Chemical hazard assessment and risk modeling. Chemical accident/incident prevention

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Effective Utilization of Databases for Preventing Chemical Accidents

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Abstract – The industrial accidents are a matter of major concern to both the public and the environment and governments aim to minimize them by laying out different regulatory bodies to keep check on the impacts of chemical releases. However, many incident databases are relied on qualitative information instead of the quantitative as quantification from some databases is challenging to be taken into account. Nevertheless, accident/incident database can help decision support systems to consolidate completely into a single index that can assist in decision making for providing safety of both public and nature. In accordance to this, accident database taxonomy has been developed to reduce the severity and occurrence of the chemical accidents. It is proposed to integrate information from three types of databases (containing data on accidents, equipment failure, and chemical substances reactivity) which can prove to be a major breakthrough in reducing accidents.

Keywords: safe process management, decision support system, risk management program, chemical accident/incident, accident reporting database, emergency notifications.

Оценка и моделирование риска химической опасности. Предупреждение аварий

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Эффективное использование баз данных для предупреждения химических аварий

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Аннотация – Промышленные аварии, особенно аварии с участием химических веществ, вызывают серьезную озабоченность в отношении их последствий, как для населения, так и окружающей среды, и правительства стремятся свести их к минимуму, создавая различные регулирующие органы для контроля за воздействием выбросов химических веществ. Однако многие базы данных, содержащие информацию об инцидентах, основаны лишь на качественной, а не на количественной информации, поскольку количественную оценку в некоторых базах данных сложно учесть. Тем не менее, база данных аварий/инцидентов может помочь системам поддержки принятия решений, полностью консолидировав данные в единый индекс, который может способствовать принятию решений в целях обеспечения безопасности, как общества, так и природы. В соответствии с этим была разработана таксономия базы данных об авариях, чтобы снизить серьезность и количество аварий на химических предприятиях. Предлагается объединить информацию из трех типов баз данных (содержащих данные об авариях, отказе оборудования и реакционной способности химических соединений), что может оказаться серьезным прорывом в снижении аварийности.

Ключевые слова: безопасное управление процессами, система поддержки принятия решений, программа управления рисками, химическая авария, база данных сообщений об авариях, аварийные уведомления.

INTRODUCTION

Databases of accidental records of where, when, and how an accident may have occurred is mandatory to record. The chemical database releases are sometimes voluntary and mandated in others [1]. Chemical release information is needed to be reported to governmental authorities, such as environmental protection agency (EPA), national disaster management, occupational safety and health administration (OSHA), and chemical weapon conventions (CWC). The risk management plans (RMP) database, OSHA statistical data, and EPA databases contain information on most significant toxic chemicals released from industries with 85% of the content regarding to twelve chemicals known as persistent organic pollutants (POPs) [2]. The sources, chemical information and release consequences are presented for those chemical releases.

The objective of this article is to explore the different databases like failure rate databases accidental databases, reactive chemical databases in order to link each other to achieve high value of chemical industrial safety. Linking failure rate databases and reactive chemical databases is needed to interconnect an appropriate information on chemicals behavior and process equipment through one database to another for improving the performance of equipment and predicting hazards of chemicals to make conclusions which help in reducing accidents [3]. The challenges with present databases include unreliable data and using less variables for report generations. Also, there is little or no information provided about the specifics of accidents occurred under wrong variables. But this doesn’t mean that the currently available databases do not provide information on hazard of chemicals. In fact, lessons from chemical accidents are learned in terms of implementation of safe industrial practices and creating awareness programs on public or national safety.

For any research, fast accidents information lessons are reviewed to reduce the occurrence and severity of upcoming incidents. All the failure data bases can help to prevent future losses. Therefore, those databases should be analyzed scrupulously and effectively in terms of industry practices to prevent reoccurrence of similar incidents [4]. The preciseness and accuracy of databases are required. Incident databases should have both accurate facts and analytical statistical tools. Accurate facts hold the information on incident specific data like type of the chemical, process unit, equipment type, toxicity, number of employees which need to be considered. Analytical statistics results are basics for determining incident root causes and, the learned lessons should be extensively published and their incorporation in practice is necessary for safer operational conditions. Deeper analysis is imperative to evaluate the root causes of emergencies, therefore, interlinking accident/incident data and development of their taxonomy are significant which can be done by performing the following tasks:

- By listing the statistical data analysis collected from several accidents, which are triggered by directly or indirectly through chemical elements.
- By analysing the interlinkages of chemical data, which contributed the accidents.
- Understanding the major contributors of the chemical accidents.
- Understanding the time and occurrence due to typical design errors in the facility.
- Expansion of safety focused designs to prevent any accident recurrence.

