates made in the maintenance applications need to be reflected in the engineering programs and vice versa in close to real-time. As this specifically pertains to the instrumentation and process safety industry, how can Safety Lifecycle Management Tools integrate into this ecosystem? The future state of this ecosystem is shown in the image below. It requires a combination of software solutions and human workflows to create an environment for success.

Approaching this problem can seem insurmountable. It is a difficult ask of IT departments and out of scope for engineers. You need Engineering IT expertise. A process-driven Engineering IT solution with connections, workflows, and stewardship that brings engineering systems, asset management, and maintenance together into an ecosystem will solve your asset management system problems and set your maintenance group up for success by reducing costly delays and errors, as well as mitigating safety risks.

A Look at Early Planning Best Practices for Plant Automation Modernization Projects

M.C. Chow

Abstract:
Today, upwards of 65% of projects fail (as defined by >25% budget overruns and >50% schedule slippage). Conversely, good front end planning leads to as much as 20% cost savings and 39% schedule reduction for total project design and construction per CII – Construction Industry Institute. Best practices in automation projects further complement these benefits. This presentation looks at the early planning processes and techniques as well as best practices that will help improve the chances of success in your process control/automation modernization projects

Optimize Costs and Mitigate Risks by Incorporating Protection System Technology Innovations and Performance/Risk-based Approaches.

David Weimer

Advancements in Passive Fire Protection (PFP) and Cryogenic Spill Protection (CSP) innovations along with the potential cost benefits of taking a performance/risk-based application approach can be a win-win for industrial capital projects. The purchase of PFP/CSP solutions and other coatings are often viewed as a nuisance item, being between 0.5-1% of the overall capital costs. Unfortunately, this approach leads to PFP/CSP solutions being viewed as a commodity item with a view to reduce costs. Viewing PFP/CSP solutions as a commodity item (material and application costs) leads to poor decision making in selecting the right material for the project at the design phase.

Envisioning coatings solutions as “just paint” might appear feasible until something goes wrong. Even for the largest oil and gas projects, the maximum amount of profit which could be gained from this commoditization process is <$20M. This is a minor consideration in comparison with the overall capital costs of the project. In marked contrast, the realized cost, if things do go wrong for a high-profile project, can be many multiples of the original purchase (in the case of a large project many multiples of original planned cost). Therefore, one can argue that commercial factors do not override the judicious selection of coating schemes such as PFP/CSP solutions which are the last line of protection for safety and environmentally critical equipment.

Significant advances have been made in PFP/CSP material development. These advances have spurred a reassessment of the historical methodologies associated with the design and application of PFP/CSP. Oil and gas facility owners and operators expect lessons learned from previous projects should lead to designs which are both increasingly optimized and which maximize mitigation of risk. To this end, technology innovation has driven PFP/CSP material advancements and product-specific performance-based design solutions far beyond what was first introduced in the early 1970s. PFP/CSP manufacturers

and designers are now able to incorporate enhanced thermal and cryogenic insulative properties using a single material system which can be tailored to specific release scenarios.

This paper will examine epoxy intumescent coatings and their applications and will question the widespread acceptance of the prescriptive approach to PFP/CSP specifications for LNG assets as outlined in API 2218. This paper will also bring to light the PFP/CSP technology developments and fire design innovations that have enabled designers to realize the potential benefits of a performance/risk-based approach to drive down costs and maximize risk mitigation to projects upon construction and in operation.

Operator Response to Alarm is an IPL, now what?

Tim Olsen

Claiming operator response to an alarm as an independent protection layer (IPL) is a relatively common practice. But, is enough emphasis given to ensuring that this IPL really has a 90% chance of success? There are a number of factors that may reduce the efficacy of an alarm coupled with operator response. This presentation will focus on several issues that can result in a potential failure the IPL, and basic practices to address them. It's important to remember that for operator response to an alarm to be an effective protection layer, the instrument must be in good working order, the alarm itself must annunciate (e.g., not be disabled, shelved or suppressed), and the human operator must know what to do and respond correctly. Sometimes, two human operators may be involved, both of whom must respond correctly. A potential failure of one or more of the above can impact the efficacy of the entire IPL.

Proper alarm rationalization, along with application of dynamic (state-based) alarming to reduce alarm floods, along with solid training, testing and maintenance programs are a must. The operator must know that he or she is essentially part of the safety system and must be trained on recognition of the IPL and proper response.

Proper practices to maintain the integrity of IPLs will ensure that the overall probability of undesired safety events remains within acceptable levels and improves overall plant safety.

Managing the broken SIS through Peak Risk Analysis

Kedar Kottawar

The paper will emphasize the importance of peak risk management to enable the chemical process industry to achieve its business objectives while minimizing the impact of potential risks. Peak risk is associated with a normal operating process when an unexpected failure happens or planned online maintenance is performed. Peak risk focuses on the scenarios where a process is facing an increased level of risk in safety, environmental, and economical aspects. Paper outlines the steps important to document compensating measures for the broken or out of service SIS. Through the implementation of various risk management strategies, the paper will show the ability to minimize potential losses. Additionally, in evaluating LOPA scenarios, in place of using time-at-risk enabling conditions for infrequent, high-risk activities of short duration, use of peak risk concept helps achieve better analysis. This paper clearly articulates and recommends to limit risk reduction to a factor of 10 for non-automated compensating measures for any given LOPA scenario.

Can Control Room Operators be More Effective?

Craig Wright

Ageing assets bring significant challenges to an organization. Natural degradation of plant and equipment, processes and equipment becoming redundant through to optimizing current facilities to prolong the life of an asset have brought challenging situations. As creeping change occurs an asset may see an increase in their alarms thus impacting the key performance indicators, adding to control operators (CRO) workload and potentially leading to safety, productivity and fatigue issues thus making the CRO less effective.

The research provides an insight into the CRO perspective on the management of alarm systems on their assets and how this contributes to ensuring the safe operations of the plant and facilities by responding to the alarms. The sample was across three offshore assets and an onshore processing plant and considered the impact of direct and indirect leadership, the environment, shift patterns, training and other additional factors. As the results from the Q&A had been analyzed we observed that although control room operators could perform their daily tasks to a high standard they highlighted a potential weak point in the lack of support from leadership roles.

Uncovered during the results was an estimated figure of deferment cost due to 'missed alarms' that required operator action to prevent escalation towards a trip function. This was in line with data showing the alarm management system across the assets did not meet key performance indicators (KPI's) while masking lower ranking alarm priorities. The CRO's highlighted that during busier than normal times they felt there was no support from line management even though their line managers are acutely aware the impact of an underperforming alarm management system that fails to meet KPI's has on them. 80% of the CRO's fed back that they had no training on managing stressors likely to occur from operator overload. An organization addressing the areas the CRO's have identified to be lacking in support may not also decrease imposed stressors and fatigue but also increase an organization's profits through reduced deferment.
The research continued to highlight that front line CRO's desired to have experienced CRO direct supervision in place to assist them. This highlights steps that an organization can take to work with and assist the frontline to enhance their alarm management system and prevent unscheduled deferment.

Process Safety Health: How Should We Approach Metrics and Monitoring and What Are Emerging Societal Expectations?

David Drerup

Process Safety Metrics and Benchmarking are concepts that have been discussed for well over a decade. While there have been attempts to do benchmarking and establish incident reporting suggested practices, like API 754, there is no suggested standard for metrics and reporting that has been widely adopted. In fact, many companies view this as personal to their culture.

With the emergence of Environmental, Social and Governance (ESG), operating companies will need to relook at how they manage their risks, including process safety. As ESG requirements continue to evolve, it is likely that financial institutions and insurance companies will demand more leading indicators and focus more on potential consequence of unwanted events as a result.

One of the key aspects of Process Safety Health (PSH) is the ability of an organization to consistently sustain high performance levels. PSH is defined as a holistic and continuous monitoring methodology covering all process safety functional reporting areas to provide a clear picture of an organization's

overall health. Increasingly, artificial intelligence and anomaly detection will play a role in PSH to produce meaningful insights into performance of your facilities to address the true dynamic nature of risk.

This presentation discusses how organizations can develop a meaningful risk profile and move beyond lagging indicators to establish predictive trends and actionable insights along with a strategy to enable this outcome.

Application of natural language processing for spill reduction in an exploration and production company

Jamison Chang

Spill reduction is a key focus for exploration and production (E&P) companies to protect people, the environment, and to maintain oil production. Natural language processing (NLP) is applied to identify causes and contributing factors of spills and leaks associated with E&P activity to reduce the frequency and severity of these events. Reviewing incident reports allow us to identify trends and areas of improvement, and NLP can be used to process the data quickly and improve data quality. Incident reports are typically free text that includes a description and cause of the event. One challenge with free-text descriptions is that further analysis and interpretation is needed in order to effectively analyze, trend, and learn from the available data. In addition, identifying the causes and contributing factors of a spill accurately can be time intensive. Root cause failure analysis (RCFA) is a key element in process safety management, but this is often focused on high severity incidents because of the time required to properly conduct the analysis. Incidents that have lower severity occur more frequently, but typically less time and resources are spent analyzing these events. Natural language processing and other data analytics techniques have been utilized to analyze a greater number of incident reports, which enables us to pinpoint causes of leaks, reduce the frequency of spills, and mitigate the impact of these events. This paper presents the challenges associated with learning from incident reports, particularly spills, and offers solutions that natural language processing can provide to improve data quality and contribute to spill reduction efforts in the context of an exploration and production company.

Safety First: Innovative Advanced Analytical and Automation Solutions for Improving Safety

Douglas C White

Federal and State regulations related to process industry safety continue to evolve. Keeping the plant safe and complying with the complex regulations is an ongoing challenge as new rules are introduced, sometimes with tight compliance deadlines. Most plants are faced with challenges relating to:

- Reducing plant safety events
- Avoiding loss of containment events
- Reducing leaks and fugitive emissions
- Operating within permit limits
- And simultaneously reducing manpower dedicated to monitoring and managing safety

One key approach to meeting these objectives is to identify potential issues early enough so that compliance and corrective action can be taken before the event occurs. New advanced analytical and

automation applications can help identify the precursors to these serious incidents and allow timely remedial measures. In this presentation, we will review recent progress in these areas and actual case studies that illustrate the impact of these new tools on plant safety issues.

Review and Validation of Phast Dispersion Model required for LNG Siting Applications in the US

Michael Harper/Frank Hart

The US Pipeline and Hazardous Materials Safety Administration (PHMSA) has published guidance and an approval process relating to the use of atmospheric dispersion models in LNG siting applications. The approval process includes the application of a model evaluation protocol (MEP) to assess the dispersion model, which includes the validation against an experimental database. The unified dispersion model (UDM) as included in Phast 6.7 was approved by PHMSA in 2011.

Since 2011, significant development of Phast and the UDM has occurred. Of particular relevance to LNG spills are the adoption of a more sophisticated approach to modelling of dispersion from and over pools; incorporation of along-wind spreading for non-instantaneous releases; and constraints on crosswind gravity spreading for cold dense clouds. Moreover, the Phast 6.7 architecture is reaching its end of life which poses technical challenges for users.
Similarly, the interim period has seen PHMSA issue updates to the MEP methodology and substantial changes to the experimental database. Therefore, a new petition to PHMSA for approval of Phast 8.4 against the most recent MEP and validation database was made. This involved review of supporting technical documentation by a PHMSA appointed expert reviewer, and detailed comparison against a wide range of experiments. The results of this validation are described, along with an analysis of the findings.

Draft approval of the petition was received in February 2023, and we expect the final decision imminently. This will mean Phast 8.4 can now be used instead of Phast 6.7 for dispersion assessments supporting LNG siting applications.

Computational fluid dynamics (CFD) studies of CO_2 dispersion

Chi-Yang Li

With the increasing attention on global climate change, the related applications in the carbon capture and storage (CCS) are gaining important in the current worldwide discussion; among these fields, the safe operation on the transportation of carbon dioxide (CO_2) is also a critical element to achieve the goal. To assure the safety operation of the gas transmission pipelines, Department of Transportation currently applies an empirical formula to calculate the potential impact radius (PIR) for thermal radiation with corresponding control measures. However, the hazardous characteristic for CO_2 is asphyxia, so the safety concern of CO_2 pipeline is the dispersion of harmful concentration. Because the computational fluid dynamics (CFD) possesses potent simulating capability on dispersion prediction with the considerations of the complex parameters, the CFD is widely applied to predict the behavior of the fluid dynamics. In this article, we are going to apply Ansys Fluent to conduct CFD on the CO_2 pipeline to study the CO_2 dispersion based on the practical conditions and scenarios of the pipeline industry.

