CHEMICAL ENGINEERING TRANSACTIONS

VOL. 71, 2018

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216

DOI: 10.3303/CET1871133

Research on Fire Risk Assessment of Chemical Tank Farm Based on Fuzzy Mathematics and Grey Relational Analysis

Bin Zhou,Dan He*

Hunan Institue of Technology, Hunan 421002, China
danhe7522@126.com

The purpose of this study is to reduce the probability of fire in the chemical tank farm. To this end, fuzzy mathematics was adopted to establish the risk evaluation index system of the chemical tank farm. Besides, the grey relational analysis was introduced into the weight determination of analytic hierarchy process (AHP), and then applied to the safety evaluation of one actual chemical tank farm, to obtain the membership fuzzy set of risk factors in this storage farm. The results show that according to the principle of maximum membership degree, the risk influencing factors of chemical tank farm are graded as “slight”; while according to the scoring method, the safety status of chemical tank farm is evaluated as “good” using the scoring method, indicating that the conclusions of both are consistent, also meeting the actual situation. Therefore, the evaluation process reduces errors caused by human subjective factors, making the overall evaluation result more objective, scientific and reasonable, which is conducive to regional planning and resource allocation of major hazards, and reducing fire hazards within the region.

1. Introduction

With the continuous development of society, the urban structure has become more complicated, e.g., there have been lots of factors causing fires. In case of the fire in the city, due to dense urban population and numerous assets, the fire can easily cause huge damage to the city, and even under the influence of some explosives, the destructive power and scope of the fire is intensified. These phenomena are easy to occur in the chemical tank farm. Thus, in order to reduce the fire in the chemical storage farm, the risk of fire should be assessed accordingly.

2. Literature review

In 1965, L. A. Zadeh, a professor at the University of California, published two ground breaking papers titled "Fuzzy Sets" and "Fuzzy Sets and Systems" in Information and Control. This laid the foundation for the theory and application of fuzzy sets. At the same time, it is also a sign of the birth of fuzzy theory. In 1974, Kumar et al. successfully developed a fuzzy controller for steam engine and boiler pressure under laboratory conditions, which has smaller response and faster overshoot than traditional control (DDC) systems (Kumar et al., 2018). In 1984, at the "Fuzzy Information Processing" International Conference, famous American scientist Fu Jingsheng (K.S.FI.) reported on the Chinese medicine expert system developed with fuzzy logic. The earlier research on fuzzy theory in China was in the mid-1970s and matured in the late 1990s. In 1982, Zhao Hong and Li Taihang established a blast furnace self-learning fuzzy forecasting system (offline). In October 1984, Tu Xiangchu developed a high-precision intelligent control cryogenic thermostat system. In 1997, Liu Zengliang collected relevant literature on fuzzy technology and application, and collected it into the "Selection of Fuzzy Technology and Application”. So far, the development of fuzzy mathematics has been extensive and in-depth, and it can be found in various subject areas. Among them, the fuzzy comprehensive evaluation method can effectively solve the prediction problem with more evaluation parameters and relatively fuzzy evaluation conclusions (Liu et al., 2015).
Hazardous chemicals are flammable, explosive, and toxic. It poses a hazard to equipment, people and the environment (Liu et al., 2018). At present, many chemical industries involved in the production of hazardous

Please cite this article as: Zhou B., He D., 2018, Research on fire risk assessment of chemical tank farm based on fuzzy mathematics and grey relational analysis, Chemical Engineering Transactions, 71, 793-798 DOI:10.3303/CET1871133

chemicals include mines, new materials, pesticides, fine chemicals, inorganic chemicals, organic raw materials, dyes, and soda ash. According to statistics, the total industrial production value reached 460 billion yuan. The production of hazardous chemicals involves a very wide range of industries. At the same time, because the chemical industry is directly exposed to fire, explosion, poison, corrosion and other risks, it faces unusually serious safety problems. In addition to the production process, in the operation and transportation of dangerous chemicals, it will inevitably encounter densely populated areas. Once an accident occurs, the consequences will be serious. The safety of hazardous chemicals determines that the government departments need to exercise their safety supervision functions (Verma and Chaudhari, 2016). However, hazardous chemicals involve a wide range of industries. The process is complex and the distribution is fragmented. Therefore, in order to supervise dangerous chemicals, strong expertise and many manpower are needed. It is difficult to work hard by the efforts of government departments alone. The use of intermediaries for the safety assessment of hazardous chemicals is an effective way. By identifying the source of hazards and identifying potential safety hazards, intermediaries complete safety product safety assessment reports, conduct qualitative and quantitative assessments of the risks faced by enterprises, and urge enterprises to improve safe production conditions (Moeinedini et al., 2018). Based on the safety assessment report presented by the enterprise, the government department makes judgments on the security status of the enterprises within the jurisdiction and exercises supervision functions according to law (Zheng et al., 2018).

