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Selvakumar P., Sivashanmugam P. *Multi-hydrolytic biocatalyst from organic solid waste and its application in municipal waste activated sludge pre-treatment towards energy recovery*. Pages 1-10.

Commercially valuable biomolecules could be produced using enormous quantities of organic solid waste (OSW) generated from agricultural and food processing industries due to their nutrient-rich organic composition. In this study, a multi-hydrolytic biocatalyst (MHB) was produced from OSW by optimizing the composition, ultrasonic pre-treatment, and parameters for anaerobic digestion. RSM was used to design the experiments for optimization of anaerobic digestion parameters. Optimum experimental conditions for MHB production which yielded maximum protease, amylase and lipase activities. The experimental results were validated using RSM and ANN modeling for accuracy. The kinetic parameters and the influence of pH and temperature on the activity and stability of the partially purified enzyme were also evaluated. To investigate the multi-activity and practical applicability of MHB, it was used for pre-treatment of municipal waste activated sludge (MWAS) because the sludge contains different complex organic molecules and this pre-treatment would help to improve the usability of the huge quantity of sludge for industrial purpose. The enzymatic pre-treatment of the sludge at optimized conditions yielded SS reduction (29.2%), an increase of sCOD (32%), sProtein (53.57%) and sCarbohydrate (76.71%). Thus, a potential low-cost multi-purpose biocatalyst could be efficiently produced from OSW and used for the enhanced treatment of MWAS.

- **Keywords:** Organic solid waste; Optimization; Anaerobic digestion; Multi-hydrolytic biocatalyst; Enzymatic sludge hydrolysis

Om Prakash, Alka Mungray, Suresh Kumar Kailasa, Shobhana Chongdar, Arvind Kumar Mungray. *Comparison of different electrode materials and modification for power enhancement in benthic microbial fuel cells (BMFCs)*. Pages 11-21.

Modification of electrode material from the environmental point of view and scale-up is as important as increasing the power density in benthic microbial fuel cells (BMFC). Here, we examined two different materials for an anode and their modification via surface treatment and surface coating. Polyaniline incorporated carbon cloth (PANI/CC), acid-treated carbon cloth (CC), grooved and acid treated graphite plate (GGP), and polyaniline coated graphite plate (PANI/GP) are used in this study. Modified anodes were compared through electrochemical techniques. It was observed that kinetic activity of PANI/CC was

376 times higher than CC anode, while PANI/GP possesses 1.8 times more kinetic activity than GGP. Power density was recorded and observed decreasing order as follows PANI/CC>CC>PANI/GP>GGP. A mechanism of electron transport model is proposed based on the structural properties of polyaniline coated carbon nanocomposites that enhances the electron flow efficiently for the generation of power with high degree. Polyaniline coated anode materials show greater wettability than their respective surface treated counterparts. Further enhancement in power generation was successfully achieved by recharging with acetate. The study tried to compare the different material and their modifications in the same environment and helps to optimize the system further based on the results obtained.

- **Keywords:** Surface coating; Anode modification; Polyaniline; Surface treatment; Electrochemistry; Power enhancement

Mohamed Mahmoud, Sherif Ismail, Ahmed Tawfik. *Post-treatment of anaerobic effluent containing 1,4-dioxane and heavy metals via auto-aerated down-flow hanging luffa (ADHL) system*. Pages 22-32.

Biodegradation of anaerobic effluent containing 1,4-dioxane and heavy metals via auto-aerated down-flow hanging luffa (ADHL) system was extensively investigated. The oxygen was naturally supplied to the consortium bacterium through windows located along the reactor height creating favorable aerobic conditions. The bioreactor efficiently removed 1,4-dioxane and total chemical oxygen demand (CODt) from anaerobic effluent without significant inhibitory effects. Removal efficiencies of CODt and 1,4-dioxane were significantly increased from 31.3±10 to 59.5±5.9% and from 43.7±11.9 to 90±4.9% at increasing the hydraulic retention time (HRT) from 5.7 to 17.3h, respectively. Moreover, ADHL system was very effective for removal of heavy metals (Cr6+, Cu2+, Fe3+, Mn2+, Ni2+) where the extracellular polymeric substances (EPS) concentrations were quite high and amounted to 12.3±1.3g/g biomass at an HRT of 17.3h. The nitrification efficiency was 3.0, 46.8 and 56.3% at HRTs of 5.7, 11.5 and 17.3h, respectively. Batch experimental results showed that the key removal mechanism of 1,4-dioxane was adsorption followed by biodegradation process.

- **Keywords:** Anaerobic effluent; Post-treatment; 1,4-dioxane; Auto-aerated down-flow hanging luffa; Heavy metals

Quelen Letícia Shimabuku, Tânia Ueda-Nakamura, Rosangela Bergamasco, Márcia Regina Fagundes-Klen. *Chick-Watson kinetics of virus inactivation with granular activated carbon modified with silver nanoparticles and/or copper oxide*. Pages 33-42.

This study aimed at analyzing the effect of silver nanoparticles (NP-Ag), copper oxide (NP-CuO) and silver and copper oxide (NP-Ag-CuO) concentrations, when impregnated with granular activated carbon (GAC), on viral inactivation. Bacteriophage T4 was used as virus indicator model and the experiments were carried out in batch mode under the controlled conditions of 25°C and pH 7. Experimental data were represented by the kinetic equation of Chick-Watson. The results indicated a significant increase in virus inactivation and in the rate constant after the incorporation of nanoparticles on the GAC surface. Virus inactivation and rate constants were greater for the samples in which the synergistic effect of silver and copper oxide nanoparticles (NP-Ag-CuO) had occurred. From these results, it is possible to conclude that granular activated carbon, modified with NP-Ag-CuO (GAC/NP6), is a potential absorbent for application in virus inactivation over short contact times. The development of nanomaterials can be applied to water treatment processes as an alternative disinfection method.

- **Keywords:** Inactivation kinetics; Virus; Nanoparticles; Silver; Copper oxide

Gökhan Balcıoğlu, Z. Beril Gönder. *Baker's yeast wastewater advanced treatment using ozonation and membrane process for irrigation reuse*. Pages 43-50.

This study focused on the advanced treatment of biologically treated baker's yeast wastewater for the purpose of irrigation reuse. The effects of pH (3, 7.5, 9, 11) and temperature (25°C, 35°C, 45°C) on the removal efficiencies were investigated for ozonation process. Ozone utilization rates were determined at different pH and temperature levels. There were not significant changes in pollutant removal efficiencies at the temperature of 25°C–45°C for ozonation process. 96–98% color, 56% COD, 67% UV254, 10% conductivity, 33% chloride, and 29% total hardness removals were obtained with ozonation process at pH 7.5 and 25°C. NF 90 and BW 30 membranes were used to improve the quality of treated wastewater. Relatively lower flux decline caused from membrane fouling (18%) was occurred for BW 30 membrane. Although higher permeate qualities were achieved with both membranes, the chloride and conductivity values as 35mg/L and 530μs/cm were relatively lower for BW 30 permeate. As a result, the treated wastewater using ozonation and membrane process met the quality of class B regarding pH, biological oxygen demand (BOD5), suspended solids (SS) and fecal coliform parameters. Also, II. class irrigation water was obtained considering SAR parameter for degree of restriction on irrigation use.

- **Keywords:** Baker's yeast wastewater; Ozonation; Nanofiltration; Reverse osmosis; Agricultural irrigation

Hosein Alidadi, Maryam Dolatabadi, Mojtaba Davoudi, Fateme Barjasteh-Askari, Farideh Jamali-Behnam, Ahmad Hosseinzadeh. *Enhanced removal of tetracycline using modified sawdust: Optimization, isotherm, kinetics, and regeneration studies*. Pages 51-60.

Removal of antibiotics from aqueous environments is of great importance because of their potential adverse effects on living organisms and enhancement of bacterial resistance. The present study deals with tetracycline (TC) removal using sawdust modified with different agents (CaCl2, NaHCO3, HCl, and FeCl3) as a function of TC concentration (5.0–25.0mgL−1), solution pH (3.0–12.0), adsorbent dose (1.0–5.0gL−1), and contact time (15.0–120.0min). Fourier Transform Infrared Spectroscopy and Scanning Electron Microscopy were employed to determine the characteristics of the adsorbent. The results showed that modification with FeCl3 was the most efficient way to increase adsorptive properties of sawdust. Optimization showed the highest removal efficiency is obtained as 98.40% at initial TC concentration 12.5mgL−1, pH 7.9, adsorbent dose=4.8gL−1, and contact time 118.3min. The Fe-modified adsorbent could reduce TC in real hospital wastewater from 0.25mgL−1 to levels not detectable by HPLC. The equilibrium data for TC adsorption were better fitted to the Freundlich model (R2=0.9891), while both models of pseudo-first-order and pseudo-second-order could well describe the kinetics of adsorption (AIC values of −18.74 and −18.32, respectively). Finally, an extensive experiment was conducted to determine single-stage regeneration of used adsorbent, showing that among 10 different regenerating solutions, distilled water (pH=4.0) and methanol demonstrated the best results with nearly 88% reclamation of water. Based on the results, Fe-modified sawdust could be an efficient adsorbent for TC removal from aqueous solutions, even from real wastewater.

- **Keywords:** Adsorption; Antibiotics removal; Modification; Regeneration; Sawdust; Tetracycline

Terry Engelder, John F. Zevenbergen. *Analysis of a gas explosion in Dimock PA (USA) during fracking operations in the Marcellus gas shale*. Pages 61-66.

On January 1, 2009, a concrete slab covering a water-pump vault of a water well 400m north of a Marcellus gas well in Dimock, Pennsylvania, USA was reported to have split into three pieces while being overturned. It was suggested that the cycling on of a water pump sparked the deflagration of a methane-air mixture causing the slab to overturn. Here, the conditions necessary to generate an explosion consistent with evidence, mainly a split and overturned concrete slab unmarked by soot or other evidence of a flame, are analyzed. Using more than one approach, calculations show that the maximum pressure to lift the concrete slab was roughly 0.3bar. Considering among others the flammable range of methane, the explosion pressure as a function of equivalence ratio, the presence of methane gradients inside the vault, the absence of soot and possible ignition sources, the analysis did not yield a well-defined, credible gas explosion scenario to explain the observed damage, although the possibility cannot be ruled out with absolute certainty.

- **Keywords:** Methane explosion; Deflagration; Fracking; Dimock; Explosion

Marzieh Bagheri, Ramin Roshandel, Jalal Shayegan. *Optimal selection of an integrated produced water treatment system in the upstream of oil industry*. Pages 67-81.

Produced water (PW), water extracted along with oil, can cause important environmental challenges due to its high volume and salinity and is considered a key factor in the economic exploitation of oil fields. Therefore, making use of a cost-effective integrated system of wastewater treatment is a fundamental requirement in oil and gas industries. In this paper, the integrated PW treatment system is presented using superstructure-based mathematical optimisation methodology which is aimed at minimising the total annual cost. Two distinct scenarios of injection and reuse in industrial scale are considered to propose an efficient and optimal integrated system. The results show that, despite the emergence of new technologies, the traditional ones such as gravity separation, hydrocyclone, and media filters, with a cost of $0.509 per cubic meter, are selected as the optimum solution for treating PW for injection purpose. Because of the poor quality of PW in Iran, reuse options are limited, and the efficient available technologies are few. Mechanical Vapor Compression (MVC) and Multi Effective Desalination (MED) technologies are investigated as two desalination options. According to the findings, a treatment system composed of MVC with appropriate pretreatment is capable of recovering 50% of the PW, which is the optimal water recycling option with a total treatment cost of 3.808$/m3. In cases of increasing the volume of PW with time, it is concluded that utilising advanced treatment system to recover a part of PW, decreases the annual cost up to 20% in comparison with the case which increases the PW injection capacity. This can be considered as a more viable management strategy for PW management in future.

- **Keywords:** Produced water treatment; Superstructure-based optimisation; Hypersaline wastewater desalination; Produced water management; Upstream of oil industry

Lixin Qian, Tiejun Chun, Hongming Long, Jiaxin Li, Zhanxia Di, Qingmin Meng, Ping Wang. *Emission reduction research and development of PCDD/Fs in the iron ore sintering*. Pages 82-91.

Iron ore sintering process is an important sector for iron and steel industry as well as a major pollution emission source of PCDD/Fs. The PCDD/Fs emission of sintering process has not been properly controlled because the flue gas presents the following characteristics, including large amount, remarkable flow fluctuations and lower concentration. The generation mechanism of PCDD/Fs in the iron ore sintering was discussed systematically and the new developments and technologies of PCDD/Fs emission reduction were also summarized from the source, process and the end treatments. Commonly, the PCDD/Fs formed in drying and preheating zone is transferred

to the lower part of the material layer which is a chemical transfer process in the iron ore sintering. Finally, the potential future development of PCDD/Fs emission reduction in the iron ore sintering was also pointed out.

