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The increasing occurrence of chemically resistant per- and poly-fluoroalkyl substances (PFASs) in the natural environment, animal tissues and even the human body poses a significant health risk. Temporal trend studies on water, sediments, bird, fish, marine mammal and the human show that the exposure of PFAS has significantly increased over the last 20–30 years. Different physical, biological and chemical treatment processes have been investigated for PFAS removal from water. However, there is a lack of detailed understating of the mechanism of removal by different methods, especially by different advanced chemical treatment processes. This article reviews PFASs removal efficacy and mechanism by the advanced chemical treatment methods from aqueous solution. Review shows that several advanced oxidation processes (e.g., electrochemical oxidation, activated persulfate oxidation, photocatalysis, UV-induced oxidation) are successful in degrading PFASs. Moreover, defluorination treatment, some thermal and non-thermal degradation processes are also found to be prominent for the degradation of PFASs with some limitations including process costs over physical treatment (e.g., sorption), production of toxic by-products and greenhouse gases. Finally, knowledge gaps concerning the advanced chemical treatment of PFASs are discussed.

- **Keywords:** PFAS; Advanced oxidation; Reduction; Photocatalysis; Wastewater treatment

Hao Wang, Enyuan Wang, Zhonghui Li, Xiaoran Wang, Qiming Zhang, Bing Li, Muhammad. Ali. *Study on sealing effect of pre-drainage gas borehole in coal seam based on air-gas mixed flow coupling model*. Pages 15-27.

The low gas extraction concentration is one of the main factors that affect the prevention and control effect of coal and gas outburst. Based on this, the factors of air leakage around the roadway and borehole are analyzed. The effect of extraction time, seal length and air leakage on the gas concentration is discussed by the fluid-solid coupling model, which is proved by the borehole environmental parameter instrument.The research findings show :(1) Influenced by roadway excavation and drilling, a large number of

cracks are created inside the coal around the roadway and the boreholes, which are the main air leakage channels for the air to flow from roadway into borehole; (2) Inside the borehole, the closer it is to the bottom of the borehole, the fewer the cracks in the coal seam, the higher the gas concentration. The critical point of air leakage in which the gas concentration is 100 % moves continuously to the bottom of the borehole with extraction time, until it is stable. The effective sealing length must exceed the position of critical point of air leakage; (3) The gas concentration is related to the sealing length and the amount of air leakage. Increasing the sealing length, and reducing the air leakage can greatly improve the extraction efficiency. Based on the above results, combined bag-type segmented grouting technique, which is to inject different sealing materials into different regions divided by the stress, is proposed to block the air leakage channel by comparing the crack characteristics of the coal surface in the abnormal stress zone and the normal stress zone by SEM technology. According to the field test results, the application of the new sealing technology blocks the crack channel, improves gas concentration and reduces the risk of coal and gas outburst. The results have important guiding significance for improving gas utilization rate, reducing greenhouse gas emission and enhancing safety in production.

- **Keywords:** Air leakage; Gas drainage; Sealing depth; Sealing technique

Mengjiao Gao, Bing Guo, Lei Zhang, Yingdi Zhang, Najiaowa Yu, Yang Liu. *Biomethane recovery from source-diverted household blackwater: Impacts from feed sulfate*. Pages 28-38.

Biomethane recovery from source-diverted blackwater through anaerobic digestion (AD) offers a sustainable alternative for modern wastewater treatment. Water-wasting conventional toilets consume great amounts of flushing water (9L per flush), which results in blackwater with chemical oxygen demand (COD) of 1006 (±61) mg/L and COD/sulfate ratio of 12.2 (±0.9). In this study, the conventional toilets collected blackwater was treated through an up-flow anaerobic sludge blanket (UASB) reactor at 35°C with a hydraulic retention time (HRT) of 2.2 days, which achieved a COD removal efficiency >80 %. Inhibition in blackwater methanogenesis was observed, which was found associated with the growth of hydrogen utilizing sulfate reducing bacteria (SRB) that competed with hydrogenotrophic methanogens and suppressed the biomethane recovery efficiency. The sludge specific hydrogenotrophic methanogenic activity (SMA [H2&CO2]) increased from 0.37 (±0.02) g CH4-COD/g volatile suspended solids (VSS)/d (treating high sulfate blackwater) to 0.52 (±0.00) g CH4-COD/g VSS/d (treating low sulfate blackwater) when sulfate-free toilet flushing water was adopted (resulting COD/sulfate ratio of 42.9 [±5.0]). This study underlines the importance of considering the impact of sulfate on blackwater methane production when designing future blackwater treatment processes.

- **Keywords:** Anaerobic digestion; Conventional toilet blackwater; Hydrogenotrophic methanogenesis; Sulfate reducing bacteria; Decentralized wastewater treatment

Hu Wen, Xiaojiao Cheng, Jian Chen, Chunru Zhang, Zhijin Yu, Zhenbao Li, Shixing Fan, Gaoming Wei, Bangkai Cheng. *Micro-pilot test for optimized pre-extraction boreholes and enhanced coalbed methane recovery by injection of liquid carbon dioxide in the Sangshuping coal mine*. Pages 39-48.

The extraction efficiency of high-gas coal seams is low in China with a large number of pre-drainage boreholes. In this study, we analyze the coal seam gas displacement mechanism using liquid carbon dioxide by combining theoretical analysis, experiments, and field tests. Changes of gas displacement efficiency with time under different

displacement flow and pressure conditions are determined. We propose a coalbed methane displacement method using liquid carbon dioxide and apply the model in a field test carried out in well No. 2 of the Sangshuping coal mine. The results show that the injection of liquid carbon dioxide in coal seams is a pressure swing adsorption process. The effective displacement radius from the in-situ tests reaches 20 m. The maximum CH4 extraction concentration in the test area is 65%, which is 2.41 times higher than that of the original coal seam (27%). The maximum methane extraction flux rate is 0.884 m3/min, which is 2.34 times that of original coal seam (0.377). Implementation of liquid carbon dioxide displacement coalbed methane technology optimizes borehole arrangement and enhances coalbed methane extraction.

- **Keywords:** Micro-pilot test; Liquid carbon dioxide; Pre-extraction borehole; Enhanced coalbed methane recovery; Sorption/desorption

Robert Zupko, Divya Kamath, Erica Coscarelli, Mark Rouleau, Daisuke Minakata. *Agent-Based model to predict the fate of the degradation of organic compounds in the aqueous-phase UV/H2O2 advanced oxidation process*. Pages 49-55.