With the rapid development of computer technology, from the late 1970s, developed countries began to study the use of computer-aided hazard identification. Over the years, many technological achievements in computer hazard identification and analysis have been obtained. For example, the SAVEII system software package developed by the Netherlands Consulting Scientists in 1989 provides quantitative risk analysis for plant design, fire, explosion, toxic spill risk assessment and accident prevention. The system has established a database of hazardous materials and meteorological conditions, including the physicochemical properties of nine substances and seventy-two meteorological models. Users can enter and save hazardous materials, special weather patterns, populations, and geographic distribution information. The personnel risk within the evaluation range is displayed as a numerical or graphical result. The system is easy to use and is suitable for safety managers and contingency planners. In 1992, Shimada et al. developed an expert system based on hazard and operability research. The system consists of an inference engine and a knowledge base. Expert systems such as HAZOP keywords, plant process structure, component characteristics, parameters, and chemical descriptions are stored in the knowledge base. When the inference engine of the expert system receives the input information or instructions, it will query the knowledge base to draw conclusions.

Similarly, domestic computer-aided hazardous chemical safety assessment technologies have also developed to some extent. In 1995, China developed a database of major hazard source assessments, grading and major hazard sources. The evaluation grading software selects the evaluation indicators based on the consequences that may cause the accident. The data information of the substance parameters in the hazard source database is read and graded for evaluation. The data results can be stored in DBF format and used in conjunction with major hazard source database software. Data information of hazard sources is established in the database of major hazard sources, and operations such as query, entry, modification, and even statistical analysis can be performed (Yang et al., 2018). Although some commercial safety evaluation software packages have been researched and developed at home and abroad, the selection of hazardous chemicals safety evaluation indicators and their weights are closely related to various factors. Therefore, each evaluation method and software package have a certain scope and limits.

The occurrence of accidents also promoted the development of risk assessment. At present, there are dozens of evaluation methods that have been proposed at home and abroad, and each method has strong pertinence. For the risk assessment technology of the tank area, foreign scholars and related institutions started earlier than China. They used a variety of methods to perform a quantitative safety assessment of the tank area. Before the 1970s, countries such as the United Kingdom and the United States mainly adopted the index evaluation method when conducting safety evaluations on tank farms. In 1964, the United States Road (DOW) Chemical Company developed the "Fire and Explosion Hazard Index Evaluation Method." The method is based on the fire and explosion potential hazards of the materials in the process. Combined with process conditions and other factors, fire and explosion indices were determined. In turn, the safety of the tank area is evaluated by measuring the magnitude of the economic loss. The chemical fire and explosion hazard index evaluation method has matured after many revisions.

After Dow Chemical Company developed the fire and explosion index evaluation method, the Imperial Chemical Company (ICI) Mond and the Dutch General Labour Administration have made appropriate amendments. This has led to the further development and application of the index evaluation method in chemical companies. In the 1970s, the probabilistic risk assessment method, that is, the regional quantitative risk assessment method, began to be applied to the quantitative safety assessment of chemical enterprises. The probabilistic risk assessment method is to determine the probability of accidents of the entire system