- **Keywords:** Iron ore sintering; PCDD/Fs; Generation mechanism; Emission reduction

Hui Min Tan, Darwin Gouwanda, Phaik Eong Poh. *Adaptive neural-fuzzy inference system vs. anaerobic digestion model No.1 for performance prediction of thermophilic anaerobic digestion of palm oil mill effluent*. Pages 92-99.

Palm oil industry generates high volume of palm oil mill effluent (POME) albeit contributing significantly to the economy of several ASEAN countries. This necessitates effective waste management methods Thermophilic high-rate anaerobic reactor accompanied by an accurate model to define and to predict the process performance can be a promising solution for POME treatment. Various mechanistic and meta-heuristic models had been developed, but not specifically designed for thermophilic anaerobic digestion of POME. This study explores the possibility of using ADM1 for estimating the performance of a thermophilic anaerobic reactor for POME treatment and compares it to Adaptive Neural-Fuzzy Inference System (ANFIS) model. A total of six prediction models were developed using ADM1 and ANFIS to estimate effluent pH, COD (Chemical Oxygen Demand), Total Suspended Solids (TSS) and methane composition. Results indicated that all ANFIS models were better than ADM1 models, with difference in the average error of up to 6.81%. However, ADM1 is more suited for better understanding of overall reaction of the system particularly via sensitivity analysis performed on the models.

- **Keywords:** Palm oil mill effluent; Anaerobic digestion; Thermophilic; Adaptive neural-fuzzy inference system; ADM1

Nilesh Ade, Guanlan Liu, Ahmad F. Al-Douri, Mahmoud M. El-Halwagi, M. Sam Mannan. *Investigating the effect of inherent safety principles on system reliability in process design*. Pages 100-110.

During the last decade, inherent safety has emerged as an area of interest in both academic and industrial research. Various regulatory bodies have enforced the consideration of inherently safer design alternatives. This enforcement, however, may not serve the purpose of reducing the risk associated with process incidents due to the drawback of risk migration associated with inherent design philosophy. The philosophy of inherent safety has emerged from the need to reduce the consequence element of risk with an objective to prevent high consequence–low likelihood events. Thus, this philosophy is plagued with the drawback of risk migration where the lowering of consequence element can lead to an undesired increased likelihood element, leading to an overall increase in risk associated with the system. The likelihood element of risk of the system under consideration depends on the system reliability. The developed methodology involves quantifying inherent safety based on the design stage under consideration using a quantification technique that utilizes process data available during the specific stage of design. This is followed by determining reliability and availability of the system using reliability databases or static reliability modeling for various design alternatives considered during the specific design stage. Lastly, the trend observed between quantified inherent safety and reliability/availability is used to determine the required relationship between inherent safety and reliability. Thus, this developed methodology evaluates the possibility of increased risk due to lowered system reliability caused by the implementation of inherent design philosophy.

- **Keywords:** Inherent safety; Reliability; Process design; Risk; Availability; Maintenance-downtime

Gona Hasani, Hiua Daraei, Behzad Shahmoradi, Fardin Gharibi, Afshin Maleki, Kaan Yetilmezsoy, Gordon McKay. *A novel ANN approach for modeling of alternating pulse current electrocoagulation-flotation (APC-ECF) process: Humic acid removal from aqueous media*. Pages 111-124.

Abstract: A novel application of artificial neural networks (ANN) combined with Taguchi orthogonal experimental design methodology (27 runs, 3 levels, 6 factors) was introduced for modeling and optimization of a new alternating pulse current electrocoagulation-flotation (APC-ECF) process for the removal of humic acid (HA) from aqueous media. Two different ANN architectures, such as multilayer perceptron (MLP NN) and generalized feed forward (GFF NN), were proposed and trained to describe the nonlinear behavior of a laboratory-scale batch APC-ECF reactor. Various operating parameters, such as initial HA concentration (C0), initial pH (pH0), electrical conductivity (EC0), current density (CD), and number of pulses (Npls), were used as inputs for the proposed networks, and the HA removal was selected as the output. According to the goodness-of-fit criteria, the computational results showed that the single hidden-layered GFF NN (5:6:1), where a sigmoid axon transfer function was used at its hidden layer and its output layer was trained by the Levenberg–Marquardt algorithm, showed the best performance (R2=0.999, MSE=0.00006). For the optimal conditions of C0=42mg/L, pH0=6.63, CD=24.3A/m2, EC0=856μS/cm, and Npls=3, the maximum HA removal was obtained based on the predicted outputs of the best ANN model (GFF NN). The results of the computational analysis clearly corroborated that ANN integrated design of experiments (DOE)-based modeling was rapidly and effectively used for predicting the optimum performance of a complex electrochemical process in removal of HA from water using aluminum electrodes in monopolar arrangement.

- **Keywords:** Artificial neural network; Design of experiments; Electrocoagulation-flotation; Humic acid

Sankhadeep Basu, Gourab Ghosh, Sudeshna Saha. *Adsorption characteristics of phosphoric acid induced activation of bio-carbon: Equilibrium, kinetics, thermodynamics and batch adsorber design*. Pages 125-142.

Activated carbon from Sterculia foetida was prepared using phosphoric acid as activating agent for efficient removal of methylene blue (MB). The effect of different operational parameters like pH (2–12), loading (1–4g/l), initial dye concentration (50–500ppm), temperature (298–328K), and contact time (0–24h) were investigated for the adsorption of MB. Langmuir, Freundlich, Temkin and Dubinin–Radushkevich models were used to analyse the equilibrium data. The Langmuir model fitted well with maximum monolayer adsorption capacity of 181.81mg/g. Adsorption kinetics followed pseudo-second order kinetic model. The adsorption process was found to be governed both by intra-particle and film diffusion. Thermodynamic parameters like entropy, enthalpy, and Gibb's free energy were also evaluated. It was found that the adsorption was spontaneous, endothermic and physisorption in nature. The liquid phase volumetric mass transfer coefficient was found to decrease from 1.03min−1 to 0.088min−1 with increase in initial concentration from 50ppm to 300ppm. A single-stage batch adsorber design for dye adsorption has been proposed based on the Langmuir isotherm model equation. The reusability study demonstrated that the prepared adsorbent could effectively be used up to 5 cycles without regeneration. The study showed that the activated carbon prepared from Sterculia foetida can be effectively used as an adsorbent for methylene blue removal from aqueous solutions.

- **Keywords:** Adsorption; Methylene blue; Activated carbon; Sterculia foetida; Isotherm; Film diffusion; Batch adsorber

Eleonora Carota, Silvia Crognale, Alessandro D'Annibale, Maurizio Petruccioli. *Bioconversion of agro-industrial waste into microbial oils by filamentous fungi.* Pages 143-151.

Abstract: Microbial oils are regarded as a sustainable alternative to vegetable oils for biodiesel manufacturing. However, in order to develop a cost-effective process, high-lipid producer microorganisms should be combined with low-cost renewable growth substrates. For this reason, the objective of the present study was to assess comparatively the oil-producing performance of 9 oleaginous fungi belonging to the Aspergillus, Mucor, Mortierella and Cunninghamella genera on three relevant and widespread waste, such as glycerol, orange peel extract (OPE) and ricotta cheese whey (RCW). This screening was performed at the shaken flask level and, among the strains under study, Mortierella isabellina NRRL 1757 turned out to be the most efficient and versatile and its lipid profile was found to be highly compatible with biodiesel production. Process transfer of M. isabellina lipid production to the lab-scale Stirred Tank Reactor on all the three waste-based media, was shown to be feasible, achieving a lipid productivity of 0.46, 1.24 and 0.91g/(Ld) on glycerol, OPE and RCW, respectively. Noteworthy, the fatty acid analysis of the oils produced, confirmed their suitability for biodiesel manufacturing, exhibiting a high similarity to palm and Jatropha oils commonly used as feedstock for this production.

- **Keywords:** Mortierella isabellina; Biodiesel; Agro-industrial waste; Filamentous fungi; Bioreactor

Carla Denize Venzke, Alexandre Giacobbo, Jane Zoppas Ferreira, Andréa Moura Bernardes, Marco Antônio Siqueira Rodrigues. *Increasing water recovery rate of membrane hybrid process on the petrochemical wastewater treatment*. Pages 152-158.

The objective of this work is to increase the recovery of water through a Reverse Osmosis+Electrodialysis Reversal (RO-EDR) hybrid process, where the EDR is used to recover water from the reject produced by the RO technology. The wastewater used in the experiments was collected in a petrochemical industry, located in southern Brazil, after conventional treatment (biological and stabilization ponds). The RO tests were carried out in a pilot equipment, having a spiral membrane module, with a membrane area of 7.2m2. For the EDR tests, it was used a pilot equipment, with 300 ion-selective membranes, with a total membrane area of 28.8m2. The results show that the application of EDR technology was adequate for the treatment of the RO reject, obtaining a removal efficiency above 90% for chlorides and alkalinity. The recovered water comply with standards for reuse in cooling towers. In addition, the full recovery of the treated water was satisfactory, reaching a recovery rate of 87.3%, turning the EDR-RO hybrid process as a prominent one.

- **Keywords:** Hybrid process; Reverse osmosis; Electrodialysis Reversal; Pretrochemical wastewater; Water reuse

R.J. Lee, Z.A. Jawad, A.L. Ahmad, H.B. Chua. *Incorporation of functionalized multi-walled carbon nanotubes (MWCNTs) into cellulose acetate butyrate (CAB) polymeric matrix to improve the CO2/N2 separation*. Pages 159-167.

Membrane-based technology has received much attention in the past decades due to attractive features offered. Through significant breakthroughs of this technology, the mixed matrix membrane (MMM) has demonstrated a promising carbon dioxide (CO2)/nitrogen (N2) separation performance. Among the polymer materials used, cellulose acetate butyrate (CAB) polymer was selected due to its outstanding

characteristics, which subsequently could improve the CO2 sorption ability. In this study, MMM was prepared by incorporating the functionalised multi-walled carbon nanotubes (MWCNTs-F) as inorganic material into the CAB polymer matrix (MMM-4F). The CAB membrane (CAB-M) was also synthesised under similar fabrication parameters via the phase-inversion method to determine the CO2/N2 separation performance. The gas permeation results showed that the CO2/N2 separation performance increased dramatically from 6.12±0.09 to 11.00±1.92 when 4wt% of MWCNTs-F was incorporated into the CAB polymer matrix. The increase in CO2 permeance within the MMM was due to the embedded MWCNTs-F within the CAB polymer matrix. In this study, the new synthesised MMM proved to possess excellent CO2/N2 separation performance. However, it could further be improved by manipulating the amount of MWCNTs-F incorporated into the CAB polymer matrix. This is suitable for the gas separation field.

- **Keywords:** Cellulose acetate butyrate; Mixed matrix membrane (MMM); Gas separation; Membrane technology; Multi-walled carbon nanotubes

Sunil Luthra, Sachin Kumar Mangla. *Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies*. Pages 168-179.

Industry 4.0 initiatives can influence whole business system via transforming the means the products are designed, produced, delivered and discarded. Industry 4.0 is relatively novel to developing nations, especially in India and needs a clear definition for proper understanding and practice in business. This paper aims to recognize key challenges to Industry 4.0 initiatives and analyze the identified key challenges to prioritize them for effective Industry 4.0 concepts for supply chain sustainability in emerging economies by taking Indian manufacturing industry perspective. Industry 4.0 initiatives can help industries to incorporate environmental protection and control initiatives as well as process safety measures in supply chains towards sustainable supply chains. However, adoption of Industry 4.0 initiatives is not so easy due to existence of many challenges. Therefore, the present research identifies 18 key challenges to Industry 4.0 initiatives for developing supply chain sustainability using an extensive literature review. These challenges were analyzed through 96 responses received from Indian manufacturing sector using a questionnaire based survey. Explanatory Factor Analysis results classified identified challenges into four key dimensions of challenges. Analytical Hierarchy Process further ranks the identified dimensions of challenges and related challenges. Findings of the study revealed that Organizational challenges holds the highest importance followed by Technological challenges, Strategic challenges, and Legal and ethical issues. This work is very useful for practitioners, policy makers, regulatory bodies and managers to develop an in-depth understanding of Industry 4.0 initiatives and eradicate the potential challenges in adopting Industry 4.0 initiatives for supply chain sustainability.

- **Keywords:** Industry 4.0 challenges; Supply chain management; Sustainability; Analytical Hierarchy Process (AHP); Explanatory Factor Analysis (EFA); Emerging economies

Mohammed Haji Alhaji, Khairuddin Sanaullah, Shanti Faridah Salleh, Rubiyah Baini, Soh Fong Lim, Andrew Ragai Henry Rigit, Khairul Anwar Mohamad Said, Afrasyab Khan. *Photo-oxidation of pre-treated palm oil mill Effluent using cylindrical column immobilized photoreactor*. Pages 180-189.

