Process Safety and Environmental Protection

Rok 2020, Volume 144

December

Jianwei Liu, Xinyue Kang, Xueli Liu, Peng Yue, Jianbin Sun, Chen Lu. *Simultaneous removal of bioaerosols, odors and volatile organic compounds from a wastewater treatment plant by a full-scale integrated reactor.* Pages 2-14.

Biological control of odors and bioaerosols in wastewater treatment plants (WWTPs) have gained more attention in recent years. The simultaneous removal of odors, volatile organic compounds (VOCs) and bioaerosols in each unit of a full-scale integrated-reactor (FIR) in a sludge dewatering room was investigated. The average removal efficiencies (REs) of odors, VOCs and bioaerosols were recorded as 98.5 %, 94.7 % and 86.4 %, respectively, at an inlet flow rate of 5760 m3/h. The RE of each unit decreased, and the activated carbon adsorption zone (AZ) played a more important role as the inlet flow rate increased. The REs of hydrophilic compounds were higher than those of hydrophobic compounds. For bioaerosols, roughly 35 % of airborne heterotrophic bacteria (HB) was removed in the low-pH zone (LPZ) while over 30 % of total fungi (TF) was removed in the neutral-pH zone (NPZ). Most bioaerosols removed by the biofilter (BF) had a particle size larger than 4.7 μm while bioaerosols with small particle size were apt to be adsorbed by AZ. The microbial community in the BF changed significantly at different units. Health risks were found to be associated with H2S rather than with bioaerosols at the FIR outlet.

- **Keywords:** Odors; VOCs; Bioaerosols; Two-phase biofilter; Adsorption; Risk assessment

S.L Aravind, S.P. Sivapirakasam, K.R. Balasubramanian, M. Surianarayanan. *Thermo-kinetic studies on azodicarbonamide/potassium periodate airbag gas generants*. Pages 15-22.

In this study, thermal characterisation of stoichiometric azodicarbonamide/potassium periodate (C2H4O2N4/KIO4) fuel/oxidizer mixtures were systematically carried out for potential application as non azide non-toxic airbag gas generants. The onset temperature of the mixture was found to be 190°C. The thermo-kinetic studies of the mixture and pure azodicarbonamide compositions at different heating rates were also carried out using Ozawa and Kissinger method and the Arrhenius parameters were computed. The activation energy of the C2H4O2N4/KIO4 mixture by Ozawa method was found to be 81.5kJ mol−1 and 78.9kJmol−1 by Kissinger method. It was found that the activation energy of the pure azodicarbonamide was higher compared to the mixture. Ballistic tank tests to obtain the pressure Vs time plots were also done and the mixture gave time

response of 45.2ms and 55.54ms to peak pressure. The experimental results have shown that C2H4O2N4/KIO4 mixture can be used as a replacement to existing azide based airbag gas generant compositions. Thus, the paper attempts to thermally characterize a non-toxic C2H4O2N4/KIO4 airbag gas generant mixture which can replace toxic azide based airbag gas generants and thereby facilitate safer driving.

- **Keywords:** Azodicarbonamide; Airbag gas generants; DSC-TGA; Thermal decomposition kinetics; Ballistic tank testing; Process safety

Huemantzin B. Ortiz-Oliveros, Rosa Ma Flores-Espinosa. *Design of a mobile dissolved air flotation system with high rate for the treatment of liquid radioactive waste.* Pages 23-31.

The global trend towards sustainable development with low carbon emissions has encouraged the expansion of nuclear energy. The nuclear reactors, under normal operating conditions or radiological emergency, generate different types of radioactive waste, mainly liquids and solids that require efficient and mobile treatment systems. This work presents the design proposal of a mobile dissolved air flotation system (mDAF) with a high rate for the treatment of liquid radioactive waste generated in the attention and response to radiological post-emergencies of nuclear power plants or environmental emergency responses associated with oil spills. The evidence obtained showed that the design used allows to reach, under the conditions of the experiment tested, removal levels higher than 95 % in the concentrations of oil waste, SO4−2, NO3-, PO3-3, Ni and Cr. Removal levels of approximately 94 % and 75 % for the total Co and 60Co, respectively, were achieved. It was possible to demonstrate the feasibility of designing a mDAF of low cost with enough versatility to treat radioactive liquid waste generated in a radiological post-emergency.

- **Keywords:** 60Co; Dissolved air flotation; Oil waste; Radioactive waste; Radiological post-emergency

Yanjun Wang, Igor Plazl, Lamiae Vernières-Hassimi, Sébastien Leveneur. *From calorimetry to thermal risk assessment: γ-Valerolactone production from the hydrogenation of alkyl levulinates*. Pages 32-41.

The use of lignocellulosic biomass as a raw material can sustain the chemical industry. There is a lack of knowledge in kinetics and thermodynamics of some of these processes, making difficult the cost analysis. For instance, the thermodynamic investigation of the hydrogenation of alkyl levulinates to γ-valerolactone (GVL) is seldom. This system is a two-step reaction comprising a hydrogenation and cyclization step. The experimental measurement of the two reaction enthalpies is challenging, and a method was developed in this manuscript. The hydrogenation of methyl levulinate (ML) and butyl levulinate (BL) in the GVL solvent was found to be an exothermic step, and the cyclization an endothermic one. The reaction enthalpy for the hydrogenation of ML in the GVL solvent, calculated to -53.25kJ/mol, is higher than the one of BL in the GVL solvent, calculated to -38.66kJ/mol. The reaction enthalpies for the cyclization step are similar for ML and BL system, i.e., +7.00kJ/mol and +6.50kJ/mol, respectively. Hence, the hydrogenation step governs the reaction temperature. A thermal risk assessment based on experiments performed under adiabatic condition was done. The thermal risk was found to be medium for this reaction system under the operating conditions used in this study.

