Process Safety and Environmental Protection

rok 2012, ročník 90

Číslo 5 (September 2012)

Arcady A. Kossoy, Yury G. Akhmetshin. *Simulation-based approach to design of inherently safer processes.* Pages 349–356.

Safety of chemical processes and plants is a matter of high priority. The design of an inherently safer process is one of very beneficial ways of achieving this goal.

The paper describes the method of designing an inherently safer process for a chosen set of equipment and materials involved by applying non-linear optimization. The optimization is aimed at finding an operational mode, which guarantees safety of the process under normal conditions and provides maximal attainable safety in case of one typical accident scenario – cooling failure. Discussion covers problem statement, choice of the optimization criteria, appropriate methods for defining control variables.

An important practical challenge is stability analysis of the optimized process mode with respect to permissible deviations of control parameters and variables from the estimated values. The original method for the stability analysis of a non-stationary process is proposed. It comprises simplified preliminary evaluation method followed by the more detailed numerical optimization-based analysis.

Several examples illustrate application of the methods proposed.

- **Keywords:** Chemical process; Inherent safety; Non-linear optimization; Mathematical simulation; Stability analysis

B. Fabiano, F. Currò. *From a survey on accidents in the downstream oil industry to the development of a detailed near-miss reporting system.* Pages 357–367.

A historical analysis with statistical investigation on accidental events in the oil industry from the beginning of the XX century till now, was performed in order to identify historical trend and go deeper into accident causes. The classification methodology was developed referring to three headings, namely plant/process, environment and organization and trying to go deeper into the analysis of the causes of the accidents reported and understand more of what is probably behind the accidents. The accident types and severity were studied, plotting the accumulated frequency–fatality curve for each item. In the subsequent applicative phase, we applied a similar classification approach to near-misses directly collected over nine years observation in a large downstream oil firm. The historical analysis was extended on each section of the refinery, paying a careful attention to all causes and consequences of the event. Data were structured for analyzing trends and identifying possible precursors of unwanted events.

According to the step-by-step approach we try to evidence how immediate causes of a near-miss could be linked in some kind of causal chain to underlying causes that should be controlled by middle or higher management, or are part of the corporate safety culture.

- **Keywords:** Accident statistics; Human factor; Near-miss; Petrochemical industry; Process and personnel safety

Uday Kumar Chakrabarti, Jigisha K. Parikh. *Applying HAZAN methodology to hazmat transportation risk assessment.* Pages 368–375.

As conceptualized and put forward by Kletz, avoiding hazard at first instance is always desirable than trying to protect or manage it. However, there could be certain hazards which may not be possible to be totally eliminated and thus shall be analyzed and assessed in order to either reduce the probability of occurrence or limit the severity of consequences. Trevor's methodologies on HAZOP and hazard analysis (HAZAN) for process hazards are quite straightforward where the hazard is considered as a point source unlike hazmat transportation which is a moving source of hazard. The authors applied the HAZAN techniques to the transportation risk assessment of three different United Nations classes of hazardous materials (hazmats) through important industrial corridors of Surat district in western India that helped local authorities not only to decide on the minimum risk routes to regulate hazmat traffic but also to prepare an effective evacuation and emergency response strategies.

- **Keywords:** Hazmat; Risk; BLEVE; Risk transect; Societal risk

Jinqiu Hu, Laibin Zhang, Wei Liang. *Opportunistic predictive maintenance for complex multi-component systems based on DBN-HAZOP model.* Pages 376–388.

Predictive maintenance (PdM) focuses on failure prediction in order to prevent failure in advance and offer sufficient information to improve inherent safety and maintenance planning. A novel opportunistic predictive maintenance-decision (OPM) method integrating of machinery prognostic and opportunistic maintenance model is proposed in this paper to indicate the optimal maintenance time with minimal cost and safety constrains. DBN-HAZOP model quantifies hazard and operability analysis by dynamic Bayesian networks to provide prospective degradation trends of each component and the overall system for maintenance decision making. It is developed by integrating the prior knowledge of the interactions and dependencies among components and also the external environment, while the online condition monitoring data which is further to update the parameters of the model. Based on the future degradation trends given by DBN-HAZOP model, a local optimal proactive maintenance practice can be determined for each component by minimizing the expected maintenance cost per time unit. Understanding that for a complex system, whenever one of the components stops to perform a predictive maintenance action, the whole complex system must be stopped, at this moment, PdM opportunities arise for the other degraded components in the system at a reduced additional cost. Therefore, this paper further proposes an opportunistic PdM strategy for global cost optimization of predictive maintenance for the whole system, which considers failure probabilities, repair costs, down time cost and set-up cost. Case studies are given throughout to show how this approach works, and the sensitivity of the results to some of the driving cost parameters has also been examined.

