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Risk Analysis of Liquid Ammonia Leakage in Chemical Plant Based on FTA-AHP Model

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Abstract*— Leakage of liquid ammonia can easily lead to poisoning or fire and explosion accidents, which seriously threatens the environment and people's life safety. Therefore, it is necessary to analyze the risk of leakage before the construction of liquid ammonia chemical plant, so as to take appropriate preventive measures to reduce the occurrence of such risks in the construction and operation of chemical plants. In this work, the Fault Tree Analysis method (FTA) is firstly used to study the liquid ammonia leakage event of chemical plants. Based on the analysis of the causality and logical relationship of various factors related to liquid ammonia leakage, the direct cause events of liquid ammonia leakage are found. Then Analytic Hierarchy Process (AHP) is used to further study the leakage accident of liquid ammonia on the basis of FTA. A hierarchical fault model is established, combining with the weight of the factors, the top seven key factors causing the leakage accident of liquid ammonia are determined. The research lays a foundation for comprehensive risk assessment of liquid ammonia leak, and provides a theoretical basis for the formulation of accident prevention measures in the construction and operation of ammonia chemical plant.

Index Terms—**liquid ammonia leakage, FTA, AHP, risk assessment.**

I. INTRODUCTION

Liquid ammonia (NH_3), also known as anhydrous ammonia, is a colorless liquid with a strong pungent odor. Ammonia is an important chemical raw material [1]. Liquid ammonia can leak into the air in the form of droplets, causing ammonia poisoning or fire and explosion accidents [2]. According to the statistical data, after the founding of the People's Republic of China, there were about 51 serious (extraordinary) typical leakage accidents in the chemical industry, involving 24 kinds of dangerous substances, and the number of liquid ammonia leakage accidents ranked first. The liquid ammonia leakage accidents result in negative social effects, property losses and the harm to the ecological environment [3]. Therefore, analyzing the risk of leakage before the construction of the liquid ammonia chemical plant and determining the key factors leading to the liquid ammonia leakage accident are necessary, which is beneficial for plants to take appropriate measures to reduce the occurrence of such risks during the construction and operation of ammonia chemical plants.

Fault Tree Analysis (FTA) aims at the selected top event, then the direct causes of the top event can be found based on the analysis of the causal and logical relationships of various factors related to the top event [4]. However, for accidents caused by more subjective and uncertain factors, FTA lacks sufficient data for accurate quantitative analysis. Analytic Hierarchy Process (AHP) decomposes a complex system into target, criterion and index and other layer, and constructs a judgment matrix. By solving the eigenvectors of the matrix, the influence degree of each factor on the upper factors is obtained, and the weight reflecting the importance degree of each factor is obtained [5],[6]. AHP has the advantages of combining qualitative and quantitative analysis. It is suitable for comprehensive safety assessment of complex systems affected by multiple factors and with hierarchical relationships.

In this work, in order to analyze the risk of leakage of liquid ammonia, FTA is used to find the direct cause of liquid ammonia leakage in chemical plants. Based on the analysis of the causality and logical relationship of various factors related to liquid ammonia leakage, the direct cause events of liquid ammonia leakage are found. Then AHP is used to further study the leakage accident of liquid ammonia and obtain the weight factor on the basis of FTA.

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Volume 8, Issue 5, September 2019

Combining with the weight of the factors, the key factors causing the liquid ammonia leakage accident are determined. This work lays a foundation for comprehensive risk assessment of liquid ammonia leak, and provides a theoretical basis for the formulation of accident prevention measures in the construction and operation of ammonia chemical plant.

II. FTA ANALYSIS

A. Construction of Fault Tree Model for Liquid Ammonia Leakage in Chemical Plant

The Fault Tree model for liquid ammonia leakage is constructed, as shown in Fig.1