- **Keywords:** Reaction enthalpies; Calorimetry; Biomass valorization; Thermal risk; Kinetic modeling; γ-Valerolactone production

Pradip Saha, Thomas V. Wagner, Jiahao Ni, Alette A.M. Langenhoff, Harry Bruning, Huub H.M. Rijnaarts. *Cooling tower water treatment*

***using a combination of electrochemical oxidation and constructed wetlands*. Pages 42-51.**

A substantial part of the freshwater used in the industry is consumed in cooling towers. Cooling towers discharge saline cooling tower blowdown (CTBD), and the reuse of CTBD in the cooling tower can lower the industrial freshwater footprint. This reuse requires CTBD desalination and a pre-treatment that removes organic chemicals before physico-chemical desalination technologies to be applied efficiently. In the present study, the pre-treatment of CTBD by a combination of electrochemical oxidation (EO) with a boron-doped diamond (BDD) or mixed-metal oxide (MMO) anode and a vertical flow constructed wetland (VFCW) was assessed in both possible configurations. The integrated VFCW-EO systems removed more organic chemicals, such as COD, TOC, and the corrosion inhibitor benzotriazole than the EO-VFCW systems. However, the EO resulted in highly toxic effluent to Vibrio fischeri and the plants in the VFCW. This toxicity was the result of the production of unwanted chlorinated organic compounds and ClO3− and ClO4− by both the BDD- and MMO-anode during EO. These toxic EO by-products were removed substantially in the VFCW during EO-VFCW treatment but did impact the removal efficiency and viability of the VFCW. Moreover, significant water loss was observed in the VFCW due to evapotranspiration. In conclusion, the negative impact of EO effluent on the VFCW and evapotranspiration of the VFCW should be considered during application.

- **Keywords:** Boron-doped diamond anode; Mixed-metal oxide anode; Vertical-flow constructed wetland; Benzotriazole; Chlorinated by-products

Ahmed M.D. Al Ketife, Fares Al Momani, Simon Judd. *A bioassimilation and bioaccumulation model for the removal of heavy metals from wastewater using algae: New strategy*. Pages 52-64.

A mathematical model for bioassimilation (BS) combined with bioaccumulation (BC) has been conducted to determine the removal and recovery of heavy metals (HMs) from wastewater using green algae. Response Surface and Box Benken Methodology (BBM) combined with best-fit simulation were used to determine ultimate uptakes. Results revealed that the percentages of HM removal (% RE r) and recovery (%HMc) are correlated with algal growth under the studied conditions. The developed mathematical model accurately predicts the % RE and HMc based on BS and BC mechanisms. Although the biosorption process exhibited higher metals uptakes than BS, the latter had a better affinity for the removal of different metals. The combined BS and BC mechanisms achieved 73 % and 69 % of Cu2+ and Pb2+removals, respectively, with the BC process is 6 folded higher than BS. Comparable percentage removal ~ 74 % was observed for Cd2+, with 99 % of the removal was based on BC. The %HMc from aqueous and solid phases out of the hydrothermal liquefaction (HTL) process was estimated at 56.5 %. Mathematical modeling of the combined BS with BC processes provides an efficient and robust tool for predicting and forecasting the performance of HMs removals and recovery via algae process.

- **Keywords:** Algae; Biosorption; Bioassimilation; Heavy metals; Mathematical model

Golshan Moradi, Sirus Zinadini, Laleh Rajabi. *Development of high flux nanofiltration membrane using para-amino benzoate ferroxane nanoparticle for enhanced antifouling behavior and dye removal*. Pages 65-78.

In this work, para-amino benzoate ferroxane nanoparticle (PABFNP) was employed as a key functional nanoparticle to improve the polyethersulfone (PES) nanofiltration membrane, and PABFNPs blended with PES (PES/PABFNPs) nanofiltration membranes

were thus prepared via phase inversion method. PABFNPs may have good compatibility with PES polymer due to intermolecular attractions including hydrogen bonding between −OH and −NH2 of PABFNPs with SO of PES. Therefore, the stable bonding between hydrophilic PABFNPs and PES leads to PES nanofiltration membrane of exceptionally high performance. The effects of PABFNPs blending ratio on the chemical structure, hydrophilicity, surface morphology, zeta potential, and antifouling behavior of the membrane samples were evaluated. The salt rejection of the PES/PABFNPs membranes was also examined. With an increase in PABFNPs blending ratio up to 0.25wt.% with PABFNP0.25 membrane, surface hydrophilicity and pure water flux were strongly increased and then decreased owing to the agglomeration of PABFNPs in the PES matrix. PABFNP0.25 membrane was found to have the lowest irreversible fouling ratio of 1 %, the highest flux recovery ratio value of 99 % and excellent long-term pH stability. The pure water flux of PABFNP0.25 membrane was 64.2kg/m2h with a high rejection for dye (99 % for Direct Red 16 and 98.42 % Methylene blue). Moreover, the algal dye rejection test was carried out to investigate the rejection performance of the PES/PABFNPs membranes towards the mixture of pollutants. As a result, by addition of PABFNPs at lower blending ratio, the membrane with satisfying antifouling behavior, long-term pH stability, and nanofiltration performance was prepared.

- **Keywords:** Nanofiltration; Antifouling; Nanoparticle; Para-amino benzoate ferroxane; Dye removal

Zhichao He, Wenguo Weng. *A dynamic and simulation-based method for quantitative risk assessment of the domino accident in chemical industry*. Pages 79-92.

A domino accident is a typical multi-hazard coupling disaster in the chemical industry that often has serious consequences and social impact. The quantitative risk assessment of domino accidents faces several difficulties caused by their complexity, unpredictability, and synergic effects. This paper proposes a new method for quantitative risk assessment of domino accidents in the chemical industry based on field theory and Monte Carlo simulation. The method is intended to obtain the dynamic distribution of the individual risk caused by the domino accident. Monte Carlo simulation is used to account for all accident scenarios and to calculate the average risk distribution. The application of field theory enables the consideration of the synergic effects. To evaluate the efficacy of the assessment method, a typical domino scenario in a chemical plant in Yancheng, China, is taken as a case study. The results show that domino accidents consist of three stages: rapid development stage, stabilization stage, and weakening stage. The risks of fire, explosion, and toxic releases also have different distribution characteristics: flat, peak, and slope. The results also show that the risk of domino accidents increases due to the synergic effects of physical effects and human vulnerability. The new risk assessment method can provide guidance for the prevention, mitigation, and risk management of domino accidents in the chemical industry.

- **Keywords:** Domino accident; Monte Carlo simulation; Synergic effects; Chemical industry

Zheng Shen, Yibiao Yu, Ke Wang, Chang Yue, Jia Miao, Meng Xia, Minyan Gu, Yalei Zhang. *Hydrothermal alkaline conversion of actual acrylonitrile wastewater to organic acids*. Pages 93-99.