Photooxidative degradation of pre-treated Palm oil mill effluent for removal of chemical oxygen demand, biological oxygen demand and color by UV/TiO2 system has been investigated in a cylindrical glass photoreactor whose outer surface has been coated with titanium dioxide whereas the UV source has been placed inside the glass tube. The

removal of these pollutants indicators has been found to follow pseudo-first-order kinetics and hence the electrical energy per order (EEO) figure-of-merit is used to calculate approximately the electrical energy efficiency of the advanced oxidation process system. The higher dissolved oxygen (10mg/L), lower initial concentration (6mg/L) and acidic medium (pH=3) have been found favorable to the photocatalytic degradation of palm oil mill effluent.

- **Keywords:** Kinetic studies; Organic pollutant indicators; Palm oil mill effluent; Photodegradation; Titanium dioxide

Maria Mitu, Elisabeth Brandes, Werner Hirsch. *Mitigation effects on the explosion safety characteristic data of ethanol/air mixtures in closed vessel*. Pages 190-199.

This paper presents new results of an experimental study on the explosion characteristics: the explosion pressure, the rate of pressure rise (or the deflagration index), the explosion delay time and the laminar burning velocity for ethanol/air mixtures with ethanol concentrations between 3.5vol% and 20.0vol% in the presence of various diluents (nitrogen, exhaust gas, water and carbon dioxide with dilution concentrations from 0vol% to 20vol%), at various initial pressures from 0.25bar to 1.0bar and at an initial temperature of 373K. The influence of the diluent type and amount on the explosion characteristics is examined together with the influence of the initial pressure. The effectiveness of the diluent gases examined varies from least effective to most effective in the following order: N2, exhaust gas, H2O, CO2. The reported data in this paper (the explosion characteristics and the laminar burning velocity) of ethanol-air mixtures in the presence of various diluents are important safety parameters, useful for design of active protection devices and for safety recommendations.

- **Keywords:** Ethanol; Additive/inert; Explosion; Safety characteristic data; Burning velocity

Hamed Mohammadi, Bijan Bina, Afshin Ebrahimi. *A novel three-dimensional electro-Fenton system and its application for degradation of anti-inflammatory pharmaceuticals: Modeling and degradation pathways*. Pages 200-213.

A novel three-dimensional electro-Fenton (3D EF) system with iron- coated nickel foam particles (NFP-Fe) and bare nickel foam as catalytic particle electrodes (CPEs) was employed in this study. Its application in degrading ibuprofen (IBP) and naproxen (NPX), two widely-used nonsteroidal anti-inflammatory drugs (NSAIDs), exhibited high catalytic efficiency in a near-neutral pH. Response surface methodology (RSM) was applied to assess the individual and interaction effects of several operating variables (pH, reaction time, concentrations of target compounds and current density) on the IBP and NPX removal efficiencies and energy consumption (EC). Based on the analysis of variance (ANOVA), the coefficient of determination (R2) was calculated and found to be above 99.4% for all the responses. The maximum IBP and NPX removal efficiencies were found to be 98.14% and 93.5% under the optimum conditions, respectively. After 60min of treatment at a current density of 15mA/cm2 and pH 3–6, EC of 3D EF (168.6 and 112.19kWh/kgCOD) was much lower than (two-dimensional) 2D EF (360.18–909.20kWh/kgCOD). The kinetics analysis showed that the abatement of COD in both systems followed apparent pseudo first-order reaction. Furthermore, based on the major reaction intermediates were identified by a novel DLLME/GC/MS and the results of previous studies, the possible degradation pathway was proposed. The aforementioned results highlighted 3D EF as a promising alternative method for the remediation of aqueous solutions contaminated with NSAIDs.

- **Keywords:** Three-dimensional electro-Fenton (3D EF); Iron- coated nickel foam (NFP-Fe); Ibuprofen; Naproxen; Degradation pathway

Mourad Chebila. *Simultaneous evaluation of safety integrity's performance indicators with a generalized implementation of common cause failures*. Pages 214-222.

The average unavailability and the average unconditional failure intensity of safety-instrumented systems represent the main performance indicators of safety integrity. This paper employs an approach based on the exploitation of the availability expression to obtain both performance measures in a simultaneous and straightforward way for any KooN configuration. The implementation of such an approach is generalized to take into account the contribution of common cause failures using any parametric model. The validation of the obtained results is verified through their application using several architectures and using Beta Factor and Binomial Failure Rate models to handle such type of dependent events. Therefore, the contribution of this paper lies in proposing one single formula that can be used to estimate the two main safety integrity's performance indicators for any KooN architecture using any kind of common cause failures parametric model.

- **Keywords:** Availability; Unconditional failure intensity; Common cause failures; KooN:G architectures

Jie Yang, Yuxing Li, Jianlu Zhu, Hui Han. *Quantitative study of the factors of LNG liquid foam stability: Operating parameters and collection containers and time*. Pages 223-231.

Liquefied natural gas (LNG) is an increasingly used fuel; thus, the study of the safety of LNG requires attention. Stable LNG foams are expected to mitigate the hazards of LNG effectively. However, the effects of three factors on the foam stability have been neglected, including the operating parameters of the foam generator, the collection containers, and the time. This study reveals the effects of the operating parameters on the deviation of stability caused by the collection container and time, which have been quantitatively studied using 336 parameters and Taguchi analysis. We found that the collection container and time influence the foam stability and cannot be ignored. The relative deviation in the stability caused by changes in the collection time can be up to 40%. In particular, the collection container affects the collapse function. Based on the effect of the operating parameters on the stability at different time, the foam stability is likely controlled throughout the whole production run. The matching of the quantity of solution on the screen with the air volume is essential to improve the foam stability.

- **Keywords:** Foam stability; Quantitative study; Operating parameters; Collecting container; Collecting time

Swagat S. Rath, Danda Srinivas Rao, Sunil Kumar Tripathy, Surendra K. Biswal. *Characterization vis-á-vis utilization of blast furnace flue dust in the roast reduction of banded iron ore*. Pages 232-244.

The present study explores the process of simultaneous roast-reduction and magnetic separation of blast furnace flue dust (BFD) and a low grade banded iron ore without using any extra reductant. The optical microscopic studies on the BFD sample revealed the presence of hematite, magnetite, silicates and unburnt carbon while the elemental mapping using Electron Probe Micro Analysis (EPMA) indicated the close association of silicates with Ca, K and Na bearing phases. The studies using the Scanning Electron Microscopy coupled with an Energy Dispersive X-ray Spectroscope (SEM-EDS) confirmed the presence of carbon both as an individual entity and in association with other phases

as carbonates. The iron ore used was banded in nature and mostly consisted of hematite and quartz. Under statistically optimized conditions such as temperature: 850°C, time: 90min and BFD to ore ratio: 0.4, the process of reduction roasting followed by low intensity magnetic separation (LIMS) could yield an iron ore concentrate of ~63% Fe at an iron recovery of ~68% from the BFD with 32% Fe and banded iron ore with 47.2% Fe. Similar results were also obtained using the same BFD to ore ratio for a roasting temperature of 950°C and a time period of 30min. The products roasted at a high temperature of 1050°C or at a temperature of 950°C with a higher residence time of 120min showed poor iron recovery and high grade in the LIMS magnetic fraction, which was attributed to the formation of feebly magnetic phases like wustite and fayalite.

- **Keywords:** Reduction roasting; Blast furnace flue dust; Banded iron ore; EPMA; SEM-EDS

M.A. Martín, R. Fernández, M.C. Gutiérrez, J.A. Siles. *Thermophilic anaerobic digestion of pre-treated orange peel: Modelling of methane production*. Pages 245-253.

The valorisation of waste generated during orange juice manufacturing (OPW) by anaerobic digestion is gaining attention due to the several economic, social and environmental advantages of the process. Given that anaerobic digestion is a process that requires rigorous control to improve the biodegradability of the waste and methane production, this paper highlights the importance of modelling for adequate process monitoring. Specifically, this study fitted three sigmoidal models (Logistic, Gompertz, and Sigmoid models) to methane production from OPW. At laboratory scale, two thermophilic continuously stirred-tank reactors working in semi-continuous mode was used. d-limonene removal of 70% was previously reached by applying a pre-treatment on OPW. The results showed a biodegradability of the pre-treated waste of up to 96.7% in COD. The Logistic, Gompertz and Sigmoid models fitted adequately to cumulative methane production (R2 was 0.9691; 0.9492 and 0.9511, respectively). However, the Logistic model showed the best fit to the experimental data even under critical conditions. Specifically, the Logistic model predicted the maximum methane production rate within loads of 2.5–5.0g COD/L. Therefore, this model might be very useful in predicting the maximum methane production rate and the maximum load that could be added without the inhibition of anaerobic digestion at real scale.

- **Keywords:** d-Limonene; Anaerobic digestion; Modelling; Sigmoidal models; Methane generation

Bing Wang, Chao Wu, Lang Huang, Laobing Zhang, Liangguo Kang, Kaixin Gao. *Prevention and control of major accidents (MAs) and particularly serious accidents (PSAs) in the industrial domain in China: Current status, recent efforts and future prospects*. Pages 254-266.

China has been experiencing dynamic industrialization because of rapid economic growth. Even with steady industrial safety improvements in recent years in China, the death rate per accident is increasing, and major accidents (MAs) as well as particularly serious accidents (PSAs) are still occurring every year. Evidently, the risk of industrial accidents, especially of MAs and PSAs is still high. Moreover, China has entered a bottleneck period for the prevention and control of MAs and PSAs. In a word, MAs and PSAs have become a significant challenge for China's industrial, social, and economic development. In recent years, especially since 2016, great attention of the Chinese government has been given to the prevention and control of MAs and PSAs. China launched its nationwide safety campaigns for firmly curbing MAs and PSAs. Some potentially effective measures and strategies in a series of safety policy documents (e.g., the 'Guidelines for Comprehensively and Resolutely Curbing MAs and PSAs' and the 'Thirteenth-Five-Year

Plan for Work Safety') were also proposed, to reduce MAs and PSAs. Firstly, this paper makes a statistical analysis of China's MAs and PSAs between the year of 2002 and 2016 to figure out the current status of MAs and PSAs in China. Then this article reviews some latest major events of the prevention and control of MAs and PSAs in China to introduce the recent efforts in the prevention and control of MAs and PSAs in China. Finally, according to a series of safety policy documents in China, and the scientific research literature from other countries, this study gives a brief introduction to the future prospects of the prevention and control of MAs and PSAs in China. Obviously, this study can provide useful evidence and suggestions for the future prevention and control of MAs and PSAs both within China and in other countries.

- **Keywords:** Major accidents (MAs); Particularly serious accidents (PSAs); Prevention and control; Industrial safety; China

Sama Azadi, Ayoub Karimi-Jashni, Sirus Javadpour. *Modeling and optimization of photocatalytic treatment of landfill leachate using tungsten-doped TiO2 nano-photocatalysts: Application of artificial neural network and genetic algorithm*. Pages 267-277.

One of the most important practices in each water and wastewater treatment process is the accurate modeling, optimization, and finding the best condition which leads to achieve maximum efficiency. Recently, artificial neural network and genetic algorithm have been accepted as efficient tools for empirical modeling and optimization, especially for non-linear phenomena. In the present study, Artificial Neural Network (ANN) was applied to model the temporal variations of landfill leachate COD in the photocatalytic treatment process using tungsten-doped TiO2 (W-doped TiO2) nano-photocatalysts. Four influential parameters on the process efficiency, pH, tungsten content (wt.%), calcination temperature (Temp), and exposure time (T) of leachate were considered to predict temporal variations of the leachate COD concentration. Different ANN structures were developed, trained, validated and tested using the data from 150 experiments. Optimal ANN structure was determined based on three performance measures, MAPE, NRMSE, and R. Prediction process inside the optimal ANN was extracted in the form of simple and user-friendly mathematical formulas. Genetic Algorithm (GA) was used to find the most efficient W-doped TiO2 nano-photocatalysts in the COD removal of landfill leachate. The process optimization was conducted at a fixed exposure time using a GA whose objective function was the mathematical formulas obtained from the optimal ANN model. Based on the modeling results, the ANN model, as a non-linear model, has a high predictive accuracy (4% mean error and 0.98 correlation coefficient) when it comes to prediction of temporal variations of the leachate COD in the photocatalytic treatment process using W-doped TiO2 nano-photocatalysts. Based on the optimization results, the most efficient W-doped TiO2 nano-photocatalysts were provided when tungsten content, calcination temperature, and leachate pH were 2.2 percent by weight, 529°C, and 6.3, respectively.