- Keywords: Predictive maintenance; Opportunistic maintenance; HAZOP; Dynamic Bayesian network; Cost optimization

Rajagopalan Srinivasan, Sathish Natarajan. *Developments in inherent safety: A review of the progress during 2001–2011 and opportunities ahead.* Pages 389–403.

This paper reviews the progress in inherent safety. A summary of the historical developments up to the year 2000 is first presented which sets the stage for a review of the key developments during the first 11 years of the 21st century. A landscape of inherent safety is developed by mapping publications on two coordinates. The first coordinate, the risk coordinate, indicates if the focus of a paper relates to inherent hazard or to the likelihood of events. The second coordinate, the management coordinate, focuses on the ways and means to understand and assess inherent safety. Out of the 187 papers that have appeared over this 11-year period, 131 pertained to developments in inherently safer design; these have been organized on the proposed landscape. The rest introduce the basic concepts of inherent safety and address its incorporation into regulation, education and accident investigation. These along with the application of inherent safety in industry are also discussed. We conclude with a discussion on recent trends in industry and suggest directions for future research.

- **Keywords:** Principles; Metrics; Risk management; Human factors; Education; Sustainability

Alba Pineda-Solano, Lina Saenz-Noval, Subramanya Nayak, Simon Waldram, Maria Papadaki, M. Sam Mannan. *Inherently safer reactors: Improved efficiency of 3-picoline N-oxidation in the temperature range 110–125 °C*. Pages 404–410.

Alkylpyridine N-oxides are important intermediates in the pharmaceutical and agrochemicals industries. The N-oxides are produced via the homogeneously catalyzed oxidation of the respective alkylpyridines using a 50% excess of hydrogen peroxide. The competitive hydrogen peroxide decomposition produces oxygen in the flammable environment of alkylpyridines and thus forms a key hazard for this reaction. In this work, the N-oxidation was performed under pressure in the temperature range of 110–125 °C with different catalyst concentrations. It was shown that temperature had an undisputable positive effect on the N-oxidation efficiency. The accurate measurement of the pressure rise due to decomposition was difficult. However, only 5% of the added H_2O_2 decomposed when stoichiometric quantities were employed, even in the temperature of 110 °C. The N-oxidation was very efficient, even when the lowest concentration of catalyst employed in this study was used.

Highlights: ► The N-oxidation of 3-picoline at temperatures in the range of 110–125 °C. ► Dramatically increases efficiency of N-oxidation. ► Dramatically favors H_2O_2 selectivity towards N-oxidation. ► Hydrogen peroxide decomposition is practically eliminated.

- **Keywords:** 3-Methylpyridine; 3-Picoline N-oxide; Hydrogen peroxide; Thermal decomposition; Reaction calorimetry

Bruce K. Vaughen, James A. Klein. *What you don't manage will leak: A tribute to Trevor Kletz.* Pages 411–418.

This paper expands on a simple concept shared with us over three decades ago by Trevor Kletz: what you don't have can't leak. Despite many efforts at eliminating hazards through inherently safer process methodologies, as encouraged by Kletz and others, the reality is that the use of hazardous materials and processes is still quite common. Therefore, we consider those processes that still handle hazardous materials – the cases where what you do not manage will leak and may cause a fire, explosion or toxic release.

Our intended audience is quite broad. As Kletz has noted over the years, it is not just the people running a process who are responsible for its safety, but also those who make decisions on its design, operation, maintenance, staffing, etc. We hope that this paper contributes to an understanding of why we continue to have hazardous materials leak, potentially leading to accidents that cause fatalities, serious injuries, property damage, and environmental harm.

We expand on the fundamental equation for risk, a function of both the frequency and the consequence of a possible event, by considering the effects of poor operational discipline on risk, and ultimately, on the possible leak or release of the hazardous material. Continued safe operation involving hazardous materials depends on and is sustained by the operational discipline of everyone involved in the design of processes and their continuing operation and maintenance. What we do not manage will leak and therein lays the fundamental challenge that Kletz continues to emphasize today.

