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Dorota Brzezinska, Adam S. Markowski. *Experimental investigation and CFD modelling of the internal car park environment in case of accidental LPG release*. Pages 5-14.

The use of new fuels (hydrogen, LPG) in daily life and industrial sites introduces new hazards which require new safety concepts. Despite the fact that LPG is used in a large number of cars, large-scale tests of accidental LPG release in the car park have not previously been performed. The problem of LPG-powered vehicles in enclosed car parks was previously evaluated only by CFD analyses. This paper describes full scale tests, which represent conditions that may occur in a garage in the event of accidental LPG release from a car's LPG installation. Over the course of the tests full scale LPG spillage experiments were performed to study emission time and flammable cloud formation according to the assumed hole diameter in the car's installation. On the basis of them, the characteristics of dispersion of LPG in the garage were obtained. The test results were used to create the appropriate CFD model of LPG release and dispersion in FDS code (NIST). The CFD model was used for a case study of the LPG release from the entirety of the car's tank in the full scale car park where the different effectiveness of various ventilation systems were observed and evaluated.

- **Keywords:** LPG; CFD; Jet fan; Ventilation; Car park; FDS

Albrecht Michael Birk. *Shock waves and condensation clouds from industrial BLEVEs and VCEs*. Pages 15-20.

It is known that the passage of a strong shock wave in a moist atmosphere usually produces a condensation cloud that is briefly visible to the human eye. Weaker shocks such as those from boiling liquid expanding explosions (BLEVE) and vapour cloud explosions (VCE) may also produce such visible condensation clouds under certain atmospheric and lighting conditions. The Sunrise Propane accident in Toronto, Canada in August 2008 involving both BLEVEs and VCE gave clear evidence of this. In this age where video footage of an explosion incident is the norm (i.e. from the smart phone of a remote observer, or from a security video camera) it is very likely that there will be visual evidence of explosions. This evidence may include the size of a condensation cloud from a shock wave. This paper presents examples of such images along with a simple analysis that allows us to estimate the overpressure of the shock wave at the edge of this condensation cloud. In many cases we can also determine the distance to this shock overpressure from the video image. With this overpressure and distance data it is possible to estimate the energy of the explosion and the overpressure and expected

damage at other distances. This could be very useful for accident analysis. Limited video footage of BLEVE tests is used to validate the method.

- **Keywords:** Condensation cloud; BLEVE; Vapour cloud explosion; Shock wave

Sebastian Festag. *Counterproductive (safety and security) strategies: The hazards of ignoring human behaviour*. Pages 21-30.

Measures are taken in order to optimise processes or to solve problems. The motivation for this can be very different, e.g. to handle problems like economic imbalances and social conflicts or to reduce risks, such as terrorist threats, industrial accidents or corporate crises. However, any change has an impact on the risk situation. During our own studies in very different fields relating to safety and security issues and the impact of the human factor, we made a remarkable discovery. In different fields, various measures are taken to handle difficult situations but the introduced measures fail to achieve their aim and intensify the risk situation. We found a counterproductive mechanism. This effect is of great interest to the work in the field of safety and security, which is why several of these studies have been intensively analysed from this point of view—in a kind of a review. With regard to methodology, the analysis of the series of case studies is based on observations and a statistical-empirical approach, with a theory for the counterproductive mechanism being derived from the observation of reality (case studies). The counterproductive phenomenon was discovered in a lot of cases, even where explicit safety and security strategies had been taken. So far, safety science has not systematically explored the hazards caused by itself. This is true for the fields of both safety and security. At the moment, the exact cause-effect relationships for the counterproductive mechanism are not well known, but human behaviour plays a fundamental role in it. It is often ignored and reduced to rational structures. Awareness of this problem is the first step towards solving this (common-cause failure) situation.

- **Keywords:** Counterproductive strategies; Counterproductive mechanism; Human behaviour; Human factor; Safety science; Collateral damage

Ronald W. McLeod. *Human factors in barrier management: Hard truths and challenges*. Pages 31-42.

Whether acting as controls in their own right, being relied on to ensure physical, hardware or electronic controls are in place and functional when needed, or as a threat to safe operations, human performance is central to the development, implementation and sustainable operation of barrier management systems. Many organisations however struggle to know how to ensure: (a) that the human performance they rely on can reasonably be expected to happen when and where it is needed; and, (b) that the controls they intend to have in place are as robust as they reasonably can be to the loss of human reliability. Drawing on real-world incidents, this paper examines some of the expectations that are widely held about human performance in barrier management systems. Those expectations are considered in the light of the reality behind how people think, behave and perform in real world tasks: what are referred to as "hard truths" of human performance. Drawing largely on the technique of Bowtie analysis, weaknesses in the way human factors are treated in current approaches to barrier management are reviewed, and improvements suggested. The paper illustrates how most human and organisational controls should be treated as safeguards rather than full barriers: they are critical to safety management, but are rarely able to meet the criteria necessary to be treated as full barriers. The equivalence of a Human Performance Standard to an Equipment Performance Standard is illustrated with a practical example.