METHODOLOGY

The incident database procedure for the safety assessment of chemical processes at facility is accomplished by an interactive online tool. As a part of various database tools, the process of safety assessment using the appropriate database has many versions having web-based applications which can be accessed by anyone [5]. In addition, the documents comprising different checklists should be available. To create a safety awareness capacity building program, it is required safety re-design based on various parameter and factors [6, 7]. The three main components are significant for any risk management system as shown in Fig. 1:

Good Engineering Design: Good engineering protocols will provide basic standard information through database to deal with crucial situations.

Good Process Design: The process needs to meet the requirements on yield, quality of outputs for updates as per demand. Parameters updating drives the safe control on process.

Good Basic Data: The basic information on physical and chemical data of raw materials, reaction parameters, reaction kinetics, side reactions, applied materials should be accurate and clearly understood.

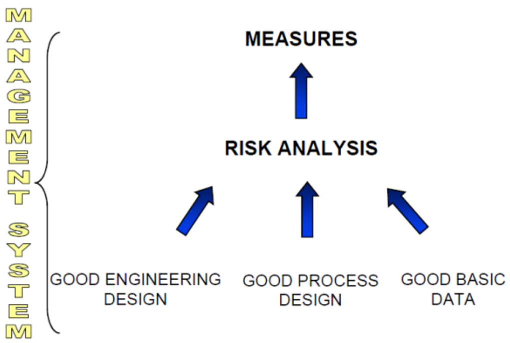

Fig. 1. Data components in risk management system.

Good Engineering Design, Good Process Design, Good Basic Data components must be routinely maintained to have a better risk management. All the three components are organised, planned, monitored, reviewed and audited by database system. After the comprehensive analysis of the input variables, risk analysis is done which yields measures clearly related to various risk levels like acceptable, improved, or eliminated.

DISCUSSION

Bond [7] developed the software for incident analysis during the process. The main aim of his database is to assess the risk at the initial level either in raw materials, process unit operations, equipment, storage etc. Trevor Klez [8] proposed the integrated database with spell check program with key words highlighted with information and user-friendly approach. HAZOP [9] is used to analyze process hazard data with the help of experienced persons and safety information of the previous history of accidents. Chung [10] has established a fuzzy search and a tool that integrates the process maintenance, design, operators with CAD and control system. Anand [11] developed the novel methodologies of data mining on fixed facility to analyze the data with systematic approach. Hazardous substance emergency events surveillance provides the information on hazardous compounds release with publishing fact sheets and audit reports [12, 13]. The official database is developed as major accidents reporting system, emergency response notification system [14], known as Accidental Release Information Program (ARIP) database. The database needs to be integrated with upgraded version so that all the incident variables information will be accessible to all stakeholders as an analysis and lessons in a stepwise identification.

Present databases need to be justified by improving the data parameters entry towards safety of the facilities. Apart from adding data on parameters, few efforts need to be done to improve risk management program database, in order to have a better analysis on safety of equipment performance. As equipment letdowns lead to initiation of the emergency event (industrial accident), so the facilities need to run through the failure database to get advanced solutions on procedures. Accident can happen because of both equipment failure and chemical reactivity associated events. Reactivity data are not available for every chemical to make the proper conclusion for correlation between the incident data and reactivity data for the reason that mislaid facts are often entered in reports, but this can be achieved by experiments and chemical computation [15, 16].

A better understanding can be achieved for plant authorities on consistency of equipment running with hazardous chemicals through the linkage between three types of databases which can prove to be a major breakthrough in reducing accidents. Fig. 2 shows various steps to analyze the risk and hazards. To take for risk assessment, at initial step the identification of the activity which leads to hazards by chemical process or maintenance problem, or human error, or safety failure, is required. Assessment is performed to build hazard consequences and frequencies in order not to repeat those errors. The reports are generated to implement the additional safety as per requirements for the facility used.