Model improvements and Validation for Buried CO2 pipeline ruptures

Michael Harper/Frank Hart

Over the past few years there has been a surge of interest in the transportation of dense phase CO_2 through large diameter pipelines as a key component in CCS projects. Modelling such releases brings unique challenges: the scale of the potential releases; the influence of crater formation over buried pipeline ruptures; and the presence of solid rather than liquid phase CO_2 at ambient pressures. Few experimental data have been published, but the two COSHER experiments of buried 6" pipeline ruptures provide the best available dataset for model validation.

The UDM (Unified Dispersion Model) is a key part of consequence analysis in the Phast software package. An initial comparison of model outputs revealed major differences to the observed COSHER plumes and significant under-predictions in ground-level concentrations. Following an analysis of the causes we improved two key aspects of the model. Firstly, the impact of the crater on the dispersion source term, using a wider diameter (and therefore lower velocity) at the crater exit plane. This leads to higher ground-level concentrations as initial vertical momentum is reduced. Secondly the introduction of a "gas blanket" model for the initial stages of the dispersion, characterized by circular spreading (including upwind spreading) of a "collapsed" CO_2 plume.

Detailed comparison of pointwise and arc-wise measured concentrations against the model before and after these improvements revealed a dramatic improvement in performance, especially as regards near-field concentrations and observed upwind spread of the cloud. The unimproved model had a large under-prediction in ground level concentrations (of most concern in a typical consequence analysis), whereas the improved model showed no bias and much improved consistency.

This work builds on earlier validation against smaller scale above ground CO_2 releases in the CO2PIPETRANS JIP (Joint Industry Project) and will provide better hazard distance estimates for buried pipeline releases. Potentially it could also improve modelling of buried pipeline ruptures for other materials, though this remains largely untested.

Path-Sampling and Dynamic Risk Assessment for Rare Un-postulated Reliability/Safety Events

Vikram Sudarshan

Chemical manufacturing processes can present significant dangers, and therefore, it is vital to incorporate safety and reliability measures during their design. To reduce the probability of catastrophic accidents, which can have grave consequences on human life and the environment, comprehensive instrumentation such as control systems, alarms, and automated Safety Instrumented Systems (SIS) are regularly utilized in chemical processes. Additionally, common reliability assessment methods such as failure mode and effect analysis (FMEA), fault-tree analysis (FTA), reliability-centered maintenance (RCM), root-cause analysis (RCA), and the like, have proven to be effective in identifying and handling postulated abnormal events that have occurred previously or are more likely to occur, based on process historian data. However, it is difficult to predict and counteract the impact of infrequent and unforeseeable un-postulated abnormal events in real-time, which, when not considered during process design, can lead to the most serious consequences. Hence, existing reliability/safety systems, alone,

might prove to be insufficient in monitoring and alerting the operator for un-postulated abnormal events.

Previously, we developed an advisory system for analyzing and monitoring process reliability, consisting of novel, multivariable alarms and reliability systems introduced using process modeling and path-sampling for un-postulated abnormal events (Sudarshan et al., 2021; Sudarshan et al., 2022). Its purpose is to augment and support existing reliability systems, suggesting actions when unanticipated reliability/quality events are approached. Our analyses were demonstrated initially on an exothermic CSTR process and led to promising alarm thresholds and reliability response actions (Sudarshan et al., 2023a). We have been extending our analyses to a polystyrene CSTR exhibiting free-radical polymerization (FRP) mechanisms. Polymerization reactors are known to exhibit complex, nonlinear behavior; e.g., output multiplicity, input multiplicity, isolas — often, it is desirable to operate at the intermediate unstable region, with potential abnormal transitions to multiple undesirable operating regions, and to avoid nonminimum phase behavior leading to inverse response. This is a control, safety, and reliability problem, hence, a good application for our analyses.

Next, simple rationalization strategies were introduced, wherein the acceptability of every alarm threshold and response action was evaluated, with the alarm thresholds and/or response actions modified accordingly, based on key statistical metrics — seeking to ensure that every alarm is a quality alarm, and its response action is justified appropriately. For the exothermic CSTR, our strategies resulted in a significant reduction in the number of nuisance alarms, focusing on only quality alarms, which, if ignored, were more likely to result in an abnormal shift in operation to the undesirable regions (Sudarshan et al., 2023b). Similar rationalization strategies are being applied to the advisory system developed for the polystyrene CSTR.

Assessment of overpressures resulting from hydrogen explosions using artificial neural networks

Tabassum Abbasi

One of the main safety aspects to be addressed in the wide-scale use of hydrogen to meet energy needs is the possibility of vapor cloud explosions (VCEs) arising from the leakage of hydrogen storage vessels. The blast waves from hydrogen VCEs can cause considerable damage to life and property. Currently, the means to estimate hydrogen VCE overpressures is to employ models which have been used for hydrocarbon VCE overpressure assessment, or from CFD studies. This approach is not suitable for hydrogen as the properties and behavior of hydrogen is dramatically different. Moreover, a hydrogen vapor cloud carries much greater risk of suffering VCE even in total absence of confinement, unlike vapor clouds of other substances which require partial confinement. This paper reports a novel approach to modelling overpressures resulting from hydrogen VCEs, using artificial neural networks (ANNs). The inputs to the ANN model are the volume of the cloud, the concentration of hydrogen in the cloud and the location at which the overpressure due to the VCE is to be estimated. The output is the overpressure. The model was trained and validated using experimental data from hydrogen explosions. The performance of the model was evaluated from the RMSE and R2 of the observed versus predicted values. The R2 of over 0.9 in the training and validation of the ANN model indicates its accuracy and demonstrates the potential for its use in predicting overpressures resulting from hydrogen explosions.

Risk Assessment: How to avoid slipping, tripping, and falling over the numbers

William Sharpe

This paper discusses how the requirement for, and application of consequence and risk-based studies such as: Quantified Risk Assessments (QRAs) and Facility Siting Studies (FSS), has become ambiguous over the last 40+ years, and the story they tell may not be as intriguing or useful as it once was. From leak frequency analysis to consequence modelling, to risk integration, numbers are paramount at every milestone of these complex safety studies, but how easy is it to become lost within these numbers, and miscommunicated to those who it effects the most?

A focus is required for clear problem definition, appropriate choice of solution and explicit results presentation. Taking the numbers of how often and how big, a story can be told not just to meet corporate standards or local regulations (i.e., defined risk tolerance criteria), but also to support making risk management decisions. Ensuring that workers and the public are safe is a continuous act of risk reduction which follows risk assessment, of the upmost importance as we face the greatest challenge of our time, to bring our world the energy it needs in the most responsible way ever imagined

Enforcing Consistency of PHA/LOPA

Edward Marszal

The chemical process industries spend hundreds of millions of dollars each year performing and documenting process hazards analysis studies like HAZOP and LOPA. Much of the value of these studies is lost, or at least not fully realized, because the lessons learned and best practices are not carried to subsequent studies or other parts of the organization. In addition, different facilitators and teams may quantify the same initiating events and safeguards with different values due to misinterpretation of standards and guidance documents. The result is PHA of identical units being done inconsistently from unit-to-unit and site-to-site with vastly different results and recommendations – putting the organization at risk from regulators, overspending on unnecessary safeguards, or acceptance of unreasonable levels of risk. Furthermore, the constantly re-inventing of the wheel by having potentially inexperienced teams re-do PHA from a blank sheet of paper is costly and time-consuming.

This paper discusses how to improve PHA quality while reducing effort and cost by enforcing the use of known and approved PHA information and metrics. This begins with the development of templates of common unit operations and common process units that are employed by an organization. Enterprise computing can be leveraged to store approved templates that are starting points for studies or nodes and checklists that can be appended into studies. In addition to templates, data libraries should be accessible during study development so that facilitators can pull library values of initiating event frequencies and safeguard failure probabilities into studies. Enforcement of use of library values can be facilitated by automatic auditing of studies to determine and highlight deviations from library values. The combination of templating and data libraries will result in more consistent PHA studies and a reduced cost to the current state of the art.

Challenges of Rolling out the Safety Management System (SMS / PSM) in newly commissioned Technical Research Center. (Shared Entity)

Hesham K Al.Subait

The Safety Management System (SMS-PSM) implementation within new shared research center-multiple owners (ARC and EXPEC) - been assessed systematically through 4 phases to ensure successful journey. The roll out of SMS/PSM consider the matured neutral entity (R&DC) leading the task to ensure successful journey. The following are the main phases of implementations:

1. Applicability SMS Assessment: Three Models for the SMS rollout. Model A was the best fit based on the SARC Organization Structure and Resources.
2. Defining the Resources and Assigning the SMS /PSM Element owner: Model A: Each SMS/PSM Element will be Led Primary PO in R&DC and secondary in ARC joined by EXPEC ARC Rep.
3. SMS Rollout and 1 to 1 Awareness Session: Three Weeks SMS Awareness Session. Started by Overall SMS Set up and structure in ARC &EXPEC, followed by 1:1 awareness session between P.PO and S.PO led by SCG in R&DC. (PO: Process Owner. (P Primary, S Secondary).
4. Competence Build up for Core SMSs:
    - Core SMSs: SMS 02, SMS 5, SMS 8 Competency Build up.
    - SMS KEY Expectations Development and KPI Measure.
    - Mid-Year Self-Assessment- *roll out implementation efficiency* - Utilizing assessment protocol.
    - Rollout adjustment/Enhancement.

Application of the Weighted Set Covering Problem Combined to Computational Fluid Dynamics for Optimization of Gas Detectors in a Chemical Plant

Raphael Tsukada

In this paper we adopted the new approach to optimize the number and location of gas detectors employing the weighted set covering problem combined with computational fluid dynamics (CFD). Possible gas leak scenarios were simulated using CFD that provide the gas plume sizes. The data were used to determine the optimization mesh size of the set covering problem. In the second stage of the approach a 0-1 integer programming model was applied to solve the problem using the Balas Algorithm.

Our case study is focused on a chemical plant with many leak points, like a real case. A 3D model was built and used to simulate several leakage point scenarios and conditions. In this case, the optimization procedure was combined with the leak frequency for the determination of the weights of the objective function.
The results obtained from the weighted set covering problem were compared with the standard procedure (without weighted procedure) results. The quantity of gas detectors and the time to detect were analyzed by means of transient CFD simulations.

The analysis shows that the weighted approach findings lead to larger quantity of detectors and the time to detect is shorter.

The Benefits of Procedural PHAs

Rene Murata/Janet Benaquisto

Procedural PHAs are a valuable tool for examining operating procedures and can be completed either while writing or updating a procedure. Historically, 70% of major accidents have occurred during non-routine operations. Additionally, in the past ten years over 40% of the incidents reviewed by the Chemical Safety Board (CSB) occurred during non-routine operations. Using a Procedural PHA to review the appropriate course of action for those operations can help identify potential hazards and suitable safeguards, thus preventing or lessening incidents.

In this presentation we teach how and why to use Procedural PHAs. Procedure heavy processes like loading/unloading, start-up/shutdown, complex valve configurations, by-pass of independent functions and batch processes benefit from using this approach.

We share how Procedural PHAs are an excellent tool for non-standard operations and show ways this approach can help you identify improvements for your procedural heavy processes to provide a more in-depth look at what could go wrong.

Best Practices for Management of Change and Maturity Level Measurements

Madonna Breen

Management of Change is a key element of PSM and world-class EHS&S programs. It is a fundamental element to keep existing processes running smoothly and to mitigate all risks when a change is required. It is also one of the four accident prevention pillars of a Risk-Based Process Safety System. Best Practices to manage changes and to gauge maturity of an MOC program help organizations continually improve. The purpose of this presentation is to introduce best practices for MOC and to show that assessing an organization's MOC maturity helps to identify any gaps and areas for improvement.

90% of what? Setting and achieving flame and gas detector performance targets

Bryant Hendrickson

Flame and gas detection systems are critical safety systems for hydrocarbon processing and storage facilities. Frequently, the design of these systems is based on simple rules of thumb that lead to ineffective coverage. In the LNG industry, much debate is currently focused on setting detector coverage targets for different areas (e.g., 60, 80, or 90% coverage), yet limited effort is being spent to establish appropriate scenario sets and to accurately quantify detector coverage. Fire hazards and flammable cloud development can generally be conceptualized for open outdoor areas, but congested areas can lead to blind spots for flame detectors and complex flammable cloud behavior. This paper will present clear and simple guidelines for setting detector coverage targets based on the results of a recent DOT-PHMSA sponsored research project; it will also provide examples on the application of 3D ray tracing, vapor dispersion modeling, and vapor cloud explosion modeling to accurately quantify flame and gas detector coverage.

