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Syaza I. Ahmad, Haslenda Hashim, Mimi H. Hassim. *Numerical Descriptive Inherent Safety Technique (NuDIST) for inherent safety assessment in petrochemical industry.*

This paper discusses the development of a new approach of inherent safety assessments called the Numerical Descriptive Inherent Safety Technique (NuDIST). Most current methods for assessing inherent safety use an index-based method. Among the disadvantages of such methods are the use of scaling in which hazards are divided into physical or chemical properties with subjective ranges and discontinuity at the sub-range boundaries. This new technique uses numerical assessment methods, can overcome the limitations inherent in the index-based methods and provides insights into the effect of safety parameters, i.e. temperature, pressure, heat of reaction, process inventory, flammability, explosiveness, toxicity and reactivity for the petrochemical industry. The results of the assessment can be used to easily identify the safest route among several alternatives for chemical synthesis or process retrofitting in addition to, highlighting potential sources of hazards. The proposed technique was tested using the methyl methacrylate manufacturing process. This test highlights the superiority of the Numerical Descriptive Inherent Safety Technique (NuDIST) over index-based methods. The results show that among the six routes of the MMA manufacturing process, the tertiary butyl alcohol (TBA) based route has the lowest total score and is considered the safest route, whereas the ethylene via propionaldehyde (C2/PA) based route has the highest score.

- **Keywords:** Safety assessment; Numerical method; Inherent safety; Petrochemical industry; Process screening; Subjective Scaling

Nathan J. Ramadhan, Yoke Kin Wan, Rex T.L. Ng, Denny K.S. Ng, Mimi H. Hassim, Kathleen B. Aviso, Raymond R. Tan. *Life cycle optimisation (LCO) of product systems with consideration of occupational fatalities.*

With the increasing pressures imposed upon industries on the environmental impacts of the manufacturing industry and chemical processes, numerous methodologies have been developed for the quantification, assessment and minimisation of waste and emissions. Meanwhile, methods for the simultaneous maximisation of economic performance within a product life cycle have also been developed. Similarly, various methodologies for screening of process alternatives based on the above factors have also been developed. However, the human lives put at risk in a supply chain constituting a life cycle tend to be overlooked as a factor of assessment, selection and optimisation of the process. Despite having life cycle assessment (LCA) methodologies for environmental assessment, no

methodology has been developed for the minimisation of work-related casualties due to the unpredictable nature of workplace accidents. To address this problem, this paper develops a multi-objective optimisation model that utilises realistic statistical data for estimating the best possible pathway. The model results in the least potential fatality directly involved within the product life cycle while simultaneously minimising operating costs throughout the entire life cycle. A case study involving the utilisation of palm-based biomass formed for the production of value-added green products in Malaysia is used to demonstrate the model.

- **Keywords:** Multi-objective optimisation; Occupational fatalities; Life cycle optimisation; Fuzzy optimisation

Kazuhiro Takeda, Takashi Hamaguchi, Naoki Kimura, Masaru Noda. *A design method of a plant alarm system for first alarm alternative signals using a modularized CE model.*

Management of a plant alarm system has been identified as one of the key safety issues because of disasters caused by alarm floods. When a chemical plant is at abnormal state, an alarm system must provide useful information to operators as the third layer of an independent protection layer (IPL). Therefore, a method of designing a plant alarm system is important for plant safety. Because the plant is maintained in the plant lifecycle, the alarm system for the plant should be properly managed through the plant lifecycle. To manage changes, the design rationales of the alarm system should be explained explicitly. This paper investigates a logical and systematic alarm system design method that explicitly explains the design rationales from know-why information for proper management of changes through the plant lifecycle. In the method, the module structure proposed by Hamaguchi et al. (2011) to assign a fault origin to be distinguished is extended. Using modules to investigate the sets of alarm sensors and the alarm limits setting for first alarm alternative signals to distinguish the fault origin, an alarm system design method is proposed. Also, the completeness of fault propagation for a branch of the cause–effect model as the plant model is explained. Using the modules and the set of fault origins to be distinguished by the alarm system, we try to explicitly explain the design rationales of the alarm system.

- **Keywords:** First alarm; Plant alarm system design; Cause–effect model; Alarm management; Plant alarm malfunction; Design rationales

K. Kidam, N.E. Hussin, O. Hassan, A. Ahmad, A. Johari, M. Hurme. *Accident prevention approach throughout process design life cycle.*

The accident rate in the chemical process industry (CPI) has not been decreasing although majority of accident causes have been identified and could have been prevented by using existing knowledge. These recurring accidents show that the existing knowledge has not been used effectively. In this paper, accident knowledge learned from earlier accident analyses are utilized to predict the common design errors during chemical plant design. An accident prevention approach throughout process design life cycle is proposed for a safer design consideration where designers are guided to identify common design errors, accident contributors and critical points to look for. The accident prevention approach has been applied to analyze the BP Texas City Refinery Explosion and Fire tragedy.