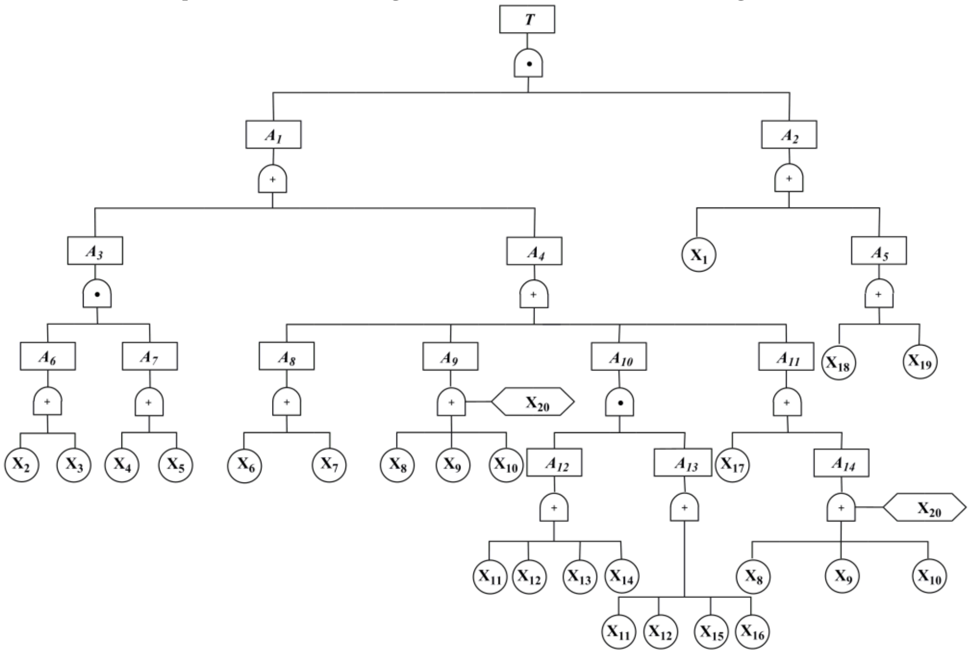

Fig. 1 Fault Tree model of liquid ammonia leakage in chemical plant

Table 1 Corresponding events of Fault Tree of liquid ammonia leakage in chemical plant

Event	Concrete content	Event	Concrete content	Event	Concrete content
T	Liquid ammonia leakage of chemical plant	A_{12}	Safety valve open	X_{11}	Excessive ambient temperature
A_1	Tank leakage	A_{13}	Blasting disc rupture	X_{12}	Overfilling
A_2	Improper emergency response	A_{14}	Angle valve leakage	X_{13}	Setting stress error
A_3	Tank leakage	X_1	No emergency training	X_{14}	Spring fatigue
A_4	Leakage of tank accessories	X_2	Poor processing	X_{15}	Poor manufacturing quality
A_5	Emergency training is not in place	X_3	Storage tank aging	X_{16}	Wrong selection
A_6	Quality problems of storage tanks	X_4	Natural force action	X_{17}	Diaphragm rupture
A_7	External forces	X_5	Construction damage	X_{18}	Leaders don't pay attention
A_8	Leakage of sealing surface	X_6	Loose bolt	X_{19}	Weak safety awareness of employees
A_9	Emergency cut-off device failure	X_7	Gasket aging	X_{20}	No review
A_{10}	Leakage of safety valve device	X_8	Valve not closed strictly		
A_{11}	Leakage of pressure gauge device	X_{10}	Water-bearing corrosion of liquid ammonia		

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B. Analysis of Minimum Cut Sets

The minimum cut set is the minimum set of basic events that can cause the top events, and can be used to study the rules of system accidents [7]. On the basis of Fig. 1, the logical operations are performed using Boolean algebra and set arithmetic rules, and the Fault Tree is simplified as follows.