- **Keywords:** Risk reduction; Accident; Inherent safety; Discipline; Human factors

Brian J. Tyler. *HAZOP study training from the 1970s to today.* Pages 419–423.

An account is given of HAZOP study training from the simple methods used initially to modern methods such as e-learning courses. An especial mention is given to the role of Trevor Kletz in initiating public courses.

- **Keywords:** HAZOP training; HAZOP courses; Trevor Kletz; HAZOP e-learning

Bahman Abdolhamidzadeh, Che Rosmani Che Hassan, Mahar Diana Hamid, Sajjad FarrokhMehr, Naser Badri, Davood Rashtchian. *Anatomy of a domino accident: Roots, triggers and lessons learnt.* Pages 424–429.

On July 24th, 2010, several explosions and fires devastated a hydrocarbon processing plant in Kharg Island, Iran. Four workers were killed and many others were severely injured. The plant became out of service for 80 days. The way the accident happened and its sequence was representing as a domino accident. In this paper, events leading up to the disaster have been analyzed in details. Graphic presentation techniques such as Fish Bone Analysis and Event Sequence Diagram (ESD) have been utilized to enhance the understanding of the accident mechanism. Finally major lessons learnt from this domino accident have been addressed.

- **Keywords:** Lessons learnt; Domino accident; Fish Bone Analysis; Event Sequence Diagram

Rosa M. Darbra, Joaquim Casal, Elsa Pastor, Juan A. Vílchez, Josep Arnaldos, Eulàlia Planas. *Risk analysis active learning through the investigation of real CASE.* Pages 430–435.

Risk analysis is a topic of high relevance in chemical engineering. Courses on this topic are being introduced increasingly into the university curricula. The investigation of real cases is an interesting opportunity to consolidate the concepts taught in such courses and to get a better engagement of students through a creative work. The exercise proposed in this paper has to be performed by a group of students to whom a set of information has been provided. In the exercise, the students play the role of an expert team: they have to deliver a final report including diverse sections such as the description of the accident, the explanation of why and how it occurred, different calculations and finally, some conclusions. From the pedagogical point of view, the

results obtained from this type of exercise are very positive and promote the students active and cooperative learning.

- **Keywords:** Active learning; Safety; Risk analysis; Accident investigation

Reyyan Koc, Nikolaos K. Kazantzis, William J. Nuttall, Yi Hua Ma. *Economic assessment of inherently safe membrane reactor technology options integrated into IGCC power plants.* Pages 436–450.

Pd/alloy-based (Pd/Cu, Pd/Au) membrane reactors embedded into Integrated Gasification Combined Cycle (IGCC) plants (IGCC-MR) enable the storage and/or use of the energy value of H_2 to produce electricity while the CO_2 enriched retentate exit stream becomes particularly suitable for high pressure CO_2 capture-sequestration. There is undoubtedly a lack of operating experience associated with IGCC-MR plants, and therefore, sound process intensification principles/practices should be followed not only to enhance process system performance but also to ensure process safety and economic feasibility of an IGCC-MR plant. Motivated by the above considerations, a comprehensive process economic assessment framework for an inherently safe membrane Pd/alloy-based reactor integrated into an IGCC plant is proposed. In particular, a detailed Net Present Value (NPV) model has been developed to evaluate the economic viability of an IGCC-MR plant where the membrane reactor module design conforms to basic inherent safety principles. Sources of irreducible uncertainty (market, regulatory and technological) are explicitly recognized such as the power plant capacity factor, Pd price, membrane life time and CO_2-taxes due to future regulatory action/policies. The effect of the above uncertainty drivers on the project's/plant's value is studied through Monte Carlo methods resulting in detailed NPV-distribution and process economic outcome profiles. The simulation results derived suggest that in the presence of (operational, economic and regulatory) uncertainties, inherently safe membrane reactor technology options integrated into IGCC plants could become economically viable. In particular, comparatively more attractive NPV distribution profiles are obtained when concrete safety risk-reducing measures are taken into account through pre-investment in process safety (equipment).

- **Keywords:** Membrane reactors; IGCC; Hydrogen production; Process intensification; Process safety; Process economic analysis; Net Present Value; Uncertainty; Monte Carlo simulation