- **Keywords:** W-doped TiO2; Landfill leachate treatment; Optimization; Artificial neural network; Genetic algorithm

Geraint O. Thomas, Richard J. Bambrey, Gwyn L. Oakley. *A study of flame acceleration and the possibility of detonation with silane mixtures*. Pages 278-285.

Mixtures of silane and nitrous oxide are one of a number of gaseous reactants used in the final stages of semiconductor device fabrication processes and whose explosion properties in confined volumes such as exhaust gas piping systems are not known. In the present paper we report the results of theoretical and experimental studies of the propensity for flame acceleration and potential deflagration to detonation transition (DDT) hazard for silane–nitrous oxide mixtures in a 50mm diameter pipe; together with

an investigation of the effectiveness of nitrogen dilution as an explosion mitigation method. Preliminary results for ethylene–oxygen nitrogen are also presented from commissioning tests in the same apparatus to illustrate the explosion development process in a much studied explosive mixture. The experimental DDT limits are compared with criteria proposed by earlier investigators, based on detonation cell width. As no cell width data was available for the silane mixtures the cell widths used were those predicted using high temperature chemical reaction data.

- **Keywords:** Detonation limits; Cell size predictions; Silane-nitrous oxide

Andrea Piazzoli, Manuela Antonelli. *Application of the Homogeneous Surface Diffusion Model for the prediction of the breakthrough in full-scale GAC filters fed on groundwater*. Pages 286-295.

Homogeneous Surface Diffusion Model (HSDM) has been widely used to simulate the breakthrough of organic micropollutants in fixed-bed adsorbers, but its practical applicability in real-scale conditions is not fully established. In this study we proposed a validated methodology to support the assessment of full-scale GAC adsorbers, providing a sound framework for a sustainable management. Specifically, we predicted the breakthrough of volatile organic compounds by the HSDM applied to full-scale granular activated carbon (GAC) adsorbers treating a complex groundwater matrix. Isotherm and short bed adsorber (SBA) tests were conducted to obtain equilibrium and mass-transfer coefficients for two contaminants (chloroform and perchloroethylene, PCE) and two GACs. Isotherm data were well described by Freundlich and Langmuir models, showing that single-component isotherms can be also used in complex water matrices, indirectly taking into account competition phenomena into the estimated parameters. The fitting of SBA data by HSDM was effective for chloroform, while PCE results were not well described, indicating that the combination of isotherm and SBA experiments to estimate HSDM parameters is not always effective, but it can depend on the characteristics of the adsorbate. Breakthrough data from the monitoring of two full-scale adsorbers were finally used to validate HSDM parameters for chloroform: its breakthrough was effectively simulated, without introducing any competition effect in HSDM equations. The model well reproduced also the release of the contaminant (resulting in chromatographic effect) by considering the variation of its influent concentration over time.

- **Keywords:** Granular activated carbon (GAC); Adsorption; Homogeneous Surface Diffusion Model (HSDM); Fixed-bed breakthrough; Volatile organic compounds (VOCs)

Min Sun Cho, Soo Chool Lee, Ho Jin Chae, Yong Mok Kwon, Joong Beom Lee, Jae Chang Kim. *Characterization of new potassium-based solid sorbents prepared using metal silicates for post-combustion CO2 capture*. Pages 296-306.

Potassium-based sorbents prepared using metal oxides as supports or additive materials are commonly applied in fast fluidized bed reactors for post-combustion CO2 capture. However, they have some disadvantages in terms of regeneration properties. To overcome these drawbacks, novel potassium-based sorbents, herein termed KAS, KCS, and KZS, prepared using aluminum silicate, calcium silicate, and zirconium silicate, respectively, were developed in this study. Unlike potassium-based sorbents prepared using metal oxides, the new sorbents exhibited high CO2 capture capacities (90–96mg CO2/g sorbent) and excellent regeneration ratios of 90% or more during multiple tests, even at a the low regeneration temperature of 200°C. These improved results were achieved because KHCO3 alone is formed during CO2 sorption without any by-product formation, and there is no loss of the active material (K2CO3) during preparation. Thus,

metal silicates can be used to prepare potassium-based solid sorbents for CO2 capture at low temperatures.

- **Keywords:** Sorbent; Carbon dioxide; Metal silicate; Regeneration; Potassium carbonate; Post-combustion CO2 capture

Fayaz Ali, Javed Ali Khan, Noor S. Shah, Murtaza Sayed, Hasan M. Khan. *Carbamazepine degradation by UV and UV-assisted AOPs: Kinetics, mechanism and toxicity investigations*. Pages 307-314.

Carbamazepine (CBZ), a widely used antiepileptic drug, was removed by UV–254nm based advanced oxidation processes. CBZ was found to be stable under sole UV, however, removal of CBZ was promoted using Fe3+ and Fe2+ with UV. Further, removal efficiency of CBZ was significantly enhanced by coupling H2O2 with UV and Fe3+/Fe2+. At 3600mJcm−2, 7.5, 60.2, 74.3 and 90.6% CBZ degradation was achieved in UV, UV/H2O2, UV/H2O2/Fe3+ and UV/H2O2/Fe2+, using CBZ, H2O2, Fe2+ and Fe3+ at 21.16, 1060.00, 17.91 and 17.91μM, respectively. Higher CBZ degradation in the presence of H2O2 was attributed to HO whose second-order rate constant with CBZ was calculated to be (8.83±0.27)×109M−1s−1. Removal of CBZ by UV/H2O2/Fe2+ system was optimum at pH 3.0, as 80.8, 90.6 and 70.4% CBZ degradation was observed at pH 2.0, 3.0 and 6.5, respectively. The removal of CBZ by UV/H2O2/Fe2+ was retarded in the presence of Cl− and humic acid as revealed from 84.5 and 56.7% CBZ degradation in the presence of Cl− and humic acid, respectively, compared to 90.6% in their absence at 3600mJcm−2. The CBZ degradation products were found to be less toxic than the parent compound, suggesting important role of UV-assisted AOPs in efficient removal and toxicity reduction of CBZ and their degradation products.

- **Keywords:** AOPs; Carbamazepine; Hydroxyl radical; Toxicity; Water treatment

Sunita Patel, Jaya Bajpai, Rajesh Saini, A.K. Bajpai, Somen Acharya. *Sustained release of pesticide (Cypermethrin) from nanocarriers: An effective technique for environmental and crop protection*. Pages 315-325.

Cypermethrin loaded calcium alginate nanocarriers were prepared and characterized by various techniques such as FTIR, FESEM, TEM, XRD, DSC, SEM-EDX, ED, particles size and zeta potential analysis. Whereas the FTIR spectral analysis confirms the presence of cypermethrin and alginate in the nanocarriers, the FESEM suggests for heterogeneous morphology of the nanocarriers surfaces when pesticide is loaded. The TEM analysis reveals that the native alginate nanocarriers have dimensions in the range of 108–127nm while encapsulation of cypermethrin changes their sizes to fall in the range of 115–119nm which is also accompanied by change in their shape. The loading of pesticide also results in slight shift of surface potential of nanocarriers from −25 to −21mV. The study showed that cypermethrin is well encapsulated (encapsulation efficiency approx 95% and cypermethrin loading approx 78%) within calcium alginate nanocarriers without any chemical deformation. The release of cypermethrin from calcium alginate nanocarriers was evaluated under varying experimental conditions. The mechanism of release of cypermethrin from alginate nanocarriers was found to follow non Fickian behavior i.e anomalous transport governed by diffusion and relaxation of the alginate chains. The whole study suggested that cypermethrin loaded calcium alginate nanocarriers could be a promising and safe candidate for sustained and slow release of cypermethrin and helpful in reducing the environment pollutions caused by excessive use of cypermethrin.

- **Keywords:** Cypermethrin; Sustained release; Sodium alginate; Nanocarriers; Encapsulation

Y.F. Khalil. *Science-based framework for ensuring safe use of hydrogen as an energy carrier and an emission-free transportation fuel*. Pages 326-340.

The objective of this research is to examine the safety-related characteristics of candidate hydrogen storage materials being considered for use in light-duty fuel-cell vehicles (LD-FCV) under the U.S. Department of Energy (DOE) Hydrogen Program. This research aims to provide useful meaning to the general DOE safety target by establishing a link between the safety-related characteristics of candidate storage materials and satisfaction of DOE safety target. Accordingly, a science-based framework has been developed and consists of standardized materials tests (based on internationally accepted ASTM and United Nations testing protocols), novel risk mitigation strategies, and subscale system demonstration. The examined storage materials include NaAlH4, AlH3, 2LiBH4+MgH2, 3Mg(NH2)2·8LiH, NH3BH3, and activated carbon (Maxsorb AX-21). The scope of safety tests covers conditions that the storage material may encounter during postulated accident scenarios such as dust cloud explosion, materials reactivity in air and other fluids, hot-surface contact, mechanical impact, and fast depressurization. The generated results uncovered potential fire and explosion risks under accidental conditions. The generated insights can be useful for assigning realistic probability values needed for quantifying risk scenarios, characterizing material's hazard class, and supporting current and new hydrogen safety codes and standards. For risk mitigation, this study showed that powder compaction could be effective in suppressing pyrophoricity of hydride powders such as NaAlH4. Also, the study has experimentally demonstrated that adding (NH4)H2PO4 as a flame retardant to the hydride powder before compaction could suppress sensitivity of hydrides like NaAlH4 to ignite due to mechanical impact. The results also revealed that Maxsorb AX-21 to be a safer hydrogen storage medium compared to the examined hydrides which exhibited potential safety concerns under certain accident conditions.

- **Keywords:** Risk assessment; Risk mitigation; Powder compaction; Pyrophoricity; Water reactivity; On-board storage

Qing-jie Luan, Li-jun Liu, Shu-wen Gong, Jing Lu, Xu Wang, Dong-mei Lv. *Clean and efficient conversion of renewable levulinic acid to levulinate esters catalyzed by an organic-salt of H4SiW12O40*. Pages 341-349.

An organic-salt of H4SiW12O40, (C10H7NO2)4H4SiW12O40, was prepared through the combination of H4SiW12O40 and quinaldic acid. The organic-salt was characterized by element analysis, FT-IR, UV–vis, XRD, SEM, TG, potentiometric titration and NH3-TPD. And its catalytic activity was tested in the synthesis of levulinate esters as a solid acid catalyst. The influences of various reaction conditions such as reaction time, catalyst amount and molar ration of ethanol to levulinic acid on the conversion of levulinic acid were investigated. The organic-salt still maintained the Keggin structure of pure H4SiW12O40 and has strong acidity. It exhibited excellent catalytic performances, including high yield of esters and good reusability. The conversion of levulinic acid could reach 98.6% in the esterification of levulinic acid and ethanol under the optimized reaction conditions. The results showed that the acid strength of catalyst played a very important role in the esterification.

- **Keywords**: Silicotungstic acid; Heterogeneous catalysis; Esterification; Levulinic acid

Radhika R., Jayalatha T., Rekha Krishnan G., Salu Jacob, Rajeev R., Benny K. George. *Adsorption performance of packed bed column for the removal of perchlorate using modified activated carbon*. Pages 350-362.

The adsorption performance of packed bed column using coconut shell based activated carbon for the removal of perchlorate from water was investigated. The influence of parameters like inlet ion concentration, flow rate and bed height on the breakthrough curves and adsorption performance were studied. The results indicated that the adsorption efficiency increased with increase in the initial concentration and the bed height, decreased with increase in the flow rate which in turn resulted in a shorter saturation time. It also revealed that the throughput volume of the aqueous solution increased with increase in bed height owing to the availability of more adsorption sites. The adsorption kinetics was analysed using three kinetic models viz. Adam- Bohart, Thomas and Yoon-Nelson models. The maximum adsorption capacity increased with increase in flow rate and initial ion concentration but decreased with increase in bed height. The perchlorate uptake data was also analyzed for first and second order kinetics. The regeneration of spent activated carbon was systematically investigated by thermal and chemical regeneration methods under different operating conditions.

- **Keywords:** Perchlorate; Activated carbon; Adsorption capacity; Breakthrough curve; Column studies; Regeneration

Emilio Rosales, Gabriel Buftia, Marta Pazos, Gabriel Lazar, M. Angeles Sanromán. *Highly active based iron-carbonaceous cathodes for heterogeneous electro-Fenton process: Application to degradation of parabens*. Pages 363-371.