- **Keywords:** Accidents; Errors; Process design life cycle; Plant design; Loss prevention; Learning from accident

H.A. Aziz, A.M. Shariff, R. Rusli, K.H. Yew. *Managing process chemicals, technology and equipment information for pilot plant based on Process Safety Management standard.*

Injuries, accidents or even fatalities while working in pilot plant are reported worldwide. The OSHA Laboratory Standard and Hazard Communication Standard have been used as a guideline to manage safety of laboratories and pilot plant. In spite of the implementation of these standards, incidents which result in injuries and property loss are continuously occurring. The implementation of OSHA Process Safety Management (PSM) Standard in pilot plant is expected to further reduce the risks of accidents. This paper presents a new system for managing process chemicals, technology and equipment information in pilot plant and the concept is developed based on Process Safety Information (PSI) element of PSM 29 CFR 1910.119(d). It provides organized strategies to manage documentations, communicate information, and written program for maintaining, revising and updating related information. Process and Instrumentation Diagram (P&ID) is used as a foundation for data management. Implementation of this system at the CO₂ Hydrocarbon Absorption System pilot plant as a case study is examined and discussed.

- **Keywords:** Process safety information; Pilot plant; Process Safety Management; Hazardous chemicals; Process technology; Equipment information

Seungkyu Dan, Chang Jun Lee, Jeongpil Park, Dongil Shin, En Sup Yoon. *Quantitative risk analysis of fire and explosion on the top-side LNG-liquefaction process of LNG-FPSO.*

Since the massive use and production of fuel oil and natural gas, the excavating locations of buried energy-carrying material are moving further away from onshore, eventually requiring floating production systems like floating production, storage and offloading (FPSO). Among those platforms, LNG-FPSO will play a leading role to satisfy the global demands for the natural gas in near future; the LNG-FPSO system is designed to deal with all the LNG processing activities, near the gas field. However, even a single disaster on an offshore plant would put the whole business into danger. In this research, the risk of fire and explosion in the LNG-FPSO is assessed by quantitative risk analysis, including frequency and consequence analyses, focusing on the LNG liquefaction process (DMR cycle). The consequence analysis is modeled by using a popular analysis tool PHAST. To assess the risk of this system, 5 release model scenarios are set for the LNG and refrigerant leakages from valves, selected as the most probable scenarios causing fire and explosion. From the results, it is found that the introduction of additional protection methods to reduce the effect of fire and explosion under ALARP criteria is not required, and two cases of the selection of independent protection layers are recommended to meet the SIL level of failure rate for safer design and operation in the offshore environment.

- **Keywords:** LNG-FPSO; Quantitative risk analysis; Safety integrity level; Fire and explosion; LNG-Liquefaction system; PHAST

Jing-Huei Lin, Shao-Wen Wu, Chao-Yin Kuo. *Degradation of gaseous 1,2-dichloroethane using a hybrid cuprous oxide catalyst.*

A hybrid catalyst (CZ50) of cuprous oxide and zeolite was prepared and used in a catalytic system in which gaseous 1,2-dichloroethane (1,2-DCE) was degraded. The effects of relative humidity (15 and 65%) and wavelength of irradiation (ultraviolet, blue, green and red light) on the degradation of 1,2-DCE were studied. The experimental results reveal that the hybrid catalyst degraded the hazardous material under visible light. A comparison of the results obtained under ultraviolet and red irradiation at a

relative humidity of 15% revealed almost equal degradation efficiencies of 83.8 and 82.2%, respectively. In the system with hybrid catalysts, a lower relative humidity favored 1,2-DCE degradation, indicating that relative humidity critically affects the degradation of hazardous materials. The most important result was that the intermediates of the degradation of 1,2-DCE included ethane, carbon dioxide, and formic acid yielded, which are mostly harmless and non-toxic materials. The experimental results indicated that the method could effectively be used to degrade hazardous materials to provide a healthy and safe environment for workers.