Advanced oxidation processes (AOPs) are promising water treatment technologies used to destroy trace organic compounds. Yet, the inability to predict the degradation fate of trace organic compounds due to their diverse chemical structures and potential for transformation byproducts greatly limits AOP effectiveness. Current prediction methods are time consuming and discontinuous because they rely on conventional kinetic models that often require solving 'stiff' ordinary differential equations numerically. In this study, we present a novel approach to AOP degradation prediction that uses an agent-based model to represent the chemical entities of individual molecular species and to simulate the movement and reactions of these entities over time in a defined space. Predicted time-dependent concentration profiles of a parent test compound, acetone, and its transformation products in UV/H2O2 AOP are shown to be consistent with our experimental observations.

- **Keywords:** Agent-based modeling; UV/H2O2 advanced oxidation process; Fate of acetone degradation

Chunwang Yi, Ce Yang, Jie Li, Juan Chen, Shen Zhang, Huan Sun. *Agglomeration behaviour of caprolactam solution concentrates triggered by cyclic dimers in the recovery process: Characterisation, mechanism, and process optimisation*. Pages 56-65.

The cyclic dimer 1,8-diazacyclotetradecane-2,9-dione is one of the most important components of caprolactam solution concentrates and triggers significant agglomeration during the recovery process in industrial polyamide-6 plants. For this reason, the agglomeration behaviour and morphology changes of cyclic dimers in solution concentrates were investigated. Precipitates separated from an ~80wt.% solution concentrate were explored. Cyclic dimers aggregated in the solution concentrates at lower temperatures to form larger, thicker, and compacted structures or multi-layers structures. An appropriate increase in the solution temperature and addition of fresh caprolactam aid in avoiding agglomeration, but high temperatures (over 140 ℃) initiate the hydrolytic polymerisation of caprolactam in the solution concentrate, which aggravates blockages. Based on these results, an optimised process model is introduced to avoid aggregation.

- **Keywords:** Caprolactam concentrates; Cyclic dimer; Morphology evolution; Agglomeration; Structure; Optimal process model

Yanli Zhao, Jian Chen, Xiao Chen, Youjie Sheng, Shouxiang Lu, Shengfeng Luo, Jun Deng. *Influence of high atmospheric pressure on flame spread over electric wire at different inclinations*. Pages 66-75.

A series of experiments of the upward flame spread over polyethylene-coated wire with copper core were conducted in a newly designed high-pressure chamber to study the effects of the wire inclination angles and ambient pressures. The angle of inclination changed from 0° to 75° and the pressure ranged from 100kPa to 400kPa. The results show that the flame spread rate increases with the inclination angle and the pressure. The characteristic lengths including the flame length, the flame base width and the pyrolysis length present an increasing trend with increasing inclination angles, while the elevated pressure results in that the flame length and flame base width decreases and the pyrolysis length increases. Moreover, a simplified heat transfer analysis model considering the convective, radiant and conductive heat feedback is proposed to discuss the flame spread mechanism. Based on the theoretical analysis, convective heat transfer from flame and conductive heat transfer from wire core play significant roles in heating the unburned insulation with the increase of inclination angles. For the cases with higher pressure, the heat transfer from flame including heat convection and heat conduction plays a dominant role in increasing the heat feedback to the unburned wire.

- **Keywords:** High pressure; Inclination angle; Flame spread; Electric wire; Heat transfer

Jiangshi Zhang, Jing Fu, Hongyu Hao, Gui Fu, Fangchao Nie, Wenyue Zhang. *Root causes of coal mine accidents: Characteristics of safety culture deficiencies based on accident statistics*. Pages 78-91.

Coal mine accidents pose a serious threat to miners and the surrounding environment. Despite a recent downward trend in the numbers of major accidents and casualties in Chinese coal mining enterprises, accident reoccurrence remains an on-going issue for the industry. This paper aims to identify the root causes, namely, the characteristics of safety culture deficiencies driving typical coal accidents. Using the accident analysis pathway of the 24Model and the logical thought of Why Because Analysis (WBA), 67 typical major accidents (gas explosion, gas outburst, flooding and fire) are analysed to identify the deficiencies in safety culture based on the determinations of the safety culture dimension and statistics of recurrent accident patterns. The related elements and occurrence frequencies of the deficiencies in safety culture can be inferred as follows: ignored safety laws and regulations (frequency is 100 %), unrealized safety priority (100 %), limited role of functional departments (86.6 %), and insufficient attention to safety education for special operation personnel and mining workers (80.6 %), among others. These characteristics are not concerned with accident types, and the most prominent characteristics are manifested in four aspects: unrealized safety priority, flaws in management actions towards safety, passive safety compliance and participation of employees, and imperfect work conditions. Specifically, we emphasize the role of departments, safety communication, safety participation and supervision climate in influencing and improving the safety culture to further reduce industrial accidents.

- **Keywords:** Coal mine accidents; Safety culture; Accident statistic; Safety communication; Safety participation

Hadis Zangeneh, Zahra Rahimi, Ali Akbar Zinatizadeh, Sayed Hossein Razavizadeh, Sirus Zinadini. *l-Histidine doped-TiO2-CdS nanocomposite blended UF membranes with photocatalytic and self-cleaning properties for remediation of effluent from a local waste stabilization pond (WSP) under visible light*. Pages 92-104.

In this study, a dual photocatalyst of TiO2-CdS doped by C, N nonmetals with the aid of l-Histidine (C, N-doped TiO2-CdS) was synthesized and then incorporated into polyethersulfone (PES) ultrafiltration (UF) membrane matrix in order to endow photocatalytic and self-antifouling properties. The resulting photocatalytic nanocomposite was first characterized by analyses of X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FT-IR), field-emission scanning electron microscopy (FE-SEM), photoluminescence (PL), and UV–Vis diffuse reflectance spectroscopy (DRS). The fabricated membranes were identified through tests of SEM, contact angle and Atomic force analysis (AFM). The membranes performance was evaluated in terms of pure water flux (PWF) and antifouling experiments in a dead end set up. To find out optimum conditions and investigate photocatalytic properties under continuous visible light irradiation, the impacts of two operating variables, i.e. working pressure (P, 1−5bar) and cross flow rate (Q, 50−150L/h) at three levels on four responses were investigated in a continuous regime using filtration of effluent from waste stabilization pound (WSP). From the results, the highest PWF, FRR and Rr were found to be 80.37kg/m2h, 80. 2 %, and 56. 1 % for the membrane modified by 0.5wt. % C, N doped TiO2-CdS contrast to 60.69kg/m2h, 33 % and 15.6 % obtained for the control membrane. At optimum conditions, i.e. 3bar and 150L/h, the values of PWF, FRR and COD removal were 150.6kg/m2h, 89.5 % and 65.26 %, respectively. An improvement of 1.4, 1.5 and 1.3 times in PWF, FRR, and COD removal, respectively, were achieved for the 0.5wt.% membrane under visible light irradiation compared to the control one. These results were attributed to super hydrophilicity, photocatalytic properties and self-antifouling.