Acrylonitrile wastewater is a kind of highly toxic industrial wastewater, but it contains a lot of valuable chemical materials. In this study, by using the most promising hydrothermal technology, we investigated the best reaction conditions and possible reaction pathways for the conversion of the three nitriles (acrylonitrile, acetonitrile, and succinonitrile) to organic acids under alkaline hydrothermal conditions. Then, the reaction conditions for the conversion of actual acrylonitrile wastewater to organic acids were

further optimized. The actual wastewater of acrylonitrile was converted into 1.33×104 mg/L acrylic acid, 1.98×104 mg/L formic acid and 9.40×103 mg/L acetic acid at optimal reaction conditions (reaction temperature 300 °C, reaction time 90 s, and initial NaOH concentration 1.0 mol/L). It is the theoretical basis of the application of the hydrothermal alkali-catalyzed method in the acrylonitrile wastewater resource engineering.

- **Keywords:** Acrylonitrile wastewater; Alkaline hydrothermal conditions; Organic acid; Resource

A. Puga, E. Rosales, M. Pazos, M.A. Sanromán. *Prompt removal of antibiotic by adsorption/electro-Fenton degradation using an iron-doped perlite as heterogeneous catalyst*. Pages 100-110.

In the current study, a novel-fangled sequential approach, adsorption/electro-Fenton, was developed for the elimination of micropollutants from aqueous matrixes. Therefore, the prompt removal of a pharmaceutical, sulfamethizole, by adsorption on carbonaceous materials is proposed. After that, the concentrated solution was treated by electro-Fenton using novel synthesized perlite-based catalyst. Initially, three different carbonaceous adsorbents (pellets carbonaceous nanogel doped with iron, honeycomb carbonaceous aerogel and orange biochar) were considered. The kinetics and isotherms of the pollutant adsorption were studied. The higher removal level was attained by the pellets with the adsorption process following a pseudo-2nd order model and being well defined by the Langmuir adsorption isotherm. After that, the pollutant was extracted from the pellets, concentrated in aqueous solution and treated by different advanced oxidation processes (anodic oxidation and electro-Fenton process). The results confirmed the higher efficiency of electro-Fenton treatment and its improvement was evaluated using a novel synthesized iron perlite catalyst. For this purpose, the synthesis of iron catalysts supported in perlite was performed by different methods (carbonisation, precipitation and hydrothermal). Among them, the hydrothermal synthesis produced catalysts with high catalytic activity, significant pollutant removal (>95 %), high stability and without iron leaching after several cycles of treatment. Based on these results, the development of a continuous treatment system was successfully carried out attaining high TOC removal values. Moreover, the feasibility of the treatment was also validated in complex water matrixes and toxicity assays demonstrated the viability of the proposed treatment for a global management of this pollutant.

- **Keywords:** Adsorption; Heterogeneous catalyst; Electro-Fenton; Continuous treatment; Perlite

Yifan Wang, Wenchao Gao, Hao Zhang, Lingyu Shao, Zhicheng Wu, Lianming Li, Deshan Sun, Chenghang Zheng, Xiang Gao. *Enhanced particle precipitation from flue gas containing ultrafine particles through precharging*. Pages 111-122.

The collection performance of wet electrostatic precipitators (ESPs) considerably deteriorates in the presence of ultrafine particles, which confer difficulties in realizing the ultra-low emission of particulate matter (PM). In this work, the use of a wet ESP combined with a perforated precharger was proposed to investigate its electrical and collection characteristics in flue gas containing ultrafine particles and compared these characteristics with those of the common wet ESP. Results indicated that the distributions of ion density and electric field were affected by ultrafine particle loadings. With increased PM0.1 concentration from 0 mg/m3 to 100 mg/m3, the average ion density of the common wet ESP decreased by more than two orders of magnitude. Meanwhile, the particle charging and transport performance deteriorated, even for large particles (10 μm), and migration velocity sharply decreased by more than 85 %. The corona

electrostatic field was significantly improved by installing the precharger. The combined wet ESP can be operated well even under problematic conditions. Additional electrons were generated by the corona discharge of the precharger, which contributed to subsequent particle capture. When the applied voltage of the precharger exceeded 15 kV, the electrostatic precipitation of 1 μm particles only slightly weakened with increased PM0.1 concentration to 40 mg/m3, and the capture of >5 μm-diameter particles was nearly unaffected by ultrafine particles.

- **Keywords:** Electrostatic precipitator; Simulation; Ultrafine particle; Particle charging; Precharger

Yawei Lu, Zhirong Wang, Trent Parker, Rongrong Yang, Shuoxun Shen, Peipei Sun, Qingsheng Wang. *Experimental studies on influencing factors of stress corrosion in rectifying column*. Pages 123-132.

Stress corrosion is the main factor that results in corrosion and fractures of rectifying columns in the process industries. Stress corrosion of rectifying columns can result in significant economic losses to chemical industries, while also having a major impact on the quality of products produced, particularly polysilicon. This gives rise to the need for research involving stress corrosion of rectifying columns. Corrosion coupons, including those with welds and bends, were used to simulate various stress conditions of stainless steel. For the experiments, a 1.5 wt.% hydrochloric acid and 2.5 wt.% sodium chloride solution was prepared to simulate realistic working conditions for the steel. The experimental methods include static coupon experiment, electrochemical experiment, scanning electron microscope and X-ray diffraction. The corrosion products of the coupons consisted mostly of grey-green materials with loose surface layers and small amounts of black matter. The corrosion products were confirmed to be FeCl2 and Fe2O3, and the corrosion degree of the bent 20° coupon was found to be greater than that of other types of coupons. Under low temperature conditions, the corrosion rate of the coupons initially decreased over time before increasing and then decreasing again. At high temperatures, the corrosion rate began to decrease earlier than at low temperatures. The bending tendency of the 20° hanging piece was the greatest and that of the 30° hanging piece was the smallest. Higher temperatures promoted stress corrosion, with increases in temperature resulting in more significant corrosion effects. The results reported herein provide a theoretical basis and technical guidance for important anticorrosion and safety designs for distillation columns to be used in the semiconductor polysilicon rectification process.

- **Keywords:** 316 L stainless-steel; Stress corrosion cracking (SCC); Corrosion rate; Corrosion morphology; Corrosion product; Temperature effects

P. Costamagna, M. Delucchi, G. Busca, A. Giordano. *System for ammonia removal from anaerobic digestion and associated ammonium sulfate production: Simulation and design considerations*. Pages 133-142.