- **Keywords:** Cuprous oxide; Degradation; Visible light; Hybrid catalyst; 1,2-Dichloroethane

Krishna Priya G.S., Santanu Bandyopadhyay, Raymond R. Tan. *Power system planning with emission constraints: Effects of CCS retrofitting.*

Today, the world's energy needs are still supplied mainly from fossil fuel based resources. This is true for electricity generation as well, thus making the power sector responsible for 45% of greenhouse gas emissions. The present climate crisis has made it necessary to minimise emissions in power generation, with low-carbon energy sources taking on greater significance in recent years. However, most low-carbon sources have inherent problems, like intermittency and high capital expenditure. A suitable alternative is carbon capture and storage (CCS) technology which allows continued fossil fuel-based electricity generation at much lower rates of emission. Two approaches are possible in the deployment of CCS technology. The first is to introduce new power plants equipped for carbon dioxide (CO₂) capture, while systematically shutting down existing coal power plants. Another is to retrofit existing power plants for CO₂ capture. These approaches are compared in this work. The study shows that allowing CCS retrofitting of existing power plants can reduce the overall cost requirement significantly. In addition, a sensitivity analysis is also done to study the effect of nuclear energy on the overall energy mix.

- **Keywords:** Emissions targeting; Power system planning; Carbon capture and storage (CCS); Optimisation; Indian energy sector; Cost minimization

Annamaria Vujanović, Lidija Čuček, Bojan Pahor, Zdravko Kravanja. *Multi-objective synthesis of a company's supply network by accounting for several environmental footprints.*

This contribution presents the multi-objective synthesis of a company's supply network by integrating renewables (biomass and other waste, and solar energy) and accounting for several environmental footprints. The synthesis is based on a Mixed-Integer Linear Programming (MILP) problem. A previously developed model by the authors for achieving energy self-sufficiency by integrating renewables into companies' supply networks has been extended for the evaluation of environmental impacts, such as energy, carbon, nitrogen, and water footprints. The achievement of an energy self-sufficient supply network has been considered whilst significantly reducing environmental impacts. The presented model is applied to multinational poultry-meat producing company. Direct (burdening) and indirect (unburdening) effects that form total effects on the environment are considered for the evaluation of environmental footprints. The results showed significant unburdening of the environment in terms of carbon and nitrogen footprints but, however, higher burdening in terms of the water footprint.

- **Keywords:** Multi-objective synthesis; Company's supply network; Renewables; Environmental impacts; Footprints; Total footprints

R.R. Tan, K.B. Aviso, A.P. Huelgas, M.A.B. Promentilla. *Fuzzy AHP approach to selection problems in process engineering involving quantitative and qualitative aspects.*

Selection problems are common in process engineering. In most cases, it is necessary to rank alternatives based on multiple criteria (e.g., cost, safety, environmental impact), which are often conflicting. In addition, some criteria may be fundamentally difficult to quantify due to data scarcity, in which case subjective assessments need to be used as a proxy. Decision analysis tools such as the analytic hierarchy process (AHP) are useful to ensure decision-making is done rationally. In this work, we propose a fuzzy AHP variant, wherein pairwise comparison of decision elements by domain experts is expressed with triangular fuzzy numbers. This approach allows the degree of confidence of the expert to be quantified explicitly; it also allows inconsistencies in judgment to be reconciled within the bounds of the fuzzy numbers to generate reasonable values for the weighting factors. We demonstrate the methodology on three case studies, involving the comparison of different types of chlor-alkali electrolytic cells, CO₂ capture techniques in cement plants and wastewater treatment options for municipal wastewater.

- **Keywords:** Decision analysis; Fuzzy AHP; Process safety; Electrolysis; CO₂ capture; Wastewater treatment

Mutahharah M. Mokhtar, Mimi H. Hassim, Rozainee M. Taib. *Health risk assessment of emissions from a coal-fired power plant using AERMOD modelling.*

Current electricity generation mix in Malaysia consists of 58% gas, 33% coal and 9% hydro. It is anticipated that by year 2019, the generation mix will be at 64% coal, 32% gas and 4% hydro. Due to the increase in coal consumption for power generation, there is a critical need to evaluate the health risks for the population living in the vicinity of a coal-fired power plant in Malaysia. To date, such study related to the plant in Malaysia has never been published. In this study, health risk assessment (HRA) for air emission from a coal-fired power plant in Malaysia was carried out. Two pollutants from the Proposed New Environmental Quality (Clean Air) Regulation 201X (Draft) (i.e. SO₂ and Hg) were assessed for non-carcinogenic health risk, and two trace elements (i.e. As and Cr) were assessed for carcinogenic health risk. Both short-term and long-term health effects were evaluated. Air dispersion modelling (AERMOD) was used to predict the ground level concentration (GLC) within 10 km radius of the emission source. Based on the HRA, different health risks were identified for short-term and long-term dispersion of the studied pollutants. The findings indicate that a detailed assessment on the short-term and long-term health effects of the emissions from coal-fired power plant in Malaysia with meteorological factor as one of the significant factors influencing the emissions level is needed.

- **Keywords:** Health risk assessment; AERMOD; Coal-fired power plant; Emission; Malaysia