based on the probability of occurrence of an accident of a component or subsystem. This method was widely used in 1974 to evaluate the safety of US civil nuclear power plants. In 1989, CCPS issued the guidance document “Quantitative Risk Assessment of Chemical Processes” for the quantitative risk assessment of the chemical industry. It provides leakage scenarios and leakage probabilities for various types of equipment such as storage tanks. The accident model generated after the leakage of dangerous goods is described in detail. Currently, it is still widely used in quantitative risk assessment of chemical companies. The quantitative risk assessment of chemical tank farms in China started relatively late. Through the theoretical study and absorption of foreign technology, corresponding guidance documents and specifications were formulated.
In 2007, Sinopec Qingdao Safety Engineering Research Institute published the “Guidelines for Quantitative Risk Assessment of Petrochemical Devices”. Based on foreign research, the book has made appropriate modifications to the specific practices of quantitative risks in petrochemical enterprises. In addition, the agency published the “Guidelines for Quantitative Risk Assessment of Tank Storage Tanks” in 2014. The application of quantitative risk assessment techniques in the tank farm area was compiled. Combined with the case, the application of the program in the quantitative risk calculation of the oil storage tank is demonstrated. In 2013, the State Administration of Work Safety issued the “Guidelines for Quantitative Risk Assessment of Chemical Enterprises” (AQ/T3046-2013). The standard stipulates the technical requirements in the process of quantitative risk assessment of chemical enterprises, and gives a detailed introduction to the tank leakage mode and the evaluation of the consequences of accidents (Tauseef et al., 2018).
To sum up, the current domestic and international research has the following shortcomings: Scholars have evaluated the fire risk in chemical storage tanks from different perspectives, and there are many literatures on fire research. However, there is almost no research combining fuzzy mathematics and grey correlation analysis methods for fire risk assessment in chemical storage tanks. Therefore, for the chemical storage tank area, a corresponding evaluation index system is established. Then, the AHP theory is introduced to obtain the weight vector. The theory of grey correlation was introduced. The fire influencing factors in the chemical storage tank area were analyzed by grey correlation. Finally, the result of grey correlation theory is brought into the scale determination of chromatographic analysis. The probability of failure was reduced, and the fire safety status of the chemical storage tank area was obtained.

3. Methods

3.1 Establishing the evaluation index system of chemical tank farm

For the chemical tank farm containing major hazard sources, the occurrence of a fire is the result of the combination between the accumulation of dangerous goods and the failure of safety management, and the layout of major hazards and fire protection facilities contained in the region directly affect fire risk indicators of the whole region. Therefore, according to the fire characteristics of the chemical storage tank farm, the characteristics of the hazardous materials in the tank farm, the passive fire prevention capacity of the tank area, the active fire prevention capability, the fire rescue capability, the safety management situation and the regional environmental impact were analysed and discussed. Each of the influencing factors was also refined, to obtain the characteristics of fire risk evaluation indicators in chemical storage tank farm. Table 1 lists the structure and interrelationship of different modules.

Table 1: Evaluation index system for chemical storage tank farm

First level evaluation index	Two level evaluation index	First level evaluation index	Two level evaluation index
U1Hazardous material characteristics	U1.1Hazardous properties of hazardous materials U1.2Reserves of dangerous substances U1.3Scope of matter explosion U1.4Scope of material leakage	U4Fire rescue capability	U2.1Fire extinguishing equipment U2.2Number of fire extinguishing agents U2.3Number of fire fighters U2.4Fire Engine Access

3.2 Factor evaluation at all levels

For the influencing factors and sub-factor sets in the above-mentioned risk evaluation index system of chemical storage tank farm, the remark sets were determined by experts. 5-grade remark sets are adopted, including very serious, serious, general, slight, very slight. In terms of any single factor, statistical method was used to obtain its membership function, e.g., in terms of the implementation of safety management system, fuzzy statistics are obtained from the evaluation results of several experts: 10% of experts believe that this factor has a very serious impact on regional security; 30% of experts believe that it has a serious impact on regional security; 30% of experts believe that the impact is general, 20% believe that the impact is slight, and 10% of experts believe that the impact is very slight. That is, judgment matrix for the implementation factor of the safety management system can be expressed by a vector: R (0.1, 0.3, 0.3, 0.2, and 0.1). Using this method, the evaluation matrix of each single factor for any first-level indicator can be obtained.

3.3 Grey relational analysis of influencing factors

In the grey system theory, the concept of grey relational analysis for each subsystem is proposed, which intends to seek the numerical relationship between subsystems (or factors) in the system through certain methods. The main steps are as follows:

Standardization (non-dimensionalization) processing. Using the reference sequence as a reference point, each data is normalized to data between 0 and 1.