- **Keywords:** WSP; Mixed matrix membranes; C, N doped TiO2-CdS; Photocatalytic capacity; Self-antifouling

Biao Xie, Shihang Li, Wei Chu, Chun Liu, Shuda Hu, Hao Jin, Fubao Zhou. *Improving filtration and pulse-jet cleaning performance of metal web filter media by coating with polytetrafluoroethylene microporous membrane*. Pages 105-114.

The metal web filter media has been widely used to purify high-temperature exhaust gas because of its good durability and reliability. Although it has fine high-temperature resistance, its filtration efficiency for fine particles is relatively low. In this study, we developed a new type of composite filter of metal web coated with polytetrafluoroethylene (PTFE) membrane, which combined the high-temperature resistance of the metal web filter and the excellent filtration performance of the membrane-coated filter media. The performance parameters of the composite filter, including pressure drop, filtration efficiency, regeneration efficiency, adhesive force, and high-temperature resistance, were investigated experimentally, and compared with those of the metal web filter and polyester fiber coated with PTFE membrane filter. Although the composite filter yielded a higher pressure drop, it exhibited a high particle collection efficiency. At a face velocity of 10.23cm/s, the filtration efficiency of the composite filter was 99.32 %. This was 1.23 and 0.10 % higher than that of the metal web filter and polyester coated with PTFE membrane filter, respectively. In addition, the composite filter has the characteristics of small cake/fabric adhesion force, low residual pressure drop, high regeneration efficiency, and long cleaning interval. The average cleaning interval and residual pressure drop of the composite filter were 421s and 425.0Pa, respectively, whereas those of the metal web filter were 291s and 658.5Pa, respectively; those of the polyester coated with PTFE membrane filter were 415s and 443.2Pa, respectively. Furthermore, the filtration test at high temperatures and thermogravimetric analysis demonstrated that the composite filter has an excellent thermal stability. At a temperature of 260°C, the average dust emission concentration of the polyester coated with PTFE membrane filter was 2.86 times larger than that of the composite filter (0.532mg/m3).

- **Keywords:** Composite filter; High-temperature exhaust gas; Pulse-jet cleaning; Dust particles

R.O. Abdel Rahman, A.A. Zaki. *Comparative analysis of nuclear waste solidification performance models: Spent ion exchanger-cement based wasteforms*. Pages 115-125.

Solidification performance for cement based radioactive wasteforms was investigated and linked to the hydraulic performance using mechanistic and empirical models. Within this context, the short-term developments of the compressive strength, porosity, and permeability of cement based matrices of varying water content were assessed. For matrices of low-water content, diffusion reaction is the dominant solidification mechanism due to super-saturation of CSH phases. As the water content increases, nucleation and growth reaction controls the process. The nature of the immobilization of inorganic ion exchangers and polymer modification in cement based matrices and its effect on the relative change in the compressive strength and permeability were investigated. The reductions in the solidification performance for cement-inorganic exchanger wasteforms were attributed to the excess amount of Ettringite in case of alumina exchangers and to the reduction in the hydrated phases formation for the rest of the inorganic exchangers. The permeability of the alumina-cement wasteform is fairly constant up to 16 % loading, whereas this behavior is noted up to 10 % loading of the rest of the inorganic exchanger and absent for organic exchangers-modified cement wasteforms.

- **Keywords:** Radioactive waste; Spent ion exchanger; Cement; Immobilization; Model

Jae Joon Lee, Hong Sik Yun, Young Jae Cho, Jae Hyeok Park. *Empirical analysis of a steam explosion in a slag yard based on a field investigation and 3D explosion damage simulation*. Pages 126-135.

Many types of explosions often occur in industrial settings, and research is being conducted to identify the causes and establish preventive measures. The aim of this study is to investigate slag yards, where metal residues are cooled in the steel industry, often causing steam explosions. The cause of accidents and explosion simulation analyses were used to investigate the sources of steam explosions in a slag yard. The explosion intensity of 4kg of TNT was measured for the purpose of predicting the intensity of a steam explosion. This was compared with a simulation of explosion damage that occurred in 2017. These results could not be produced from small-scale experiments, and they indicate that damage resulting from actual explosions poses a potential risk to pipes that cannot be directly observed. We conclude that this damage can lead to a domino accident, and this study provides results for estimating the possibility of future damage.

- **Keywords:** Steam explosion; Steel mill; Explosion damage simulation; Slag yard; Molten metal

Zeyang Song, Xinyan Huang, Claudia Kuenzer, Hongqing Zhu, Juncheng Jiang, Xuhai Pan, Xiaoxing Zhong. *Chimney effect induced by smoldering fire in a U-shaped porous channel: A governing mechanism of the persistent underground coal fires*. Pages 136-147.

This paper presents underground coal fires (UCF) induced natural ventilation through a U-shaped porous channel. Height of the U-shaped channel (the fire depth) is one of key elements determining the accessibility of air supply to UCF. Conventionally, we acknowledge that under the external wind driving force, air supply to underground space should decay with increasing the fire depth. However, under the thermal buoyancy force

induced by UCF, responses of air supply and UCF to the fire depth are uncertain. Herein we propose a 1/20-scale experimental framework to measure air velocity, and to quantify the burning rate, the fire spread rate and the burning temperature of UCF at different fire depths (H = 1.6–4.6 m) with variable aperture sizes (Φ = 1–4 cm). A one-dimensional model correlating the air velocity with the fire depth is validated and then extrapolates laboratory-scale free channels into field-scale (H = 100 m) percolation channels. We find the 'chimney effect' – air supply driven by the buoyant smoke of UCF is unexpectedly enhanced with increasing the fire depth; the enhanced air supply due to the chimney effect facilitates burning of coal. The chimney effect, serving as a self-sustaining mechanism of air supply to UCF, is a significant governing mechanism for persistent UCF burning for hundreds or even thousands of years.