A side-stream ammonia stripping system coupled with a full-scale anaerobic digestion plant is considered. The system is based on an ammonia stripping unit (thin film evaporator, TFE), a Venturi scrubber and a reactive absorption column. A portion of the sludge treated in the digesters is continuously withdrawn and transferred to the TFE, where ammonia is stripped through a biogas stream. The ammonia rich biogas is then treated with a sulfuric acid/water solution in the Venturi scrubber and in the absorption column, with production of an ammonium sulfate solution, which is stored in a tank until utilization as a fertilizer. The aim of this paper is to provide a comprehensive engineering framework supporting the design of a full-scale ammonia stripping system with associated ammonium sulfate production, to be coupled with pre-existing anaerobic digestion plants. On the one hand, an analytical equation is proposed for the simulation of ammonia desorption and the design of the ammonia stripping unit as a function of the

selected operating conditions of flowrate, temperature and pH. On the other hand, corrosion issues affecting the storage tank are studied. Corrosion tests, carried out on a selected paint system, demonstrate no development of coating degradation or disbonding, even if local damage occurs in the film. Thus, guidelines to avoid corrosion are given.

- **Keywords:** Ammonia stripping; Ammonium sulfate; Anaerobic digestion; Biogas; Modeling; Thin film evaporator

Qingwei Bu, Qingshan Li, Yibo Cao, Hongmei Cao. *A new method for identifying persistent, bioaccumulative, and toxic organic pollutants in coking wastewater*. Pages 158-165.

Coking wastewater contains various priority organic pollutants of critical environmental and public health concern owing to their persistent, bioaccumulative, and toxic (PBT) properties. Considering the large amount of coking wastewater that is produced, it is crucial to establish a PBT list that can offer priority targets for monitoring and management. In this study, we developed a new ranking method and applied it to the situation of China. One hundred and thirty-one PBT organic pollutants were identified from 779 candidates found in coking wastewater. Among them, approximately two-thirds (67 %) of the PBT organic pollutants were polycyclic aromatic hydrocarbons (PAHs) and their alkyl substitutes. Furthermore, 80 % of the candidate PAHs were identified as the priority PBTs, indicating that PAHs from coking wastewater should be more concerned for environmental management and scientific research. The results of this new method were compared with conventional screening methods and related studies, indicating that the newly developed screening method presented here is more flexible.

- **Keywords:** Identification; Ranking; PBTs; POPs; Coking wastewater

Jie Hou, Wen-mei Gai, Wu-yi Cheng, Yun-feng Deng. *Prediction model of traffic loading rate for large-scale evacuations in unconventional emergencies: A real case survey*. Pages 166-176.

In large-scale regional evacuation, public pre-evacuation time estimation is an important link of evacuation analysis and emergency management. This paper redefines the concept of "pre-evacuation time" based on the characteristics of unconventional emergencies. A new prediction model of traffic loading rate for large-scale evacuations based on a real case survey was proposed. The model takes into account two groups of people who have received evacuation order/message (EOM) and have not received EOM. The analysis shows that the probability distributions of the pre-evacuation times of those who received and did not receive an EOM conform to Weibull distributions. The earlier the EOM is received, the shorter the average pre-evacuation time of the people is. At the same time, to further study the characteristics of the pre-evacuation time of the evacuating population, the distribution of the pre-evacuation time is discussed from three aspects: the time of receipt of the EOM, the source of EOM, and the channels of receipt of the EOM. The new model and method can more accurately estimate the loading rate of evacuation traffic flow in large-scale evacuation when the public cannot be accurately informed of the EOM time.

- **Keywords:** Emergency evacuation; Decision-making; Pre-evacuation time; Unconventional emergencies; Diffusion of EOM; Toxic-cloud releases

Daniela Sanches de Almeida, Leila Droprinchinski Martins, Edvani Curti Muniz, Anderson Paulo Rudke, Rafaela Squizzato, Alexandra Beal, Paulo Ricardo de Souza, Daniela Patrícia Freire Bonfim, Mônica Lopes Aguiar,

Marcelino Luiz Gimenes. *Biodegradable CA/CPB electrospun nanofibers for efficient retention of airborne nanoparticles*. Pages 177-185.

The increase of the industrialization process brought the growth of pollutant emissions into the atmosphere. At the same time, the demand for advances in aerosol filtration is evolving towards more sustainable technologies. Electrospinning is gaining notoriety, once it enables to produce polymeric nanofibers with different additives and also the obtaining of small pore sizes and fiber diameters; desirable features for air filtration materials. Therefore, this work aims to evaluate the filtration performance of cellulose acetate (CA) nanofibers and cationic surfactant cetylpyridinium bromide (CPB) produced by electrospinning technique for retention of aerosol nanoparticles. The pressure drop and collection efficiency measurements of sodium chloride (NaCl) aerosol particles (diameters from 7 to 300 nm) were performed using Scanning Mobility Particle Sizer (SMPS). The average diameter of the electrospun nanofibers used was 239 nm, ranging from 113 to 398 nm. Experimental results indicated that the nanofibers showed good permeability (10−11 m2) and high-efficiency filtration for aerosol nanoparticles (about 100 %), which can include black carbon (BC) and the new coronavirus. The pressure drop was 1.8 kPa at 1.6 cm s-1, which is similar to reported for some high-efficiency nanofiber filters. In addition, it also retains BC particles present in air, which was about 90 % for 375 nm and about 60 % for the 880 nm wavelength. Finally, this research provided information for future designs of indoor air filters and filter media for facial masks with renewable, non-toxic biodegradable, and potential antibacterial characteristics.

- **Keywords:** Nanofiber; Indoor air filtration; Nano-and microparticles retention; Air pollution

Liming Yuan, Tom Dubaniewicz, Isaac Zlochower, Rick Thomas, Naseem Rayyan. *Experimental study on thermal runaway and vented gases of lithium-ion cells*. Pages 186-192.

Lithium-ion (Li-ion) batteries have become more prevalent in mining to power a wide range of devices from handheld tools to mobile mining equipment. However, the benefits associated with using Li-ion batteries may come with a higher risk of a fire or an explosion. The major cause for a Li-ion battery fire is thermal runaway. If unmitigated, a thermal runaway can lead to cell rupture and the venting of toxic and highly flammables gases. Those flammable gases can cause a fire or explosion if ignited. In this study, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted experiments to monitor the heating of a Li-ion cell with different battery chemistries using an accelerating rate calorimeter (ARC). Inside the ARC, the cell was exposed to increasing temperatures until it reached a thermal runaway. Samples of vented gases after the thermal runaway were collected and analyzed using a gas chromatograph. Major gas components were identified, and their concentrations were measured. The results of this study can be useful in reducing the hazard of Li-ion battery fires.