Performance of External Steel Shell Full Containment LNG Tanks Subject to Blast, Fire, and Impact Loads

Onder Akinci

A full-containment tank system consists of a secondary container, constructed of either metal or prestressed concrete, designed to contain any spilled LNG from the inner tank. However, the current regulations in the US require that if the outer wall is used as a storage tank impounding system, then it must be constructed of concrete. The objective of this study is to determine whether a metal secondary container provides an adequate level of safety and operational integrity comparable to that of an alternative concrete secondary container. The research aims to provide a better understanding of the ultimate capacity and resilience of a 9% nickel steel secondary container subjected to accidental loads including blast, fire, projectile impact, and thermal shock. The fire and blast loads considered for this study were determined from previous projects and literature using statistical methods. Detailed finite element models of both small and large capacity LNG tanks with steel secondary steel container are developed for the assessment. Response of the analyzed tanks are checked against the performance criteria developed as part of this study to evaluate structural integrity and leak tightness. Additionally, the response of steel tanks is compared with that of a concrete tank. Fragility analyses are performed to compare the degrees of safety margin for LNG tanks with steel and concrete secondary containers. This approach is expected to provide an enhanced basis of comparing the effectiveness of the two secondary containment types against accidental loads.

Plume Sight, An ultra-flexible accident modelling tool

Ravi Kedarasetti

The modeling of release of hazardous or inflammable materials and the dispersion of the released material plays a crucial role in risk and consequence analysis. While there are dozens of widely accepted open-source models for dispersion modeling, most of the consequence tools and packages are restricted to using one or two models. This can severely restrict the scope and accuracy of the consequence model since the dispersion models have limited capabilities. For example, depending on the temperature of the release gas the best-suited dispersion model can be a dense gas model or a PBL-based (Planetary Boundary Layer) model. Moreover, capabilities for simulating time varying releases, multi-phase releases etc. vary from one model to other, which can severely limit the accuracy of the consequence and risk analysis. Through Plume Sight, we overcome the limitations of any single dispersion model by providing users with access to multiple dispersion models simultaneously.

Plume Sight is a release and dispersion modeling tool that leverages multiple EPA recommended dispersion models and provides extensive insights to the consequence analysis. Plume Sight is built for Equity Engineering Inc's cloud-based computing platform - the Equity Engineering Cloud (https://e2g.com/industry-insights-ar/launching-the-new-equity-engineering-cloud-eec-platform/). Plume Sight consists of a multi-model pre-processor that can convert user input to model input, a cloud platform for performing the dispersion calculation, and a post-processor with three-dimensional visualization capability. Plume Sight is offered through a web-based interface built using ReactJS, that allows for an interactive interface based that is instantly updated based on user's choices. The user inputs are converted to the formats required by the various codes that allows the calculations to be performed on our cloud-based computing platform. Finally, the results from the calculation are post-processed in our 3D visualization platform to offer insights about the spread of the release gas.

Currently, PlumeSight can perform simulations using SLAB DEGADIS and AERMOD. More models will be available in the future.

In addition to the dispersion models, Plume Sight also includes release models for calculating release rates from storage tanks and pipelines. The source models can account for a wide variety of storage and flow conditions including cryogenic, insulated, and padded storage. The source models account for uncertainty in the opening size based on guidelines specified in API581. Currently Plume Sight offers a single set of source models for each storage and flow condition, but this will be extended to include multiple source models available in the literature. Additionally, future versions of Plume Sight will be coupled to our transient network simulator "Simpulse" so that users can evaluate the effect of the network on the spill and the effect of the spill on the dynamics of the pipeline network.

New Methods for Learning from Incidents Involving Human & Organizational Performance

Norman Ritchie

“Human & Organizational Performance (HOP) issues may be complex and can cover a broad range of disciplines. Investigating unplanned events such as safety incidents and operational problems from the HOP perspective requires a different approach than conventional incident analysis methodologies allow. This presentation offers new methods that can be applied through the entire process of responding to the learning opportunities presented by unplanned events, including data acquisition, analysis, and developing appropriate and optimized corrective actions for HOP causal factors.

Key takeaways from this presentation include differentiating between HOP failure types in an unplanned event and quickly developing and validating appropriate corrective actions to maximize organizational learning and future risk reduction.”

Model-based fault diagnosis and fault tolerant control for safety-critical chemical reactors

Pu Du

In safety-critical chemical reactors with potential hazards, reaction kinetics and heat transfer parameters are usually known and a mathematical model is available. It is then meaningful to base fault detection and isolation algorithms on the first-principles model as opposed to statistics so that physically meaningful residual signals are generated from material and/or energy balances not closing, leading to reliable fault diagnosis. In addition, in order to maintain the safety of the entire system, it is necessary to take appropriate control action based on the mathematical model and the identified faults, to minimize their impact and thus ensure safe operation. In the present work, these ideas will be formulated and illustrated through a CSTR case study.

Fault detection and isolation in linear systems have been studied extensively[1] and recently, there have been generalizations to a large class of nonlinear systems[2,3]. The approach involves designing a set of disturbance-decoupled linear residual generators, each one becoming active only when a specific fault occurs[2,3]. Once an abnormal event happens and the corresponding fault is detected and isolated, appropriate control action must be taken in order to prevent severe consequences caused by the fault. Re-tuning the controller and/or changing the manipulated input could be involved in the control action.

The concepts of Dynamic Safe Set (DSS)[4], defined as a maximal admissible set, and Dynamic Safety Margin (DSM)[4], defined as the distance from the boundary of the DSS, play a critical role in formulating and designing the control strategy. Monitoring the position of the system in the interior of the DSS, including the size of the DSM, provides criteria for adapting control action after the occurrence of an abnormal event.

In this work, we first study detectability in groups of faults during the operation of the CSTR. And we have found that one fault from each group can be effectively isolated via appropriate residual generators, despite persistent disturbances in the reaction rate, both in open-loop and in closed-loop under temperature control manipulating jacket coolant flow rate or jacket coolant inlet temperature. During the operation of the reactor, state estimates from a nonlinear observer track the system in state space and determine the corresponding DSS. The proposed fault tolerant control strategy monitors the DSM (distance of the system state from the boundary of the DSS) and, when it gets below a certain limit as a result of an abnormal event, the controller parameters are retuned and/or the manipulated input is switched. Simulation results show the effectiveness of the proposed fault tolerant control strategy in dealing with cooling system faults.

EEG-Based Integrated Support System for Improved Training and Human Performance for Safe Process Plant Operation

Hossam A.Gabbar

Oil and Gas plant operators have a large responsibility on their shoulders to perform safe plant operations in different operating conditions. They must allow stable and maximum production while inspecting and maintaining the safety of the plant. This type of occupation comes with high amounts of mental fatigue, and a small mistake can have grave consequences. Electroencephalography (EEG) is a method of gathering the electromagnetic waves emitted by the human brain. We propose a safety system by monitoring brainwaves for signs of mental fatigue. This requires an analysis of the tasks and mental models of the operator, as well as risk factors on mental fatigue and attention that operators face when performing their tasks. The brain waves generated from experiencing mental fatigue can then be monitored. We analyzed these factors and developed an EEG-based monitoring system, which aims to alert plant operators when levels of mental fatigue and attention start affecting their performance in task completion. Results showed that the system can detect the levels of stress that the monitored individual is experiencing, correlating with the difficulty of the task and other environmental factors. The next step of analysis lies in the complete assessment of human brain states and mental models. This will provide benefits in the scope of human focus, stress, engagement, and relaxation. Training programs are conducted with consideration of human mental models and impacts on training effectiveness. Analyzing these mental state properties will indicate human performance for different training modules. AI algorithms are adopted to analyze raw human brain data for different operation scenarios and tasks and correlate with human performance.

PSM Evergreening with Artificial Intelligence

Angel Casal/Vishal Lagad

Maintaining updated process safety information is a critical and challenging requirement in any Process Safety Management (PSM) system. Hazard identification and risk assessments, including Hazard and Operability (HAZOP) studies, typically are “snapshots” in time, do not come in digital form and require to

be periodically updated or revalidated to be relevant. Using these studies to effectively support common operational decision-making processes which require risk assessments is also very problematic.

The objective of the paper is to describe how Artificial Intelligence (AI) can be used to build and maintain a “live” functional twin of any industrial facility where process safety information is continuously updated and accessible to support standard risk management processes, which is the basic feature underpinning the concept of “PSM evergreening”.

Enhancing Process Safety by implementing Risk Based Emergency Response and Crisis Management Plan with Consequence Modelling

Surendra Mahakalkar

Earlier SEC facility is having generic Pre-Incident Plan and because of this, the facility is having the Insurance Survey Recommendation and other Auditor Recommendation.

Scalable machine learning: bridging the divide, encouraging new applications in oil, and gas, and near surface environmental and engineering geophysics

Gary Young

Artificial intelligence (AI) and machine learning (ML) are rapidly growing in research and application to many geophysical data processing, imaging, and interpretation workflows. In many instances, such applications have the potential to encourage crossover applications from one industry to another: oil and gas exploration to near surface and vice-versa. One such example showcased here is using three dimensional geophysical methods for imaging near surface cultural targets. While commonly used in mining and oil and gas exploration, the method has been frequently deemed redundant in terms of adding value in near surface applications, where the key objective is commonly mapping the lateral extent or relying on key “signatures” like diffraction hyperbolas to identify the location of the target. Reports of significantly improved resolution in inversion results using AI and ML in oil and gas applications, have opened the possibility for using AI based geophysical inversions for new applications in near surface geophysics. A major bottle neck for widespread commercial use of AI based 3D inversion in all realms of geophysics has been the prohibitively high computational cost involved in applying the method for large scale three dimensional inverse problems.

Key changes to the form of the simulated input data used for training and the corresponding design of the architecture of the hidden layers enable approximately O(n) (where n is the number of layers in the network) reduction in the computational complexity of the training architecture. Combined with multi-GPU distributed deep learning (DDL) algorithms optimized specifically for training large scale ML data, this results in significant improvements in resolution of inversion results relative to conventional least squares imaging, while computational efficiency improves by order of magnitude compared to several commonly used open-source ML architectures and platforms.
When deployed for inversion of dense, closely spaced high resolution handheld magnetometer data collected over a buried pipe in a field in Texas, the resolved three-dimensional geometry and location using the new algorithm showed over 6-fold improvement compared to conventional three-dimensional least squares inversion. When applied to an 18-fold larger data set collected by a drone-based magnetometer over a field in California, the buried complex metallic pipe like structure was resolved

using little over 2 days of compute time. Similar exercise undertaken in google Collab GPU platform using state-of-the-art google tensor flow would have taken 3 – 6 months to complete, suggesting a 50 – 100-fold improvement in computational efficiency.

The method was also benchmarked against Los Alamos National Laboratory's (LANL) open-source seismic full waveform inversion (FWI) dataset. LANL trained 24000 seismic data sets simulated from various 2D velocity models using 32 P100 Tesla GPU machines in 2 hours. When inferenced on 6000 previously unseen test models, the root mean square error (RMSE) in the inverted normalized velocity models was 0.018. The current workflow on the same data set achieved a comparable RMSE of 0.012 on 6000 unseen test models after training 24000 models in 50 minutes using just 4 GPU (V100) machines, achieving nearly 20-fold improvement in computational efficiency.
In addition to magnetic and seismic data, the method is being developed for applications to electromagnetic and full tensor gravity gradiometer (FTG) data. Given the significant improvements in resolution and computational efficiency, it is expected that successful ground truth-based field trials of AI based geophysical data inversion has the potential to unlock several new application areas while dramatically improving the business impact of such applications in existing ones.

In this presentation, we will highlight some recent examples of applications of the remote sensing and imaging technology to see buried pipes in offshore marine settings using remote sensing devices. With properly designed acquisition, the technology can be used to monitor asset integrity, delineating spills, and identify potential pipe movement due to geomechanically hazards without using expensive invasive equipment, and / or excavation.