$$T = A_1 \cdot A_2$$
$$= (A_3+A_4) \cdot (X_1+A_5)$$
$$= (A_6 \cdot A_7 + A_8 + A_9 + A_{10} + A_{11}) \cdot (X_1 + X_{18} + X_{19})$$
$$= [(X_2 + X_3) \cdot (X_4 + X_5) + X_6 + X_7 + X_{20} \cdot (X_8 + X_9 + X_{10}) + A_{12} \cdot A_{13} + X_{17} + A_{14}] \cdot (X_1 + X_{18} + X_{19})$$
$$= (X_2 \cdot X_4 + X_2 \cdot X_5 + X_3 \cdot X_4 + X_3 \cdot X_5 + X_6 + X_7 + X_8 \cdot X_{20} + X_9 \cdot X_{20} + X_{10} \cdot X_{20} + X_{11} + X_{12} + X_{13} \cdot X_{15} + X_{13} \cdot X_{16} + X_{14} \cdot X_{15} + X_{14} \cdot X_{16} + X_{17}) \cdot (X_1 + X_{18} + X_{19})$$
$$= X_1 \cdot X_2 \cdot X_4 + X_1 \cdot X_2 \cdot X_5 + X_1 \cdot X_3 \cdot X_4 + X_1 \cdot X_3 \cdot X_5 + X_1 \cdot X_6 + X_1 \cdot X_7 + X_1 \cdot X_8 \cdot X_{20} + X_1 \cdot X_9 \cdot X_{20} + X_1 \cdot X_{10} \cdot X_{20} + X_1 \cdot X_{11} + X_1 \cdot X_{12} + X_1 \cdot X_{13} \cdot X_{15} + X_1 \cdot X_{13} \cdot X_{16} + X_1 \cdot X_{14} \cdot X_{15} + X_1 \cdot X_{14} \cdot X_{16} + X_1 \cdot X_{17} + X_2 \cdot X_4 \cdot X_{18} + X_2 \cdot X_5 \cdot X_{18} + X_3 \cdot X_4 \cdot X_{18} + X_3 \cdot X_5 \cdot X_{18} + X_6 \cdot X_{18} + X_7 \cdot X_{18} + X_8 \cdot X_{18} \cdot X_{20} + X_9 \cdot X_{18} \cdot X_{20} + X_{10} \cdot X_{18} \cdot X_{20} + X_{11} \cdot X_{18} + X_{12} \cdot X_{18} + X_{13} \cdot X_{15} \cdot X_{18} + X_{13} \cdot X_{16} \cdot X_{18} + X_{14} \cdot X_{15} \cdot X_{18} + X_{14} \cdot X_{16} \cdot X_{18} + X_{17} \cdot X_{18} + X_2 \cdot X_4 \cdot X_{19} + X_2 \cdot X_5 \cdot X_{19} + X_3 \cdot X_4 \cdot X_{19} + X_3 \cdot X_5 \cdot X_{19} + X_6 \cdot X_{19} + X_7 \cdot X_{19} + X_8 \cdot X_{19} \cdot X_{20} + X_9 \cdot X_{19} \cdot X_{20} + X_{10} \cdot X_{19} \cdot X_{20} + X_{11} \cdot X_{19} + X_{12} \cdot X_{19} + X_{13} \cdot X_{15} \cdot X_{19} + X_{13} \cdot X_{16} \cdot X_{19} + X_{14} \cdot X_{15} \cdot X_{19} + X_{14} \cdot X_{16} \cdot X_{19} + X_{17} \cdot X_{19}$$

The 48 minimum cut sets of Fault Tree of liquid ammonia leakage are obtained as follows.

$E_1=\{X_1,X_2,X_4\}$, $E_2=\{X_1,X_2,X_5\}$, $E_3=\{X_1,X_3,X_4\}$, $E_4=\{X_1,X_3,X_5\}$, $E_5=\{X_1,X_6\}$, $E_6=\{X_1,X_7\}$, $E_7=\{X_1,X_8,X_{20}\}$, $E_8=\{X_1,X_9,X_{20}\}$, $E_9=\{X_1,X_{10},X_{20}\}$, $E_{10}=\{X_1,X_{11}\}$, $E_{11}=\{X_1,X_{12}\}$, $E_{12}=\{X_1,X_{13},X_{15}\}$, $E_{13}=\{X_1,X_{13},X_{16}\}$, $E_{14}=\{X_1,X_{14},X_{15}\}$, $E_{15}=\{X_1,X_{14},X_{16}\}$, $E_{16}=\{X_1,X_{17}\}$, $E_{17}=\{X_2,X_4,X_{18}\}$, $E_{18}=\{X_2,X_5,X_{18}\}$, $E_{19}=\{X_3,X_4,X_{18}\}$, $E_{20}=\{X_3,X_5,X_{18}\}$, $E_{21}=\{X_6,X_{18}\}$, $E_{22}=\{X_7,X_{18}\}$, $E_{23}=\{X_8,X_{18},X_{20}\}$, $E_{24}=\{X_9,X_{18},X_{20}\}$, $E_{25}=\{X_{10},X_{18},X_{20}\}$, $E_{26}=\{X_{11},X_{18}\}$, $E_{27}=\{X_{12},X_{18}\}$, $E_{28}=\{X_{13},X_{15},X_{18}\}$, $E_{29}=\{X_{13},X_{16},X_{18}\}$, $E_{30}=\{X_{14},X_{15},X_{18}\}$, $E_{31}=\{X_{14},X_{16},X_{18}\}$, $E_{32}=\{X_{17},X_{18}\}$, $E_{33}=\{X_2,X_4,X_{19}\}$, $E_{34}=\{X_2,X_5,X_{19}\}$, $E_{35}=\{X_3,X_4,X_{19}\}$, $E_{36}=\{X_3,X_5,X_{19}\}$, $E_{37}=\{X_6,X_{19}\}$, $E_{38}=\{X_7,X_{19}\}$, $E_{39}=\{X_8,X_{19},X_{20}\}$, $E_{40}=\{X_9,X_{19},X_{20}\}$, $E_{41}=\{X_{10},X_{19},X_{20}\}$, $E_{42}=\{X_{11},X_{19},X_{20}\}$, $E_{43}=\{X_{12},X_{19}\}$, $E_{44}=\{X_{13},X_{15},X_{19}\}$, $E_{45}=\{X_{13},X_{16},X_{19}\}$, $E_{46}=\{X_{14},X_{15},X_{19}\}$, $E_{47}=\{X_{14},X_{16},X_{19}\}$, $E_{48}=\{X_{17},X_{19}\}$.