- **Keywords:** Human factors; Barrier management; Bowtie analysis; Human and organisational factors; Human factors engineering; Cognitive bias

L. Mage, N. Baati, A. Nanchen, F. Stoessel, Th. Meyer. *A systematic approach for thermal stability predictions of chemicals and their risk assessment: Pattern recognition and compounds classification based on thermal decomposition curves*. Pages 43-52.

In the context of process and product design, predictive models are increasingly employed. Decomposition properties of chemicals may be experimentally determined through calorimetric measurements, and a few molecular structure-based models- which correlate the molecular structure of compounds with their decomposition properties- are also available. The aim of this paper is to improve predictive modeling of decomposition characteristics derived from Differential Scanning Calorimetry (DSC) (Baati et al., 2016), through the implementation of pattern recognition as a primary classification. For this purpose, the entire decomposition peaks of the molecules are represented and treated with image processing algorithms to identify the different patterns. Predictive modeling is then performed within the categories and compared to a global model prediction. Firstly, DSC thermograms (or curves) are analyzed to identify similar decomposition patterns in order to develop a clustering based on their overall thermal behavior instead of their structural similarities. Secondly, the repartition of the structural groups in the clusters is evaluated in order to determine the most influential functional groups on the thermal decomposition behavior. From this analysis, a systematic classification is developed to assign molecules of unknown thermal behavior to a particular cluster. Thirdly, predictive models of thermal characteristics are constructed within the different classes allowing predicting the entire DSC curve. The primary classification based on the pattern recognition increases the predictive performance of the regressions models

- **Keywords:** Pattern recognition; Classification; Thermal stability; Predicitve models; Molecular structure; Risk assessment

Ian Cameron, Sam Mannan, Erzsébet Németh, Sunhwa Park, Hans Pasman, William Rogers, Benjamin Seligmann. *Process hazard analysis, hazard identification and scenario definition: Are the conventional tools sufficient, or should and can we do much better?* Pages 53-70.

Hazard identification is the first and most crucial step in any risk assessment. Since the late 1960s it has been done in a systematic manner using hazard and operability studies (HAZOP) and failure mode and effect analysis (FMEA). In the area of process safety these methods have been successful in that they have gained global recognition. There still remain numerous and significant challenges when using these methodologies. These relate to the quality of human imagination in eliciting failure events and subsequent causal pathways, the breadth and depth of outcomes, application across operational modes, the repetitive nature of the methods and the substantial effort expended in performing this important step within risk management practice. The present article summarizes the attempts and actual successes that have been made over the last 30 years to deal with many of these challenges. It analyzes what should be done in the case of a full systems approach and describes promising developments in that direction. It shows two examples of how applying experience and historical data with Bayesian network, HAZOP and FMEA can help in addressing issues in operational risk management.

- **Keywords:** Process hazards; Hazard identification; HAZOP automation; Scenario generation; System approach; Dynamic Bayesian net

Pierre Lauret, Frederic Heymes, Serge Forestier, Laurent Aprin, Alexis Pey, Marcia Perrin. *Forecasting powder dispersion in a complex environment using Artificial Neural Networks*. Pages 71-76.

Atmospheric dispersion prediction skill is required for any industry processing hazardous material. This is a sensitive task since many parameters are involved: source term, atmospheric conditions, and local configuration. Behavior of dust dispersion is difficult because of the diameter scattering, agglomeration, sedimentation, range of densities... Furthermore, production sites may be located inside a complex environment such as urban areas, where accuracy of classical dispersion models is low. This paper aims to evaluate the efficiency of an Artificial Neural Networks (ANN) model to predict dust dispersion in an urban area without prior knowledge of the source term. The experimental database consists of 290 daily mean concentration measurements on a site located 500 m away from the emission source. The inputs are selected from meteorological data from a MeteoSwiss station located 4.5 km south. The training phase is done through early stopping application. ANN model selection is performed on the best coefficient of determination value. Model performance is evaluated using classical air quality criteria and shows good results. Nevertheless, ANN model tends to underestimate high concentrations while overestimating low concentrations. Results are included within acceptable range. Improvements can be achieved by adding information of the source term as an input for the ANN model.