Safe Winterization and protection from Cold Waves of Chemical and Oil and Gas facilities

Valerio Cozzani

Natural events are a widely recognized hazard for the Oil&Gas and the chemical industry. Evidence from past accidents shows that severe scenarios may be triggered by natural events at sites where relevant quantities of hazardous substances are handled, due to the possible generation of cascading events resulting in severe technological accidents (Natech scenarios). A number of previous studies address the potential cascading events triggered by earthquakes, floods, and storms. However, a recent study evidenced the potential hazard of Natech scenarios triggered by cold waves and winter storms resulting in extremely low temperatures. The analysis of a dataset of over 740 Natech events highlighted that severe major accidents may be caused by cold waves affecting the industrial infrastructure.
In the light of such results, the analysis of guidelines provided for the safe winterization of chemical and oil&gas facilities shows that, besides the baseline measures suggested, additional precautions may be advisable and specific safety systems should be considered for installation.

In the present study, starting from the specific cause-consequence chains identified in past accident analysis, the failure modes of equipment and safety barriers were examined in detail, also applying specific hazard identification techniques. The analysis provided the identification of specific vulnerabilities to be considered in the identification of potential accident scenarios caused by cold waves, and in the analysis of the available and effective safety barriers able to prevent and/or mitigate such accidents. Mitigation measures addressing the identified vulnerabilities and additional specific safety systems and safety procedures were identified, aiming at the development of evidence-based comprehensive winterization programs.

Comparative Analysis of International and US Safety Regulations for Offshore CO2 transportation for CCUS Purposes

Ahmed Elkady

Carbon Capture, Utilization, and Storage (CCUS) is a vital solution to reduce carbon emissions and combat climate change. Offshore CO2 pipelines are an efficient and cost-effective method for transporting large volumes of CO2 for offshore storage. However, offshore CO2 transportation presents unique safety and environmental challenges, requiring comprehensive regulatory frameworks to ensure safe and environmentally responsible transportation of CO2.

This paper examines the safety regulations for offshore CO2 transportation for CCUS purposes in the United States, Norway, European Union, and Australia. The study finds that all jurisdictions share a commitment to safety and environmental protection, but there are differences in the regulatory frameworks across the jurisdictions. In the United States, regulating offshore CO2 transportation is shared between the Pipeline and Hazardous Materials Safety Administration's (PHMSA) and the Bureau of Safety and Environmental Enforcement's (BSEE) using titles 49 under Code of Federal Regulations (CFR) part 195 and 30 CFR part 250. In Norway, regulations are based upon recommended practices and operating standards of Det Norske Veritas (DNV), while in the European Union, the directives of the European Commission govern offshore CO2 pipelines. In Australia, the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) and the Clean Energy Regulator (CER) are the key regulatory bodies. The United States lacks a comprehensive federal regulatory framework specific to offshore CO2 transportation, while the European Union has a more robust regulatory framework although it faces challenges in inducing low carbon investment. The study highlights the existence of regulatory gaps and inefficiencies, calling for international coordination to ensure effective regulation of CO2 offshore pipeline transport for CCUS purposes.

This paper serves as a valuable resource for policymakers, researchers, and industry stakeholders seeking to better understand the regulatory landscape for offshore CO2 transportation and storage. It identifies areas where regulatory frameworks can be improved to address existing gaps and inefficiencies. Overall, comprehensive and coordinated regulatory frameworks are crucial to ensure the safe and responsible transport of CO2 for offshore storage and further development of CCUS technologies

AMOG Consulting Symposium Presentation with Technical Paper Abstract Submission for 2023 Mary Kay O'Connor Safety and Risk Conference (26th Process Safety International Symposium)

Alex Waugh

A key goal of the process industry is achieving a balance between safety risk minimisation and cost reduction. This paper applies reliability centred maintenance analysis techniques, which AMOG have used effectively in a Naval systems context, and demonstrates their transferability to the process industry context as a means of semi-quantitative safety risk reduction. These analytical techniques can be applied to inform decision makers when considering alterations to operational and maintenance factors such as maintenance deferrals, equipment utilisation and level of maintenance (corrective, preventative and condition-based).

We outline in the paper a methodology for optimising planned maintenance over the plant lifecycle to minimise safety risk to ALARP and reduce the forecast maintenance costs, whilst also considering constraints such as projected shutdown windows and the operational cycle of the plant. This methodology provides valuable insights into system safety performance throughout the plant life cycle, which can inform decision makers when considering scenarios related to operational and maintenance scheduling.

We demonstrate, by means of information redacted examples, a methodology for Reliability, Availability, and Maintainability (RAM) modelling of a system that can assist decision-makers by providing predictions of safety risk in various scenarios. Utilisation of these results may be useful for decision makers in a qualitative or semi-quantitative manner, providing refined input into failure rate(s) and IPL effectiveness for LOPA analysis. This methodology is also intended to shift focus towards optimisation of system safety performance by utilising a repeatable methodology for finding the optimal balance between total cost and minimisation of safety risks.

Economic Tool for Quantifying Process Risks of End-of-Life Lithium-Ion Batteries

Sankhadeep Sarkar

Lithium-ion batteries has seen an exponential rise in usage in transportation (projected to reach US$ 56 billion by 2024) given the prospect of reducing carbon footprint in operation. However, the prospect of LIB usage has presented critical challenges in continuous supply of raw materials (790 tons of mineral rich brine is needed to produce 1 ton of lithium-ion) and waste management of EOL batteries (whose capacity falls below 80%). Recycling of batteries can be a possible alternative, also improving the energy stored cost over energy invested (ESOI).

Three major recycling methods are being employed industrially – pyrometallury (high temperature process with subsequent separation of metal alloys with low metal recovery), hydrometallury (acidic/basic leaching with subsequent concentration and purification to gain highest purity) and direct recycling (direct re-use of spent electrodes). However, these recycling methods present some challenging problems – are these processes chemically stable with different battery compositions? Can abnormality in process result in an environmental emission? Is these economically viable given low volume-high capital cost?

Various challenging process risks associated with different battery recycling strategies are incorporated in a quantitative tool. The methodology includes - process evaluation, risk analysis (e.g. stabilization of high voltage modules, contamination of electrolytes and cathodes), and preventive control assessment which are then translated to an economic indicator to provide quantitative business insights on the important decision variables that can drive a sustainable future of recycling EOL lithium-ion batteries.

Popcorn Polymer Accumulation, Pipe Rupture, Explosions, and Fires at TPC Group Chemical Plant Butadiene Unit

Harold Griffin

On November 27, 2019, a series of explosions occurred at the TPC Group (TPC) Port Neches Operations (PNO) facility, located in Port Neches, Texas, after highly flammable butadiene released from the process unit. The explosions caused a process tower to propel through the air and land within the facility, other process towers to fall within the unit, extensive facility damage, and fires that burned for

more than a month within the facility. The butadiene unit was destroyed, forcing the facility to cease butadiene production operations indefinitely. Two TPC PNO employees and a contractor reported minor injuries, and according to media reports, at least five local residents reported injuries. Officials in Jefferson County, Texas declared the county to be in a state of disaster and issued a mandatory four-mile radius evacuation order that affected people in the cities of Port Neches, Groves, Nederland, and a portion of Port Arthur. The explosion also led to reduced usage of the Sabine-Neches Waterway, the nation's third largest waterway by cargo volume. This presentation discusses the CSB's incident investigation, safety issues, and key lessons learned.

Safer Hybrid Model-based Model Predictive Controller: Integration of Attention Mechanisms and Safety Constraints for Chemical Processes

Parth Shah

The chemical industry is undergoing a significant transformation, which is driven by recent advancements in artificial intelligence (AI) and machine learning (ML) techniques that harness large quantities of process data from chemical plants and help in improving the safety of the operation. At the forefront of this revolution are hybrid models, which have gained substantial popularity over purely data-driven approaches such as deep and recurrent neural networks (DNN and RNN) and long short-term memory (LSTM) networks [1, 2]. This is because hybrid models combine a first-principles model with a suitable data-driven approach, benefiting from both *a priori* system information and feature-rich process data to synergistically provide better predictions than purely data-driven ML models [3, 4]. Although the literature is rife with DNN-based hybrid models for fermentation, paper and pulp process, hydraulic fracking, and other chemical systems that show good predictive performance [5,6], these models have limitations and do not adapt well to process fluctuations leading to unsafe process operations. Most chemical systems exhibit process uncertainties, such as sensor noise, feed and temperature fluctuations, and changing kinetics, which can distort the measurements fed to the hybrid model and result in a noticeable plant-model mismatch. When these models are used inside a model predictive controller (MPC), these process uncertainties might cause the control inputs to breach the safety threshold of the process, leading to alarms, shutdowns, and emergency protocols [7,8]. Therefore, the development of a safer hybrid model-based controller is needed that can (a) account for these process uncertainties by accurately predicting the time-varying parameters and (b) consider safety constraints in the optimization problem that sets a limit on the occurrence of unsafe events.

Recently, attention-based ML models have been in the spotlight due to their remarkable ability to establish strong correlations between input and outputs, even in the presence of system noise or uncertainties. These models adeptly focus on short- and long-term dependences in the evolution of system states [9,10]. In essence, the attention mechanism performs a scaled-dot product calculation between various input vectors, enabling it to selectively pay attention to significant long-term (e.g., concentration evolution) and short-term (e.g., sudden change in temperature due to control actions) process alterations by assigning higher attention scores to such instances. As a result, the attention mechanism serves as a filtering mechanism to dynamically handle process uncertainties and data noise by effectively dampening weak correlations and amplifying strong interactions between the system states. On the other hand, LSTM-based sequential time-series models have shown superior predictive performance due to their ability to explicitly consider the time evolution of system states (i.e., battery dynamics, stock market estimates, energy forecasting) as opposed to DNNs. While the combination of the attention mechanism and LSTM can pose a highly effective solution accounting for process uncertainties

by selective attention to changes in system dynamics and accurately predicting time-varying parameters, the safety aspect of the operation is left unresolved.

To this end, we propose a novel attention-LSTM-based hybrid model for a complex, non-trivial fed-batch fermentation process and then design a hybrid model-based controller with safety constraints. Specifically, the input to the data-driven module of the hybrid model consists of state measurements for the previous time steps. This input is sent through an encoder module to lift the states into higher dimensions. Then an attention mechanism with a subsequent LSTM layer is applied to obtain time-series predictions of uncertain parameters for the next step. The uncertain parameters are a lumped representation of different process variations, such as varying bacterial kinetics, and feed and temperature fluctuations, and are represented by the most sensitive kinetic parameters determined through global sensitivity analysis [5]. Next, the predicted uncertain parameters are then fed to the first-principles model, which includes mass and energy balance equations, concentration dynamics, and kinetic equations to obtain state predictions for the next time step. The training and validation dataset is generated by simulating a high-fidelity (HF) model of a fermenter system for over 100 different arbitrarily initialized operating conditions, such as temperature, substrate flow rate, and catalyst rate. Finally, the developed hybrid model is incorporated within an MPC to achieve set-point targets for product amount by determining optimal input profiles for feed flow rate and temperature. To ensure safer operation, safety constraints are added that include the limits on temperature, flow rates, and their rate of change. These safety constraints are integrated with features like alarms and emergency protocols that can be activated in case of unexpected events. In a nutshell, the combined benefits of attention mechanism, LSTM-based sequential modeling, and safety constraints inside an MPC give rise to inherently safer controllers that can regulate process uncertainties by determining optimal control actions while providing accurate process predictions. This work lays the foundation for furthering safety-based controller design by considering robust or chance-constrained optimization in conjunction with attention-based hybrid models.

Managing the Risk of MOC

Jack Chosnek

During the execution of a change using Management of Change (MOC), the risk to the facility is increased because things are in flux until the change is completed and documented and personnel trained. During this time P&IDs, SOPs, and other procedures are being developed or changed. Construction or tie-ins in preparation, or as part of the change, are going on. Thus, during the change until it is complete, the potential for error, and therefore the risk, is increased. This potential for error emanates from the use of not-yet implemented P&IDs, use of unapproved procedures (or use of old procedures after the change), and unintended connections to piping which contains hazardous materials. Additional risk results from an incorrect workflow where the appropriate individuals were not included in the review or approvals. Another, less common but possible risk, is unknowingly impacting an existing safeguard by changing related equipment.

Thus, the MOC process needs to be carefully managed, not only for an individual MOC but the aggregate of all the MOCs that are being worked on at the same time. The MOC system needs to provide easy simultaneous access to all personnel and be fully searchable. The longer it takes to complete a change the higher the risk and the MOC system needs to be monitored for late and/or undocumented MOCs. Metrics that show the open and past due MOCs in any period of time should be part of the system. To ensure proper review and approval there should be pre-configured workflows for the different kinds of

changes. It is important to have a system that is easy to use as this removes a barrier to doing good MOC as complexity leads to error and even avoidance or bypass of the MOC system. Such a system will be illustrated.