Personal care products are known as endocrine-disrupting compounds and their degradation is a matter of concern to avoid their release into the environment. For this reason, the main objective of this study is to develop an effective advanced oxidation process able to degrade a paraben as methyl paraben (MePa). Initially, the efficiency of two electrodes, Graphite felt (GF) and Ruthenium (Ru), was compared on the degradation of MePa by anodic oxidation (AO) and electro-Fenton (EF). Near complete degradation was obtained after 1h when Graphite felt (GF) was used as cathode in EF, showing the superiority of this treatment over AO. To improve this process, heterogeneous EF through inclusion of iron into the cathode was carried out. To do that, four iron-carbonaceous cathodes were prepared based on GF (raw or activated with H2SO4, named AGF-1) showing a significant iron content (25–30%) and attaining high degradation values (95–100%) in all of them. From preliminary experiments was determined that by the use of AGF-1 as cathode the electrode performance improved, reducing significantly the treatment time required and the total amount of MePa contained in the solution had disappeared after 30min with a TOC reduction of 98.68% after 120min. The profiles of MePa exhibit an exponential decay throughout time being satisfactorily described by pseudo-first order reaction kinetic showing a maximum degradation rate of around 0.143min−1 at optimal conditions (100mA and pH 3). In addition, the selected cathode showed high structural and catalytic stability after several reuses. Finally, key steps of a plausible degradation pathway were tailored in accordance with identified and quantified intermediate products of the degradation process.

- **Keywords:** Activated graphite felt; Anodic oxidation; Heterogeneous electro-Fenton; Iron carbonaceous cathodes; Methyl paraben; Personal care products

Jose Alcides Gobbo, Christianne M. Busso, Simone Cristina O. Gobbo, Henrique Carreão. *Making the links among environmental protection, process safety, and industry 4.0*. Pages 372-382.

Industry 4.0 is an emerging concept in production systems and is described as a concept that encompasses technologies such as the Internet of Things, big data, cyber-physical systems, and smart objects. Industry 4.0 will present new challenges and opportunities for process safety and environmental protection (PSEP) researchers and managers. There

is a gap in the literature in identifying the main concepts related to industry 4.0 and PSEP, as well as the potential integration between these subjects. In line with this gap, this paper focuses on identifying and systemizing information regarding the integration of PSEP and industry 4.0 concepts and technologies. While identifying relationships, we also address non-existent intersections between keyword co-occurrence networks in PSEP and industry 4.0. The main outputs of this research are: (a) identification and discussion of potential connections between PSEP with industry 4.0 concepts; and (b) an in-depth discussion of potential benefits in integrating industry 4.0 concepts and technologies into PSEP fields. It can be concluded that there is much more collaborative research between environmental protection and industry 4.0 than between process safety and industry 4.0. Also, environmental protection research is characterized by a wide variety of research themes and multidisciplinary endeavours, in contrast with industry 4.0.

- **Keywords:** Industry 4.0; Environmental protection; Process safety; Bibliometric networks

Chunhui Zhang, Shan Jiang, Jiawei Tang, Yizhen Zhang, Yuying Cui, Changluo Su, Yao Qu, Lei Wei, Heshan Cao, Jingwei Quan. *Adsorptive performance of coal based magnetic activated carbon for perfluorinated compounds from treated landfill leachate effluents*. Pages 383-389.

Coal based powder Magnetic activated carbon (MAC) were prepared, characterized and used successfully for adsorption of PFCs in treated landfill leachate effluents. The morphologies and surface chemistries of MAC were studies by N2 gas adsorption isotherms, SEM, and Lakeshore 7300 vibrating sample magnetometer. The surface areas (SBET), the Langmuir surface area (SLangmuir), the micropore volume and the total pore volume of MAC were calculated according to the corresponding N2 isotherms. Batch adsorption studies were performed at different adsorption dosage and contact time. With 8g/150mL adsorption dosage and 120min contact time, after adsorption by MAC, the removal efficiencies of PFHxA, PFHpA, PFOA, PFNA and PFDoA in leachate samples can reach 72.8–89.6%, respectively. The MAC can be recycled by the high-intensity magnetic separators. The optimal regeneration time for ultrasonic is 4h.

- **Keywords:** Perfluorinated compounds (PFCs); Magnetic activated carbon (MAC); Landfill leachate; Adsorptive performance; Coal based activated carbon

Jinjia Zhang, David Cliff, Kaili Xu, Greg You. *Focusing on the patterns and characteristics of extraordinarily severe gas explosion accidents in Chinese coal mines*. Pages 390-398.

Abstract: Extraordinarily severe gas explosion accidents (ESGEAs) (thirty fatalities or more in one accident) have a high occurrence frequency in Chinese coal mines. There are 126 ESGEAs that occurred in China from 1950 to 2015, and they were investigated through statistical methods in this study to review the overall circumstances and to provide quantitative information on ESGEAs. Statistical characteristics about accident-related factors, such as gas accumulation, ignition sources, operating locations, accident time, coal mine regions and coal mine ownership, were assessed in this paper. The statistical analysis shows that disorganized ventilation fan management was the most frequent cause of gas accumulation in ESGEAs, while illegal blasting was the most prominent cause of the ignition source in ESGEAs. Furthermore, ESGEAs were found to occur frequently in certain provinces (e.g., Shanxi, Henan and Heilongjiang) and during November and December of the year. Moreover, most accidents and the largest death tolls generally occur in state-owned coal mines. Based on the results of statistical studies, some countermeasures were proposed in this study.

- **Keywords:** Coal mine; Gas explosion; Extraordinarily severe accidents; Accident statistics; Countermeasures

Nawel Jemil, Noomen Hmidet, Hanen Ben Ayed, Moncef Nasri. *Physicochemical characterization of Enterobacter cloacae C3 lipopeptides and their applications in enhancing diesel oil biodegradation*. Pages 399-407.

Enterobacter cloacae C3 strain was isolated from a soil contaminated by natural-gas condensate in Sfax City, Tunisia. This strain was selected for further studies based on its high surface activities. The physicochemical properties and stability of produced biosurfactants were investigated. Biosurfactants from E. cloacae C3 strain are able to reduce the surface tension of Landy medium from 65 to 32mN/m. The produced biosurfactants were identified as lipopeptides using thin layer chromatography (TLC) technique. Acid precipitated lipopeptides have critical micelle concentration of 100mg/l. They showed good emulsification activities against different hydrocarbon substrates in comparison with chemical surfactants Tween 80 and SDS, and they were effective in a wide range of temperature and pH. Good performance of diesel oil solubilization was exhibited by lipopeptides C3 at extreme environmental conditions, which is essential for enhancing oil recovery. The degradation of diesel oil (2.0%, v/v) in mineral-salts medium reached a maximum value of 48% after about 15days of incubation, in the presence of 0.1% (w/v) lipopeptides. These results suggest the importance of lipopeptides C3 production for application in bioremediation of environments polluted with various hydrocarbons.

- **Keywords:** Enterobacter cloacae C3; Lipopeptides; Physicochemical properties; Lipopeptides stability; Diesel oil solubilization; Bioremediation

Sachin S. Kamble, Angappa Gunasekaran, Shradha A. Gawankar. *Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives*. Pages 408-425.

Industry 4.0 and its other synonyms like Smart Manufacturing, Smart Production or Internet of Things, have been identified as major contributors in the context of digital and automated manufacturing environment. The term industry 4.0 comprises a variety of technologies to enable the development of the value chain resulting in reduced manufacturing lead times, and improved product quality and organizational performance. Industry 4.0 has attracted much attention in the recent literature, however there are very few systematic and extensive review of research that captures the dynamic nature of this topic. The rapidly growing interest from both academics and practitioners in Industry 4.0 has urged the need for review of up-to-date research and development to develop a new agenda. Selected 85 papers were classified in five research categories namely conceptual papers on Industry 4.0, human-machine interactions, machine-equipment interactions, technologies of Industry 4.0 and sustainability. The review primarily attempted to seek answers to the following two questions: (1) What are different research approaches used to study Industry 4.0? and (2) What is the current status of research in the domains of Industry 4.0?. We propose a sustainable Industry 4.0 framework based on the findings of the review with three critical components viz., Industry 4.0 technologies, process integration and sustainable outcomes. Finally, the scope of future research is discussed in detail.

- **Keywords:** Industry 4.0; Smart manufacturing; Internet of things; Process safety; Augmented reality; Sustainability; Big data

Chen-Rui Cao, Shang-Hao Liu, Mitali Das, Chi-Min Shu. *Evaluation for the thermokinetics of the autocatalytic reaction of cumene hydroperoxide mixed with phenol through isothermal approaches and simulations*. Pages 426-438.

In the petrochemical industry, estimation methods based on isothermal micro-calorimetry are used to precisely analyze the thermal hazards and risks associated with chemicals and to develop an inherently safer design (ISD). Here, a thermal activity monitor III (TAM III) was used under various isothermal conditions to obtain the thermokinetics parameters of reaction mechanisms. Cumene hydroperoxide (CHP), a typical organic peroxide, is decomposed by the action of sulfuric acid to yield phenol and acetone in equimolar quantities. CHP undergoes multiple complex reactions when an autocatalytic reaction occurs under isothermal decomposition. The following reaction scheme was considered in this study: $A+nB \rightleftharpoons (n+1)B$, $A \rightleftharpoons B$, $B \rightarrow C$. This type of reaction generally accelerates as the reactant is consumed, and an autocatalytic substance is produced. As a result, an ISD is required for preparation, manufacturing, transportation, storage, and even elimination. The rich behavioral patterns of these autocatalytic reactions were revealed through multiple specific illustrations.

- **Keywords:** Inherently safer design; Thermal activity monitor III; Isothermal conditions; Cumene hydroperoxide; Autocatalytic reaction

Bao-Cang Han, Wei-Li Jiang, Yong Zhang, Wei Wei, Jiao Chen. *Profile of organic carbon and nitrogen removal by a continuous flowing conventional activated sludge reactor with pulse aeration*. Pages 439-445.

This study aimed to investigate the effect of pulse aeration (on/off time 5/10min) on the pollutants removal efficiencies and on the evolution of the denitrifying bacteria communities of a continuous flowing completely mixed activated sludge reactor. Organic matters and nitrogen removal were evaluated and the denitrifying bacteria community structure was analyzed by MiSeq sequencing technology. Results showed that the TOC removal rates were steadily above 81.6% and the NH_4^+-N removal rates were 92.1%±0.5% when the pulse aerated activated sludge reactor was operated with the optimized pulse aeration cycle (PAC) of 5/10min. There was no significant impact on both TOC and NH_4^+-N removal efficiencies, while the average TN removal rate of the pulse aerated reactor (58.4%) was significantly higher than that of the constantly aerated one (30.6%). The removal efficiencies of both organics and nitrogen were stable during the 60-day acclimation period regardless of the changing DO concentration fluctuated in pulse mode. Although the denitrifier bacterial compositions varied between the pulse aerated group and the constantly aerated group, the denitrifier community richness and diversity were similar. Boost of the TN removal was mainly due to the anoxic denitrifying environment provided by the non-aerated phase in each PAC.

- **Keywords:** Activated sludge; Pulse aeration; Nitrogen removal; Denitrifier; Bacteria community

Sergiu Vasilie, Florica Manea, Anamaria Baciu, Aniela Pop. *Dual use of boron-doped diamond electrode in antibiotics-containing water treatment and process control*. Pages 446-453.

This study aimed to investigate the dual role of boron-doped diamond (BDD) electrode and electrooxidation process in the electrochemical degradation of tetracycline (TC) – as model of antibiotics considered emergent pollutants in water – and also in the electrochemical detection based process control. Cyclic voltammetry (CV) was used to determine the operating parameters for both TC degradation/mineralization and its electrochemical detection in the process control. The operating parameters such as current density, pH and TC concentration range were set to achieve the best process performance. The mechanism and kinetics of TC electrodegradation are also discussed. A current density of $50 Am^{-2}$ and pH 5 were found to be optimum for TC degradation and mineralization in a concentration range between 25 and $100 mgL^{-1}$. Furthermore, these

conditions enhanced the biodegradability character of TC during a subsequent biological treatment step in a wastewater treatment plant (WWTP). The versatility of the BDD electrode also made possibile for it to be used for the electrochemical detection of TC using CV, allowing the process control with the same electrode, hence confirming the dual role of the electrode material.

- **Keywords:** Boron-doped diamond electrode; Tetracycline; Emergent pollutant in water; Electrooxidation process; Electrochemical detection

Mardhati Zainal Abidin, Risza Rusli, Faisal Khan, Azmi Mohd Shariff. *Development of inherent safety benefits index to analyse the impact of inherent safety implementation*. Pages 454-472.

Over the years notable accidents have occurred in the chemical process industry thus creating a major concern for the safeness of its operation. The disasters led to the dire consequences that claimed human life and health as well as monetary losses. Inherently safer design is an effective solution to prevent accidents because it postulates that the best way to reduce risk is to avoid the hazard rather than control the hazard. Although the implementation of inherently safer design can give great advantages and cost optimal operation throughout process's life cycle, slow adoption of this principle into real design practice can be observed. This is partly because the inability to realise the benefits of inherent safety implementation among industrial practitioner. This paper presents a methodology for evaluating inherently safer design alternatives and identifying the benefits using an index-based approach at preliminary design stage. The proposed methodology is applied to ammonia storage with the objective of preventing and minimising toxic release. The results have shown that the new methodology can identify the best inherently safer design and the benefits where it is capable to reduce the severity of accident and the requirement to manage hazardous process.