- **Keywords:** Lithium-ion battery; Temperature; Thermal runaway; Flammable gases

Bruno José Chiaramonte de Castro, Rafael Sartim, Vádila Giovana Guerra, Mônica Lopes Aguiar. *Hybrid air filters: A review of the main equipment configurations and results*. Pages 193-207.

Electrostatic precipitators and bag filters are traditionally used to separate particulate matter from gas streams. The combination of these two technologies originated the hybrid filters. Several configurations of hybrid filters were developed in the last three

decades, mainly for application in the treatment of flue gas from coal-fired power plants. Two of them stood out for the amount of applications and works that intended to study them: the Compact Hybrid Particulate Collector (COHPAC) and the Advanced Hybrid Particulate Collector (AHPC). This paper aimed to present the characteristics of these two constructions and to review the main results of hybrid filtration performance obtained in laboratory tests and industrial applications. The two configurations proved to be efficient both for the collection of particulate matter, particularly of submicron particles, and for the removal of mercury and heavy metals. In general, the pressure drop in hybrid filters is lower than in conventional bag filters, while the cycle length and the lifespan of the bags are longer. However, in some cases, the formation of dense cakes on the surface of the bags may suppress the advantages of using hybrid devices.

- **Keywords:** Hybrid filters; Filtration efficiency; Collection efficiency; Gas filtration; Particulate matter; Submicron particles

Mina Kheirtalab, Reza Abedini, Mohsen Ghorbani. *A novel ternary mixed matrix membrane comprising polyvinyl alcohol (PVA)-modified poly (ether-block-amide)(Pebax®1657)/graphene oxide nanoparticles for CO2 separation*. Pages 208-224.

A novel ternary mixed matrix membrane (MMM) with different amounts of filler loading (2, 4 and 6 wt.%) was fabricated, in which the synthesized Graphene Oxide (GO) nanoparticles incorporated into a polyvinyl alcohol (PVA) modified poly (ether-block-amide) (Pebax®1657). PVA as an affordable additive provides a suitable affinity to separate CO2. Moreover, the presence of GO within the Pebax matrix causes an extra intermolecular space which enhances the CO2 permeability through the MMMs. In this study, pure Pebax membrane was modified via adding different amounts of PVA (0–20 wt. %). The results showed that the CO2 permeability increased from 79.42 barrer (for neat Pebax) to 81.24 barrer (for Pebax/PVA (10 wt.%)) and 90.7 barrer (for Pebax/PVA(15 wt.%)) and also the CO2/CH4 selectivity increased from 12.37 (for neat Pebax) to 16.41 (for Pebax/PVA (10 wt%). Furthermore, the CO2/N2 selectivity dramatically increased (from 36.93 for neat Pebax to 74.34 for Pebax/PVA(15 wt.%) at the pressure of 2 bar and temperature of 30 °C. The synthesized GO nanoparticles were incorporated (2, 4 and 6 wt. %) into the both Pebax/PVA(10 wt.%) and Pebax/PVA(15 wt.%) matrix to fabricate the Pebax/PVA/GO MMMs. The results showed that the Pebax/PVA (10 wt.%)/GO (6 wt.%) with the CO2 permeability of 236.48 barrer and CO2/CH4 selectivity of 33.63 and also Pebax/PVA(15 wt.%)/GO (6 wt.%) with CO2 permeability of 228.34 barrer and CO2/N2 selectivity of 124.09 implied the best performance among all the prepared membranes for CO2/CH4 and CO2/N2 separation, respectively. The Pebax/PVA/GO MMM indicates promising applications in CO2 separation processes.

- **Keywords:** Pebax®1657; PVA; Graphene oxide; Ternary mixed matrix membrane; Gas; Separation

Ching-Shih Lin, Kuo-Lun Tung, Yi-Li Lin, Cheng-Di Dong, Chiu-Wen Chen, Chung-Hsin Wu. *Fabrication and modification of forward osmosis membranes by using graphene oxide for dye rejection and sludge concentration*. Pages 225-235.

In this study, the preparation procedures for the polysulfone (PSf) substrate and polyamide (PA) selective layers were systematically investigated to determine their effects on the separation performance of thin-film composite (TFC) forward osmosis (FO) membranes in terms of the permeate flux (Jw) and reverse solute flux (Js). Furthermore, the PA active layer was modified by adding different proportions of an emerging material, graphene oxide (GO), to increase Jw and decrease Js. The experimental results indicated

that special attention should be paid to the preparation of the PSf casting solution, which required thorough degassing, sealing, and humidity and temperature control. The optimum casting height was discovered to be 175 μm. For PA layer formation, the same amount of polymer solutions (resulting thickness of 78.5 μm) on the top surface of the PSf substrate (on the side facing the water during phase inversion) resulted in the highest FO performance. GO modification of the PA layer at the dosage of 0.0175 wt% considerably enhanced Jw to 14 L m−2 h−1 and reduced Js to 0.23 mol m−2 h−1. However, higher GO dosage (0.02 wt%) led to lower membrane performance due to aggregation of GO nanoparticles, as confirmed using scanning electron microscopy. Next, the prepared membranes were applied to dye rejection and sludge concentration for water recovery. The virgin and modified FO membranes both exhibited high rejection efficiency (≥96.0 %) for dyes commonly used in the textile industry. The 0.0175 %-GO-modified FO membrane exhibited a higher concentration factor (1.67) and greater water recovery (40.0 %) than the virgin membrane (1.45 and 31.2 %, respectively). Therefore, the application of FO for water recovery is economic and environmentally friendly in terms of saving the transportation cost of sludge disposal while recovering water for reuse in wastewater treatment plants.

- **Keywords:** Forward osmosis; Polyamide membrane modification; Interfacial polymerization; Phase inversion; Dye rejection; Sludge concentration

Biplob Kumar Pramanik, Rajeev Roychand, Sirajum Monira, Muhammed Bhuiyan, Veeriah Jegatheesan. *Fate of road-dust associated microplastics and per- and polyfluorinated substances in stormwater*. Pages 236-241.

Emerging contaminants such as microplastics (MPs) and per- and polyfluorinated substances (PFAS) in the water environment have been documented as the major environmental threat due to their negative impact on the ecosystem. Road dust has been recognised as a potential source of these emerging pollutants in stormwater which are eventually released into open water bodies. The aim of this study was to identify the existence of MPs and PFAS in Australian road dust and stormwater samples. We found that different MP types such as polyethylene, nylon, polyester and cotton were identified in the stormwater samples. The main type of MPs in stormwater was microfibres which accounted for more than 50 %. It was also found that PFAS was detected in Australian road dust from industrial and heavily trafficked areas. Although there was no PFAS in stormwater in the selected industrial and heavy traffic study area, they can be found in airport and defence sites. This study indicated that road dust acts as the potential origin of MPs and PFAS in urban stormwater runoff.

