Analysis of Liquid Ammonia Leakage Accidents based on Safety System Engineering Theory

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Abstract

Liquid ammonia leakage accidents can cause serious consequences. This paper makes research on the liquid ammonia leakage accidents based on safety system engineering theory model. Shanghai Baoshan"8.31" liquid ammonia leakage accident is used as an example in this paper and the direct and indirect reasons of the accident are analyzed and combined into four factors: human, material , management and environment. The fault tree is drawn, then the minimal cut sets, the minimal radius set and the structural importance degree are calculated to obtain the method to improve the system security. Based on the analysis on the causing factors and the fault trees, this paper establishes the theoretical risk control system model of liquid ammonia leakage accidents. According to the model, the corresponding countermeasures for liquid ammonia leakage accident prevention are put forward, providing the basis to prevent liquid ammonia leakage accidents scientifically, reasonably and effectively.

Keywords: Liquid ammonia leakage, Security System Engineering Theory, Safety evaluation

0 Introductions

In recent years, because of China economic growth rate become accelerated, the contact of the chemical industry of life in urban areas is becoming more and more widely. Ammonia is one of the chemical productions which plays an important role in people's life. While explosion and poisoning accidents is easily happen in ammonia production, transportation and storage if pipe, valves, tanks and other materials are damaged and it will lead liquid ammonia leakage and cause serious harm to people and environment. So it is important to make some research on liquid ammonia leakage accident to prevent massive losses of lives and properties are caused by liquid ammonia leakage.

Security System Engineering Theory has been widely used in the field of safety production management; it is used in this paper to do some research on analysis of the liquid ammonia leakage accident. Countermeasure can be achieved by analyzing the super-large liquid ammonia leakage accident which happened in Baoshan district, Shanghai in 2013.

1 Case Study of the super-large liquid ammonia leakage accident which happened in Baoshan district

1.1 Accident process

On August 31, 2013 8:15AM,Weng card company employees started to work. It was about 10:45 AM, ammonia compressor plant operator Pan Zexu was doing hot ammonia defrost operation in ammonia adjust station and then the gas header pipe cap of the individual quick freezing machine which was standed at the northern of the workshop fall off and causing ammonia leakage. When the accident happened, weng card company staff immediately called 119, 120, 110, at the same time they took some action to save themselves and others. Then the fire control, public security, safety supervision, quality and technical supervision departments have arrived at the scene and took rescue work. At last 15 people were killed, 7 people seriously injured, 18 people were slightly injured [1].

1.2 Accident analysis

The direct reason of the accident was that ammonia compressor plant operator using hot ammonia defrost mode to operate and this operation was a serious illegal operating mode.
The indirect reason of the accident including that:

1. Weng card company

1. It have illegal behaviors in design, construction and production. It built some illegal constructions which were on the south, west, north of the main body building and removed the equipment and facilities to the west side construction and organize workers work in it.
2. The company changed the function layout without authorization after the main body building was completed. It changed the individual quick freezing machine production line, deep processing of aquatic products area and part of the aquatic product processing workshop into cold storage area.
3. The company couldn't do water defrosting operation according to procedures because of the water defrosting device is missing.
4. The operators couldn't monitor the key defrosting measurement equipment and control the hot ammonia defrosting valve at the same time because of the ammonia adjust station layout was not reasonable.
5. Workers in the processing workshop worked near the ammonia refrigeration equipment and pipe line.
6. The safe production responsibility system, safe production regulations and safe technology operating rules were not committing; The company didn't identify major hazards according to the national standard and relevant laws. The company didn't equip with necessary emergency rescue equipment according to the security warning marks.
7. Company management and special operations people did not obtain evidence and they did not take safety education and training.
8. The company arranged temporary workers without authorization and did not take safety education to them or tell them where have risk factors in the workplace.

2. Government Regulators

Baoshan district government, Baoshan city industrial park, quality and technical supervision bureau, safety supervision bureau, land planning bureau and public security fire control team did not perform their duties well.
The influencing factors of the accident can be deduced into human factors, material factors, management factors and environmental factors and also divided them into direct factors and indirect factors.

3. Analysis of Shanghai Baoshan "8.31"Liquid Ammonia Leakage Accidents FTA

In FTA method, logical reasoning is used to identify and evaluate the risks of various systems. Not only the direct cause of accidents can be analyzed, but also the potential causes of accidents can be deeply revealed. The method aims in forming a variety of reasons for the result, then constructing according to the logical relationship and looking for ways to prevent the outcome measures. Then draw a tree diagram [2].

