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Chemical Process Risk Evaluation Based on Fuzzy Mathematics Theory

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Chemical industry is the pillar industry of the fast development of national economy. The risk of chemical process is an important part of its industry’s development. In this paper, according to the determined influencing factors based on the chemical process of intrinsic safety and the selection principle of evaluation indexes, chemical process risk evaluation index system based on intrinsic safety is established. Combined with several years' monitoring data and using hierarchical analysis model to calculate the weight coefficient of each evaluation index, the chemical process risk based on intrinsic safety is divided into four levels, such as Level I low risk, Level II medium risk, Level III high risk, Level IV highest risk. By means of the monitoring data to carry on its scoring, according to membership function to obtain the fuzzy comprehensive evaluation matrix, chemical process risk evaluation model based on intrinsic safety is then established, taking a certain chemical process for example to carry on a simulation calculation. Its combination is in accordance with the local situation. This method is professional, reasonable and scientific, which provides a theoretical basis for the chemical process risk evaluation.

1. Introduction

In the background of economic rapid development and scientific progress, the development of chemical industry not only reflects the constant renewal of equipment production mode of chemical process, but also the style and the quantity of chemical products that have been increasing. Together with the expansion of chemical production scale, in the mass production of chemical products, because of its own nature, there exist many raw materials that are inflammable, explosive and toxic (Chan, 2008; Giovanni et al., 2016). In the latest decade, with the sustained and rapid development of economy, the process of industrialization is growing, chemical production scale expands unceasingly, the production equipment is becoming more and more large-scale, the production process is more and more complex, the accident possibility and the severity of accident consequence is also increasing. The typical examples are: on November 13, 2005, in Double-benzene Plant of PetroChina Jilin Petrochemical Co. there happens a super explosion accident of dangerous chemicals in aniline unit, which killed eight people, 1 person seriously wounded and 59 slightly injured, evacuated the crowd 10000 people, at the same time, caused the severe pollution of the downstream and the regional water pollution abroad.

On August 26, 2008, the organic workshop of Guangxi Guangwei Chemical Co., Ltd. happened explosion accident, 20 people killed, 61 people injured, and more than 11500 people were evacuated emergently. There was also a massive explosion in Tianjin Port. On the other hand, with the progress of our society, people's safety consciousness is increasing remarkably, the idea of people-oriented is in the hearts of the people, the safety of chemical production is put forward a higher requirement. This contradiction needs the reliable safety science and technology to control the accident risk in an acceptable range. Therefore, the safety of chemical process and equipment production should be paid attention to, and scientific analysis should be carried on so as to ensure that chemical process and equipment is in the production of safe and orderly state. On the basis of practical work experience, the safety of chemical process is evaluated (Kletz, 1998).

At present, domestic chemical process risk evaluation focuses on the traditional accident prevention measures and emergency measures, but not considering reducing the risk from its source. Intrinsic safety is to reduce or eliminate the risk from its source. It is a kind of risk management method of source control. In the process of

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chemical process risk evaluation to implement intrinsic safety evaluation, it is helpful to carry on the optimization process to eliminate or reduce risk in the early stages of system design, avoiding causing great losses, so as to replace the complex safety protection device in the system, which provides important theoretical significance and practical significance to the evaluation research of chemical process risk based on intrinsic safety.

2. Chemical process risk evaluation system based on intrinsic safety

2.1 Intrinsic safety

The basic concept of intrinsic safety is considering the potential risk of chemical process and equipment radically so as to avoid it in the design process. Its basic idea is to use chemical process and the design of the equipment itself to eliminate or reduce system risk. Intrinsic safety is an active risk management method. It includes four basic strategies. The specific details are shown as follows:

(1) Minimization, that is, the amount of hazardous substances in less system

Generally, the less the hazardous substances in the chemical process system is, the smaller the accident possibility is, the lower the danger coefficient is, and the lighter the accident consequence is.

(2) Alternative, namely, use safe or less dangerous substances or process to substitute more dangerous substances or process so as to reduce the risk.

(3) Aalleviation, using the smallest form of hazardous substances or process conditions

Alleviation principle is that in this process of chemical process dangerous operation, the operation conditions of relative safety is adopted, or reduce dangerous materials, or use the storage and transportation of relative safety, and etc.

(4) Simplification, namely, through the process design to simplify the operation process.

Simple chemical process is usually safer than complex chemical process, reducing the chance of human error (Fan et al, 2008).