- **Keywords:** Natural ventilation; Thermal buoyancy; Subsurface fire; Stack effect

Mahesh Kodoth, Shu Aoyama, Junji Sakamoto, Naoya Kasai, Yehia Khalil, Tadahiro Shibutani, Atsumi Miyake. *Leak frequency analysis for hydrogen-based technology using bayesian and frequentist methods*. Pages 148-156.

Dealing with hazardous environments such as hydrogen poses considerable risks to property, people, and the environment. Leak frequency analysis is a method of understanding the characteristics of risks at hydrogen refueling stations (HRSs). This paper proposes leak rate estimation using time-based evaluation methods that utilize historical HRS accident information. In addition, leak frequency estimates from another two methods (non-parametric and leak-hole-size) were examined. In the non-parametric approach, the leak frequency is estimated based on a Bayesian update. The results from these three approaches are summarized to understand the trend of leak rate data. The leak rate data from the time-based method displays a similar trend to the leak size based method. However, the non-parametric method tends to be conservative due to high failure observations (new evidences) during the Bayesian update. Finally, the unrevealed leak time was calculated as a function of the leak frequency. The quantitative insights of this study can be used to set performance standards for the availability and reliability in the operation and maintenance of HRSs.

- **Keywords:** Leak frequency; Unrevealed leak time; Hydrogen refueling station; Time-Based model; Bayesian update

Christian Blum, Marta Verdaguer, Hèctor Monclús, Manel Poch. *A new optimization model for wastewater treatment planning with a temporal component*. Pages 157-168.

The management of wastewater systems constitutes a complex problem in the environmental engineering field. The variability and uncertainty of the inflows of wastewater treatment plants involve a real risk of reducing the effectiveness of the treatments and worsen the ecological state of river basins. An adequate reduction of contaminants requires an optimal combination of wastewater contributions that must constitute the treatment inflow. The problem is complex because of different dynamics and casuistics of wastewater generation, especially when the waste is from industrial activities. In addition, a realistic focus requires consideration of the temporal component due to the distances from the treatment. This paper presents a new optimization model for planning the wastewater inflow in a consistent way, with the novelty from the inclusion of this temporal component. Under the assumption of a complete knowledge of the future, the problem can be expressed as a quadratically constrained program (QCP). With growing problem size, solvers such as CONOPT have increasing difficulties to find good solutions to such problems. Therefore, we propose solving this problem as an online optimization problem in which the quadratic terms are eliminated. Our approach was

applied to a virtual case study based on a high number (200) of industrial wastewater generators (located in 4 different zones) and a single wastewater treatment plant. The results obtained evidence the applicability of the model to plan favourably the operation of treatments and contribute to sustainability in the context of the internet of things.

- **Keywords:** Wastewater management; Sewage system; Optimization model; Online optimization; Global optimization problem; Temporal component

Raphael R.C. Santos, Sávio S.V. Vianna. *Stratified flows and associated shear instabilities modelling over an inclined plan*. Pages 169-181.

We investigate isothermal continuous gravity currents down on an incline of 5°. The front region with strong mixing and the shallower layer behind it are modelled using computational fluid dynamics in order to discuss the dilution process in accidental releases. The simulations were performed using two different customised packages for compressible and a non-compressible flows. The heavy fluid dilution was analysed considering RANS (Reynolds Average Navier Stokes) approach and three turbulence models k−ε, k−ω SST and RNG k−ε. The simulated gravity currents were compared with experimental by means of the density distribution in the flow and volume of the current. As far as dense gas cloud prediction is concerned, the numerical findings agree with the experimental data and there seems to be good indication that the solvers are suitable for consequence analysis. Shear instabilities caused by the flow of two fluids near the interface zone are well captured by RNG k−ε turbulence model. The simulations show that the modelling of small scale turbulence and associated rate of deformation are important to mimic the wavy instabilities and curling of the interface region of the released and ambient fluid. Such process is of paramount importance when predicting the mixing and dilution of the released material. Analysis of the results shows that better agreement is observed when the proper modelling of the shear instabilities is considered as well as the extra source of turbulence due to the effects of buoyancy.

- **Keywords:** Stratified flows; CFD simulation; OpenFOAM; Turbulence model

Lívia Silva Botta, Tiago Palladino Delforno, Camila Abreu B. Silva Rabelo, Edson Luiz Silva, Maria Bernadete Amâncio Varesche. *Microbial community analyses by high-throughput sequencing of rumen microorganisms fermenting office paper in mesophilic and thermophilic lysimeters*. Pages 182-193.

This study explored the hydrolysis and fermentation of paper with hydrogen (H2) and volatile fatty acid (VFA) recovery using a natural microbial consortium added to lysimeters. Serial dilutions of rumen fluid in natura were performed to obtain a fermentative nonmethanogen consortium, which was used as inoculum in lysimeters under two different incubation temperatures, L1 at 35°C and L2 at 55°C. H2 was detected in both lysimeters: 791.5mL (L1) and 70.4mL (L2). In L1, the production of 16,856mgL−1 acetic acid was likely due to the occurrence of homoacetogenesis. Under thermophilic conditions, L2, a low volume of H2 was detected, and the highlight was the production of ethanol and methanol at 2289 and 5614mgL−1, respectively. According to the Shannon index, there was great diversity of microorganism populations in the rumen fluid in natura (6.34) compared with the purified rumen fluid (2.73), L1 (2.67) and L2 (3.21). The most abundant genus in the rumen fluid in natura was Prevotella (37.5 %); in the purified consortium (68.7 %) and L1 (63.8), Dysgonomonas; and in L2 (88.7 %), Thermicanus. In conclusion, the temperature influenced the microbial community structure, the metabolic route and, consequently, the main byproducts produced by the fermentative activity at 35°C and 55°C.

- **Keywords:** Hydrogen; Volatile fatty acid; Homoacetogenesis; Lysimeter; Dysgonomonas; Thermicanus

Herald Wilson Ambrose, Calvin Tse-Liang Chin, Eugene Hong, Ligy Philip, G.K. Suraishkumar, Tushar Kanti Sen, Mehdi Khiadani. *Effect of hybrid (microwave-H2O2) feed sludge pretreatment on single and two-stage anaerobic digestion efficiency of real mixed sewage sludge*. Pages 194-202.