- **Keywords:** Inherent safety; Index-based methodology; Benefits; Technical and organisational measures; Hazardous process management; Regulation

Noor S. Shah, Allah Ditta Rizwan, Javed Ali Khan, Murtaza Sayed, Zia Ul Haq Khan, Behzad Murtaza, Jibran Iqbal, Salah Ud Din, Muhammad Imran, Muhammad Nadeem, Ala'a H. Al-Muhtaseb, Nawshad Muhammad, Hasan M. Khan, Moinuddin Ghauri, Gohar Zaman. *Toxicities, kinetics and degradation pathways investigation of ciprofloxacin degradation using iron-mediated H2O2 based advanced oxidation processes*. Pages 473-482.

Ciprofloxacin (CIP) is a widespread emerging water pollutant and thus its removal from aquatic environment is vital. The use of Fe3+/H2O2 and Fe2+/H2O2 resulted in 38 and 64% removal of CIP (8.0ppm), respectively, within 80min reaction time (pH 5.8, [H2O2]0=80ppm, and [iron]0=20ppm). Low pH, high temperature, high dose of H2O2 and Fe2+, and low CIP concentration facilitated removal of CIP. The radical scavenger studies proved in situ generated OH to be involved primarily in the removal of CIP. The effect of temperature was used to estimate enthalpy and activation energies of the removal of CIP. At 800min reaction time, the Fe2+/H2O2 resulted in 54% mineralization of CIP using 16.0ppm [CIP]0, 320.0ppm [H2O2]0, and 40.0ppm [Fe2+]0. The potential degradation pathways of CIP established from the degradation of CIP by OH and products evolved was found to be initiated at C6 through the loss of fluoride ion. The acute and chronic toxicities of CIP and its degradation products were estimated with the final product found to be non-toxic. The results suggest that Fe2+/H2O2-mediated AOPs have high potential for degradation as well as toxicity elimination of CIP and its degradation products.

- **Keywords:** AOPs; Ciprofloxacin; Degradation pathways; Toxicity assessment; Water treatment

Yuanjiang Chang, Xiangfei Wu, Guoming Chen, Jihua Ye, Bin Chen, Liangbin Xu, Jianliang Zhou, Zhiming Yin, Keren Ren. *Comprehensive risk assessment of deepwater drilling riser using fuzzy Petri net model*. Pages 483-497.

Drilling risers are the critical connection of subsea wellhead and the floating drilling unit. With exploration and development of oil and gas resources moving into deepwater, drilling riser operations have been characterized with high safety risk and occurrence rate of accidents causing high drilling downtime and drilling cost. In the present study, a Fuzzy Petri Net (FPN) methodology is proposed to evaluate the comprehensive risk of deepwater drilling risers. A risk index evaluation system was established based on analyses of drilling riser accidents and identification of risk factors, and the AHP-EM method was used to determine the weights of them. A 9-tuple set was defined to model drilling riser risks according to the FPN theories, and by using the fuzzy reasoning algorithm, risk values of risk factors at different levels and the integrated system were gained by iteration of state matrix. A specific case study of deepwater drilling risers of NANHAI-8 drilling unit in Liuhua oilfield in South China Sea is presented to illustrate the application of proposed approach, and some suggestions drawn from the investigation are presented to further mitigate the risk of drilling riser operations. The case study showed that FPN is a practical and reliable method in comprehensive risk evaluation of deepwater drilling riser system.

- **Keywords:** Deepwater drilling riser; Risk assessment; Fuzzy petri net; Fuzzy reasoning algorithm; Combination weighting method

Denglong Ma, Wei Tan, Qingsheng Wang, Zaoxiao Zhang, Jianmin Gao, Xiaoqiao Wang, Fengshe Xia. *Location of contaminant emission source in atmosphere based on optimal correlated matching of concentration distribution*. Pages 498-510.

Source location is crucial to manage contaminant emissions in atmosphere, In order to determine the source location without dependence on the absolute measurement data, a method based on optimal correlated matching of concentration distribution (OCMCD) was proposed. First, the estimation efficiency, accuracy and dependence on source strength of OCMCD were compared with the common method which estimates multiple parameters of the source term simultaneously. The results show that the method of OCMCD performs better than the common multiple parameters estimation method based on the mean errors between prediction and measurement in both estimation accuracy and efficiency. The test results with different sets of source strength manifest that OCMCD relies minimally on the source strength Then, a wind direction correction parameter and a weighted term of normalization concentration error were introduced into the model to compensate some missed information and improve the location results. The influence of data noises on the estimation accuracy of OCMCD method was also verified by adding extra manual noises on the measurement data. Then, the dependence of estimation performance with OCMCD method on atmosphere conditions were investigated statistically with experiment release cases. The results showed that source location was identified well in most of cases. Finally, OCMCD method was extended to determine the source location during the source trace process with a mobile sensor. The test results with a simulation scenario based on Zigzag search strategy demonstrate that the source location determined by OCMCD source criterion is much closer to the real source position than that determined by the criterion of the maximum concentration. Therefore, the results have proven the feasibility and superiority of OCMCD proposed in this paper to estimate source location in cases of both static sensor distribution and

mobile sensors. OCMCD will be a potentially useful method to identify emission source location in atmosphere.

- **Keywords:** Source trace; Gas emission; Hazard identification; Optimization algorithms; Source term estimation

Fen Wang, Junxia Yu, Zhenyue Zhang, Yuanlai Xu, Ru-an Chi. *An amino-functionalized ramie stalk-based adsorbent for highly effective Cu2+ removal from water: Adsorption performance and mechanism*. Pages 511-522.

This study reports a potential application of a local agricultural waste, ramie stalk, as a raw material to design a highly effective adsorbent by chemical modification with tetraethylenepentamine for Cu2+ removal from water. Surface morphology and chemical structure, elements components and physicochemical properties of the adsorbent were characterized by using SEM, EDX, FTIR, Zeta potential Meter and XPS. After modification, the amine groups were successfully grafted onto the surface of ramie stalk, which have multilayered and porous structures. A batch and fixed-bed column method were used to investigate the adsorption performance and mechanism of Cu2+. The optimum pH for Cu2+ adsorption was found to be 5. In the batch adsorption experiment, the data of the kinetic experiment were better fitted by the pseudo-second-order model (R2=0.9917), indicating that the adsorption of Cu2+ by modified Ramie stalk was mainly controlled by chemical adsorption. The adsorption equilibrium isotherm could be better described by Langmuir model (R2=0.9929) which suggested a monolayer sorption and the maximum adsorption capacity was 0.587mmolg−1. In the dynamic adsorption experiment, the operation conditions, such as flow rate, initial concentration, and bed height were evaluated. The experiments results showed that with the higher initial concentration and the lower bed height, the adsorption capacity of the adsorbent increased and the fixed-bed column displayed good capacity for treating water under dynamic condition. The coordination bonding between Cu2+ and amine groups on the modified ramie stalk is the main adsorption mechanism. The new type adsorbent exhibited good reusability for 5 cycles without deterioration in its adsorption performances. Ramie stalk could be utilized effectively as an efficient adsorbent for treatment of the copper contaminated water environment.

- **Keywords:** Ramie stalk; Chemical modification; Copper ions; Adsorption performance and mechanism

Federico Volpin, Emilie Fons, Laura Chekli, Jung Eun Kim, Am Jang, Ho Kyong Shon. *Hybrid forward osmosis-reverse osmosis for wastewater reuse and seawater desalination: Understanding the optimal feed solution to minimise fouling*. Pages 523-532.

To enhance the seawater desalination energy efficiency forward osmosis – reverse osmosis (FO-RO) hybrid system has recently been developed. In this process, the FO "pre-treatment" step is designed to use seawater (SW) as draw solution to filter the wastewater (WW) while reducing the seawater osmotic pressure. Thereby reducing the operating pressure of the RO to desalinate the diluted SW. However, membrane fouling is a major issue that needs to be addressed. Proper selection of suitable WWs is necessary before proceeding with large-scale FO-RO desalination plants. In this study, long-term experiments were carried out, using state-of-the-art FO membrane, using real WW and SW solutions. A combination of water flux modelling and membrane characterisation were used to assess the degree of membrane fouling and the impact on the process performance. Initial water flux as high as 22.5Lm−2h−1 was observed when using secondary effluent. It was also found that secondary effluent causes negligible flux decline. On the other hand, biologically treated wastewater and primary effluent caused

mild and severe flux decline respectively (25% and 50% of flux decline after 80 hours, compared to no-fouling conditions). Ammonia leakage to the diluted seawater was also measured, concluding that, if biologically treated wastewater is used as feed, the final NH4+ concentration in the draw is likely to be negligible.

- **Keywords:** Forward osmosis; Membrane fouling; Osmotic dilution; Seawater; Wastewater

Weijun Li, Qinggui Cao, Min He, Yibo Sun. *Industrial non-routine operation process risk assessment using job safety analysis (JSA) and a revised Petri net*. Pages 533-538.

An important feature of the industrial non-routine operation processes is the time sequence constraint among its steps. Therefore, the main hazard source could be the risk originating from the out-of-sequence scenarios. The traditional job safety analysis (JSA) method does not take account of time sequence constraint and should be adapted to address this problem. A graphical model based on Petri net is defined and further integrated into JSA. A non-routine operation process can be divided into steps according to JSA and then be represented as the basic unit of the revised Petri net. Through the graphical model, abnormal time sequence scenarios and their corresponding abnormal events can be identified. The united method can address time sequence and provide an intuitive and logical risk assessment procedures. The results can also provide effective guidance for workers and supervisors in the non-routine operations process.

- **Keywords:** Job safety assessment; Risk assessment; Non-routine operation; Revised Petri net

Morteza Banihashemi, Kamyar Movagharnejad. *Use of group contribution method and intelligent algorithms to predict the flash temperature of binary mixtures*. Pages 539-550.

513 flash point temperatures of 42 different binary mixtures were collected from various sources. Two soft-computing models of Artificial Neural Network (ANN) and optimized Adaptive Neuro-Fuzzy Inference System with Genetic Algorithm (ANFIS-GA) were established to predict these flash temperatures. Mole fraction of component 1, flash temperature of each component and Van der Waals R and Q for each component constitute the 5 input variables of both models. It was tried to improve the predictions of these two models using the group contribution method (GCM) based on the functional groups of the UNIQUAC activity equation. The mixing parameters of 215 binary data were first calculated and then the results were extended to the entire mixture data. Two new parameters of A12 and A21 based on the GCM were also added to each model to form two new 7 input-variable models. The results of the new models were compared with the previous results and it was observed that the % AARD of the ANN and ANFIS-GA models were reduced from 0.48% and 1.8% to 0.36% and 1.7%, respectively.

- **Keywords:** Flash point; Binary mixtures; Group contribution method; Artificial neural network; ANFIS-GA

Ruipengyu Li, Weeratunge Malalasekera, Salah Ibrahim, Bo Liu. *On the mechanism of pressure rise in vented explosions: A numerical study*. Pages 551-564.

Accidental gas explosions are a significant concern in process industries. In an explosion event, the promotion of flame acceleration due to turbulence generated from obstacles is responsible for many severe damages. This paper discusses the numerical evaluation and the mechanism of pressure rise in vented explosions in the presence of obstructions

using computational fluid dynamics (CFD). The large eddy simulation (LES) technique is employed with a dynamic flame surface density (DFSD) in the combustion model to account for the filtered chemical source term. The experimental test case considered for the validation of simulations is a small-scale explosion chamber with removable baffle plates and obstacles. It is found that the maximum overpressure increases with the baffle plates moved downstream from the ignition source or when additional baffles are placed in sequence. Large separation between baffles and the central obstacle results in lower overpressure due to the relaminarisation of the flame front. The trend of explosion overpressure is related to the competition between the strength of venting and expansion in the explosion chamber. Extensive interactions between the flame and the obstruction-generated turbulence are found to wrinkle the flame front and increase the burning rate. Satisfactory agreements have been obtained between LES and the experimental data. This confirms the capability of the developed model in predicting essential safety-related parameters in vented explosions. Results reveal the potential of using LES in the selection of design aspects for loss prevention, such as the area of vents and distance between congested regions in chemical processing plants.

- **Keywords:** Pressure rise; Vented explosions; Obstacles; Dynamic model; LES

Ni Guanhua, Xie Hongchao, Li Zhao, Zhuansun Lingxun, Niu Yunyun. *Improving the permeability of coal seam with pulsating hydraulic fracturing technique: A case study in Changping coal mine, China*. Pages 565-572.