- **Keywords:** Road dust; Stormwater; Microplastics and per- and polyfluorinated substances

Xiaoxue Guo, Jie Ji, Faisal Khan, Long Ding. *Fuzzy bayesian network based on an improved similarity aggregation method for risk assessment of storage tank accident*. Pages 242-252.

Fuzzy Bayesian network (FBN) has been widely used for risk assessment of accidents in process industries to deal with complex causality and uncertainty arise from complex interdependence among risk factors, insufficient data and complex environment. The similarity aggregation method (SAM) is a method of aggregating fuzzy opinions considering consensus degree. However, SAM does not take into account the deviations caused by individual differences in dealing with consistency, which will bring a certain degree of uncertainty. Therefore, this work proposes an improved SAM based FBN model to better deal with various types of uncertainty. This methodology makes the prediction results of the storage tank accident more accurate and reliable. The result analysis

indicates that the improved SAM is of significance to improving the reliability of the input data of FBN. Then, the critical analysis of the root node shows the effectiveness and reliability of FBN in identifying the critical events of the storage tank accident. The proposed method can predict the probability of storage tank accidents, determine the proportion of main contributing factors and identify the critical causes of storage tank accidents more reliably and accurately. It can provide important supporting information for decision makers to optimize risk management strategies.

- **Keywords:** Fuzzy bayesian network; Similarity aggregation method; Storage tank

Shaona Wang, Rongfang Yuan, Huilun Chen, Fei Wang, Beihai Zhou. *Effect of sulfonamides on the dissolved organic matter fluorescence in biogas slurry during anaerobic fermentation according to the PARAFAC analysis*. Pages 253-262.

The biogas slurry produced by anaerobic fermentation process contained a large amount of dissolved organic matter (DOM). In this study, the reason for the effect of sulfanilamide antibiotics (SAs) on DOM components was revealed by analyzing the interaction between microbial community structure and DOM composition in the biogas slurry. Four components of DOM, including tyrosine-like, tryptophan-like or xenobiotic-like, Ultraviolet A (UVA) humic-like and UVA marine humic-like substances, were identified from all the samples through fluorescence excitation emission matrix-parallel factor (EEM-PARAFAC) analysis. The most abundant phyla in biogas slurry were identified to be Firmicutes (60.99 %), Bacteroidetes (19.65 %), Proteobacteria (15.33 %) and Actinobacteria (3.15 %). The contents of soluble microbial byproduct-like substances were related to the growth and metabolism of high abundance of bacterial phyla. Firmicutes could lead to the content change of tyrosine-like substance. The content of the xenobiotic-like substance was negatively correlated with the abundances of Bacteroidetes and Proteobacteria. The addition of high concentration SAs inhibited the growth and reproduction of Firmicutes, resulting in the decrease of the content of tyrosine-like substance. The addition of 100 mg/L sulfaquinoxaline and sulfamethoxydiazine reduced the content of tyrosine-like by 47.5 % and 41.2 %, respectively. The change of tryptophan-like groups was opposite to that of the tyrosine-like. However, the addition of sulfamethoxazole had little effect on the content of all the abovementioned substances.

- **Keywords:** Biogas slurry; Sulfonamide antibiotics; EEM-PARAFAC; Dissolved organic matter; Microbial community structure

Brady Manescau, Léo Courty, Lahna Acherar, Bruno Coudour, Hui-Ying Wang, Jean-Pierre Garo. *Effects of ventilation conditions and procedures during a fire in a reduced-scale room*. Pages 263-272.

This paper deals with the consequences of applying ventilation procedures during confined fires. If the air intake duct is closed after the beginning of the fire, another risk may appear, namely the ignition of unburnt gases in extraction ducts. This configuration is typical of many industrial installations equipped with ventilation networks. Heptane and dodecane pool fires were performed in a reduced-scale compartment equipped with a mechanical ventilation network. Heat release rate, temperatures and unburnt species concentration were measured for different pan diameters, different ventilation flows, with and without closing the intake duct, to study fire development and the potential risk of ignition in the exhaust system. Empirical correlations to estimate unburnt species concentrations are given. Based on these correlations, lower flammability limit calculations and scaling laws, a risk assessment methodology is proposed and a decision support tool is provided. Experimental results clearly show that the auto-ignition of unburnt gases can happen near the extraction duct, with and without closing the intake duct.

- **Keywords:** Compartment fire experiments; Underventilation; Ignition risk assessment; Species concentration; Ventilation procedures

Nai-Yun Zheng, Mengshan Lee, Yi-Li Lin, Bharath Samannan. *Microwave-assisted wet co-torrefaction of food sludge and lignocellulose biowaste for biochar production and nutrient recovery*. Pages 273-283.

Microwave-assisted wet co-torrefaction of food sludge (FS) and six widely produced lignocellulose biowaste samples were performed for biochar production. Factors including the torrefaction temperature, reaction time, biowaste type, and blending ratio of sludge and biowaste were evaluated. Biochar produced from FS torrefied at 150 °C for 20 min exhibited the greatest enhancement of carbon content and higher heating value (HHV). Blending sludge with macadamia husk at a ratio of 25/75 (db%) under the same wet torrefaction condition further improved biochar quality, enhanced the fixed carbon content, caused the highest HHV (19.6 MJ/kg), and considerably decreased the ash content. Thermogravimetric analysis indicated that sludge and biowaste degradation followed first-order kinetics, and the resultant biochar exhibited improved thermal stability, combustion efficiency, and safety for biofuel applications because of the increase in the activation energy, frequency factor, and ignition and combustion temperatures. Biochar is an excellent coal substitute for power generation because of its enhanced energy efficiency (energy return on investment: 7.4) and environmental friendliness (45.2 % reduction in greenhouse gas emissions compared with using bituminous coal). Moreover, the protein and carbohydrate contents in the supernatant of FS co-torrefied with biowaste at different blending ratios increased by 1.8–9.0 and 0.8–3.4, respectively. These contents can be recycled back to the activated sludge unit as a nutrient source, rendering the process green and sustainable without any waste production.