2.2 The evaluation index selection principle of chemical process risk based on intrinsic safety

Generally, chemical process involves flammable, explosive or toxic materials, intermediates, products and equipment. In this production, physical and chemical reaction would happen, involving chemical explosion, physical explosion, fire explosion, poisoning, choking and etc. Therefore, once it has been chosen, it is hard to be changed again. When determining the chemical process, its reliability and risk must be comprehensively analyzed and evaluated. Its selection of evaluation indexes must be in strict accordance with the standards (Rahman et al, 2005). The details are shown as follows:

(1)Scientific principle

The selected indexes much be scientific, implement the national standard. Only in this way, the selected indexes could be scientific, reflect the risk size of chemical process correctly. And its evaluation result would have reference value (Faisal and Khan, 2003).

(2) Comprehensive principle

Chemical process is a very complex system. Its risk is the outcome of multiple factors' interaction. Therefore, when establishing the evaluation index system, all influencing factors should be considered, trying to be comprehensive, achieving the independence of each index, not repeating, which could reflect the whole situation of chemical process.

(3) Pertinence principle

Referring to the process, materials and equipment of chemical process based on intrinsic safety, there are many factors affecting chemical process risk. The factors with different material, different number, and different process differ from the others. Therefore, selecting evaluation indexes must be pertinent.

(4) Feasibility principle

In the process of selecting chemical process risk evaluation indexes, the quantitative analysis index should be chosen as much as possible, namely, all the selected indexes could be measured or judged according to the known data. Meanwhile, the selected indexes should have clear meaning, conform to the national and local policies and regulations, have the operability and practicability, and be suited to local conditions.

2.3 Chemical process risk evaluation system based on intrinsic safety

Chemical process risk evaluation index system based on intrinsic safety is an organic evaluation system formed by various indexes of revealing the quantity, quality, condition, technology, equipment of things from one series (Gentile, 2004). According to the characteristics of chemical process and the basic principle of intrinsic safety, based on the selecting principles of evaluation indexes, combined with the experience abroad, a chemical process risk evaluation index system based on intrinsic safety is established (Gupta and Edwards, 2003). The details are shown in table 1.

Table 1: Chemical process risk evaluation index system based on intrinsic safety

Target	First-level indexes	Second-level indexes	Third-level indexes
Chemical process evaluation based on intrinsic safety	Intrinsic safety indexes of chemical substance	The risk of chemical substance	(1) flammability (2) explosion (3) toxicity (4) corrosivity
		The risk of chemical reaction	(5) chemical reaction heat (6) chemical activity
	Intrinsic safety indexes of technological conditions		(7) process temperature (8) process pressure (9) storage

2.4 The evaluation index weight calculation of chemical process risk based on intrinsic safety
Expert analysis, evaluation and AHP is used to calculate the evaluation index weight of chemical process risk based on intrinsic safety, the detailed calculation results are shown in table 2-table 6

Table 2: The first-level index weight of chemical process risk evaluation

Target	Chemical process risk evaluation based on intrinsic safety			The largest eigenvalue	Consistency ratio
First-level indexes	Intrinsic safety indexes of chemical substance	Intrinsic safety indexes of technological conditions	weight		
Intrinsic safety indexes of chemical substance	1	1	0.5	2.0000	0.0000
Intrinsic safety indexes of technological conditions	1	1	0.5		

Table 3: The second-level index weight of chemical process risk evaluation

First-level indexes	Intrinsic safety indexes of chemical substance			The largest eigenvalue	Consistency ratio
Second-level indexes	The risk of chemical substance	The risk of chemical reaction	weight		
The risk of chemical substance	1	1/3	0.25	2.0000	0.0000
The risk of chemical reaction	3	1	0.75		

Table 4: The third-level index weight of chemical process risk evaluation

Second-level indexes	The risk of chemical substance					The largest eigenvalue	Consistency ratio
Third-level indexes	flammability	explosion	toxicity	corrosivity	Weight		
flammability	1	1/6	1/3	5	0.1238	4.2501	0.0937
explosion	6	1	4	9	0.5956		
toxicity	3	1/4	1	7	0.2396		
corrosivity	1/5	1/9	1/7	1	0.0410		

Table 5: The third-level index weight of chemical process risk evaluation

Second-level indexes	The risk of chemical reaction			The largest eigenvalue	Consistency ratio
Third-level indexes	chemical reaction heat	chemical activity	Weight		
chemical reaction heat	1	2	0.6667	2.0000	0.0000
chemical activity	1/2	1	0.3333		