To improve the gas permeability of coal seams, industrial experiments of pulsating hydraulic fracturing (PHF) were carried out, and physical properties, including the reasonable fracture radius, gas extraction concentration, water content, permeability, pore and mineral composition of a coal seam, were investigated. The results show that the pulsating peak pressure is the main influencing factor of the fracturing radius, and the free surfaces of the fractured holes and guide holes can realize the directional penetration of the fractured area in the coal seam. The initial gas concentration of the fractured holes and the guide holes are 1.2–1.8 times and 1.5–2.2 times that of the ordinary hole, respectively. The gas concentration decreases with time, and the decay phase of the ordinary hole is approximately 14days after fracturing, while the fractured holes and guide holes are 38days and 34days, and the gas concentrations are stable at 40% and 50%, respectively. The water content is approximately 2%, which is only 1.1 times that of the original coal seam. At the same time, the permeability coefficient of the coal seam increases by 48–217 times. Due to the erosion of pulsating water, the mineral crystals embedded in the coal are transported to the surface to form an erosion hole, which leads to improving the gas permeability of the coal seam by PHF.

- **Keywords:** Pulsating hydraulic fracturing; Gas extraction concentration; Water content; Permeability; Mineral crystals

Zongqing Tang, Shengqiang Yang, Guang Xu, Mostafa Sharifzadeh, Cheng Zhai. *Investigation of the effect of low-temperature oxidation on extraction efficiency and capacity of coalbed methane*. Pages 573-581.

To improve the extraction efficiency and capacity of coalbed methane (CBM) to the greatest extent possible, this study explores the effects of the internal mechanism of low-temperature oxidation of CBM reservoirs during CBM extraction. The evolution of the porosity and the methane adsorption and desorption characteristics of the coal matrix during low-temperature oxidation were separately explored using a nuclear magnetic resonance (NMR) spectrometer and a high-pressure gas adsorption analyzer. Moreover, the internal evolution mechanism was determined using gas chromatography and the experimental data of the proximate analysis parameters. This study shows that with an

increase in the degree and temperature of low-temperature oxidation of CBM reservoirs, the moisture and volatile matter inside the coal matrix continuously decrease. This causes the number of pores with different diameters, porosity, and permeability in the coal matrix to be greatly improved, while the width and quantity of the flow channels for CBM increase synchronously. As a result, the resistance to CBM extraction declines and its efficiency improves. With constant CBM extraction, the maximum methane adsorption capacity of the coal matrix decreases, whereas the methane desorption capacity increases, under low pressures (lower than 1.74MPa) owing to changes in the structures and quantities of pores inside the coal matrix. As a result, the maximum extraction capacity for CBM is improved. Finally, to guarantee CBM extraction safety and maximize its extraction capacity, it is necessary to control the temperature of the borehole used for extracting CBM to approximately 80°C.

- **Keywords:** Extraction of coalbed methane; Low-temperature oxidation; Porosity development; Adsorption and desorption; Promotion effect

Yunpei Liang, Fakai Wang, Xuelong Li, Chenglin Jiang, Lei Li, Yulong Chen. *Study on the influence factors of the initial expansion energy of released gas*. Pages 582-592.

Coal and gas outburst is a serious coal and rock dynamic disaster, and effective prediction is essential to control. The initial expansion energy of released gas (IEERG) is a new method to predict coal and gas outburst, which depends primarily on the gas pressure and degree of coal fragmentation. The IEERG reflects the effects of the ground stress, the gas pressure, and coal strength on the coal and gas outburst. On the basis of the single factor on the IEERG, three factors have been studied by orthogonal experiments, including gas pressure, coal particle size, and moisture. The results show that the influence of gas pressure, coal particle size, and water content on the IEERG decreases in turn; that gas expansion energy increases significantly as gas pressure increases; and that the greater the gas pressure, the faster the increase. The index Wp of IEERG first increases and then decreases with an increase in coal particle size and decreases with an increase in moisture content. Through this work, the main influencing factors of gas expansion energy have been defined. This method offers an important theoretical and practical significance to predict coal and gas outbursts.

- **Keywords:** Initial expansion energy of released gas; Coal particle size; Gas pressure; Moisture; Orthogonal experiment

Lara B. Liboni, Luisa H.B. Liboni, Luciana O. Cezarino. *Electric utility 4.0: Trends and challenges towards process safety and environmental protection*. Pages 593-605.

The traditional manufacturing business model is changing for new emerging models. Many changes are related to the industry 4.0 challenge and among them there is a concern regarding how industries will meet the objectives of sustainable operations, especially on that of environmental protection and process safety. Some industries are making great efforts to get aligned with the industry 4.0 paradigm, and for the Electric System Industry, it is no different. Because of its strategic and environmental importance, the electric system industry must be investigated. In this article we used qualitative research based on a systemic approach, using the Soft System Methodology (SSM) to address the challenges brought by the industry 4.0 paradigm in the electric system industry in Brazil, focusing on the topic of environmental protection and process safety. Moreover, we point out important capabilities needed by these companies to keep up with the new industrial revolution. Results from the SSM have exposed important management gaps and hence have shown new possible management models that can contribute to the modernization of the electric utilities in Brazil, making these industries more sustainable. In fact, it is imperative for companies to detail the organizational

capabilities they will need to thrive in the business process. Therefore, we conclude the paper by indicating the three main dynamic capabilities that have emerged: new policies to enable innovation, bureaucracy reduction, and investments in education.

- **Keywords:** Environmental protection; Process safety; Electric utility; Electric system; Industry 4.0; Soft System Methodology (SSM); Dynamic capabilities

L.L. Moura, K.L.S. Duarte, E.P. Santiago, C.F. Mahler, J.P. Bassin. *Strategies to re-establish stable granulation after filamentous outgrowth: Insights from lab-scale experiments*. Pages 606-615.

Aerobic granular sludge (AGS) is a promising technology for wastewater treatment. However, maintaining the granular biomass stability is not trivial. During the long-term operation of AGS systems, we observed that uncontrolled sludge retention time led to the appearance of substantially large and fluffy granules characterized by a dark anaerobic inner core. Such conditions favoured the proliferation of filamentous bacteria and deterioration of AGS properties. Consequently, granules disintegration became inevitable. We decided to assess two operational strategies to supress filamentous overgrowth and recover the granular biomass stability. Strategy 1 involved the enhancement of shear stress by increasing the aeration intensity (from 1.34 to 1.87cms−1), while strategy 2 relied on the combination of enhanced aeration and iron (10mgL−1) addition. The implementation of strategy 1 contributed to decrease the average diameter of AGS (4.7–4.1mm) and sludge volume index (SVI) (300–110mLg−1). Nevertheless, filamentous bacteria remained intact. Conversely, prolonged shear stress combined with iron supplementation (strategy 2) led to significant improvements in the physical characteristics of the granules. Very small particles acting as precursors of mature AGS were observed while big-size granules (>4mm) were no longer detected. Moreover, filamentous overgrowth was controlled and the growth of new granules was stimulated. No adverse effect on the conversion processes (COD and nitrogen removal) was observed in the AGS system and stable granulation was achieved from this period onwards. To better explain the role of the implemented strategies, some hypothesis are presented and discussed.

- **Keywords:** Degranulation; Filamentous outgrowth; Granular sludge stability; Shear stress; Iron addition

Cassio Brunoro Ahumada, Noor Quddus, M. Sam Mannan. *A method for facility layout optimisation including stochastic risk assessment*. Pages 616-628.

Facility siting and layout configuration are essential factors during design and expansion of any industrial installation. In the recent past, cost-driven layout arrangements and the proximity of chemical facilities to densely populated areas, among other factors, have also contributed to the severity and propagation of various chemical incidents. Although several studies have been reported to address such problems, there is still a need for incorporating safety into the facility layout problem (FLP); especially for a method combining quantitative risk assessment (QRA) and layout reformulation. Based on that, the objective of this study is to develop a framework integrating layout formulation with a quantitative risk assessment method to support risk-based decisions throughout the lifecycle of process facilities. The proposed methodology is divided into three steps: risk calculation, determination of safety distances, and layout optimisation. In the first stage, an in-house code has been developed to quantify risks associated with loss of human life and structural damage stochastically. Subsequently, minimum separation distances between process units are obtained to prevent escalation events. In the last stage, risk maps and safety distances are accounted in a mixed-integer linear programming (MILP) for layout optimisation. The application of the proposed methodology is demonstrated through a case study. Sensitivity analysis is performed by varying risk values, safe

distances, and risk acceptance criteria. Even though different layout options are generated, a trend is observed towards placing the equipment by its type.

- **Keywords:** Layout optimisation; Quantitative risk assessment (QRA); Uncertainty; Escalation events

Giorgio Vilardi, Javier Rodríguez-Rodríguez, Javier Miguel Ochando-Pulido, Nicola Verdone, Antonio Martinez-Ferez, Luca Di Palma. *Large Laboratory-Plant application for the treatment of a Tannery wastewater by Fenton oxidation: Fe(II) and nZVI catalysts comparison and kinetic modelling*. Pages 629-638.

This study reports a comparison among Conventional Fenton oxidation (CF) and Heterogeneous Fenton oxidation (HF) processes performed at large lab-scale on a Tannery Wastewater (TW). The heterogeneous Fenton process was carried out by using self lab-prepared nano zero-valent iron particles as solid catalyst. Two different catalyst/oxidant (Cat/Ox) (w/w) ratio were examined: a study on the pH solution influence on the process efficiency, monitoring the COD, TP, H2O2 and Cr(VI) variation over the reaction time was carried out. The process was conducted for 10h in batch mode for the first 2h, followed by 8h in continuous mode. HF demonstrated better performance, with respect to CF, towards both the removal of Chemical Oxygen Demand (COD), up to 75.5±2.1%, and Total Polyphenols (TP), up to 85.1±0.7%, from the TW. The CF optimal operating parameters were Cat/Ox (w/w)=0.2 and pH=2.5 whereas to maximize the HF efficiency a larger Cat/Ox (w/w) ratio, i.e. 0.5, was necessary. In addition, a lower amount of iron sludge was produced by HF with respect to CF (17.5–21.6%). Finally, a kinetic model on the reactions occurring in the HF/TW system was proposed and successfully used to fit experimental data.

- **Keywords:** Heterogeneous-Fenton; nZVI; Tannery; Large lab-scale; Continuous-reactor

Guozheng Song, Faisal Khan, Ming Yang. *Security assessment of process facilities – Intrusion modeling*. Pages 639-650

The process industry is confronted with terrorism threats. Effective security management demands the ability to defend facilities against different intrusion scenarios. This study first presented various intrusion scenarios to explain the corresponding intrusion process using graphical barriers. Subsequently, this work dynamically analyzed the successful intrusion probabilities and security potentials of barriers using a Bayesian network considering the dependency of barriers and interaction of different intrusion scenarios. It was observed that successful intrusion probabilities and security potentials are strong functions of intrusion scenarios. Therefore, extensive intrusion scenarios must be considered while assessing and designing the security systems of process facilities.

- **Keywords:** Intrusion scenario; Intrusion process analysis; Bayesian network model; Dependency modeling; Probability update

Yinxiang Xu, Hualin Wang, Zhenhua Wang, Yuanyuan Fang, Yi Liu, Tao Zeng, Zhongbin Liu, Ming Liu. *Hydrocyclone breakage of activated sludge to exploit internal carbon sources and simultaneously enhance microbial activity*. Pages 651-659.

Breaking activated sludge (AS) for organic compounds as supplemental carbon sources is beneficial for enhanced nitrogen removal from wastewater with low carbon/nitrogen ratios, but it is usually limited by the severe deterioration of microbial activity in wastewater treatment systems. In this paper, the hydrocyclone breakage method was

proposed to treat AS to release carbon sources and simultaneously enhance microbial activity. The effects of hydrocyclone breakage on carbon sources release and physicochemical properties of AS were emphatically investigated through various batch experiments. The results indicated that the internal carbon sources were effectively released from AS after hydrocyclone breakage, and the soluble chemical oxygen demand (SCOD) and polysaccharides concentrations were increased by over 100% at higher inlet flow rates of the hydrocyclone. Importantly, the sludge aggregates were broken into smaller pieces which still had a good settleability and low expansibility in wastewater treatment systems. The denitrification rate of AS improved 45.5% after hydrocyclone treatment. Meanwhile, extracellular polymeric substances (EPS) on AS surfaces and porous channels were also cleaned by shearing exfoliation and centrifugal desorption. Therefore, the hydrocyclone breakage for AS showed great advantages in releasing partial carbon sources and synchronously enhancing microbial activity of survival microorganism for advanced nitrogen removal.