Calculate the relational degree. The correlation coefficient between each point K on the comparison sequence Xi and the reference sequence X reference point was calculated. Then, the average value of each coefficient, i.e., the relational degree ri of X and X0, was derived as: $r_i = \frac{1}{N}\sum_{k=1}^{N} \mathfrak{H}_i(k)$. By comparison of different relation degrees, it's found that the larger the value, the higher the relational degree.

In the grey relational analysis of each sub-factor, the first impact index under each influencing factor was used as the reference sequence, other factors as the comparison sequence, and the matrix obtained by the expert scoring as the normalized sequence. Thus, the grey relational degree of different impact indicators was calculated.

3.4 Determining the impact indicators weights by AHP

In the regional fire evaluation index system, different evaluation indicators have different contributions to the system. The weight determination of the evaluation indicators is an important part of the system risk assessment, which directly affects the rationality of the evaluation results.

Analytic hierarchy process (AHP) decomposes the system into different elements through analysis for the factors and correlation of complex systems, and form an ordered hierarchical structure by grouping them according to the dominance relationship; then, through the pairwise comparison and judgment, the relative importance of the factors at each layer is determined, and the judgment matrix is established; finally, by calculating the maximum eigenvalues and the corresponding eigenvectors of the matrix, the order of importance for each layer of elements to the upper layer is obtained, and the weight vector is established.

The next element dominated by the criterion layer element C is denoted as U1, U2...Un. For criterion C, the decision maker compares the degree of importance for two elements Ui and Uj, and assigns degree of importance according to the proportional scale defined in Table 2, forming a judgment matrix A=(aih)n×n, where aih is the scale of importance for the elements Ui and Uj relative to criterion c.

Table 2: meaning of scale scale

Scale scale	Meaning
1	The two elements are of the same importance.
3	Compared with the two elements, the former is slightly more important than the latter.
5	Compared with the two elements, the former is more important than the latter.
7	Compared with the two elements, the former is obviously more important than the latter.
9	Compared with the two elements, the former is more important than the latter.
2 , 4 , 6 , 8	Represents the intermediate value of the adjacent judgment.

4. Results

4.1 Overview of the example

The example was mainly taken to verify the effectiveness of the method. There are three hazardous chemical storage tank farms in one enterprise, namely the main tank area, the auxiliary tank area and the intermediate tank area. Table 3 lists the characteristics of the storage materials, the storage capacity and the identification results for major hazard sources of hazardous chemicals in the storage tank farm. Figure1 shows the chemical storage tank farm.

Figure 1: chemical storage tank farm

Table 3: Identification of major hazard installations in chemical plant area

Tank area	Dangerous substance	Material properties	Critical quantity	Actual reserves	Identification of major hazard installations
Main tank area	ethyl acetate	flash point：-4℃	500	80	The main tank area, auxiliary tank farm and intermediate tank farm are dangerous sources.
	methanol	flash point：11℃	500	60	
	Vinyl nitrile	flash point：1℃ toxicityLD: 78mg/kg	50	30	
Auxiliary tank area	liquid ammonia	Limit of explosive plant15.7%	10	40	
Middle tank	methanol	flash point：11℃	100	25	Major hazards

4.2 Fuzzy comprehensive evaluation

Firstly, the factors affecting the storage tank farm were judged. The evaluation results are shown in Table 4. Secondly, the fuzzy comprehensive evaluation was made for other influencing factors. According to the above calculation method, the fuzzy comprehensive evaluation of other single factors was carried out, so as to obtain the fuzzy comprehensive evaluation of the whole system. The results are shown in Table 5.

Table 4: evaluation results

influence factor		Comment set				
		Very serious	serious	commonly	Slight	Very slight
Fire prevention capacity of tank farm	Fire compartment design	0	0.2	0.3	0.3	0.2
	Fire isolation	0.1	0.2	0.4	0.3	0
	Electrical fire protection equipment	0.1	0.2	0.3	0.3	0.1

Table 5: fuzzy comprehensive evaluation of influencing factors in industrial storage tank farm

influence factor	Evaluation results
Properties of hazardous materials	(0.0489，0.1275，0.2663，0.3595，0.1988)
Active fire prevention capacity in tank farm	(0.0895，0-1 154，0.2677，0.4637，o.0637)
Passive fire prevention capacity in tank farm	(0.1386，0.1503，0.3766，0.3346，0)
Fire rescue capability	(0.0637，0.1，o.3209，0.3363，0.1791)
Safety management	(0.1649，o.1298，0.238，0.3673，0.1)