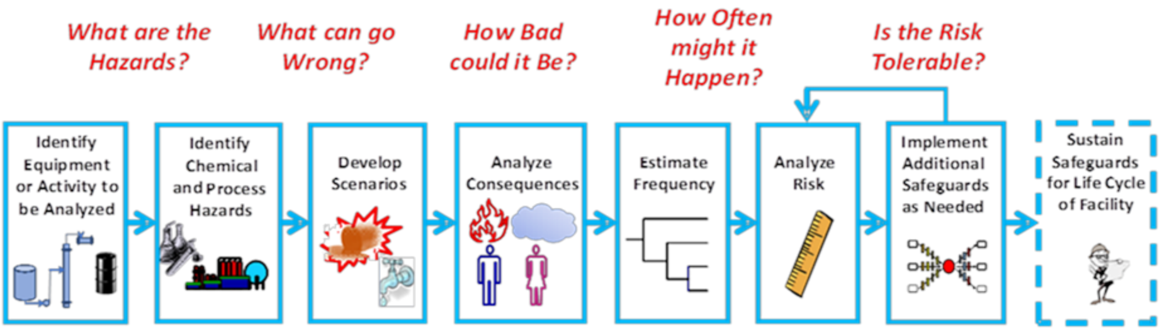

Fig. 2. Various steps to analyze the risk and hazard of accidents.

Risk assessments through damages are lessons to avoid future risks. The Fig. 3 provides the various steps of risk levels that can be minimized though incorporating the hazards data information in administrative systems.

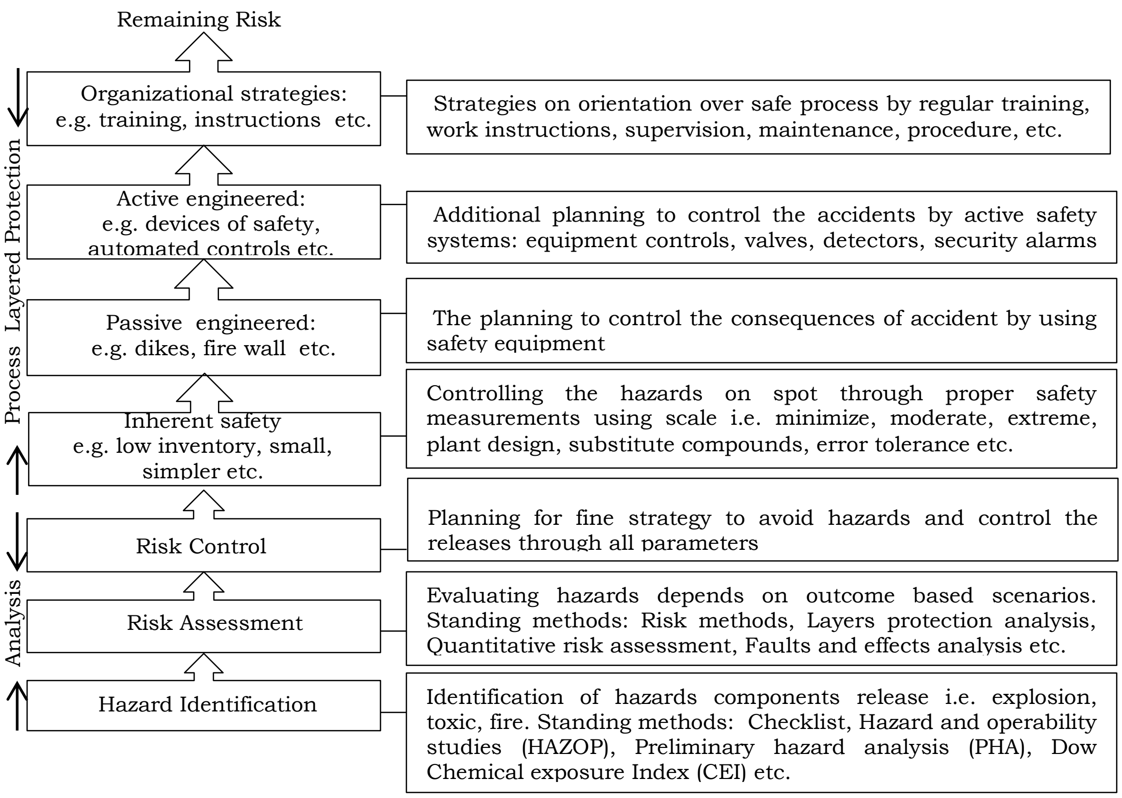

Fig. 3. Various steps in layered system of protection in risk management approach.