Integrated Process Hazard Analysis, Bowties and Barrier Management

Paul Tours

The process safety management of industrial facilities involves the identification, evaluation, and control of potential risks and hazards that could lead to accidents or incidents. Traditionally, this has been done through process hazard analysis (PHA) techniques, which involve identifying potential hazards and their consequences, and developing controls to mitigate these risks.

Tomorrows approach to process safety management combines PHA, bowtie analysis, and cumulative risk visualization. Through a common integration of these techniques, it is possible to recontextualize the way risks are assessed and managed, providing a more comprehensive and dynamic view of the risks associated with a process.
The approach uses PHA to identify potential hazards and their consequences, and share them to bowties to represent the links between hazards, threats, and controls. These bowties are then used to identify areas of cumulative risk, which are visualized.

By this incredible combination of techniques, a highly efficient and holistic view of the risks can be better understood. We believe this approach will drastically improve process safety management practices and noticeably reduce the risk of accidents and incidents in industrial facilities.

Setting up the right leading process safety indicators to support the lagging metrics and drive continuous improvement: A Gas company case study

Bahman Abdolhamidzadeh

Discovering weaknesses in the control barriers when a major process safety incident occurs is too late and too costly. Obviously, companies prefer to measure their process safety performance before an incident informs them about it. Despite this fact, the lack of adequate process safety performance indicators to measure has been cited by Chemical Safety Board (CSB) as a contributing factor in several recent major process safety accidents.
In this paper, the critical importance of leading process safety metrics (Tier 3 and 4 according to API 754 framework) is explained. Since these two metric groups are normally facility-specific and less well defined compared to the Tier 1 and 2 lagging indicators, practical guidelines, and examples for selecting them are offered. Additionally, Tier 3 and 4 process safety indicators are compared in terms of functionality and concept.

This paper also overviews the implementation journey for PG&E gas company and describes how a process safety indicators dashboard was developed, maintained, and improved. Practical challenges in selecting and monitoring Tier 3 and 4 (leading) process safety metrics are discussed. Additionally, Key strengths of the PG&E process safety dashboard have been outlined in this paper.

The Importance of Operations & Maintenance PSM Training

Chet S. Barton

Training of non-safety professionals such as operators, maintenance personnel, project managers, and other engineers to understand and competently operate your Safety Instrumented Systems is often overlooked, but those people actually are in contact more than anyone else, during the longest part of the Safety Lifecycle – the Operate and Maintain phase.

OSHA 1910.119 (Process Safety Management of Highly Hazardous Chemicals) calls for a written plan for employee participation, consulting with employees about the development of process hazards analyses, and provide any information developed under the section. This information is to enable the employee who is involved in operating the process in question, to identify and understand the hazards posed by those processes. It also defers to Recognized and Generally Accepted Good Engineering Practice (RAGAGEP). IEC 61511 requires that persons involved with SIS being competent with experience and training, adequate for the tasks they are doing. It also says "Operators shall be trained on the function and operation of the SIS in their area."

Operators, maintenance personnel, and others who may be tangentially involved or work around the safety system in a process area (i.e. not Process Safety professionals responsible for evaluating and mitigating hazards) need to understand what hazards are present, and what measures have been taken to address them. They need to understand that Safety Systems and Functions have been designed and put in place to protect them and their coworkers from specific scenarios, that alarms (process alarms, fault alarms, etc.) have meaning and should be paid suitable attention, and bypassing for maintenance or testing is a serious matter. They also need to understand that any other non-SIS layer of protection plays an important role, even if it isn't labeled as "SIS". Training is often neglected, even by companies that otherwise embrace PSM.

Training is relatively inexpensive, and can make the Safety System more effective by engaging the operation and maintenance team for future evaluations, increasing safety awareness, and promoting a safety culture.

It's Mastery, not Magic: Blueprint for Enhancing Safety Culture

Kristin Robbins

It's a new era for safety culture. Gone are the days of perceiving culture as a static, top-down pyramid where training is considered a check-off-the-box to-do that transforms performance into being "safer" after a single dose of learning. Peak safety competence doesn't happen overnight, like magic; it's cultivated. Safety is a journey, and the road to get there requires longevity, consistency, and commitment fueled by continuous learning. Its practices are embedded into the organization's culture, largely manifested by how management codifies knowledge, and learning and development.

This paper explores the definition of a learning culture, the value of knowledge management, and the benefits of using technology to facilitate continuous learning. Practical tips and real-life examples of learning and development programs that positively impacted safety culture will be shared. Top three components of a learning and development plan will be identified to reveal a blueprint to improve your organization's safety culture.

Integrated Operational Risk Management

Tarkowska Malik

Unsafe systems of work, poorly maintained equipment, inadequate planning and lack of proper information or training are just some of the well-known root causes which may contribute to a major accident event in the oil and gas industry. All the above is especially important for the safe operation of a safety critical element. These, along with appropriate operational risk management processes, can significantly support risk reduction in the plant, as well as effectiveness improvement of the safety performance.

A safety critical element is any part of the plant the failure of which can contribute to a major accident event. One of the processes regulating proper risk management of a SCE is the maintenance deferral process. It controls on how to manage a not carried out before the planned due date maintenance work. The consequences of not performing maintenance will lead to increased safety hazards, as well as endangering the safe to operate condition of the plant. For this reason, each maintenance deferral process must be completed with an operational risk assessment. Two main parties are involved in proper completion of the process, the maintenance planner, and the integrity lead. They must assure a new due date in accordance with the identified and approved risks and temporary control measures for the duration of the deferral.

Maintenance deferral process can be implemented using various approaches, a traditional paper-based, or more advanced, system-based followed by a training. The aim of this paper is to present an integrated systems-based approach, which has shown improved enforcement and quality of the process including enhanced collaboration between the disciplines. Especially designed workflow for the process has integrated the two leading systems, the maintenance, and the integrity, locking in the individual disciplines' steps into one flow.

It is hoped this paper will further inform safety representatives about digitalized operational risk management processes in the plants.

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AN INTEGRATED APPROACH FOR DEVELOPING RECOMMENDATIONS IN HAZARD EVALUATIONS AND INCIDENT INVESTIGATIONS

Henrique Paula

There are several approaches utilized when developing recommendations (actions for improvements) in process safety management activities such as audits, process hazard analyses, incident investigations, or root cause analyses. One high-level approach is to focus on the ***strategy*** for risk control: avoidance (or elimination), transfer, mitigation, or acceptance. "Mitigation" can focus on (a) reducing the frequency (or probability) of a risk scenario or (b) mitigating its impact (or consequence). These strategies are recommended and widely used in the context of enterprise risk management and project risk management. They are also consistent with the ***risk triplet*** because they address (a) elimination of what can go wrong, (b) mitigation of the consequence, and/or (c) reduction of the probability.

Another approach focuses on the ***hierarchy*** of controls, including elimination (same as in the previous two approaches), inherent safety, engineering controls, administrative controls, and personal protection equipment (PPE). Engineering and administrative controls are explicitly addressed in OSHA's PSM and EPA's RMP regulations, and PPE is extensively addressed in occupational safety efforts and regulations. And it is also possible to focus the root causes (e.g., management systems weaknesses). That is, focus on developing ways of avoiding deficiencies in the ***processes*** that create or allow the root causes to exist. Finally, it is possible to focus on ***culture and organizational factors***, including leadership, cultural environment, accountability, and the organization.

This paper presents an integrated methodology that accounts for these five approaches for developing recommendations. It also introduces a chart that aids analysts, investigators, and auditors in using the integrated approach. The chart is equivalent to a root cause map, which is often used in incident investigations in chemical process incidents.

Runaway oxidation testing for solids: Case studies and pitfalls

Pranav Bagaria

Under certain conditions, high surface area organic solids may undergo runaway oxidation reactions resulting in smoldering/or fire. Calorimetric techniques can provide insight into these reactions that can be used for kinetic modeling. When coupled with heat transfer simulations, this data can be used to predict hazards at larger scale under process conditions in order to develop appropriate prevention/mitigation measures. However, there are various factors pertaining to proclivity toward high surface area oxidation (chemical composition, particle size/morphology, pore density), heat transfer (kinetic data extrapolation, thermal conductivity of the pile), and process conditions (color, humidity, convection) that can be easily overlooked, resulting in inaccurate risk assessment. This work aims at highlighting the importance of these factors on oxidation kinetics, heat transfer evaluation and data application for accurate risk assessment through multiple case studies. Open Cup ARC test data and

Frank-Kamenetskii heat transfer theory will be leveraged in our case studies to elucidate the significant impact of these factors on runaway oxidation risk for high surface area organic solids.

Use of a two-parameter Weibull distribution for the description of the effect of the particle size distribution on dust explosion properties

Asma Abousrafa

Combustible dust explosion properties have been long known to have a strong dependency on the physical characteristics of the dust particle which include the particle size distribution. The comparison of the dust explosion properties reported in the literature for a given dust material is often difficult because of the lack of the description of the particle size distribution usually limited to the median (d50), mean, percentiles (d10, d50, and d90), etc. A different approach is necessary to describe the dependency of dust explosion properties to the particle size distribution using a continuous probability distribution. An example of a two-parameter distribution is a normal distribution described by a standard deviation (σ) and mean (μ), however this can only represent symmetrical bell-shaped distributions. The particle size analysis obtained experimentally is often described as a skewed bell-shaped histogram which cannot be fitted using a normal distribution.

The purpose of this study is to explore the use of a two-parameter (shape and scale) Weibull distribution to describe a particle size distribution. A series of experimental data on Minimum Explosive Concentration (MEC) of dust samples for which the particles distribution is measured was used for the analysis. Each of the dust sample particle size distribution was fitted by a Weibull probability density function with an estimation of the shape and scale parameters. A three-dimensional plot of measured MEC values as a function of the two Weibull parameters was generated. The results show a surface-plot with a clear trend on the influence of shape and scale parameters of a dust sample particle size distribution on the MEC. The approach was tested with experimental values of MEC for samples of sulfur and polyethylene dust particles. The paper discusses the advantages of using such approach to describe the effect of the particle size distribution on dust explosion properties.

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Photocatalytic Degradation of Produced Water by TiO_2-rGO-CdS Nanotubes

Raghava Kommalapatti

Produced water (PW) from shale gas or hydraulic fractured wells contain a large quantity of suspended solids, organic compounds, and dissolved salt. It is mostly injected into an underground reservoir after traditional treatment because such a method is not sufficient to remove the organic components. Photocatalysis is a process that uses light energy to break down pollutants. This research focuses on the synthesis of TiO2-rGO-CdS multi-leg Nanotubes (MLNTs) by electrochemical anodization to produce a photocatalyst for treating produced water. Photocatalyst has shown to be very effective in the degradation of contaminants in water. To fabricate the MLNTs, Titanium foil (Ti) is used as the anode while the platinum foil is used as the cathode in an electrolyte mixture and a voltage of 50v is applied between both electrons. The anodized Ti foil is thermally treated at a temperature of 500oC to obtain the first phase of TiO2, known as the anatase phase. The Electrophoresis technique which involves using charges and size in separating particles is utilized in depositing reduced graphene oxide (rGO) onto the TiO2 nanotubes. CdS is then deposited on the TiO2-rGO MLNTs using chemical bath deposition. The synthesized TiO2-rGO-CdS is optimized by varying the quantity of the nanoparticles before being characterized by SEM, FT-IR, TGA and XRD techniques. The performance of the photocatalyst is evaluated by comparing the total organic carbon (TOC) and the chemical oxygen demand (COD) of the PW before and after the treatment.

A Detailed Strength, Weakness, and Opportunity Analysis of Existing Sustainability Metrics

Mitchell Huffman

As the human population grows, the strain on resources and the environment grows exponentially. Sustainable practices are therefore necessary to protect the planet as well as preserve the standard of living of those inhabiting it. The quantification of sustainability is vital in order to monitor and regulate industry practices. Therefore, it is necessary to understand the development of the field of sustainability quantification. Frameworks such as life cycle assessment, impact assessment, and the triple bottom line provide approaches to quantify, understand, and implement sustainability concepts. Many studies have expanded on these frameworks to provide a variety of methods to quantify sustainability in industry, with various strengths and weaknesses. Sustainability metrics to this point have lacked an inclusion of safety, time dependence, and quantification of the interrelations between sustainability pillars. To determine the validity of existing metrics, the consistency of their results must be compared. When utilizing existing sustainability indices, significant variation was found both in the final quantification of sustainability for a single process, and in the determination of a more sustainable process when comparing two processes. These inconsistencies imply the need for additional considerations within the various indices. Therefore, an interrelated, time dependent quadruple bottom line is necessary to provide a thorough assessment of the sustainability of a process.