The impacts of hybrid microwave-oxidative (MW-H2O2) feed sludge pretreatment on performance efficiency of conventional single-stage and a novel two-stage semi-continuous anaerobic digestion of mixed waste activated sludge were studied to enhance biogas production and digestate quality. Untreated two-stage anaerobic digestion (thermophilic followed by mesophilic) achieved 76.4 ml/gTCOD methane yield compared to 40.4 ml/gTCOD achieved through conventional mesophilic anaerobic digestion, with an increase in methane percentage. Application of hybrid (MW-H2O2) sludge pretreatment in the two-stage digestion enhanced initial sludge hydrolysis/solubilisation and consequently achieved 143.4 ml/gTCOD methane yield. Also, the highest methane percentage of 71 % was achieved during peak methanogenesis stage in this process. The synergetic effects of hybrid pretreatment were also confirmed by the higher release of extracellular polymeric substances. Oxidative stress exerted by the pretreatment resulted in the accumulation of superoxide radicals in the initial thermophilic phase; followed by increased sludge activity and biomethanation in the later phase of two-stage digestion. Hybrid feed sludge pretreatment in the two-stage system achieved a 73 % volatile solids reduction and more than 90 % reduction of faecal coliform. The various kinetic model parameters were determined by the application of the modified Gompertz model. These results illustrate that a novel semi-continuous two-stage anaerobic digester with hybrid feed sludge pretreatment improved sludge hydrolysis, sludge solubilisation, biogas production, sludge stabilization and reduces sludge retention time, and also achieves "class-A" biosolids by significant pathogen destruction.

- **Keywords:** Microwave; Hydrogen peroxide; Two-stage anaerobic digestion; Biogas production; Sludge hydrolysis; Superoxide

Matt Clay, Moray Kidd, Andrew Gale, Tim Boardman, Jim Murphy, Tony Wynn, Steven Naylor, Jo Ellwood. *Understanding loss of containment of non-radiological chemotoxic materials in the civil nuclear and process industrie*s. Pages 203-213.

Loss of containment of toxic and flammable inventories from process plant is associated with a long history of major accidents including fires, explosions and toxic releases. Such accidents affect both workers and the offsite public. These issues are often associated with the onshore process industries which incorporate a very wide range of segments including pharmaceutical manufacture, tank storage, downstream oil & gas, fine and speciality chemical manufacture as well as many others. What may be less well appreciated is that while the Civil Nuclear sector has a key focus on containment of radiological materials, it also maintains significant inventories of flammable and toxic materials, which it terms 'chemotoxic' hazards. It follows that a very broad range of industries have a desire to prevent and mitigate the potential for loss of containment events which release chemotoxic materials. Existing sources of loss of containment intelligence include the Health & Safety Executive (HSE) and other databases which can be interrogated to glean process safety insights. Such systems incorporate some limited coding of data, but often feature much greater detail within unstructured free text. Systematic interrogation of such free text fields could yield greater detail within process safety insights as well as a potentially larger number of records with which to draw insight. The Discovering Safety Programme is a multidisciplinary initiative funded by the

Lloyd's Register Foundation. The programme aims to improve plateaued safety performance through better insight via data analysis tools including text mining and natural language processing. This paper describes the early stages of a project within the Discovering Safety Programme to obtain process safety insights from HSE's regulatory database. This work includes analysis of coded information, proposals to extract intelligence from unstructured free text and also exploration of whether process safety intelligence can be extracted from a subset of occupational safety incidents. The paper describes the findings from industry consultation, including the civil nuclear sector.

- **Keywords:** Loss of containment; Process safety; Chemotoxic; Nuclear; Process industry; Process engineering; Process integrity; Data analytics

Jiabin Li, Ningning Song. *Graphene oxide-induced variations in the processing performance, microbial community dynamics and heavy metal speciation during pig manure composting*. Pages 214-222.

Graphene oxide (GO) addition is a simple, cost effective, and efficient way to accelerate compost maturation, however, little research focused on the mechanism of GO-based aerobic composting. The present study aimed to determine the effects of GO on the physicochemical and biological characteristics during pig manure composting. Four treatments were conducted with the addition of GO (0, 0.1 %, 0.25 % and 0.5 % dry weight of the composting mass, respectively). Results showed that the GO addition effectively promoted physicochemical parameters and compost maturity, and particularly improved the seed germination index (GI), with 0.25 % GO addition had the highest GI of 112% at the end of composting. The GO addition also significantly improved the organic matter degradation and reduced nitrogen loss. Beneficial properties of GO optimized composting environment, accelerated the process of composting and facilitated microbial growth during the composting process. The contents of exchangeable Cu and Zn significantly were reduced by GO addition after composting, and the 0.5 % GO respectively contributed 74.86 % and 43.05 % of the Cu and Zn passivation. Generally, 0.25 % GO addition was beneficial for microbial growth and compost maturity, while 0.5 % GO addition effectively reduced nitrogen loss and the heavy metals mobility during the composting process.

- **Keywords:** Compost; Graphene oxide; Heavy metals; Maturity extent; Pig manure

Clara V. Faria, Bárbara C. Ricci, Ana F.R. Silva, Miriam C.S. Amaral, Fabiana V. Fonseca. *Removal of micropollutants in domestic wastewater by expanded granular sludge bed membrane bioreactor*. Pages 223-233.

Sewage treatment plants effluent is considered the primary source of many micropollutants in aquatic systems since their biological treatment is commonly unable to remove persistent micropollutants. However, its efficacy can be achieved with the aid of advanced treatment technologies, such as membrane processes. This work evaluated the removal efficiency of 7 pharmaceuticals (Ketoprofen, Prednisone, Fenofibrate, Fluconazole, Betamethasone, Loratadine and 17α-Ethinyl estradiol) in a hybrid system (EGSB-MBR) where an ultrafiltration membrane was submerged in an anaerobic expanded granular sludge bed (EGSB) reactor. This integrated system improved the removal efficiencies of pharmaceuticals (>84 %) and chemical oxygen demand (COD). The EGSB reactor alone showed COD reductions around 92 %, while the EGSB-MBR system achieved COD reductions above 98 %. Furthermore, the permeate showed lower concentrations of nutrients (P, N-NH4+) and volatile fatty acids (VFAs) than the effluent from the anaerobic reactor alone. Anaerobic biodegradability tests, together with bioreactor results, pointed out the mechanisms involved in the removal of each drug. The risk assessment showed that the permeate presented a low probability of risk to human health and that the UF membrane was able to reduce the risk of the final effluent.