3.1 Construction of FTA

Each FTA varies from the nature of the object system and the purpose of the analysis, while the procedure of analysis is also different. The user should determine the analysis program according to the actual needs and requirements. Generally speaking, the general procedure of the FTA is: be familiar with the system, investigate the accident, determine the top event, investigate the cause of the accident, draw the fault tree, qualitative analysis and quantitative analysis, make safe measures[2]. The procedure of the FTA is shown in figure 2.

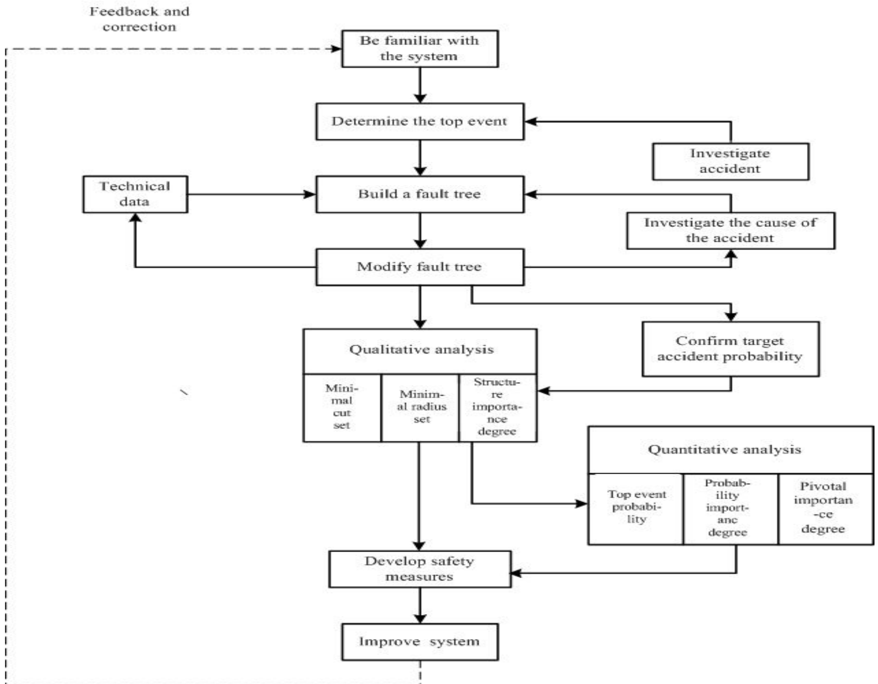

Fig.1 procedure of the FTA

3.2 Drawing and analysis of FTA

3.2.1 Drawing FTA

According to the principle of FTA, the " Shanghai ”8.31” Liquid Ammonia Leakage Accidents " must be the top event at first, then FTA is drawing step by step, liquid ammonia leakage accidents fault tree is shown in figure 2 and each symbol of basic event is shown in Tab 1

Tab 1 Symbol of each basic event]

Symbol	Event type	Symbol	Event type
T	Shanghai ”8.31” Liquid Ammonia Leakage Accidents	X_1	Incorrect operation of operator
A_1	Management problems	X_2	Training of operators is not qualified
A_2	Equipment failure	X_3	Special operations people did not obtain evidence and go to work
A_3	Rule-breaking operations	X_4	Workers in the processing workshop worked near the ammonia refrigeration equipment and pipe line.
A_4	The operation is not well	X_5	The safe production responsibility system is not committing
A_5	Rule-breaking design and construction production	X_6	The operators couldn’t monitor the key defrosting measurement equipment and control the hot ammonia defrosting valve at the same time
A_6	The company changed the individual quick freezing machine system without authorization	X_7	The company couldn’t do water defrosting operation according to procedures because of the water defrosting device is missing
A_7	There is a serious defects in the individual quick freezing machine gas collecting pipe	X_8	The equipment in the company didn’t repair all the year

3.2.2 Using Boolean algebra calculation method to calculate the minimal cut sets and the minimal radius set of FTA

1) the minimal cut sets calculation

It can be found that there are 8 minimal cut set in this liquid ammonia leakage fault tree by calculation: $\{X_1,X_2,X_6\}$, $\{X_1,X_2,X_7\}$, $\{X_4,X_6,X_8\}$, $\{X_4,X_7,X_8\}$, $\{X_5,X_6,X_8\}$, $\{X_5,X_7,X_8\}$, $\{X_1,X_3,X_6\}$, $\{X_1,X_3,X_7\}$