The flow chart represents that a hazard possibility may have arisen at any chemical plant in the form of fire, toxic chemical release, or explosion. These hazards are to be eliminated by an integrally protective designing a multilayered system which is divided into inherent safety, passive engineered and active engineered categories. The default parameters of any passive layer indicate design involved in processes and operations which can lead to blast. The active engineered system operates safety controls, alarms, pressure valves, indicators that clearly depend on chemical plant process. The technical approaches are included in the final layer to provide strategy working guidelines and procedures of individual defensive equipment.

The data on accident related variables of a database can be extended by comparing its information to that from another database (failure rate, accidental and reactive chemical databases) [17]. Initially, the understanding of all the hazards of the process is essential to prioritize, and secondly, the estimation of the risk assessment is required taking into account chances of accident consequences. Afterwards, the applicable plans should be developed to minimize the risks by controlling it in every possible way. Applying only accidental database irrespective of its prominence is incomplete by reason of:

- The database is typically based on initial statements prepared instantaneously after the accident/incident happened so the released details may be inaccurate.
- The facts of the data are not certified. Reports parameters are not advanced.
- The few reports have shortcomings like manipulation, duplicates, and more than one report related to one release.
- Transcription miscalculations over calling may cause errors in quality of insufficient data.

The Major Accident Reporting System (MARS) is a free searchable database containing more than 400 reports of the major accidents from European Union. The MARS database is well organized with detailed structured information on safety understanding performance analysis [18]. Still, every chemical database delivers insufficient information or conclusion as single chemical has many paths of reactions which can lead to accidents. The accidental databases help to conduct search for accidental chemical release, for example, ERNS database covers the release of various hazardous compounds and oils [19]. ARIP database contains data of substantial releases [20] and is integrated with ERNS database (Emergency Response Notification System) for more precise information on facilities which is updated periodically and the data do not represent geographical dissemination of releases over a certain period. The decision support system (DSS) is a smart system to provide the best single decision from numerous combinations of decisions accessible to screening. The single decision means the DSS makes the decision instead of the user and the user does not even need to delegate combinations of decisions to DSS [21]. The system provides an option to select the combinations of decisions which are functionally proceeding through the following steps:

- The user adds the entries with the deviations in his process.
- The system calculates the information like data from chemical reactivity database, incident database, equipment database and incident decision database from the known accident databases.
- These calculated data on decision are represented as a mathematical model to aid with combinations of decisions to screen.

This user manual of DSS demonstrates to be a smart thinking system. The integration with process control models in this type of system will deliver safe process with finding irregularities in the system in two steps to enable the decision. First step is modeling using the database;

- The data is chosen for facilitating decision-making. This is the most important decision criteria.
- Then storage of collected data is determined and is placed in the appropriate table.
- Next, the different data must be integrated in the database model.

There are three main objects describing a chemical incident. These objects are type of the incident, chemical component involved, and equipment engaged in the process, basing on their compliances it is necessary to take decision using primary database [22, 23]. For effective decisions, DSS database is loaded with variables of information on incident, chemical compounds involved, equipment information, while decisions on incidents are mandatory to store as tables. To get a good decision support system, a relational model between these objects and the database model suggested is based on the requirement that the incident must be well investigated and documented. Second step is decision implementation using information resulted which will further form a basis for execution. But in spite of the robust functionality of the system, some issues must be addressed before using the system. It is clear that any decision that is selected will be one derived directly from analysis of chemical incident information only. Such analysis will be devoid of a risk assessment or hazard assessment study for the scenario selected. Future focus on integrated systems is able to provide better decision support than using chemical incident information solely in the procedure of risk and hazards assessments and analysis.

Table 1 provides the usage of data analysis on incidents with risk assessment and management. Data analysis mainly contains date, time, week, location, event, reasons of the event, sampling details, effect on living organisms, distance from spill area to population residence, evacuation, and type of released compounds. Chemical risk assessment factors depend on chemical substance physical and chemical characteristics like odor, state, flash point, melting & boiling point, relative density, vapor pressure, auto-ignition temperature, solubility, flammability, surface tension, oxidizing properties, explosive properties, explosive limits, viscosity, dissociation constant, etc. The general aim of analysis is (i) to determine physical and chemical properties of hazardous compounds; (ii) to list out the information and risk aspects on injuries and facility damage; (iii) to make conclusions how to mitigate the further harmful consequences from hazardous compounds [24].