There are 48 basic causes of chemical ammonia leakage accidents in chemical plants. Since the minimum cut set represents the danger of the system, in general, the more the minimum cut set, the more dangerous the system, so the risk of liquid ammonia leakage in the chemical plant must be paid enough attention.

C. Analysis of Minimum Path Set

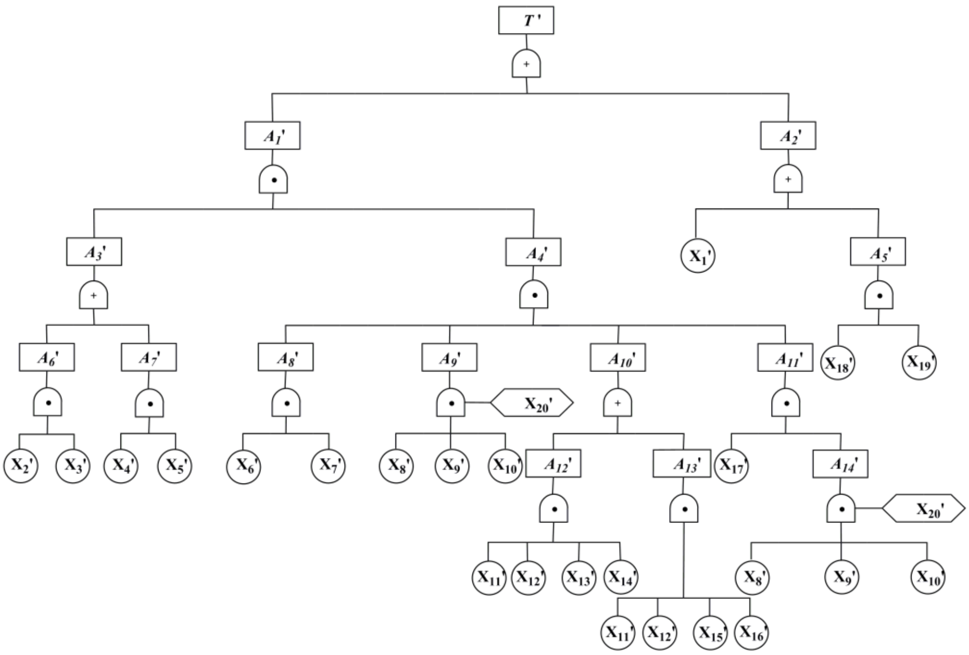

Fig. 2 Success Tree model of liquid ammonia leakage in chemical plant

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Minimum path set is the minimum set of basic events needed to ensure that the top event does not occur [7]. Through the minimal path set, a feasible scheme to avoid the top events can be obtained, thus providing a basis for accident control. The method of finding the minimum path set is to use its duality with the minimum cut set , transforming the "and door" of the Fault Tree into "or door", "or door" into "and door", and "occurrence" of various events into "no occurrence" to obtain the Success Tree dually with the Fault Tree. Then, the minimum cut set of the Success Tree is obtained by using Boolean algebra method, which is the minimum path set of the Fault Tree.