Constructing a Process Risk Index Empowered by ASPEN Plus Simulation

Yutian Qian

A safety index, or its counterpart, a risk index, is widely used in the applications regarding the inherent safer designs. Starting from the Dow Fire & Explosion Index first introduced in 1960s, many risk indices have been proposed with various system properties as foci. The quantitative nature of indices makes them advantageous in identifying the potential hazards since a net score that is comparable with the alternatives could help determine inherent safer designs. Unlike the conventional qualitative evaluations, such as Hazard and Operability method (HAZOP), risk indices may not require detailed process information that is retrieved from on-site settings. This characteristic makes risk indices suitable tools for risk assessment during the preliminary design of a process or even a complete industrial complex. In the wake of Industry 4.0 where process simulations become even more prevalent, constructing a risk index that are seamlessly integrated into process simulation results will be highly beneficial.

In this work, we attempt to construct a process safety risk index that is formulated based on the process stream parameters provided by Aspen Plus process simulations. The process properties, such as the mass flow rate, temperature, pressure and the stream enthalpy, are combined with the material properties to calculate the initial index values. With the consideration of adding or removing any desried piece of process equipment in safety instrumented systems, credits and penalties are applied to the initial index values and obtain the final results. The results will then be translated into a straightforward graphic presentation in the form similar to the traffic light to reflect the degree of potential hazard that exists in the design of the process. It is anticipated that potential application of such indices include (i) preliminary process design in the industry and (ii) routine practices of process simulations in the Chemical Engineering design classroom.

SIS Lifecycle: Design Phase vs Operations Phase – A Reality Check!

N. Muthiah

The Presenter spent more than a decade working for Engineering Companies with Project Design and Specifications mindset. Presenter recently switch sides to work for an Owner/Operator multi-asset Refinery Company. With this new vantage point, Presenter would like to share thoughts on things that matters in Operations and Maintenance Phase that maybe overlooked during the Design Phase.
In this presentation, the following topics will be addressed.

1) Safe State: is it always shutting down the Unit?
2) SIL Certified Devices: are they always the best solution? What's the catch?
3) SIS Logic: is Creative Design a desired skill set? Or should we Keep It Simple and Straightforward?
4) FAT / SAT – what's the deal with Diagnostic Alarms?
5) Logic Solver –Hardware and Software bugs, faults, corrections and required upgrades.

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SIS, Digitalization and the Hidden Cost of Uncertainty

Gregorio Aguilar

Safety Instrumented Systems (SIS) are often our last lines of defense when a process excursion leads to a potentially hazardous situation. And the SIS Safety Lifecycle is a continuous improvement work process that enables us to design protective functions that are capable of mitigating those hazards while still being cost effective. However, there are assumptions through each phase of the lifecycle that can lead to a failure in the operation of our safety instrumented functions. From higher than anticipated demand rates to field devices with lower than expected reliability to bypasses implemented longer than the allowed duration, uncertainty associated with our assumptions can have catastrophic consequences associated with production, safety, maintenance, reputation and compliance. Often that uncertainty is hidden. But advances in digital technology can shine a light.

Imagine a world where process safety risk is predictable, where assets deficiencies are self-revealing and managed by exception and where functional safety programs are built on a foundation of data that has been liberated from silos, integrated into a common platform and contextualized across the functional safety lifecycle.
Imagine if . . .

- An Operator gets alerts on anomalies based on machine learning (ML) that analyzes past data including incidents, maintenance history and time series data, despite the process operating within alarms.
- An engineer can find all data associated to his/her SIS in one click improving time spent troubleshooting, analysis and investigations.
- A machine predicts a failure, notifies a gatekeeper and initiates a notification and work order to execute the necessary repairs
- A turnaround is planned in less time by enabling automatic scope definition and prioritization through leveraging ML on past data and current/future risks

This paper will present how new technology being implemented at Celanese such as an operational data platform, improved interconnectivity using 5G and the use of advanced analytics can be applied to increase visibility of our process safety risk and improve the effectiveness of our safety instrumented systems. By leveraging data and digital technologies, we can move towards a future where safety is more predictable, assets are managed more efficiently, and functional safety programs are more effective in protecting people, the environment and the business. It's time to embrace the digital

transformation of functional safety and take advantage of the opportunities it presents for continuous improvement and increased safety.

Datacentric digitalization of functional safety in project execution

Janardhanan Kallambettu

Achieving functional safety requires addressing both random and systematic failures. Random failures are predicable, whereas, at present, systematic failures are not. The impact of random failures can be addressed by the selection of reliable devices or systems. However, systematic failure is related in a deterministic way to a certain cause, which can only be eliminated by a modification of the design or manufacturing process, operational and maintenance procedures, documentation, or other pertinent factors. Devices designed, manufactured, and assessed in accordance with IEC 61508, reduces the systematic failures of a product. However, the systematic failures during the project execution, operation and maintenance phases can be minimized by methodically following a functional safety management plan and applying verification of all the lifecycle activities. It is a challenge for the Engineering, Procurement and Construction (EPC) companies to control systematic failures during the project execution phase due to various factors, such as resource constraints, project schedules, and maintaining independence in verification activities involving volumes of disparate data and many deliverables. This paper presents an automation database tool which uses a datacentric solution to these challenges by digitizing and integrating the data from various commercial tools such as Instrument Index (Intergraph Smart® Instrumentation), HAZOP/LOPA, SIL verification, and other safety lifecycle tools to automate the verification and validation of the data, check for consistency, identify the omissions and commissions, and generate project deliverables with traceability and minimal manual intervention. This datacentric digitalization tool has been deployed on two major LNG projects, realizing significant benefits by minimizing the systematic failures, reducing manual effort and the overall functional safety project costs.

Using Credible Failure Rates for SIS Ensures Process Safety

Angela E. Summers, William M. Goble, Rajeev Limaye, Linde; Juan Gutierrez (PANEL DISCUSSION)

Many individual device failure rates being published by manufacturers and certifying agencies are deemed by members of the panel, many SIF designers, and practicing engineers in the field to be too low. This is especially true for mechanical final elements. SIFs designed using these unrealistic failure rates often result in SIL levels on paper which would be achievable only under the most optimistic assumptions regarding installation, operation, and maintenance. These SILs are unlikely to be achieved in the field. The panel discusses the underlying causes of this serious safety issue and proposes some possible solutions.

The Failure Rate Data Landscape – Credible Data for Safety Instrumented Function Design Verification

Iwan van Beurden

Failure rate data obtained from field failure data analysis is called “estimated” failure rate data. This analysis does require a certain understanding of statistics. But perhaps more importantly, credible data requires an understanding of how the failure data is collected, source of the failure data, and what

failure data is discarded. Given credible estimated failure rate data, that information can be used to establish a credible, realistic failure rate prediction method using the FMEDA technique. Good credible data is being provided by some companies/organizations. Yet there are others who have published failure rate data that is highly optimistic. This paper presents an overview of failure rate data sources and the issues that should be considered before using that data for SIF verification calculations.

How to justify, ethically and financially, investing in a Safety Instrumented System (SIS)

Luis Garcia

In the process industry, the evaluation of Safety Instrumented Systems (SIS) is becoming more top-of-mind. A SIS is a set of complex devices with special care requirements to maintain their safety performance.

Now, is it worth to have a SIS?

The cost of the equipment involved and the need for specialized personnel to manage and monitor such systems, naturally, makes users wonder if it is worth the effort to have them. For once, the safety of your plant is critical for operations and without a SIS your plant might be at an unacceptable level of risk, according to the authority having jurisdiction. But is there a financial penalty?

In this presentation we will not only take a closer look at the engineering needs for one implementation example, but we will also look at the financial justification for investing in such layer of protection.

At the end of the presentation, attendees will be able to perform a cost-benefit analysis for such investment as compared to the cost of risk which a Safety Instrumented Function (SIF) may protect against. The attendees will be able to appreciate when or if there is no choice, but to utilize such complex technologies.

IEA IPL & SIF Design and Maintenance Benchmarking—Where Do You Stand with the Herd and the Hunters?

PANEL DISCUSSION

Facilitators: Patrick Skweres—SIS-Tech, John Thibodeaux—Dow Chemical

Background: Once the protection layers and integrity levels are determined using HAZOP, LOPA, FTA or other techniques, are you implementing and maintaining in the most cost-effective manner across the life cycle.

Ground rules: Great deal of information to be gathered/exchanged in a short amount of time, if company representatives can sit in close proximity together and provide “company” answers. Stick to “the facts” limit the venting.

SIL-3 Proof Testing - No Plant Shutdown Required

Greg Hall

I will discuss SIS interlock designs which allow segmented and on-line proof testing of SIL-1, -2 or -3 SIS without requiring a plant shutdown. The cost of proof testing SIS interlocks has increased because "100% proof test coverage" is no longer used in SIL verification calculations due to changes in IEC 61511. Test intervals have been shortened and do not align with plant turnaround schedules. Segmented and on-line testing are allowed by the standard and are used to complete proof testing on-schedule. Overdue testing affects the ability of an SIS to meet the required Risk Reduction required by the SIS verification calculations. When a failure is detected either during normal run time or during testing, some designs allow on-line repair or replacement of initiators or final elements while maintaining the required Risk Reduction and eliminating a plant shutdown to make repairs.

Case Study: Management has decided to defer your upcoming SIS proof testing. Now what?

Michael Scott

Your boss walks into your office and states that plant management has decided to defer the upcoming planned shutdown for two years due to extremely high product demand. The specific question put to you is:

"The decision is final to extend the shutdown. What I need to know is what is our risk and what can we do to mitigate any potential increased risk knowing we've deferred Safety Instrumented System testing an additional 2 years?"

This white paper will walk through the typical steps / analysis one must complete to be able to answer this simple but complex question. This includes reviewing:

- Updated SIL Verification Calculations that include the new extended Test Interval
- Review the LOPA Target Risk Reduction Factor (RRF) versus Achieved RRF with the extended Test Interval to identify all Risk Gaps
- Review current performance status of these Safety Instrumented Functions (SIFs):
    - Are any of these functions already overdue for testing?
    - Are any of these functions being bypassed excessively?
    - Are any of the field devices used in these SIFs experiencing "high" failures?
    - Are any of these SIFs experiencing "high" demands?
- Review areas of potential high risk to identify any other potential compensating measures that could be implemented to mitigate / reduce risks

With this large compliment of data, the final challenge is how to communicate the potential increased risk to business in a way that management can readily understand and thus be empowered to make informed business decisions with regards to the various potential other compensating measures being recommended.

Hazard Recognition of Proton Exchange Membrane (PEM) Hydrogen Production and Storage Installation

Mohd Fadly Adnan

Touted as the fuel of the future to decarbonize critical economic sectors, hydrogen holds the key for many businesses and nations that have set their sights on achieving net-zero carbon emissions by 2050. This aspiration has set the economy gear shifted towards emerging green hydrogen production and installation facilities for use in transportation and power generation sector. To ensure safe and sustainable growth of this expanding new energy vector, the associated inherent hazard of such installation should be recognized for intervention measure to be implemented. According to OSHA, one of the "root causes" of workplace injuries and incidents is the failure to identify or recognize hazards that are present, or that could have been anticipated.

In PETRONAS, acknowledging this new potential threat to further safeguard the new energy business, it is paramount to perform dedicated safety analysis for green hydrogen production and storage. This paper focused on sharing of the hazard identification in a typical Proton Exchange Membrane (PEM) Hydrogen production/storage through qualitative (HAZID, HAZOP) and quantitative assessment (Dispersion Modelling) which influenced some of the design criteria consideration. Key risk scenarios, safeguard and mitigation measure proposed based on the study are detailed out in this article.