It is important to assess the consequences of worst, moderate, alternate scenario for probability of release. It is crucial that risk assessment and management correspond to each other and both can be documented with three technical steps: (i) risk assessment comprises identification of hazards and assessment of dose response. The relationship of adverse effects and dose of exposure of the hazardous compound need to be identified, (ii) exposure assessment comprises identifying the levels of doses exposed, (iii) the final step is risk characterization and appraising the incident harshness of hazards. Risk analysis and risk evaluations are categorized into few elements to have a better understanding. The questionable elements are (i) What went wrong?, (ii) Is it often?, (iii) Any consequences occurred?, (iv) So further what? [25]. In nutshells, before any regulatory decision it should be kept in mind that risk assessment needs to be considered before making any risk decision by both qualitative and quantitative analysis.

Table 1. Parameters which need to be considered while database entry

Data Category	Data parameters	Action Plan
Event reporting information	Reporting party Data and time reported	Comparison Interruptions Data Analysis Risk management Strategies
Facility/Event location	Facility name Facility location Event location	
Event information	The incident time and date The incident transportation Information on facility Type of elements involved Elements Concentration Mode effects Final result of the incident	
Causes	Primary source Secondary source Information on equipment	
Damage	Damage of properties Major and minor injuries Evacuation Deceases Effect on environment	
Action to cleanup	Maintenance and controlling procedures Announcement / Waring Repairs / Prevention	
Remarks	Documental report on entire assessment	

The quantitative methods for risk assessment can be evaluated quantitatively by adding the CAS number to database [26]. All the CAS numbered compounds must have occupational exposure limits ranges with their webpage links, call center numbers and corresponding emails. At present, the database (MARS) comprises 1341 compounds from 18 organizations. The vast varieties of occupational exposure limits (OELs) ranges are reported by many organizations, in fact, the limits can be verified by integrating the databases. The qualitative methods of risk assessment can be evaluated qualitatively by precise documentation analysis. All the OELs must be consistent with standards with the factor of 100. The documents should be linked with search option to find the critical effects of released points (incident occurred points). The released point was taken as primary information for key studies [27, 28]. Later, all the cited risk interpretations and evaluations are compared for lessons to learn for future strategies. The proposed concept of chemical accident/incident risk management system is shown in Fig. 4.

Fig. 4. General concept of chemical accident/incident risk management system.

CONCLUSION

The web based technical information on chemical accident information reporting system (CAIRS) is monitoring and providing the updates on failures of chemical accidents and also shares this information to all the stakeholders. The local authorities need to evaluate regularly on the chemicals' stockpiles, safety management, security and awareness programs for all the stakeholders. The directives on assurance of compliance are significant from central level to district coordinator to assist the emergency prevention. The disaster management coordinators and stakeholders should declare the key persons with their contact numbers as a handbook to control the information in a more effective way. The disaster management will address the key issues of i) Flow of information; ii) Reporting incident data in a format; iii) Deficiency in communication; iv) Deficiency in support and infrastructure; v) Compliances on provision of the directives; vi) Compliances of transportation of dangerous substances; and vii) Tendency of first responders to rush into the scene without proper briefing.

The current databases containing unstructured data on emergencies also provide significant information for analysis of incidents. The integration of such databases is important for mining the variables to compile and open the lessons to be learned for public. The errors in equipment operation, knowledge on chemical properties of materials are needed to be emphasized in databases and training programs.

The disaster management authority should issue the guidelines for various disasters including chemical accidents/incidents to set up the emergency response centers to store the technical database (contact address and emergency numbers) for evacuation on any mishap. These centers will coordinate with state and local disaster/crisis group on chemical emergency relief plans through capacity building programs.

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References:

1. Amyotte, P.R., Khan, F.I., & Dastidar, A.G. (2003). Reduce dust explosions the inherently safer way. *Chemical Engineering Progress*, *99*(10), 36 - 43.
2. Barton, J., & Rogers, R.L. (1997). *Chemical Reaction Hazards*, 2^{nd} Edition Rugby, UK: IchemE.
3. Bretherick, L. (2007). *Bretherick's Handbook of Reactive Chemical Hazards*, 7th Edition, Elsevier.
4. Centre for Chemical Process Safety, *Guidelines for Chemical Reactivity Evaluation and Application to Process Design*. New York: AIChE, 1995.
5. Sepeda, A.L. (2005). Lessons learned from process incident database and the process safety incident database (PSID) approach sponsored by the Center for Chemical Process Safety. *Journal of Hazardous Materials*, *130*, 9 - 14. https://doi.org/10.1016/j.jhazmat.2005.07.061
6. Goulding, J.P. (1994). *European Union Seminar on Safety and Runaway Reactions*. Frankfurt.
7. Bond, J. (2003). C-MIST, Linking an accident database to design and operational software. *IChemE Symposium*, *Hazards XVII*, Manchester, UK, 2003
8. Kletz, T.A. (2006). Searchlights from the past. *In* 9^{th} *Annual Symposium*, Mary Kay O'Connor Process Safety Center, Tezas A&M University, College Station, TX.
9. Kletz, T.A. (1986). HAZOP & HAZAN notes on the identification and assessment of hazards. Rugby, Warwickshire, UK: Institution of Chemical Engineers.
10. Chung, P.W.H., & Jefferson, M. (1998). A fuzzy approach to accessing accident databases, *Applied Intelligence*, *9*, 129 - 137. https://doi.org/10.1023/A:1008263918762
11. Anand, S. (2005). *Novel applications of data mining methodologies to incident database* (M.S. Thesis). Texas AM University, Collage Station, T.X.
12. Agency for Toxic Substances & Disease Registry, http://www.atsdr.cdc.gov/HS/HSEES/hsees.html (accessed 19.11.2020)
13. Rogers, R.L., & Hallam, S.A. (1991). Chemical approach to inherent safety. *Trans I. Chem. E.*, *69*, 149 - 152.
14. Mannan, M.S. (2005). *Lee's loss prevention in the process industries: hazard identification, assessment and control*, 3rd ed. Butterworth – Heinemann, Massachusetts: Elsevier.
15. Hale, A.R., Ale, B.J.M., Goossens, L.H.J., Heijer, T., Bellamy, L.J., Mud, M.L., Roelen, A., Baksteen, H., Post, J., Papazoglou, I.A., Bloemhoff, A., & Oh, J.I.H. (2007). Modeling accidents for proioritizing. *Reliability Engineering and system safety*, *92*(12), 1701 - 1715. https://doi.org/10.1016/j.ress.2006.09.025
16. Wang, J., & Yan, M. (2019). Application of an improved model for accident analysis: a case study. *Int. J. Environ. Res. Public Health*, *16*, 2756 - 2767. https://doi.org/10.3390/ijerph16152756
17. Nisbet, R., Elder, J., & Miner, G. (2009). *Handbook of statistical Analysis and Datamining Applications*. Burlington: Elsevier.
18. Major Accident Reporting System (MARS). https://ec.europa.eu/jrc/en/scientific-tool/major-accident-reporting-system (accessed 19.11.2020).
19. ERNS database. https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=&dirEntryId=2874 (accessed 19.11.2020).
20. Accidental Release Information Program (ARIP) database. https://www.envirosource.com/domino/thielen/envrsrc.nsf/BookSearch/BAD2747A3FD150D58625662F000B86A7?OpenDocument (accessed 19.11.2020).
21. Garland, R.W. (2004). Electronic management of change process. *Process Safety Progress*, *23*(4), 244 - 251. https://doi.org/10.1002/prs.10036

22. Abbasi, T., Pasman, H.J., & Abbasi, S.A. (2010). A scheme for the classification of explosions in the chemical process industry. *Journal of Hazardous Materials*, *174*, 270 - 280. https://doi.org/10.1016/j.jhazmat.2009.09.047
23. Jianhao, W., Gui, F., & Mingwei, Y. (2020). Investigation and analysis of a hazardous chemical accident in the process industry: triggers, roots, and lessons learned. *Processes*, *8*(4), 477 - 494. https://doi.org/10.3390/pr8040477
24. Ale, B.J.M. (2002). Risk assessment practices in the Netherlands. *Safety Science*, *40*(1-4), 105 - 126. https://doi.org/10.1016/S0925-7535(01)00044-3
25. Al-Qurashi, F., Sharma, G., Rogers, W.J., & Mannan, M.S. (2001). Applications of relational chemical process safety databases for lowering mean failure rates. *Process Safety Progress*, *20*(4), 280 -285. https://doi.org/10.1002/prs.680200410
26. AIChE/CCPS, Center for Chemical Process Safety, Guidelines for Chemical Process quantitative Risk analysis, 2nd edition, 2000.
27. Steinbach, J. (1999). *Safety Assessment for Chemical Processes*. Weinheim: Wiley, VCM.
28. Perry, R.H. (1998). Chilton. C.H. *Perry's Chemical Engineers' Handbook,* 7th Edition. New York: McGraw-Hill International Editions.