Table 6: The third-level index weight of chemical process risk evaluation

First-level indexes	Intrinsic safety indexes of technological conditions			The largest eigenvalue	Consistency ratio
Third-level indexes	process temperature	process pressure	storage		
process temperature	1	4	7	3.0324	0.0311
process pressure	1/4	1	3		
storage	1/7	1/3	1		

Due to all the consistency ratio *CR* is less than 0.10, it could be thought that all weight value could pass the consistency check.
From the comprehensiveness above, we could get the weight table of chemical process risk evaluation indexes based on intrinsic safety as follows:

Table 7: Chemical process evaluation index weight value based on intrinsic safety

Target	First-level indexes	Weight	Second-level indexes	Weight	Third-level indexes	Weight
Chemical process evaluation based on intrinsic safety	Intrinsic safety indexes of chemical substance	0.5	The risk of chemical substance	0.25	(1) flammability (2) explosion (3) toxicity (4) corrosivity	0.1238 0.5956 0.2396 0.0410
			The risk of chemical reaction	0.75	(5) chemical reaction heat (6) chemical activity	0.6667 0.3333
	Intrinsic safety indexes of technological conditions	0.5			(7) process temperature (8) process pressure (9) storage	0.7050 0.2110 0.0840

3. The chemical process risk evaluation model based on fuzzy mathematics theory

3.1 The establishment of chemical process risk evaluation factor set based on intrinsic safety

All third-level indexes of chemical process risk evaluation index system based on intrinsic safety are regarded as the factor set of fuzzy evaluation model, that is, U={flammability u_1, explosion u_2, toxicity u_3, corrosivity u_4, chemical reaction heat u_5, chemical activity u_6, process temperature u_7, process pressure u_8, storage u_9}.

3.2 The establishment of chemical process risk evaluation set based on intrinsic safety

Divide chemical process risk into four levels, such as level I low risk, level II medium risk, level III high risk, level IV highest risk, establish four-level scale set, that is, $N=(n_1,n_2,n_3,n_4)$= (level Ⅰ low risk, level Ⅱ medium risk, level III high risk, level IV highest risk).
The corresponding values of each level is (1, 0.75, 0.5, 0.25).

3.3 The determination of membership degree

According to the membership function of half trapezoid and trapezoid distribution, the membership function of chemical process risk level could be determined as follows:

Level I low risk: $$r_{i1}=\begin{cases}1, & 9\le x\le 10,\\ \frac{1}{2}(x-7), & 7\le x<9,\\ 0, & x<7.\end{cases}$$

Level II medium risk $$r_{i2}=\begin{cases}\frac{1}{2}(x-7), & 7\le x<9,\\ 1, & 5\le x<7,\\ \frac{1}{2}(5-x), & 3\le x<5,\\ 0, & x\ge 9, x<3.\end{cases}$$

Level III high risk $$r_{i3}=\begin{cases}\frac{1}{2}(x-5), & 5\le x<7,\\ 1, & 3\le x<5,\\ \frac{1}{2}(3-x), & 1\le x<3,\\ 0, & x\ge 7, x<1.\end{cases}$$

Level IV highest risk $$r_{i4}=\begin{cases}1, & x<1,\\ \frac{1}{2}(3-x), & 1\le x<3,\\ 0, & x\ge 5.\end{cases}$$

x is the average value experts score on the third-level indexes.
Based on the established four-level scale sets, carry on the fuzzy evaluation to chemical process risk factor set, determine the membership degree matrix, and set up the fuzzy mapping:

$$f: P\to F(N),\ P_i\to \frac{r_{i1}}{n_1}+\frac{r_{i2}}{n_2}+\frac{r_{i3}}{n_3}+\frac{r_{i4}}{n_4},$$

And $0\le r_{ij}\le 1$, $i=1,2,\cdots;\ j=i=1,2,3,4$.

Therefore, we could get the fuzzy evaluation decision matrix of chemical process risk evaluation:

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{14} \\ r_{21} & r_{22} & \cdots & r_{24} \\ \vdots & \vdots & & \vdots \\ r_{s1} & r_{s5} & \cdots & r_{s4} \end{bmatrix},$$

$r_{ij}=A(P_i, n_j)$ indicates that evaluation factor P_i is evaluated as the membership degree of level n_j, s is the factor number of evaluation factor P_i.
Substitute the score that experts give to chemical process risk evaluation into the membership function, and we could get the fuzzy evaluation decision matrix of the corresponding factors as follows:

$R_{11}=(r_{ij})_{4\times4}$, $R_{12}=(r_{ij})_{2\times4}$, $R_2=(r_{ij})_{3\times4}$.