A Comparative Study: Transporting Hydrogen or Ammonia

Jeff Marx

One of the recent trends in the energy industry is the switch to fuels with a lower carbon footprint. This has driven the expanded use of hydrogen for vehicular use and power generation. However, there exist several obstacles to making hydrogen a ubiquitous fuel. While the safety hazards associated with hydrogen are known and fairly well understood, there remains the challenge to transport sufficient quantities of hydrogen, in an economical way, to the locations where it is needed. A proposed solution to this problem is to convert hydrogen into ammonia, which allows transport of the hydrogen in a (non-cryogenic) liquid form. Closer to the use point, hydrogen would then be extracted from the ammonia and distributed as a pressurized gas. This solution provides a greater energy density and some ease of transportation but introduces the new hazard of ammonia toxicity. It then becomes incumbent upon process safety professionals to evaluate the transportation of hydrogen and transportation of ammonia to understand the benefits and risks of each. Focusing on the potential consequences of loss of containment events during transportation, a more comprehensive analysis can also integrate other factors, such as energy density, extra processing, and construction of additional facilities, that need to be considered in a comparative study.

DID OSHA GET THE 14 ELEMENTS OF PSM CORRECT? – Rethinking the 14 Elements of PSM as Processes – not Programs

Gregory Milewski

OSHA issued the Process Safety Management of Highly Hazardous Chemicals standard (PSM) in 1992, to addresses the significant / catastrophic chemical incidents that had occurred in the 1980's and 1990's.

The Refining and Chemical industry has developed experience and robust Process Safety Management programs for past 30+ years.

Yet, since the promulgation of OSHA's PSM standard in 1992, the refining, oil production, and chemical processing industries continue to experience significant / catastrophic incidents.

Researching the results of incident investigations by OSHA, and the Chemical Safety Board, and using benchmark studies by ACC Process Safety Committee, Center for Chemical Process Safety (CCPS) and the TEEX Mary Kay O'Connor Process Safety Center, and a review of learnings from OSHA's 2017 National Emphasis Program (NEP) this paper reexamines the objectives of the 14 elements in the OSHA Standard.

While OSHA proclaimed that the PSM Standard was a performance-based standard, the 14 elements can really be characterized as activities or programs to implement for a process safety management system. Instead of a listing of activities or programs, this paper intends to make a case for the 14 elements to be processes or performance criteria to achieve.

Risk-driven Model Predictive Controller

Sahithi Akundi

We present a dynamic risk-based model predictive control approach for real-time process safety management in nonlinear process systems. The probabilistic constraints on safety-critical variables are introduced to make the model predictive controller risk-informed. Risk-based controller optimization offers advantage in determining the control inputs based on the current state by considering the risk throughout the receding horizon process. A dynamic optimization problem is formulated to integrate process control and proactive risk management by introducing chance-constraints to reformulate the probabilistic constraints in deterministic terms. Bayesian inference is utilized to update the risk based on the past evidence along the horizon. The potential and effectiveness of the proposed methodology is demonstrated utilizing the example of the safety-critical control of continuous stirred tank reactor at T2 laboratories.

Asset Management: How to Approach the Digital Solution Evolution

Nicolas Obando

Objectives/Scope: An iterative and common-sense approach for readying systems, tools, processes and people for Industry 4.0 and the Industrial Internet of Things (IIoT). While technology offers the industry a multitude of solutions to manage their assets on-stream, in real-time and with intuitive model representations, it is often the gradual and practical improvements that stand the test of time. This paper will outline a stepwise approach to developing a powerful digital solution for asset management.

Methods, Procedures, Process: An overall asset management strategy not only addresses the physical assets that handle process streams, but also the tools, software, data and people that manage these assets. The convergence of these resources into work processes that manage operational risk has led many operators to rely on digital solutions to optimize decision-making and reduce human error. Our approach to managing the evolution of digital solutions involves the following major steps:

1- Definition of the desired end goal or result (e.g., reduction in risk, optimization of production, regulatory compliance, etc.)
2- Identification of the current program maturity and readily available resources
3- Development of an implementation plan and corrective actions to address program evolutionary gaps.

The intention is to develop milestones along the implementation plan in order to achieve incremental benefits from program evolution and the adoption of technological advancements. This will allow organic growth to drive momentum based on proof-of-concept victories (e.g., snowball effect).

Results, Observations, Conclusions: Achievable goal setting, with a phased approach, designed to lead to an overall outcome, has resulted in positive program maturity and avoidance of the "false start" narrative.

Novel/Additive Information: In this paper, we will provide comprehensive asset management approaches, supported by case studies, to achieve digital solutions that can help operators move from hard-copy data managed assets to sensor-enabled "digital twin" and various iterations along the way.

Development of a Blast-Resistant Roll-Up Door

Chris LeBoeuf

Conventional roller shutter doors can become hazardous debris when subjected to blast loading. To mitigate this hazard, Gliderol and ABS Consulting developed a blast-resistant roll-up door system. Design development was separated into two phases incorporating finite element analysis (FE) to design the door system and shock tube testing to validate the design in both phases. The first phase included analysis of concept and performance testing of door components to gather data necessary to develop an FE model of the entire door. The second phase involved refinement of the design and detailed design of the system, analysis, and validation of the full-scale door system.

> A Blast Mitigating Shutter (PL 1) has been tested and shown to be capable of achieving limited permanent damage in response to a blast load with a peak pressure 10.5 psi and peak impulse 150 psi-ms.

> A Blast Resistant Shutter (PL 2) has been tested and shown to be capable of achieving limited permanent damage and be fully retained in response to a blast load with a peak pressure 5.8 psi and peak impulse 72 psi-ms.

As part of this presentation details of both phases will be discussed. Design blast loads and structural performance requirements are presented. Candidate geometries considered for the curtain panels are described along with connections and anchorage configurations. FE modelling techniques for accurately capturing large deflections and dynamic responses are discussed. A comparison of component blast testing with the FE model results is presented.

Profitability and Process Safety in Chemical Supply Chains with Demand Variability Considerations

Austin Johnes

With rising demands being placed on supply chains worldwide, supply chain design is not limited to solely maximizing profits. Supply chains need to be able to withstand internal factors regarding potential risks and accidents that can occur. This is especially important for chemical supply chains, where there is risk involved with the storing, transporting, and processing of hazardous materials. Thus, at the design stage of the supply chain, it becomes important not only to maximize profits but also to take the safety of the chemical supply chain into account. Additionally, supply chains are not static. Time-dependent factors such as feed cost, availability, product demand, and product cost must be considered. To address these issues, we propose a framework for the incorporation of safety indices into the design of dynamic supply chains. Within this framework, we demonstrate the following: a method for incorporation of safety indices and relating this to the supply chain design level, the complexity that arises within the supply chain due to the additional consideration of safety for chemical processes, and an optimization-based approach in order to configure a supply chain that minimizes both cost and risk over the observed time period. To illustrate the applicability of this framework, we consider the production of glyphosate, a commonly used herbicide, and demonstrate the design of an inherently safer supply chain. First, we develop process flowsheets to synthesize glyphosate based on production methods that are commonly used in industry. For each process flowsheet, the cost of the equipment, feed streams, and utilities are calculated. Additionally, the hazards associated with the equipment and components involved in the processes are identified using safety indices and eventually converted into an economic risk. Finally, a mixed-integer non-linear programming (MINLP) model is developed for the supply chain to minimize the total cost, economic risk, or both the risk and cost of the supply chain while also ensuring that the supply chain is cost-effective. This model is applied to various seasonal demand profiles of glyphosate. Results from the MINLP model demonstrate the tradeoffs between safe design and cost for the supply chain and how this, along with demand variability, affects the overall decisions for the configuration of the supply chain.

Performance- and Risk-Based Approach Toward Combustible Dust Hazard Analysis & Mitigation Design

Nicholas Reding

Combustible dust explosions present a significant threat toward life and capital loss for industries that process, store, convey, or produce combustible dust. Regulatory requirements for process safety of combustible dust industries in the United States are often based on applicable standards produced by the National Fire Protection Association (NFPA).

In accordance with NFPA 652 *Standard on the Fundamentals of Combustible Dust*, new and existing facilities are required to undergo a comprehensive (and reoccurring) evaluation of the process or facility areas where fire, flash fire, or explosion hazards may exist due to the presence of combustible particulate solids. Such a Dust Hazard Analysis (DHA) may include analyzing compliance with the prescriptive requirements of all applicable NFPA standards. There are, however, scenarios where meeting all

prescriptive requirements is not feasible or practicable, and where alternative approaches (equivalent design, risk evaluation, or performance-based design) would be preferable.

Through case study evaluations of discrete applications, including protection by a combination of partial inerting & explosion venting and advantages of insertable dust collectors for conveyor systems as opposed to centralized dust collection, this work will demonstrate how alternate strategies to prescriptive requirements can be assessed and implemented. The analysis begins by identifying situations along the process flow where a prescriptive approach to the DHA may offer an insufficient solution for the hazard or application at hand. With these scenarios in mind, this paper proposes use of non-prescriptive logic as a cost-effective means of both quantifying the dust hazard severity potential and generating safe recommendations for explosion prevention and protection design.

Data-Driven Model for Multiphase Leak Detection Using Dimensional Analysis Technique

Abinash Barooah, M. Rahman

Objectives:

Human safety, the economy, the environment, and a company's reputation all depend on the timely and accurate identification of pipeline leaks. There is, however, no straightforward model for accurately predicting leak characteristics under various flow regimes. The present study seeks to close this gap by utilizing dimensional analysis to build a pipeline leak detection model that uses only the inlet and outlet parameters.

Methodology, procedure, and process:

A wide range of geometric (pipe diameter, pipe length, leak location, leak opening diameter), operating (inlet and outlet pressure, outlet liquid fraction, flowing liquid hold up), and hydrodynamic (Newtonian, non-Newtonian, air, CO_2, N_2, H_2) parameters are used to create the gas-liquid two-phase flow data-driven model. This allows the model to be comprehensive and system independent. The appropriate input and output parameters are identified by correlation analysis, and the non-dimensional parameters are produced using the Buckingham Pi technique. The data sets are gathered using a combination of simulation, experimental, mechanistic model, and literature data, and they are validated using separate literature data sets.

Results, observation, and conclusion:

The developed model showed a higher accuracy as compared to the available literature models with a MAPE of less than 20% and was able to identify the leak pressure, flow rate, leak volume fraction, and two-phase flow regime. Model shrinkage using the power law method helped to decrease the non-dimensional parameters which was supported by statistical analysis. Furthermore, the developed contour plots helped to identify the location of the leak for a wide range of two-phase flow operating conditions.

Novel/Additive information of the study:

The created data-driven model covers a wide range of geometrical, hydrodynamic, and operating circumstances, providing a simple and accurate solution that avoids the need for expensive and time-

consuming sophisticated simulations. This innovative method simplifies the leak detection processes, increasing effectiveness and cutting costs related to costly sensor installations.

Approach to Hazardous Area Classification Study for Ammonia Systems

Fakhrul Farhan Mohd

The world's energy sector is actively searching for new energy sources to diversify the energy mix and meet the growing demand for energy while reducing greenhouse gas emissions. Accordingly, Ammonia is considered as one of the top contenders of new energy due to its high energy density, low GHG emissions, and can be produced using renewable energy sources. Ammonia is known to have a higher Lower Flammable Limit (LFL) and ignition energy in comparison with other flammable gases, which means that it is less likely to ignite than other flammable gases. If ammonia is not managed properly, it can be hazardous to human health and the environment due to it toxic and flammable nature. Therefore, proper consideration shall be made to ensure safe design and operation. In the past, methane was used as a representative fluid category for HAC studies, due to no specific fluid category defined for ammonia in standards. This approach caused an overestimated HAC zone radius, resulting in unnecessary and substantial cost for installing an explosion (Ex) rated equipment. This paper will share PETRONAS' new approach to determine HAC zone radius for ammonia service. With this approach, it will optimize the design and operational costs without jeopardizing the safety of their personnel and facilities.

ALARP Demonstration Approach during PHA Revalidation in Oil and Gas Facility

Mohd Fadly Adnan

ALARP Demonstration Approach during PHA Revalidation in Oil & Gas Facility Abstract In Oil & Gas industries, major accidents have the potential to present a danger to employees and the local population and can result to significant business interruption causing in hundreds of millions of dollars of physical damage. Therefore, steps must be taken to address Major Accident Hazard (MAH) threats and minimize the risk of serious incidents as part of a comprehensive Process Safety Management (PSM) program. Process Hazard Analysis (PHA) is a fundamental element of PSM and one of key tools for understanding MAHs alongside others, such as Mechanical Integrity and Management of Change (MOC).

This paper describes the approach of As Low As Reasonably Practicable (ALARP) Demonstration during PHA Revalidation. It will not only provide guidance to review the control barriers but also to evaluate the control and recovery barriers effectiveness, which will eventually determine the adequacy in achieving ALARP. This will assist participants to better understand ways to facilitate HAZOP and make more firmed decision on the adequacy of safeguards. An effective ALARP Demonstration during PHA Revalidation will constructively provide an efficient workshop with an ultimate objective to generate a safer environment to employees.