- **Keywords:** EGSB; Membrane bioreactor; Pharmaceuticals; Anaerobic digestion; Ultrafiltration; Risk assessment

Shaona Wang, Rongfang Yuan, Chengchen Liu, Beihai Zhou. *Effect of Fe2+ adding period on the biogas production and microbial community distribution during the dry anaerobic digestion process*. Pages 234-241.

Fe2+ is essential for the improvement of biogas production and the growth of anaerobic microorganisms; however, it is often excessively added to anaerobic digesters, leading to the inhibition of biogas production. In this study, the dosing frequency of Fe2+ for the mesophilic and thermophilic biogas fermentation of high-solid swine manure was optimized. The most significant enhancing effect (13.44 %–33.22 %) induced by Fe2+ addition was observed with dosing frequency of 400mg/L for every 5 d, and the maximum efficiency for unit concentration of Fe2+ occurred when the dosing frequency was 400mg/L for every 15 d. Maximum biogas production was obtained in the group with dosing frequency of 400mg/L for every 5 d, and biogas production potential was 465.24mL/(g volatile solid (VS)) based on modified Gompertz predicted model with a maximum rate of 16.72mL/(gVS·d), which was higher than that of the control group (6.78mL/(gVS·d)). In addition, Fe2+ dosing displayed a stimulatory effect on SCOD removal, the SCOD removal with dosing frequency of 400mg/L for every 5 d were highest in all reactors. The optimum dosing frequency of Fe2+ positively affected the microbial community structure. 16S rRNA gene sequencing revealed that the abundances of Firmicutes and Euryarchaeota were increased, which could enhance the hydrolysis-acidification and methanogenesis process during anaerobic digestion process.

- **Keywords:** Fe2+ addition frequency; Biogas production; Microbial community structure; Dry anaerobic digestion; Swine manure

De Huang, Jian Liu, Lijun Deng. *A hybrid-encoding adaptive evolutionary strategy algorithm for windage alteration fault diagnosis*. Pages 242-252.

It is critically important that windage alteration faults (WAFs) within mine ventilation systems be quickly identified and mitigated in order to ensure a safe mine production environment. Thus, we propose a Hybrid-Encoding adaptive Evolution Strategy (ES) Algorithm to diagnose the fault's location and volume quickly and accurately, as it combines classification and regression features. The Euclidean distance between the airflow set calculated via fault diagnosis and the airflow set obtained by the monitoring system was used as the objective function value. Six benchmark functions and one thousand six hundred tests were carried out to verify the feasibility of using Hybrid-Encoding for WAFs diagnosis. The effectiveness of adaptive ES was demonstrated by Genetic Algorithm (GA), Differential Evolution Algorithm (DEA), and Particle Swarm Optimization (PSO). The experimental results fully validate the Hybrid-Encoding adaptive ES superiority in terms of accuracy, precision, diagnostic errors, robustness, computational efficiency, and convergence speed, etc. Diagnostic accuracy and precision during field testing were both 92.5 %, and 93.75 % of the results showed relative errors of < 5 %. Thus, our proposed Hybrid-Encoding adaptive ES Algorithm meets the requirements for fault diagnosis accuracy at the mine production site.

- **Keywords:** Windage alteration faults; Mine ventilation; Hybrid-Encoding; Fault diagnosis; Evolution strategy

Fu-chuan Jiang, En Lai, Yu-xuan Shan, Fu-hao Tang, Hu-gang Li. *A set theory-based model for safety investment and accident control in coal mines*. Pages 253-258.

Mechanization and automation of the coal industry as well as increasing the government support for safety in coal mines in China resulted in a significant decrease in the death rate per million tons of coal produced. Nonetheless, major accidents still occur. As one of the five factors of safe production, safety investment plays a key role in ensuring the safe production of coal in mining enterprises. Coal mining enterprises can ensure safe production in the mines and maximize profits through optimum safety investment. In this study, safety system engineering principles and subsets in set theory were combined to develop a novel safety investment index system. The safety investment indices were categorized into human, machine, environment, and the intersection of these three indices. The elements in each investment set were examined, and a multivariate model of safety investment and accident control was created using gray forecasting theory. In addition, a case study was conducted to validate the reliability of the model. The results indicated that the proposed model can provide theoretical evidence and guidance for safety investment decision making in coal mining enterprises.

- **Keywords:** Coal mine; Accident; Safety; Safety investment; Gray forecasting method

F.A. Essa, Ammar H. Elsheikh, Almoataz A. Algazzar, Ravishankar Sathyamurthy, Mohamed Kamal Ahmed Ali, Mohamed Abd Elaziz, K.H. Salman. *Eco-friendly coffee-based colloid for performance augmentation of solar stills*. Pages 259-267.

Recently, nanofluids have been extensively used in water desalination systems because of their superior photo-thermal properties and heat transfer characteristics. Most of inorganic nanoparticles such as metal, metal oxides and carbon have adverse environmental impacts due to the risk related to their production and disposal processes as well as the toxicity of some types of them. In addition, their high production cost is another issue that motivates researchers to find low cost and eco-friendly alternatives to inorganic nanoparticles. In this study, coffee-based colloid has been proposed as an organic, low cost, and eco-friendly alternative to conventional inorganic-based nanofluids to augment the fresh water productivity of solar stills (SS). The performance of the modified solar still (MSS) has been experimentally investigated and compared with another conventional solar still (CSS) under the same conditions. The daily freshwater productivity obtained from the MSS was 4865.73 ml/m2 which was greater than that of CSS by 35.14 %. Energy and exergy efficiencies of MSS were improved by 35.34 % and 46.44 %, respectively, compared with that of CSS. Finally, the economic evaluation of the MSS is carried out via performing cost analysis. The cost of distilled water per liter produced by the modified solar still is 0.0136 $/l.

- **Keywords:** Eco-friendly desalination; Nanofluids; Solar still; Solar energy

Yuan Sun, Xuewen Cao, Fachun Liang, Jiang Bian. *Investigation on underwater gas leakage and dispersion behaviors based on coupled Eulerian-Lagrangian CFD model*. Pages 268-279.