3.4 The result analysis of chemical process risk evaluation based on intrinsic safety.
With the aid of the weighted model $M(\bullet,+)$, using the calculated weight of chemical process risk evaluation index, the fuzzy evaluation decision matrix of second-level is first calculated as follows: $R_1=\begin{bmatrix}\omega_{31}\bullet R_{11}\\ \omega_{32}\bullet R_{12}\end{bmatrix}$

The fuzzy evaluation decision matrix of first-level indexes could be calculated: $R=\begin{bmatrix}\omega_{21}\bullet R_{1}\\ \omega_{33}\bullet R_{2}\end{bmatrix}$,

And $\omega_{31}=(0.1238, 0.5956, 0.2396, 0.0410)$, $\omega_{32}=(0.6667, 0.3333)$, $\omega_{33}=(0.7050, 0.2110, 0.0840)$, $\omega_{21}=(0.25, 0.75)$.
According to the weight of first-level indexes to calculate, the comprehensive evaluation result Q of chemical process risk could be obtained as follows: $Q=\omega_1\bullet R=(q_1,q_2,q_3,q_4)$,

And $\omega_1=(0.5, 0.5)$.

According to the four-level scale set $N=(n_1,n_2,n_3,n_4)$ of chemical process risk to calculate, the final score could be obtained as follows: $S=Q\bullet N=(q_1,q_2,q_3,q_4)\bullet\begin{bmatrix}n_1\\n_2\\n_3\\n_4\end{bmatrix}$.

By comprehensive consideration of chemical process risk evaluation based on intrinsic safety and the analysis of evaluation model, we could get:
(1)when $S>0.7$, it indicates that chemical process risk evaluation belongs to level I low risk.
(2) when $0.5<S\le0.7$, it indicates that chemical process risk evaluation belongs to level II medium risk.
(3) when $0.3<S\le0.5$, it indicates that chemical process risk evaluation belongs to level III high risk.
(4) when $S\le0.3$, it indicates that chemical process risk evaluation belongs to level IV highest risk.

4. A simulation calculation aiming at certain chemical factory's chemical process risk evaluation in Weifang

Carrying on the data collection and field investigation to the third-level indexes of certain chemical factory's chemical process in Weifang, using experts to score, its grading result is shown in table 8.

Table 8: The grading result of certain chemical factory's chemical process risk in Weifang

Target	First-level indexes	Second-level indexes	Third-level indexes	The average mark of experts' grading
Chemical process evaluation based on intrinsic safety	Intrinsic safety indexes of chemical substance	The risk of chemical substance	(1) flammability (2) explosion (3) toxicity (4) corrosivity	5 6 3 4
			(5) chemical reaction heat (6) chemical activity	6 7
	Intrinsic safety indexes of technological conditions	Second-level indexes	(7) process temperature (8) process pressure (9) storage	4 3 2

Substitute the experts' evaluation results into the membership function, the fuzzy evaluation decision matrix of certain chemical factory's chemical process evaluation in Weifang could be obtained as follows:

$$R_{11} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}, \ R_{12} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \end{pmatrix}, \ R_3 = \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0.5 & 0.5 \end{pmatrix},$$

From calculation, the final score of certain chemical factory's chemical process evaluation in Weifang could be obtained as follows: *S*=*Q*•*N*=0.4102.
Because $0.3 < S \leq 0.5$, it indicates that certain chemical factory's chemical process evaluation in Weifang belongs to Level Ⅲ high risk.

5. Conclusion

Chemical process risk evaluation is an important part of chemical industry. The size of its risk is related to the development prospect of chemical industry, and also related to the regional development level and the future development direction (Palaniappan et al, 2002). In this paper, on the basis of the basic theory of intrinsic safety, the evaluation index system of chemical process based on intrinsic safety is put forward. It could be more scientific and effective to choose chemical process using the fuzzy mathematics theory to establish the risk evaluation model of chemical process. At the same time, because of the complexity of chemical process and its risk factors, the quantification method of intrinsic safety indexes should be further studied, the scientificity and rationality of chemical process intrinsic safety should be further improved.

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