$T' = A_1' + A_2'$

$= A_3' \cdot A_4' + X_1' \cdot A_5'$

$= (A_6' + A_7') \cdot A_8' \cdot A_9' \cdot A_{10}' \cdot A_{11}' + X_1' \cdot X_{18}' \cdot X_{19}'$

$= (X_2' \cdot X_3' + X_4' \cdot X_5') \cdot X_6' \cdot X_7' \cdot X_8' \cdot X_9' \cdot X_{10}' \cdot X_{20}' \cdot (A_{12}' + A_{13}') \cdot X_{17}' + X_1' \cdot X_{18}' \cdot X_{19}'$

$= (X_2' \cdot X_3' \cdot X_6' \cdot X_7' \cdot X_8' \cdot X_9' \cdot X_{10}' \cdot X_{20}' + X_4' \cdot X_5' \cdot X_6' \cdot X_7' \cdot X_8' \cdot X_9' \cdot X_{10}' \cdot X_{20}') \cdot (X_{11}' \cdot X_{12}' \cdot X_{13}' \cdot X_{14}' + X_{11}' \cdot X_{12}' \cdot X_{15}' \cdot X_{16}') \cdot X_{17}' + X_1' \cdot X_{18}' \cdot X_{19}'$

$= X_2' \cdot X_3' \cdot X_6' \cdot X_7' \cdot X_8' \cdot X_9' \cdot X_{10}' \cdot X_{11}' \cdot X_{12}' \cdot X_{13}' \cdot X_{14}' \cdot X_{17}' \cdot X_{20}' + X_4' \cdot X_5' \cdot X_6' \cdot X_7' \cdot X_8' \cdot X_9' \cdot X_{10}' \cdot X_{11}' \cdot X_{12}' \cdot X_{13}' \cdot X_{14}' \cdot X_{17}' \cdot X_{20}' + X_2' \cdot X_3' \cdot X_6' \cdot X_7' \cdot X_8' \cdot X_9' \cdot X_{10}' \cdot X_{11}' \cdot X_{12}' \cdot X_{15}' \cdot X_{16}' \cdot X_{17}' \cdot X_{20}' + X_4' \cdot X_5' \cdot X_6' \cdot X_7' \cdot X_8' \cdot X_9' \cdot X_{10}' \cdot X_{11}' \cdot X_{12}' \cdot X_{15}' \cdot X_{16}' \cdot X_{17}' \cdot X_{20}' + X_1' \cdot X_{18}' \cdot X_{19}'$

Five minimum path sets can be obtained by calculation, as shown below.

$P_1=\{X_2,X_3,X_6,X_7,X_8,X_9,X_{10},X_{11},X_{12},X_{13},X_{14},X_{17},X_{20}\}$, $P_2=\{X_2,X_3,X_6,X_7,X_8,X_9,X_{10},X_{11},X_{12},X_{15},X_{16},X_{17},X_{20}\}$,
$P_3=\{X_4,X_5,X_6,X_7,X_8,X_9,X_{10},X_{11},X_{12},X_{13},X_{14},X_{17},X_{20}\}$, $P_4=\{X_4,X_5,X_6,X_7,X_8,X_9,X_{10},X_{11},X_{12},X_{15},X_{16},X_{17},X_{20}\}$,
$P_5=\{X_1,X_{18},X_{19}\}$.

This shows that there are five possible ways to prevent the leakage of liquid ammonia. As long as the basic events of the minimum path set do not occur at the same time, the liquid ammonia leakage accident can be prevented.

D. Analysis of Structural Importance

Structural importance analysis is to analyze the importance of each basic event from the Fault Tree structure or to analyze the impact of each basic event on the occurrence of the top event under the assumption that the occurrence probability of each basic event is equal. After determining the minimum cut set of liquid ammonia leakage accident, the approximate calculation of structural importance is carried out by using equation (1).

$$I_{\varphi(i)} = 1 - \prod_{x_i \in k_i} \left(1 - 1/2^{n_j - 1}\right) \qquad (1)$$

Where k is the total number of minimum cut sets; k_j is the j-th minimum cut set; n_j is the total number of basic events of the k_j where the i-th basic event is located.

According to equation (1), the order of structural importance of each basic event in liquid ammonia leakage accident can be obtained.

$I[X_1] = I[X_{18}] = I[X_{19}] > I[X_6] = I[X_7] = I[X_8] = I[X_9] = I[X_{10}] = I[X_{11}] = I[X_{12}] = I[X_{17}] = I[X_{20}] > I[X_2] = I[X_3] = I[X_4] = I[X_5] = I[X_{13}] = I[X_{14}] = I[X_{15}] = I[X_{16}]$

From the structural importance analysis, it can be seen that the structure importance related to management defects is greater than that related to equipment reasons. Therefore, during the construction period of chemical plants, leaders should pay more attention to safety production; improve the on-site disposal plan according to the requirements of emergency plans, set up monitoring system and voice alarm system for liquid ammonia storage tank area and unloading area.