5. Conclusions

In this paper, the failure factor is assigned, and the severity of the failure factor is inversely proportional to the score. According to the principle “the higher the score, the lower the failure factor and the greater the safety of the system", the evaluation was made, indicating good fire safety in the chemical storage tank farm. The grey relational degree calculation is introduced in the fuzzy evaluation process, the qualitative and quantitative analysis are organically combined, and various influencing factors on the evaluation system are comprehensively considered, which can fully reflect the ambiguity of the evaluation factors and the evaluation process, and also reduce the error caused by the subjective factors of the experts. This is more objective and practical than the general evaluation method, and the evaluation results are more scientific and reliable.

Acknowledgement

Research on Heat Management Strategy of High Performance Data Room, Hunan Institute of Technology School-level scientific research projects, (HY12006)

Reference

Guo K., 2016, Empirical study on factors of student satisfaction in higher education, RISTI - Revista Iberica de Sistemas e Tecnologias de Informacao, E11, 344-355

Kumar A.M., Rajakarunakaran S., Pitchipoo P., Vimalesan R., 2018, Fuzzy based risk prioritisation in an auto LPG dispensing station, Safety science, 101, 231-247, DOI: 10.1016/j.ssci.2017.09.011

Liu J., Guo L., Jiang J., Hao L., Liu R., Wang P., 2015, Evaluation and selection of emergency treatment technology based on dynamic fuzzy GRA method for chemical contingency spills, Journal of hazardous materials, 299, 306-315, DOI: 10.1016/j.jhazmat.2015.06.048

Liu Y., Kong Z., Zhang Q., 2018, Failure modes and effects analysis (FMEA) for the security of the supply chain system of the gas station in China, Ecotoxicology and environmental safety, 164, 325-330, DOI: 10.1016/j.jhazmat.2015.06.048

Moeinedini M., Raissi S., Khalili-Damghani K., 2018, A fuzzy fault tree analysis based risk assessment approach for enterprise resource planning projects: A case study in an Iranian foodservice distributor, International Journal of Quality & Reliability Management, 35(5), 1115-1141, DOI: 10.1108/IJQRM-03-2016-0037

Tauseef S.M., Abbasi T., Pompapathi V., Abbasi S.A., 2018, Case studies of 28 major accidents of fires/explosions in storage tank farms in the backdrop of available codes/standards/models for safely configuring such tank farms, Process Safety and Environmental Protection, 120, 331-338, DOI: 10.1016/j.psep.2018.09.017

Sivam S.P., Sundar S., Saravanan K., Pradeep N., Moorthy K.S., Rajendrakumar S., 2018, Grey relational analysis and anova to determine the optimum process parameters for friction stir welding of Ti and Mg alloys, Periodica Polytechnica Mechanical Engineering, 62(4), 277-283, DOI: 10.3311/PPme.12117

Verma S., Chaudhari S., 2016, Highlights from the literature on risk assessment techniques adopted in the mining industry: a review of past contributions, recent developments and future scope, International Journal of Mining Science and Technology, 26(4), 691-702, DOI: 10.1016/j.ijmst.2016.05.023

Wang G.Y., Li M.Z., 2018, Fire Source Position Strategy for Chemical Plants Based on Image and Numerical Simulation Technology, Chemical Engineering Transactions, 67, 55-60, DOI: 10.3303/CET1867010

Yang Y., Chen G., Chen P., 2018, The probability prediction method of domino effect triggered by lightning in chemical tank farm, Process Safety and Environmental Protection, 116, 106-114, DOI: 10.1016/j.psep.2018.01.019

Yin K.D., Xu Y., Li X.M., Jin X., 2018, Sectoral relationship analysis on China's marine-land economy based on a novel grey periodic relational model, Journal of Cleaner Production, 197, 815-826, DOI: 10.1016/j.jclepro.2018.06.071

Zheng J., Guo S., Gao L., Xue D., Zhao N., Ma H., 2018, Inferring Gender of Micro-Blog Users based on Multi-Classifiers Fusion, International Journal of Performability Engineering, 14(2), 349, DOI: 10.23940/ijpe.18.02. p16.349356