- **Keywords:** Co-torrefaction; Microwave heating; Biochar; Thermogravimetric analysis; Kinetics; Nutrient recovery

Hao Wang, Enyuan Wang, Zhonghui Li, Rongxi Shen, Xiaofei Liu, Xiangyang Gao, Bing Li, Qiming Zhang. *Study on safety pressure of water jet breaking coal based on the characteristic analysis of electromagnetic radiation signal*. Pages 284-296.

Hydraulic flushing (HF), which uses water jet with high pressure to break coal, is widely used in the prevention and control of coal and gas (methane) outburst in coal mines. The key of HF technology is to determine the proper water pressure of water jet, otherwise, serious construction accidents will be induced during the period of water jet breaking coal. In this paper, coal, which is determined to be a typical piezoelectric material by the analysis the composition with X-ray diffraction method, can generate electromagnetic radiation (EMR) signal under external load because of the piezoelectric effect. Then, two mechanical stages of water jet breaking coal are analyzed theoretically to explore the relation between initial water pressure of water jet and EMR signal. Accordingly, a new method based on the analysis of EMR emitted from the deformation of coal under the action of water jet with different initial pressure is proposed to determine safe water pressure. The research results are as follows: (1) According to the field test, EMR has obvious regional characteristics. when the coal is impacted by water jet with safe pressure, maximum, average and frequency of EMR are more normal than that of invalid water pressure and dangerous water pressure;(2) From the perspective of coal rupture, the development of pores and fractures in the coal is fast and the macroscopic fracture scale, which is simulated in the same calculation steps, is large under the impact of water jet with safe pressure. Furthermore, the coal mass does not have a serious instability phenomenon, which means the suitability of safe water pressure;(3) The fractal characteristics of EMR frequency which can present nonlinear and self-similarity

characteristics of coal fracture process vary with pressure of water jet. When the initial water pressure of the water jet is safe, the value of the Δσ is smaller than that in invalid water pressure, but bigger than that in dangerous water pressure. This method has certain guiding significance for determining the safe water pressure of HF.

- **Keywords:** Hydraulic flushing; Water jet; Safe water pressure; Electromagnetic radiation; Coal rupture

Hao Huynh Nhut, Van Le Thi Thanh, Luu Tran Le. *Removal of H2S in biogas using biotrickling filter: Recent development*. Pages 297-309.

The presence of hydrogen sulfide (H2S) in biogas negatively affects human health and corrodes metal. Therefore, the removal of H2S from biogas before using is an essential requirement in many cases. Recently, biotrickling filters (BTFs) have been widely applied to the treatment of H2S on both laboratory and industrial scales. However, BTFs method also has some drawbacks such as low mass transfer efficiency, clogging the bed filter due to further elemental sulfur (S) excess accumulation, and biogas dilution. This paper reviews the recent development of aerobic BTF systems and solutions for those limitations during the H2S oxidation process in biogas. In addition, the factors affecting H2S removal efficiency, including sulfur-oxidizing bacteria, biofilm, packing material, pH, dissolved oxygen (DO), empty bed retention time (EBRT), ingredients of nutrients for the growth of bacteria, trickling liquid and gas velocity, are also discussed. Finally, the current strength of research in the field of H2S removal in biogas using BTF and its future prospects are also suggested. Some of highest elimination capacity (EC) of 78.57 g H2S/m3h, 144 g H2S/m3h, 228.6 g H2S/m3h were obtained from previous experiments.

- **Keywords:** H2S; Biotrickling filters; Mass transfer; Sulfur-oxidizing bacteria; Biofilm

Renan Alves Viegas, Francisco de Assis da Silva Mota, Ana Paula Cabral Seixas Costa, Francisco Francielle Pinheiro dos Santos. *A multi-criteria-based hazard and operability analysis for process safety*. Pages 310-321.

Multi-criteria Decision Making (MCDM) is widely used for problem-solving in various research fields and has shown good results in risk analysis as well. However, given the gaps found in previous studies in the context of risk analysis, this article proposes and conducts a novel MCDM-based HAZOP analysis: a hybrid methodology with an MCDM approach, Strategic Options Development and Analysis (SODA), and Intuitionistic Fuzzy Sets (IFS). We combine their advantages by using SODA with Intuitionistic Fuzzy Cognitive Maps and by reducing the inherent uncertainty and subjectivity of HAZOP with an IFS-based MCDM sorting algorithm. To demonstrate the usefulness and flexibility of this approach, a real application with a continuous pyrolysis system was conducted, and a comparative analysis was made of the main related studies to demonstrate the advantages of the approach now proposed. On applying it, 40 hazards were identified (seven more than a previous analysis conducted in 2016), and only 3 (7.5 %) of them required special attention. Among the positive points highlighted by the team, the most cited were the resource-saving, greater focus and objectivity, and a more realistic perception of hazards. In particular, we show that our methodology is more consistent and appropriate than those in previous related articles. To assist future users, we provide a framework for the application.

- **Keywords:** Risk analysis; HAZOP; Multi-criteria decision making; SODA; Intuitionistic fuzzy sets; Sorting problem

F.A. Essa, Mohamed Abd Elaziz, Ammar H. Elsheikh. *Prediction of power consumption and water productivity of seawater greenhouse system*

***using random vector functional link network integrated with artificial ecosystem-based optimization*. Pages 322-329.**

The seawater greenhouse desalination technology is a kind of desalination plant which simulates the water cycle through seawater evaporation and condensation into freshwater. A novel random vector functional link (RVFL) network integrated with artificial ecosystem-based optimization (AEO) algorithm is proposed to predict the performance of the seawater greenhouse (SWGH) system. Power consumption and water productivity of the SWGH are predicted using the proposed RVFL-AEO model. The statistical analyses using different statistical criteria such as root mean square error, mean absolute error, mean relative error, efficiency coefficient, coefficient of determination, overall index, and coefficient of residual mass are also carried out to examine the efficiency of the proposed neural network. The statistical tools obtained a perfect match between the experimental and the proposed model results. The performance of the RVFL-AEO model is compared with that of the conventional RVFL model. RVFL-AEO showed a better performance compared with RVFL; which indicates the role of AEO in obtaining the optimal RVFL parameters that enhances the accuracy of the model.

- **Keywords:** Seawater greenhouse; Artificial neural network; Desalination; Random vector functional link; Artificial ecosystem-based optimization

Ashish Ranjan Kumar, Steven Schafrik. *Multiphase CFD modeling and laboratory testing of a Vortecone for mining and industrial dust scrubbing applications.* Pages 330-336.