III. AHP ANALYSIS

A. Establishment of Analytical Hierarchy Structure Model for Leakage of Liquid Ammonia in Chemical Plant

In order to further determine the weight factor causing liquid ammonia leakage accidents, and to integrate the basic events in FTA model with AHP, P_1 and P_2 obtained from the minimum path set analysis of liquid ammonia leakage accident tree are summarized as criterion layer B_1. P_3 and P_4 are regarded as criterion layer B_2, and P_5 is considered as criterion layer B_3. Then the basic events in criterion layer B are classified as criterion layer C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}, and the relationship between each factor of index layer and basic events is shown in Table 2. An analytical hierarchy structure model for the leakage of liquid ammonia from a plant is established as shown in Fig. 3.

Table 2. The corresponding relationship between index level factors of AHP model and basic event factors of FTA model

Serial number	Index level factors	Basic events of Fault Tree
1	Operational error C_1	X_8, X_{12}, X_{13}, X_{16}, X_{20}
2	Tank defect C_2	X_2, X_3
3	Parts aging C_3	X_6, X_7, X_{14}
4	Annex question C_4	X_9, X_{15}, X_{17}
5	Corrosion of tank C_5	X_{10}
6	Environmental factors C_6	X_{11}
7	External force C_7	X_4, X_5
8	No safety training C_8	X_8
9	Leaders don't pay attention C_9	X_9
10	Weak safety awareness of employees C_{10}	X_{10}

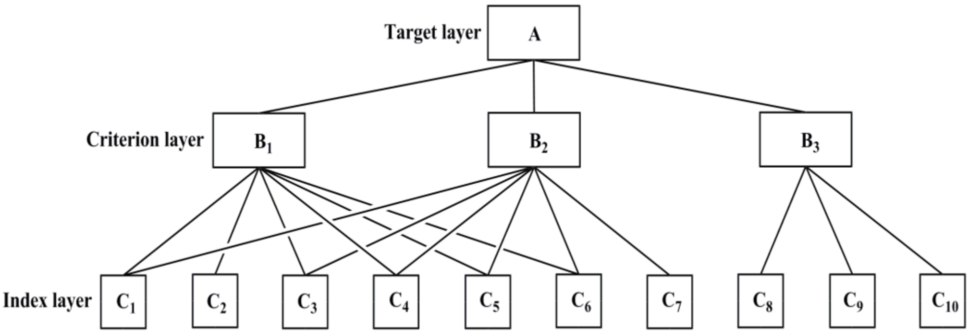

Fig. 3 Analytical hierarchy structure model of liquid ammonia leakage accident

B. Construction of Judgment Matrix

Judgment matrix is the basis of *AHP*. By analyzing the relative importance of many factors at each level relative to one of the factors at the previous level, the judgement matrix is constructed by comparing the factors in two ways. Its symbol ($U=(u_{ij})_{m\times n}$) is that the comparison result of the i factor relative to the j factor is represented. The value of each factor in the judgment matrix is determined by using 1~9 scale method [8]-[11], based on the structure importance obtained by Fault Tree analysis. The meanings of the judgment matrix are shown in Table 3.

Table 3 The meanings of the judgment matrix

Scale	Meaning and Explanation
1	Two factors are equally important
3	Among the two factors, the former is slightly more important than the latter
5	Among the two factors, the former is obviously more important than the latter
7	Among the two factors, the former is much more important than the latter
9	Among the two factors, the former is more important than the latter
2,4,6,8	The importance of this factor lies between the above two factors
1,1/2,…,1/9	The importance of the two factors is contrary to the above situation

C. Determining the Weight of factors under Single Criteria

The sum product method is used to solve the weight (ω_i) of the factors in judgment matrix and the maximum eigenvalue (λ_{max}). The results are shown in Table 4~6. The detailed calculation steps are as follows [12].

(1) Each column element of the matrix ($U=(u_{ij})_{m\times n}$)is normalized.

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Volume 8, Issue 5, September 2019

$$u_{ij}' = \frac{u_{ij}}{\sum_{i=1}^{n} u_{ij}} \quad i,j = 1,2,\ldots,n \tag{1}$$

(2) The judgement matrices of each column after normalization are added by columns.

$$\omega_i' = \sum_{j=1}^{n} u_{ij}' \quad i,j = 1,2,\ldots,n \tag{2}$$

(3) Normalization of vectors ($W' = (\omega_1', \omega_2', \ldots, \omega_n')^T$).

$$\omega_i = \frac{\omega_i'}{\sum_{i=1}^{n} \omega_i'} \quad i,j = 1,2,\ldots,n \tag{3}$$

(4) Computing the maximum eigenvalue of the judgment matrix (λ_{max}).