Energy waste, environmental pollution, loss of human life and property can be caused once underwater gas leakage occurs. It is of great significance to establish an emergency response mechanism for underwater gas leakage and diffusion. A 3D model based on coupled Eulerian-Lagrangian approach is carried out to investigate the underwater release characteristics and diffusion law of gas leakage. The model is validated by the experimental data from literature and the results are accord with the experimental values. Influencing factors such as marine environment, leaking rate, current speed, and water depth are analyzed by numerical simulation. The calculation results indicate that ocean condition mainly affects underwater gas migration behaviors and gas plume consumes the longest rise time under wave and current. Water depth, current speed and

leaking rate significantly influence the underwater gas migration but have limited effect on gas diffusion in atmosphere. The investigation will give some advice for emergency response formulation.

- **Keywords:** Leakage; Gas plume; Underwater migration; Eulerian-Lagrangian approach

Lulu Zhou, Beibei Wang, Juncheng Jiang, Genserik Reniers, Longfei Liu. *A mathematical method for predicting flammability limits of gas mixtures*. Pages 280-287.

The relationship between flammability limits (FL) of gas mixtures and their molecular structures was studied in this research based on the quantitative structure-property relationship (QSPR) method. The genetic algorithm (GA) was used to select an optimal subset of descriptors which show a significant contribution to the properties. The external validation, which checking the stability and predictive capability of the obtained models, was focus of this study. Three different external validations were employed to build the models. Moreover, the applicability domain for the models was also defined. The selected descriptors and obtained models were then extended to predict the FL values of existing or new mixtures based only on mixtures composition and their molecular structures.

- **Keywords:** Flammability limit; Gas mixtures; Quantitative structure–property relationship

Yan Shao, Jiahui Ruan, Xiaoxin Li, Yibiao Li, Huanhao Chen. *Structured Fe3O4-doped ordered mesoporous carbon catalyst supported on sintered metal fibers for intensifying phenol degradation*. Pages 288-295.

Microfibrous-structured catalysts are materials that address the mass/heat transfer limitation and achieve catalytic process intensification, showing great promise for enabling practical environmental catalysis such as continuous wastewater treatment process. In this work, Fe3O4-doped ordered mesoporous carbon (OMC) catalyst supported on porous sintered metal fibers (Fe-OMC/SMFs) was prepared using a new yet simple "one-pot" method and used as a Fenton-like heterogeneous catalyst. The obtained catalysts were carefully characterized by TGA-DTG, BET, XRD, SEM-EDS, XPS and H2-TPR techniques. Structured reactor was designed and developed using developed microfibrous-structured catalysts, demonstrating an excellent catalytic performance for continuous heterogeneous Fenton oxidation of phenol. Specifically, both phenol and H2O2 conversions increased slightly as carbonization temperatures increasing from 400 to 1000°C. Compared to Fe-OMC pellet catalyst, the developed structured catalyst showed an improved catalytic activity (i.e. ~100 % phenol/H2O2 conversions), and remarkable long-term stability (i.e. ~100 % phenol conversion over a 7-h longevity test). Additionally, the developed Fe-OMC/SMFs catalyst showed Fe leaching amounts of ~10mgL−1 during reaction, being significantly lower than that of Fe-OMC pellet catalyst (i.e. ~500mgL−1). Experimental results revealed that well-dispersed Fe3O4 nanoparticles in OMC and three-dimensional microfibrous networks and large void volume of SMFs support are significantly benefit to enhance mass transfer and contacting efficiency between active sites and reactants, and thus achieve the process intensification of catalytic degradation of phenol.

- **Keywords:** Structured reactor; Heterogeneous Fenton; Phenol degradation; Sintered metal fibers (SMFs); Process intensification

Abouzar Yousefi, Manuel Rodriguez Hernandez. *A novel methodology to measure safety level of a process plant using a system theory based method (STAMP)*. Pages 296-309.

Major accidents continue to happen in the process industry and often have serious consequences. There are questions on how these accidents happen and how we can monitor safety in a process plant to prevent these accidents. In order to explain how accidents happen, different accident causation models have been used, whereas most of them were developed long time ago. Significant changes have occurred in the industry and traditional models may have limitations in identifying causes of accidents in modern industry within complex sociotechnical environment. Consequently, new accident models based on systems theory have been developed lately. Safety is often measured by number of accidents, mishaps or near misses. This retrospective approach cannot help enough to prevent accidents. In this paper, a novel methodology is introduced to measure safety level in process plants with the purpose of preventing accidents. This methodology is based on Systems Theoretic Accident Model and Processes (STAMP), which is one of the systemic accident model developed recently. The methodology is tested using real data from a process plant and obtained promising results are provided in this paper.

- **Keywords:** Safety measurement; STAMP; STPA; Safety indicator; Systemic accident; Model

Dongpeng Guo, Peng Zhao, Ran Wang, Rentai Yao, Jimin Hu. *Numerical simulations of the flow field and pollutant dispersion in an idealized urban area under different atmospheric stability conditions*. Pages 310-323.

This study simulated the flow and near-field plume dispersion in an urban-like environment under unstable, neutral and stable atmospheric stratification using the steady Reynolds-averaged Navier-Stokes (RANS) methodology. First, a validation study for two trials of the Mock Urban Setting Test (MUST) experiments is performed to examine the predictive performance of the computational fluid dynamics (CFD) model, Fluidyn-PANACHE. The effects of atmospheric stability on the flow structure in street canyons under perpendicular incident flow conditions are investigated. In addition, the patterns of urban dispersion in different cases of stability are also analysed under perpendicular and oblique wind direction conditions. The results show that in the urban environment, the influence of atmospheric stability on the canyon vortex intensity, flow structure and plume dispersion is apparent; intense thermal turbulence enhances the vortex intensity and plume dilution in the street canyon under unstable conditions; when the atmospheric conditions are stable, the vertical profile of the streamwise velocity is significantly decreased by the obstacles, and the concentration level and spread of pollutants increase in the street canyon due to relatively weak turbulent motions; plume deflection within the obstacle array is noteworthy when the incident flow is oblique; in particular, the transport of the plume is basically independent of the wind direction very near the ground.

- **Keywords:** CFD modelling; Flow; Urban dispersion; Plume deflection; Atmospheric stability

Bo Liu, Yuyuan Zhang, Xiangbao Meng, Jinshe Chen, Junfeng Wang, Xiang Wang, Yansong Zhang. *Study on explosion characteristics of the inert substances at Longkou oil shale of China*. Pages 324-333.