- **Keywords:** Atmospheric dispersion modeling; Artificial Neural Networks; Dust forecasting

David Torrado, Valentina Buitrago, Pierre-Alexandre Glaude, Olivier Dufaud. *Explosions of methane/air/nanoparticles mixtures: Comparison between carbon black and inert particles*. Pages 77-88.

During incomplete combustions or nano-size carbon blacks generation, atmospheres of carbonaceous nanopowders and combustible gases are encountered. These hybrid mixtures exhibit specific explosive behaviors, which can notably be caused by the modification of the initial turbulence level or by changes in oxidation reactions. In order to either support or reject such assertions, various nanoparticles/methane mixtures were tested, some with carbonaceous nanopowders, some with inert nanopowders (alumina). The aim of this work is then to compare the influences of alumina and carbon black nanoparticles insertion on the explosion severity and on the flame velocity of methane. Tests were performed in a 20 L explosion sphere and in a 1 m vertical flame propagation tube. An estimation of the unstretched flame velocity is obtained assuming a linear relationship between the burning velocity and Karlovitz stretch factor. It appears that the use of carbon black nanoparticles increases the explosion overpressure for lean methane mixtures by approximately 10%. Similar behaviors have been observed for hybrid mixtures involving alumina particles for fuel lean conditions. For alumina, non-significant changes are observed for fuel rich mixtures. Moreover, a considerable diminution of the explosion severity was noted for fuel rich mixtures when carbon black nanoparticles are dispersed into the reaction vessel. Regarding the flame propagation test for stoichiometric methane concentration, higher unstretched burning velocities were obtained for carbon black hybrid mixtures compared to alumina mixtures. These results suggest soot or carbonaceous nanopowders not only impact the oxidation kinetics, but also the flame stretching and heat transfer.

- **Keywords:** Nanoparticles; Hybrid mixtures; Dust explosions; Burning velocity; Flame propagation; Radiation

Emilio Palazzi, Carlo Caviglione, Andrea P. Reverberi, Bruno Fabiano. *A short-cut analytical model of hydrocarbon pool fire of different geometries, with enhanced view factor evaluation*. Pages 89-101.

In analyzing pool fires and the potential for domino effects, the most important aspects to be addressed on the basis of a proper consequence analysis are the evaluation of thermal radiation, the issues of interplant spacing, the employees' safety zones and fire

wall specifications. Even if scientific literature on pool-fire is sparse and modeling is well developed, the usual approach considers circular geometry, pseudo steady-state conditions, uniform flame temperature, cylindrical/conical flame shape with height depending on pool diameter. The specific analysis of rather complicated situations (partial confinement, irregular shapes, complex kinetics, heavy hydrocarbon fire, unsteady-state) usually requires the use of sophisticated integral models and/or time consuming CFD calculations, but when conservative results are enough, analytical models can be more useful especially in hazard assessment. We propose a modelling of a pool fire of a multi-component hydrocarbon mixture, under semi-confined geometry. The physical model of the pool is solved to provide a description of a variable heat emitting flame area, as a function of the vertical flame axis, thus representing a peculiar novelty of the approach. Starting from a real accident in a downstream oil industry involving pool fire of a heavy liquid HC mixture and domino effect, the application to an industrial case study is presented, in order to evidence the effective potentialities of the method.

- **Keywords:** Accident escalation; Coal tar; Combustion; Hydrocarbons; Mathematical model; Pool fire

Gabriele Landucci, Francesca Argenti, Valerio Cozzani, Genserik Reniers. *Assessment of attack likelihood to support security risk assessment studies for chemical facilities*. Pages 102-114.

Chemical and process facilities may be the target of external acts of interference, aimed at causing cascading events, which may escalate into severe fires, explosions or toxic dispersions. Recent accidents that occurred in European chemical facilities presented these features, showing that industry must address with the greatest urgency the need of increasing the attention to security issues. Objective, performance-based methods to verify the adequateness of the resources dedicated to the protection of assets against external attacks are needed. In the present study, a probabilistic risk analysis approach supported by a model based on Bayesian Networks is adopted to address the quantitative assessment of the attack likelihood and to incorporate the functional analysis of physical protection systems (PPS) applied the security of process and storage installations. A case study of industrial interest is analysed to exemplify the methodology, which may be adopted to evaluate the PPS in place in a given facility. The methodology also allows for a quantitative evaluation of attack success credibility and for the identification of the more critical escalation scenarios, thus supporting safety and security reviews of chemical and process facilities.

- **Keywords:** Security risk; Likelihood; Physical protection systems; Probabilistic assessment; Bayesian Networks; Major accident hazard