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{UW}{\omega_i} \quad i,j = 1,2,\ldots,n \tag{4}$$

Table 4 Judgment matrix U_0 of criterion layer B for target layer A

U_0	B_1	B_2	B_3	ω_i
B_1	1	3	1/7	0.155
B_2	1/3	1	1/9	0.069
B_3	7	9	1	0.776
		λ_{max} = 3.083		

Table 5 Judgment matrix U_1 of index layer C for standard layer B_1

U_1	C_1	C_2	C_3	C_4	C_5	C_6	ω_i
C_1	1	5	1/4	1/2	7	1/3	0.1347
C_2	1/5	1	1/6	1/4	2	1/5	0.0472
C_3	4	6	1	3	9	2	0.376
C_4	2	4	1/3	1	5	1/3	0.1483
C_5	1/7	1/2	1/9	1/5	1	1/7	0.0295
C_6	3	5	1/2	3	7	1	0.2645
				λ_{max}=6.333			

Table 6. Judgment matrix U_2 of index layer C for standard layer B_2

U_2	C_1	C_3	C_4	C_5	C_6	C_7	ω_i
C_1	1	1/4	1/2	7	1/3	6	0.1355
C_3	4	1	3	9	2	8	0.3838
C_4	2	1/3	1	5	1/3	4	0.1443

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C_5	1/7	1/9	1/5	1	1/7	1/2	0.0292
C_6	3	1/2	3	7	1	6	0.2662
C_7	1/6	1/8	1/4	2	1/6	1	0.0412
$\lambda_{max} = 6.335$							

Table 7 Judgment matrix U_3 of index layer C for standard layer B_3

U_3	C_8	C_9	C_{10}	ω_i
C_8	1	1/5	1/3	0.08
C_9	5	1	2	0.581
C_{10}	3	1/2	1	0.309
$\lambda_{max} = 3.069$				

D. Consistency Check of Hierarchical Single Sorting

Hierarchical single ranking refers to the importance ranking of many factors at the same level relative to one factor at the previous level. Generally, the constructed factor judgment matrix can reflect the difference of one factor's influence, but when many factors are compared, inconsistency often occurs, so consistency test is necessary.

Table 8 Indexes of judgement matrix U

Judgment matrix	Maximum eigenvalue (λ_{max})	Number of factors (n)	Consistency index (CI)	Mean random consistency index (RI)	Consistency ratio (CR)
U_0	3.083	3	0.0415	0.58	0.0716
U_1	6.333	6	0.0666	1.24	0.0537
U_2	6.335	6	0.0670	1.24	0.0540
U_3	3.069	3	0.0345	0.58	0.0595

The formula of consistency index is $CI = \frac{\lambda_{max} - n}{n - 1}$. The formula of consistency ratio CR is $CR = \frac{CI}{RI}$. The average random consistency index RI assignment is shown in Table 9.

Table 9 RI value of mean random consistency index

Order number	RI	Order number	RI	Order number	RI
1	0	5	1.12	9	1.45
2	0	6	1.24	10	1.49
3	0.58	7	1.32	11	1.52
4	0.9	8	1.41	12	1.54

When the random consistency ratio $CR = \frac{CI}{RI} < 0.10$, it can be considered that the ranking results of analytic hierarchy process have good consistency, that is, the distribution of weight coefficients is reasonable; otherwise, it is necessary to adjust the values of the judgment matrix [6].

As can be seen from Table 9, the CR values of consistency ratios of judgment matrices U_1, U_2 and U_3 are all less than 0.10, so it can be considered that the ranking results of analytic hierarchy process have satisfactory consistency.

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E. Analysis of results

Table 10 shows that the major factors influencing the leak accident of liquid ammonia are: lack of attention by leaders, weak safety awareness of employees, lack of safety training, parts aging, quality problems, environmental factors and operational errors. Therefore, the following suggestions are put forward:

(1) Choose leaders who have experience in production and construction and know the technical process. Leaders need to be familiar with the basic principles and process flow of each production workshop, be able to analyze and judge the major problems that may arise in production, and formulate a safety rules and regulations suitable for the actual enterprise, and prepare emergency rescue plans with pertinence, feasibility, timeliness and comprehensiveness in accordance with their own production technology, operation environment and equipment status and other links.