Dust exposure-related occupation diseases are irreversible and have led to debilitating outcomes in personnel. Particles like coal dust generated in mines and accumulated above a critical concentration are explosive. Fibrous type multi-layered filters are the primary dust particle capturing element in flooded-bed dust scrubbers. However, these filters get clogged due to prolonged dust accumulation. This paper investigates the interaction of dust, water, and airflow in CFD in a non-clogging Vortecone filter. The Vortecone accelerates the particle-laden fluid, forces it into rapid swirling fluid motion, and pushes particles to separate and capture them. Filter capture performance in several air and water quantities regimes with aerosol particles exceeding 2.0 μm from a coal-dust laden airstream is described here. Detailed computational fluid dynamics models mimicking steady-state flow regime and transient-state air-water interface motion are presented. Particle tracking and their capture on water film using volume of fraction approach to determine the cleaning efficiency for different particle sizes is presented. Experimental cleaning efficiency results obtained from iso-kinetic sampling and optical particle counting agree with the computer models. Laboratory tests run on the Vortecone showed coal-dust cleaning efficiency exceeding 75% for particles 2.8 μm in size and 90% for 4.7 μm for all airflows.

- **Keywords:** Dust scrubber; Optical particle counting; Computational fluid dynamics modeling; Cleaning efficiency; Multi-phase flows; Mining engineering

Minggao Yu, Xueyan Wang, Kai Zheng, Shixin Han, Chuandong Chen, Rongjun Si, Lei Wang. *Investigation of methane/air explosion suppression by modified montmorillonite inhibitor*. Pages 337-348.

Methane explosion threats the safety in mining, gas recovery and the related downstream industry. The present study examined the suppression effect of KHCO3 (K) modified montmorillonite (K/MMT) inhibitor on reducing the hazard of methane/air mixtures explosion. The characteristic indices of explosion containing the maximum pressure (Pmax), the maximum rate of pressure rise ((dP/dt)max), the time of pressure

peak arriving (tmax), were experimentally obtained in a standard 20 L explosion device. The hazard mitigating effect of each modified inhibitor was evaluated. which also elucidated the inhibition mechanism based on the characteristic parameters of K/MMT. Results showed that the K/MMT demonstrates better suppression effect than monomer inhibitor and the maximum decrease of Pmax (34.9 %) and (dP/dt)max (94.4 %) occurs when 45 wt% KHCO3 are loaded (45 wt%-K/MMT). When 45 wt%-K/MMT is used, 0.125 g/L is the optimal concentration to decrease KG to a minimum of 0.849 MPa m/s. This work presents an efficient modified inhibitor by using innovative technology, which is applied to mitigate or prevent disaster. The technology also provides theoretical support and technical guidance for the future development of inhibitors.

- **Keywords:** Montmorillonite; Methane explosion; Inhibitors; Suppression characteristics

Mohammad Heidari, Maryam Tahmasebpoor, Andy Antzaras, Angeliki A. Lemonidou. *CO2 capture and fluidity performance of CaO-based sorbents: Effect of Zr, Al and Ce additives in tri-, bi- and mono-metallic configurations*. Pages 349-365.

The Calcium-looping (CaL) technology is based on the reversible carbonation reaction of CaO with CO2 and has been developing rapidly as a potential low cost process for post-combustion CO2 capture. One of the main challenges of CaL process, is the identification of CaO-based sorbents that can maintain their activity in multiple cycles and have proper fluidization. The present study focusses on the influence of Zr, Al and Ce additives in mono-, bi- (Zr/Ce, Zr/Al and Al/Ce) and tri-metallic (Zr/Al/Ce) configurations on the performance of synthetic CaO-based sorbents. The developed sorbents presented a substantially improved performance over multiple cycles compared to limestone-derived CaO, due to the formation of stable, mixed Ca-inert phases. Incorporation of Al, Al/Ce and Zr/Al/Ce in CaO structure led to the development of sorbents with small crystallites and porous morphology, resulting in improved stability with less than 25 % deactivation after 50 cycles. The enhanced stability of the Zr/Al/Ce-promoted sorbent was attributed to the formation of CaZrO3 and Ca3Al2O6 mixed phases in the CaO matrix, providing a porous and stable structure. The fluidizability of the most promising sorbents was also investigated. SiO2 nanoparticles were mechanically mixed with the sorbents in different fractions to improve their fluidization performance. A minimum amount of 15 wt% SiO2 was required in order to achieve a completely smooth and homogeneous fluidization without gas channeling, bubbles or even fine agglomerates. The highest bed expansion, accompanied by a high Richardson-Zaki index n (5.9) and low Umf (2.2 cm/s) were obtained with a Ca/Zr/Al/Ce +15 wt% SiO2.

- **Keywords:** Calcium looping; CO2capture; CaO-based promoted sorbents; Fluidization agent

Rong Wang, Qiuling Yan, Pengxin Su, Jiancheng Shu, Mengjun Chen, Zhengxue Xiao, Yubin Han, Zhiqiang Cheng. *Metal mobility and toxicity of zinc hydrometallurgical residues*. Pages 366-371.

About 80 % of zinc is produced by "roasting-leaching-purifying-electrodeposition". Lead-silver and jarosite residues are generated during this process, posing a serious threat to the ecosystem and environment since it contains a lot of heavy metals such as Pb. To better understand metal mobility and toxicity of these two zinc hydrothermal residues, it was analyzed by standard leaching toxicity procedures, bioavailability test and sequential extraction procedures. The results showed that the main phases of lead-silver and jarosite residues are KFe3(SO4)2(OH)6, CaSO4·2H2O, PbSO4, Fe3O4 and ZnFe2O4. These two residues contain a high content of Fe, Pb and Zn and also a significant amount of precious metals, such as Ag and In, showing a great resource potential. Meanwhile,

lead-silver and jarosite residues are classified as hazardous waste both in China and the USA since their toxicity leaching concentration of Cd, Pb and Se exceeds the threshold of 1, 5 and 1 ppm. Metals contained in these two residues could easily be released to the environment, especially Cd, Pb and Zn, though metals are mainly in the form of residual, higher than 85 %. In addition, lead-silver and jarosite residues also show a significant biohazardous potential since EDTA and DTPA extractable Zn, Pb, Mn, Cd, Cu and As of these two residues are considerably high. All these results could help the zinc manufactories, governments and also the recycling companies better understand the risk of zinc hydrometallurgical residues and urge them to hind this harm to the ecosystem, and most importantly the human being itself.

- **Keywords:** Lead-silver residues; Jarosite residues; Metal mobility; Bioavailability; Leaching toxicity