- **Keywords:** Hydrocyclone breakage; Activated sludge; Carbon source; Microbial activity; Shear force

Junyan Zhang, Baoping Cai, Kabwe Mulenga, Yiliu Liu, Min Xie. *Bayesian network-based risk analysis methodology: A case of atmospheric and vacuum distillation unit*. Pages 660-674.

Chemical and petrochemical accidents, such as fires and explosions, do not happen frequently but have considerable consequences. These accidents compromise not only human safety but also cause significant economic losses and environmental contamination. The increasing complexity of chemical infrastructures increases the requirements of risk prevention. Thus, risk analysis for petrochemical systems is essential in helping analysts find the weakest process in the entire system and be used to strengthen the process and improve safety. Risk analysis has been previously studied; however, traditional methods have limitations. This study proposes a methodology that is based on Bayesian networks by giving a model for system risk analysis. The event is classified into three categories; cause, incident, and accident, according to criticality and thus, the model is analyzed as a three-layered structure. The application of the methodology is demonstrated by analyzing a vacuum distillation and an atmospheric unit. An exact reasoning method is used to infer the causality and probability within the events. After inferring the relationship between causes and accidents, mutual information and variance of beliefs are calculated to find the most sensitive event in an accident. Subsequently, means of strengthening operations to prevent accidents are suggested. This study may help companies decrease the cost of risk reduction.

- **Keywords:** Risk analysis; Bayesian networks; Chemical plant; Three-layer hierarchical model

A.G. Skerman, S. Heubeck, D.J. Batstone, S. Tait. *On-farm trials of practical options for hydrogen sulphide removal from piggery biogas*. Pages 675-683.

Manure-derived biogas is increasingly used at Australian piggeries to produce heat and generate electricity. However, high concentrations of hydrogen sulphide (H2S) in piggery biogas is discouraging further use, because of a lack of practical, cost-effective H2S removal options. To address this issue, on-farm trials were conducted at two piggeries. One trial tested H2S oxidation; adding small amounts of air to biogas, upstream of a low-cost enhanced surface treatment vessel which was fabricated on-farm with intrinsic safety measures. Covered anaerobic pond (CAP) effluent provided a convenient, low-cost nutrient source for the biofilm of naturally-occurring microorganisms in the packed column. This treatment was effective, removing over 90% of the H2S in a single pass and reducing H2S concentrations from 4000ppm to <400ppm. Another trial tested

chemisorption performance of natural, iron-rich red soil, mixed with a ground sugar cane mulch bulking agent, in comparison with cg5 commercial media (iron-oxide pellets). The red soil removed H2S, but had a substantially lower capacity (~2gS/kg red soil) than the cg5 (~200gS/kg media). Accordingly, red soil is unlikely to be feasible as a primary treatment medium, but may be useful for final polishing after an oxidation step has removed most of the H2S.

- **Keywords:** Biogas; Hydrogen sulphide; Iron oxide; Micro-aeration; Pig; Manure

Jean-Baptiste Mawulé Dassekpo, Jiaqian Ning, Xiaoxiong Zha. *Potential solidification/stabilization of clay-waste using green geopolymer remediation technologies*. Pages 684-693.

Solidification and stabilization is a remediation technique for hazardous wastes that promotes resource recycling and reduces the environmental burdens of waste management. To accomplish this successfully, different types of wastes or hazardous materials are treated with different binders and techniques. This study proposed a green remediation approach to treat and recycle clay-waste by using solidification/stabilisation which is enhanced by the injection of two chemical solutions, sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) and partial addition of low-calcium class F fly ash. The unconfined and compressive strength tests were conducted to investigate the mechanical properties of the developed geopolymer pastes at different time conditions. The change in the microstructures was characterized by using Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Microanalysis (EDX). The effects of Si/Al ratio on the compressive strength and the microstructure of the solidified geopolymer product are also summarized in this paper. In addition, the normalized weight variations after 28days curing in deionized water (pH=7.0) was highlighted and the leaching behavior of heavy metals in the clay-waste based geopolymer specimens after soaking up to 14days was examined with atomic absorption spectroscopy. Experimental results demonstrate the potential treatment, solidification and stabilization of the clay-waste by employing geopolymer remediation technologies and the optimum compressive strength can be obtained with a ratio of 30% fly ash. The collected clay-waste has strength of up to 5–20MPa at 28days curing which meet suitable mechanical properties and compact microstructure characterization.

- **Keywords:** Solidification/stabilization; Green remediation; Clay-waste; Mechanical properties; Si/Al ratio; Leaching; Heavy metals; SEM-EDX

Chao Zhang, Jiansong Wu, Xiaofeng Hu, Shunjiang Ni. *A probabilistic analysis model of oil pipeline accidents based on an integrated Event-Evolution-Bayesian (EEB) model*. Pages 694-703.

Over the past several decades, the high frequency of oil pipeline accidents has drawn substantial attention around the world. Many oil pipeline accident analysis models have been established based on the event tree method, the Bayesian network method and Computational Fluid Dynamics (CFD) simulation models. Considering the disadvantages of current models for comprehensively representing the incident evolution process and quantitative analysis for consequences, this paper proposes a probabilistic analysis model for oil pipeline accidents that integrates three methods the event tree (E), the incident evolution diagram (E) and the Bayesian network (B). Therefore, the model is called the "EEB model". The EEB model can identify the initial event and secondary events, illustrate the accident evolution path, identify the key influencing factors, analyze their effects, and calculate the probabilities of different consequences of oil pipeline network accidents. Compared with other models, the EEB model considers more factors, such as key environmental conditions and the emergency response. Probabilistic analysis of different consequences, including casualties, economic losses, environmental pollution and the influence on social order, can be obtained. For a general scenario of an oil

pipeline network accident, the probabilities for different consequences are 71.3% for "less than 5 persons affected", 68.2% for "less than 10 million RMB lost", 50.4% for "less than 1km2 of water pollution" and 59.5% for "influence on social order of less than 100 persons". The risk for the accident can be estimated by assuming the probability of the initial event as P. The model also denotes the emergency targets to be achieved and the response missions to be executed. Based on this information, a response plan can be developed for decision making. Since the incident evolution process is complex, the effects of the influencing factors should be analyzed. The EEB model highlights the significant influences of the water area (e.g., the probability of "10–50km2 of water pollution" decreases from 38.7% for "near and large" water bodies to 17.4% for "far and small" water bodies) and the emergency response (e.g., the probability of "50–100 million RMB economic loss" increases from 11.5% for an "effective" response to 29.3% for a "poor" response). The probabilistic analysis obtained by the EEB is more comprehensive than those of other models, and the results can be used for risk analysis, decision making and effect analysis of oil pipeline networks.

- **Keywords:** Oil pipeline accident; Probability analysis model; Event tree; Evolution diagram; Bayesian network; EEB model

Winston Lik Khai Lim, Edwin Chin Yau Chung, Chien Hwa Chong, Nicholas Tze Kai Ong, Wee Seong Hew, Nurasatifah binti Kahar, Zhen Jie Goh. *Removal of fluoride and aluminium using plant-based coagulants wrapped with fibrous thin film*. Pages 704-710.

The coagulation activity of Moringa oleifera seed and Hibiscus esculentus (okra) mucilage were assessed for their ability to remove both anionic and cationic contaminants in aluminium sulphate and hydrofluoric acid synthetic wastewater. The effect of encasing these coagulants in a fibrous thin film along with their effect on pH and concentration were also assessed. Assessment using the jar test showed a 79.9% aluminium reduction and 91.7% fluoride reduction using okra mucilage and Moringa oleifera, respectively. Besides that, there was no effect on both the pH and coagulation activity in the application of fibrous thin film. The plant-based coagulation activity is comparable with conventional coagulant as fluoride removal treated by polyaluminium chloride formulation was 85.3±0.8% with the optimum dosage of 3g/L. The significance of these findings in the application of fibrous thin film with plant-based coagulants could be an advantage for industries to commercialise mechanically prepared coagulants, which has a much longer shelf life as compared to chemically prepared coagulants, as it has the potential to reduce the turbidity associated with mechanically prepared coagulants. Also, these results indicate the possibility of having a cost-effective yet environmentally friendly water treatment solution that combines the application of both plant-based and conventional coagulants.

- **Keywords:** Moringa oleifera; Hibiscus esculentus; Fibrous thin film; Aluminium; Fluoride; Wastewater treatment

Armin Rezayan, Majid Taghizadeh. *Synthesis of magnetic mesoporous nanocrystalline KOH/ZSM-5-Fe3O4 for biodiesel production: Process optimization and kinetics study*. Pages 711-721.

This study attempts to synthesize magnetic mesoporous nanocrystalline KOH/ZSM-5-Fe3O4 and employ them for biodiesel production through transesterification of canola oil. In this respect, ZSM-5 zeolite has been selected as an appropriate support since it possesses a high specific surface area and noticeable porosity that can enhance physical contact between oil molecules and the catalyst. After synthesis of the catalyst, different characterization techniques including XRD, FESEM, BET, XRF and VSM were used to unravel physical and chemical features of the zeolite based materials. Then, the prepared

catalysts were applied to transesterification of canola oil to produce biodiesel. Furthermore, impacts of reaction time, catalyst amount and alcohol to oil molar ratio parameters on the process were investigated by Box-Behnken method. Optimization of the process gave maximum biodiesel yield of 93.65% at 65°C reaction temperature, 3.26h reaction time, 12.3 molar ratio of alcohol to oil and 9.03% catalyst loading. Moreover, magnetic property of the catalytic facilitated its separation from the reaction mixture. So that, the catalyst was removed after completion of the process by an external magnetic field and reused for five successive cycles. Acceptable yield (above 80%) was achieved for the first three cycles. In addition, the kinetics of the transesterification reaction was explored, which declared that the process obeys the behavior of pseudo-first order reactions with activation energy of 122.7kJmol−1 and frequency factor of 2.15×1017min−1.

- **Keywords:** Mesoporous; KOH/ZSM-5-Fe3O4; Biodiesel; Transesterification; Box-Behnken method

Izabella Dascalu, Simona Somacescu, Cristian Hornoiu, Jose M. Calderon-Moreno, Nicolae Stanica, Hermine Stroescu, Mihai Anastasescu, Mariuca Gartner. *Sol-gel Zn, Fe modified SnO2 powders for CO sensors and magnetic applications*. Pages 722-729.

Abstract: Zn, Fe modified SnO2 powders were prepared by sol-gel method using Tripropylamine as chelating agent and Polyvinylpyrrolidone K90 as dispersant and stabilizer. Two compositions were taken into account: Zn, Fe modified SnO2 – 20mol% Zn, 10mol% Fe and Zn, Fe modified SnO2 – 20mol% Zn, 30mol% Fe, denoted further as SZFe1and SZFe2 respectively. The properties and the influence of Fe amount on structure, morphology and surface chemistry, electrical and magnetic properties have been investigated. The X-ray diffraction analysis showed the formation of a polycrystalline mixture of cassiterite – SnO2, hematite – Fe2O3, franklinite – ZnFe2O4 and zincite – ZnO for the samples with different Fe content. The magnetization of SZFe2 sample was found to be composed of a ferromagnetic and a paramagnetic phase. The presence of Fe in the powders composition improved the electrical properties, demonstrating performant features in sensing characteristics (tested in CO gas concentrations varied from 50 to 1000ppm). The magnetic investigations suggest their possible future applications as soft magnetic materials.

- **Keywords:** Oxides; Sol-gel chemistry; Surface properties; Electrical properties; CO gas sensor

Md. Abdul Moktadir, Syed Mithun Ali, Simonov Kusi-Sarpong, Md. Aftab Ali Shaikh. *Assessing challenges for implementing Industry 4.0: Implications for process safety and environmental protection*. Pages 730-741.

Researchers and practitioners are giving significant attention to Industry 4.0 due to its numerous benefits to manufacturing organizations. Several aspects of Industry 4.0 have been studied in the literature. However, studies on the challenges for implementing Industry 4.0 in manufacturing operations have received less attention. To address this gap, this study identifies a set of challenges (framework) for implementing Industry 4.0 in manufacturing industries. This framework is evaluated in the leather industry of Bangladesh aided by a novel multi-criteria decision-making method named Best-Worst method (BWM). The findings of the study showed that 'lack of technological infrastructure' is the most pressing challenge that may hurdle the implementation of Industry 4.0 whereas 'environmental side-effects' is the less among the challenges that may hinder implementation of Industry 4.0 in the Bangladeshi leather industry. This result may help decision makers, industrial managers and practitioners in the

Bangladeshi leather industry to realize the actual challenges confronting them when attempting to implement Industry 4.0 and focus their attention on how to address these challenges to pave ways for a successful implementation of Industry 4.0.

- **Keywords:** Best worst method (BWM); Challenges; Environmental protection; Process safety; Industry 4.0; Internet of things (IoT); Leather industry; Smart technology