The Lees' process knowledge compilation project is important because of past and future of process safety

Hans Pasman (Tanjin)

The renewal in risk assessment methods over mainly the last two decades, puts everything in the 30-40 years before in the shadow. This is mainly due to the digitization and the availability of data. Also, how to handle uncertainty has been progressed. Risk assessment is making a prediction on possible future accident events. Unless one is clearvoyant any prediction is to a certain extent unreliable. But like the weather forecast observations and computing enhance prediction accuracy significantly. At the same time past achievements, particularly in consequence analysis, should not be forgotten. Young generations may rely too much on software packages.

What is Researched on Process Electrification and What does that mean for Process Safety?

Hans Pasman (Edison)

To be distinguished are electrochemical and electrified processes. Electrolyzers, fuel cells and batteries belong to the first category, power-to-heat and cool applications and small molecule syntheses to the second. Nitrogen and hydrogen or water vapor to ammonia in a catalytic plasma reactor, generated by dielectric barrier discharge, intends to eliminate the Haber-Bosch synthesis. Other possibilities are conversion of carbon-dioxide and water to syngas or non-oxidative coupling of methane to higher hydrocarbons. The discharge activates and the catalyst fosters selectivity. For process safety of these new technologies, we need improved process hazard analysis, requiring digitized PFS and P&ID following ISO 15926.

Optimizing Fire and Gas detection of an Offshore Platform using 3D F&G Mapping and CFD Modeling: A Comprehensive Approach

Basil Fysal

The design of reliable and consistent Fire and Gas (FGS) detection layouts lacks a universally accepted methodology, technique, or standard. The adequacy of FGS designs has historically relied on rules of thumb, engineering heuristics, and Recognized and Generally Accepted Good Engineering Practices (RAGAGEPs). However, these approaches often suffer from flaws such as over or under engineering. The effective positioning of Flame and Gas Detectors in offshore installations, where congestion levels are high, presents a significant challenge. Ensuring that each fire zone receives adequate coverage, an effective field of view, and detector range to eliminate obstructions and blind spots is crucial. Suitably designed FGS reduces risk, optimizes the number of detectors, and meets desired performance targets. Early detection by a robust FGS system is critical, particularly in offshore facilities where multiple ignition and leak sources are present. This case study demonstrates the effectiveness of a 3D Fire and Gas mapping study, which optimizes and locates detectors to deliver cost-benefit results. The 3D mapping approach enhances coverage and demonstrates intended performance, taking into account sensitivity, detection range, radiant heat output, and voting logic. Additionally, risk-based gas mapping is implemented with CFD modeling to analogize the results with the 3D gas mapping study. CFD modeling predicts the impact of potential explosions, accounting for complex fluid flow patterns and detailed dispersion analysis. The study uses 3-D F&G mapping and CFD modeling to analyze and optimize the detector layout for an offshore platform, identifying important aspects and critical outcomes.

The Unrealized Potential of an Effective Safety Requirements Specification

Greg Hardin

The Safety Requirements Specification (SRS) is a required part of the Safety Lifecycle, as defined by the ANSI/ISA-61511-2018 standard and other standards under the umbrella of IEC-61508. It should be a central repository of information that is kept current throughout the Safety Lifecycle. Too often however, the SRS is used as documentation of what was done rather than in its intended role in planning for and following the Safety Lifecycle and is not updated once created. This paper will review examples of poor specifications, the problems that inevitably ensue, and offer suggestions for improving specifications and assigning priorities to the different elements.

ISA TR84 Recommendations for Cybersecure Safety System Projects

Anupa Beharrysingh

ISA-TR84.00.09-2023 Part 1, Cyber Security Related to the Safety Lifecycle, is expected to be issued this year. This technical report aims to put the safety and cyber security lifecycle side by side and discuss the requirements at each step/phase.

There are three primary methods in which safety systems are connected (or not) to automation systems: interfaced, integrated, or separate. There are many stages in a safety system project, the report provides guidance on cybersecurity assessment and resulting actions that should occur at each stage.

This paper will discuss the essential elements of the forthcoming technical report as well as it's impacts with respect to automation system connectivity and cybersecurity on greenfield and brownfield safety system projects.

Digital Twins and Industrial Cybersecurity

Matt Malone

Digital twins have been used for many years in automation manufacturing operations for years. The technology consists of a digital replication of assets, processes, devices, and systems. The typical use case of digital twins has been for training operators, testing new processes, virtual commissioning, and decommissioning. However, with the increased application of cybersecurity solutions within OT networks, a new use case for a digital twin platform has emerged. This presentation will cover ways that a digital twin for an industrial control automation system (IACS) can also be used for red teaming and penetration testing in a low-risk environment, testing new secure network design, and simulating response for a cyberattack. As companies convert their industrial cybersecurity programs from a "break/fix model" to a "risk management" model, the application of an existing digital twin can provide sustainability of existing systems to further improve their cyber defense posture.

Securing Industrial Control Systems: Implementing Zero Trust Architecture in OT Environments

Brad Mozisek

As technological advancements continue to reshape our world, cyber security has become an increasingly vital concern. The rise of Remote Operations, Open Process Automation, and the convergence of IT/OT systems have challenged the traditional Purdue model, calling for a re-evaluation of our approaches to cyber security in industrial settings.

Given the potential physical consequences of cyber-attacks in OT environments, the implementation of Zero Trust principles is of paramount importance. However, the adoption of such practices in OT environments presents unique challenges, including the updating of device protocols, continuous monitoring, and the integration of legacy systems.

To enable Zero Trust in OT environments, new advancements in technology, such as OPA, OPC UA protocols, and HMI systems, are needed to provide critical security and flexibility that can adapt to evolving threat landscapes. The assessment and adoption of IT technologies beyond conventional industrial domains should be considered and implemented as appropriate. This presentation explores the paths toward implementing Zero Trust in an OT environment, including the need for stakeholder engagement and ongoing monitoring and evaluation.

We will explore the following questions:

1. What is Zero Trust Architecture (ZTA)?
2. What ZTA technologies are available?
3. What is the current state of utilization for ZTA?
4. What are the next steps to adopt and incorporate in industrial control systems?

Control Strategies to Improve Biological and Chemical Reactor Performance

Gregory McMillan

The design of temperature, level, pressure, and composition loops is essential for the best reactor performance. The design is highly dependent upon the reactor technology and type of product stream, the design opportunities for better batch reactor control particularly for biologics is frequently overlooked. Here we provide an insightful view of the wide spectrum of reactor control strategies for best reactor performance.

Safety and Security Impact of Emerging Technologies: How Standards are Addressing the Needs of Owner/Operators

Howard Elton

Abstract

- Open Process Automation is coming

- Alternatives to the Purdue model are being aggressively pursued, and some consider the Purdue model to be 'out of date.'
- The device layer at level 0 is targeted more and more for connectivity to the web and to the enterprise level – IIoT is coming to the plant floor rapidly
- Standards are converging around these dominant themes to address the issues that operating companies face when trying to safely operate their plants while juggling these rapidly emerging technologies and the benefits they can bring to profitability.

All these things must be managed inside the company's risk profile and regulatory frameworks for their industries.

The purpose of this presentation is to describe how the standards are addressing these issues, how manufacturers are adjusting their products to fit into this rapidly evolving marketplace, and how operating companies can retain their mandates for no losses in safety or security.

How AI and Machine Learning Can Improve Process Safety Performance

Jimmy Miller

Since 2020, the trending focus in the process automation and safety industry has been Digital Transformation. While this concept has gained traction and a large portion of our industry truly sees the value that can be realized by beginning their digital transformation journey, many of these efforts have fizzled due to the difficulty in harnessing large volumes of data into actionable insights. The utilization of artificial intelligence (AI) and machine learning (ML) has gained significant attention in recent months. The use of AI and ML algorithms can provide valuable insights into safety hazards and risk mitigation strategies, leading to improved safety performance and reduced accidents in industrial processes.

This paper explores the value of utilizing AI and ML in improving industrial process and functional safety. It discusses how these technologies can be used to identify safety risks, predict potential hazards, and optimize safety measures. Additionally, it explores the benefits of AI and ML in automating safety management tasks and reducing human error.

Overall, this paper highlights the potential of AI and ML in improving industrial process and functional safety and provides an overview of their benefits and limitations. It concludes that the integration of AI and ML into process safety management systems can lead to safer working environments, increased efficiency, improved maintenance procedures and reduced costs.

Calibration and Analysis of Gas Detection of Multicomponent Releases

Edward Marszal

Gas detection of materials accidentally released from chemical processes is a complex engineering problem. The determination of the required number of detectors and where they should be located is difficult in the best of circumstances. The problem becomes significantly more complex when a single detector is expected to be able to detect many different chemicals, or mixtures of chemicals. Gas detectors are calibrated to detect a single specific chemical. Exposure to a different chemical will not result in the same measurement as for the calibrated chemical. For instance, if a gas detector is calibrated to alarm when methane concentration of 10,000 PPM, when that detector is exposed to a

10,000 PPM of ethylene, it will have an entirely different response. This disparity of response of the detector to the same concentration of gas because the detector is only accurate when measuring the calibrated gas. Furthermore, this problem spans multiple different gas detection technologies.

This paper discusses how detection of multicomponent gas systems is more complex than single species detection. The paper presents considerations for the design of gas detection where multicomponent releases are present. These considerations include the best options for which gas to use for calibration of the detectors, which species and concentration should be used for gas dispersion calculations for mapping, and the situation in which different detectors will be required to detect different species of gas.

Don't Get Overwhelmed – A Practical Approach to Flow Meter Technology Selection

Logan Mueller

Every day you are confronted with more options than ever before. Take paint colors as an example. Should you use antique white, whisper white, natural white, dove white, or hog bristle white to paint the trim on your house? What about grocery options. . . Should you buy your bread at Safeway, your meat at King Soopers, and your vegetables at Sprouts? Maybe you should commit to one grocery store and buy everything you need at Whole Foods? What about phones? Are you best off using Apple? After all, Microsoft, Google or Samsung might make a better phone. The choices are limitless, and the options can quickly begin to feel overwhelming.

Instrumentation, specifically flow meters, is no different. With an ever-increasing technology pool, and a wide variety of metering solutions, knowing where to start can feel like a monumental task. Further complicating the matter is the knowledge that implementation of incorrect instrumentation at critical measurement points can be costly and dangerous. As knowledge pools deplete with an aging and retiring workforce, it is vital that newer engineers, technicians, and managers can quickly get up to speed. This presentation will walk attendees through Emerson's philosophy around flow meter technology selection. By following a few simple principles, attendees will dramatically increase their comfort levels and confidence in the decision-making process.

Digital sensing technology and reliability analytics for liquid analysis resulting in increased reliability and improved cost

Bart Propst

The purpose of our presentation is to provide a real-world example of utilizing digital sensing technology for liquid analysis so that you can achieve increased reliability and reduced cost in your applications. The presentation will also demonstrate reliability analytical tools to document the improved cost and maintenance frequency of this technology.

To do this, we will present the maintenance challenges and costs associated with two specific pH applications; the specific digital technology utilized as a corrective measure; the implemented maintenance strategy; the effects of the implemented changes to maintenance activities and associated costs. This presentation is jointly presented by M4Knick and Ascend Performance Materials.

Control Valve Performance - You Don't Know What You Don't Know!

James Beall

In the 1990's, a study of over 5000 control loops revealed that 30% of the loops were INCREASING process variability due to POOR control valve performance. On a recent control foundation improvement project, over 50% of the loops had poor performance due to significant control valve performance issues. Poor control valve performance continues to be a widespread source of poor control loop performance. A control valve may be properly selected based on physical specifications, but its operational performance may not meet the requirements to achieve the required process performance. Properly specifying valve performance metrics such as dead band, resolution, process gain, step response time, and response regions are vital. Industry standard ISA/ANSI-75.25 provides definitions and test procedures for positioning and response time performance of control valve but does not provide guidance on selecting appropriate control valve performance specifications for a specific application. This presentation explains the impact of valve performance parameters and how to specify them to achieve the desired ***process*** performance. The definition and importance of these performance metrics will be explained, and field examples will be provided. The metrics can also be used to diagnose and improve existing control valve performance when it does not meet the required control loop performance. The benefits include longer valve life, reduced process variability and improved process performance!