(2) The construction team should fully consider the safety production. The liquid ammonia storage tank area is centrally arranged on the downwind side of the plant area to ensure the fire protection distance with other adjacent factories or facilities. Ammonia leak detector, anti-static and lightning protection facilities should be installed, and fire dikes should be constructed.

(3) Selecting excellent construction personnels. Select counterpart professional and technical personnel with practical operation experience. Through training, they can grasp process operation and control, equipment maintenance and use, safety rules and regulations. Furthermore, they must be audited and approved before they can be employed or on duty.

(4) Improve the supply channels of equipment and create an environment conducive to safe production. It is necessary to ensure that the components used in the factory are manufactured by enterprises with production licenses, and the quality of which conforms to the national standards, and are installed by professionally trained personnels.

Table 10. Hierarchical ordering

Serial number	Index level	Weight	Serial number	Index level	Weight
1	C_9	0.4509	6	C_6	0.0297
2	C_{10}	0.2398	7	C_1	0.0151
3	C_8	0.0621	8	C_2	0.0073
4	C_3	0.0424	9	C_5	0.0033
5	C_4	0.0329	10	C_7	0.0028

IV. CONCLUSION

In order to reduce the risk of liquid ammonia leakage during the construction and operation of chemical plants, the risk analysis of liquid ammonia leakage was carried out by FTA-AHP method. Firstly, based on the analysis of causality and logic relationship of various factors related to liquid ammonia leakage, the direct cause of liquid ammonia leakage is found by FTA. AHP is used to further study the leakage accident of liquid ammonia on the basis of FTA. Then a hierarchical fault model is established, combining with the weight of the factors, the top seven key factors causing the leakage accident of liquid ammonia are determined. The major factors influencing the leak accident of liquid ammonia are: lack of attention by leaders, weak safety awareness of employees, lack of safety training, and aging of parts, quality problems, environmental factors and operational errors. In view of the key factors, management suggestions are put forward. The research lays a foundation for comprehensive risk assessment of liquid ammonia leak, and provides a theoretical basis for the formulation of accident prevention measures in the construction and operation of ammonia chemical plant.

REFERENCES

[1] L. L. Cheng, “Discussion on hazards and safety prevention and control of liquid ammonia leakage,” IEEE Trans. China Chemical Trade, vol. 11, no. 2, pp. 213, 2019.

[2] H. R. Wang, “Reliability study of emergency rescue system for leakage accident of liquid ammonia tank,” IEEE Trans. 2017.

[3] X. H. Pan and J. C. Jiang, “Statistical analysis and accident model of heavy (extra) large leakage,” IEEE Trans. Chemical Industry and Engineering. vol. 19, no. 3, pp. 245-253, 2002.

[4] X. C. Du and M. Q. Cai, “Fault tree analysis and risk prediction of liquid ammonia leakage,” IEEE Trans. Journal of Environmental Engineering., vol.2, no. 10, pp. 1430-1432, 2008.

[5] J. Y. Guo, Z. B. Zhang and Q. Y. Sun, “Research and application of analytic hierarchy process,” IEEE Trans. Chinese Journal of Safety Science., vol.18, no. 5, pp. 148-153, 2008.

[6] C. N. Yi, H. Hu and K. B. Liao, “FTA-AHP method research and application,” IEEE Trans. China Safety Production Science and Technology. vol.9, no. 11, pp. 167-173, 2013.

[7] Z. S. Xu, “Safety systems engineering,” IEEE Trans. Mechanical Industry Press., 2007.

[8] M. Chu, “Construction of judgement matrix in analytic hierarchy process,” IEEE Trans. Nanjing: Nanjing University of Science and Technology. 2005.

[9] Q. M. Jiang and C. H. Chen, “A multi-dimensional fuzzy decision support strategy,” IEEE Trans. Decision Support Systems., vol.38, no. 1, pp. 91-98, 2005.

[10] B. J. Zhang, “AHP and its application case,” IEEE Trans. Electronic Industry Press., 2014.

[11] F. Y. Yu, “Linear algebra and its application,” IEEE Trans. Publishing House., 2014.

[12] C. P. Wei, “The theoretical basis and properties of the neutralization product method in analytic hierarchy process,” IEEE Trans. Systems engineering theory and practice., vol.19, no. 9, pp. 113-115, 1999.

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