According to the chemical analysis, we found the inert substances of fossils in Longkou oil shale in China are mainly calcium carbonate (CaCO3) and quartz (SiO2). Their influence on the explosive characteristics of oil shale dust, through the macroscopic explosion experiments and microscopic analysis, was investigated. We found that CaCO3 has better explosion suppression effect than SiO2. There are two suppression effects during the oil shale dust explosion: adhesion and isolation of inert substances; inerting effect of carbon

dioxide (CO2) generated from the complex reaction of CaCO3 and SiO2. Due to the existence of two suppression effects, the combustion of oil shale particles stops when the heat generated by the two combustion paths is less than the heat dissipated, i.e., the explosion either comes to an end or fails to occur.

- **Keywords:** Oil shale; Inert matters; Explosion characteristics; Suppression mechanisms

Yusra A. Abd Al-Khodor, Talib M. Albayati. *Employing sodium hydroxide in desulfurization of the actual heavy crude oil: Theoretical optimization and experimental evaluation*. Pages 334-342.

The desulfurization of the actual heavy crude oil is one of the most important processes in petroleum industries due to the low quality of those types of oil and containing large amounts of sulfur compounds, high viscosity and density. In the present work, the desulfurization of the actual heavy crude oil with a sulfur content 5.8 wt. % from Al-Halfaya Oil Field in southern Iraq was studied using a sodium hydroxide-assisted process. Effects of the operating conditions such as: reaction time (30–60 min), temperature (30–50 °C), the amount of NaOH in its solution (10–30 gm), and mixing speed (300–500 rpm) were investigated. The desulfurization process was achieved in a batch reactor by implementation of the experimental design technique. The objective function (response) was the sulfur content wt. % while a response surface method (RSM) was applied to define the significant factors that affect the desulfurization process. It was found that effects of the four variables take the following sequence: mixing speed > weight of NaOH > time > temperature. The optimum conditions of the proposed model were obtained using optimization techniques and found as follows: time = 60 min., temperature = 40 °C, NaOH solution = 18gm and mixing speed = 500 rpm. The optimum conditions of the sulfur content were applied experimentally and theoretically was equal to 2.5 and 2.3 wt. %, respectively. It is concluded that the efficiency of the sulfur removal content for actual heavy crude oil by this process was 56.89 %.

- **Keywords:** Desulfurization; Response surface methodology; Actual heavy crude oil; Environment; Optimization; Sodium hydroxide

Hojatollah Haji Andevary, Azam Akbari, Zahra Rajabi, Mohammadreza Omidkhah. *Towards a room temperature oxidative desulfurization of refractory compounds over 1-octyl-3-methylimidazolium tetrachloroferrates/silica gel: The beneficial effects of immobilization*. Pages 343-352.

A successful immobilization of 1-octyl-3-methylimidazolium tetrachloroferrates ([Omim][FeCl4]) thin films on a silica gel while remaining its mesoporousity, was accomplished in this work. The developed catalyst was highly active and cost-effective for deep oxidative desulfurization of refractory thiophenic compounds at room temperature utilizing H2O2 oxidation agent. The reaction products were well separated from fuel by the catalyst itself under a beneficial solvent-free condition. The catalyst was characterized applying different analyses of FT-IR, TGA, XRD, SEM, EDS, AFM, N2 adsorption desorption, BET, and BJH. A sufficiently large pore diameter (~6.2 nm) and high surface area (~490 m2/g) of the silica gel for supporting the Lewis acidic [Omim][FeCl4] having a proper anion and cation structure, synergistically enabled a high efficient and selective catalyst for removal of refractory thiophenes. The influences of reaction temperature and time, loading amount of ionic liquid (IL), catalyst and oxidant amount as crucial reaction factors were evaluated in order to have a maximum desulfurization yield. Impressively, only a very low IL loading of 5 wt.% on the silica gel support achieved complete elimination of dibenzothiophene at the optimal mild conditions and room temperature. In the presence of a non-sulfur aromatic hydrocarbon beside

different thiophenic models, the desulfurization selectivity of [Omim][FeCl4] increased from 0.92 to 0.95 via immobilization on the silica gel support. A significant decline in the IL consumption was verified as another beneficial effect of this immobilization. The catalyst could be easily separated having a capability for 100 % removal of dibenzothiophene after recycling four times. Meanwhile, GC–MS analysis was employed for further founding of the desulfurization pathway.

- **Keywords:** Catalyst; Ionic liquid; Deep Desulfurization; Refractory sulfur compounds

Xiaofei Liu, Wen Nie, Wenjie Zhou, Changqi Liu, Qiang Liu, Cunhou Wei. *The optimization of a dust suppression and clean production scheme in a TBM-constructed tunnel based on an orthogonal experiment*. Pages 353-370.

This study aims to examine whether clean production can be achieved by using a ventilation dust removal system in a tunnel being constructed using a tunnel boring machine (TBM). The section between the Guizhou-Road Station and the Guipaijing Station on the No. 1 line of the Qingdao Metro was selected as the study area, and the effectiveness of a ventilation dust removal system on the diffusion distance and mean concentration of dust in the excavating area was investigated through the use of a CFD-based numerical simulation. Firstly, it was found that when the first pressure quantity, exhaust quantity, and position of the pressure inlet and exhaust inlet of the ventilation dust removal system all remained unchanged, the secondary pressure quantity corresponding to the optimal dust suppression effect was determined to be 8 m^3/s. Next, an orthogonal experiment was performed on the position of the pressure inlet and exhaust inlet and the forced-to-absorbed airflow quantity ratio in order to examine the effect of different combinations on the dust suppression effect in the tunnel. By selecting the dust diffusion distance, mean dust concentration in the tunnel and dust-collecting efficiency as the evaluation indexes, three favorable schemes were determined, from which the optimal scheme was selected. In the optimal combination, the secondary pressure inlet and exhaust inlet were 28 m and 11m away from the tunnel face respectively and the forced-to-absorbed airflow quantity ratio was 1.6. After the scheme's optimization, the dust diffusion distance in the tunnel was shortened considerably by 53 %, the mean dust concentration was reduced to 1.52E-06 kg/m^3, and the dust-collecting efficiency was enhanced by 13.19 %. Under these optimal conditions, a ventilation dust removal system can maximize the operational efficiency and ensure a clean air environment during any production activities.

- **Keywords:** TBM construction; Dust suppression effect; Numerical simulation; Dust concentration; Orthogonal experiment