2) the minimal sets calculation

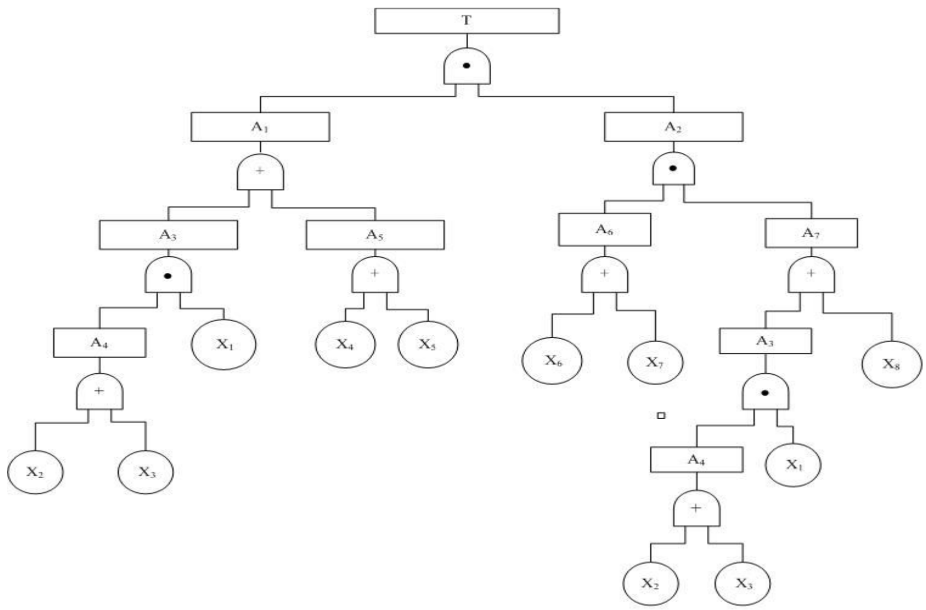

Fig.2 Shanghai Baoshan liquid ammonia leakage accident fault tree

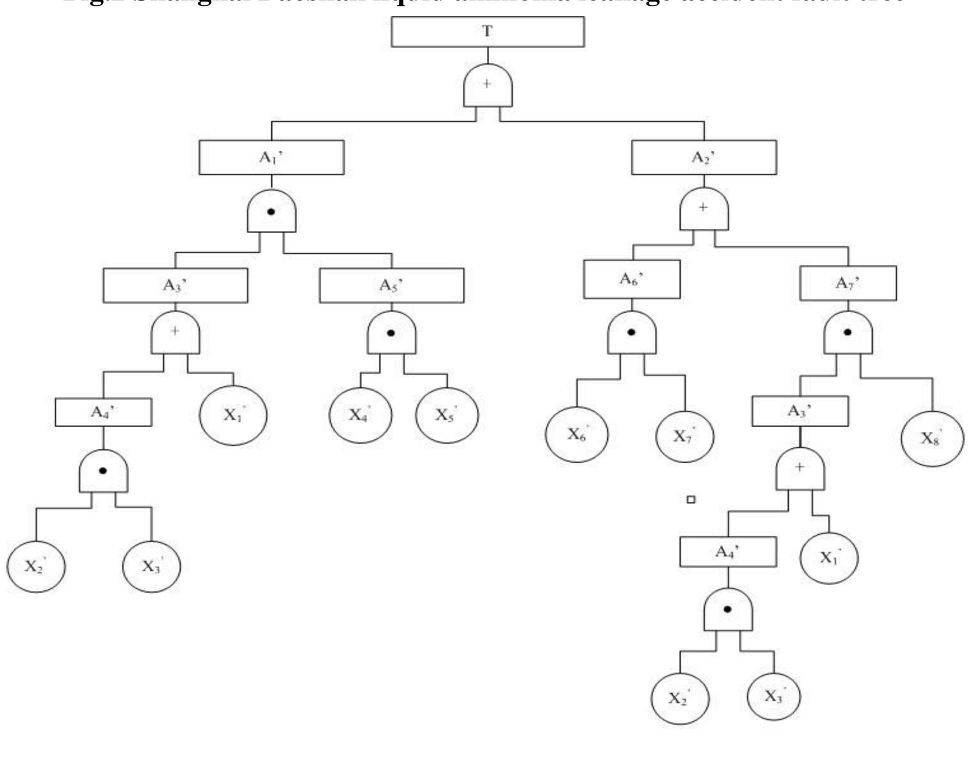

Fig.3 Shanghai Baoshan liquid ammonia leakage success tree

It can be found that there are 5 minimal radius set in this liquid ammonia leakage fault tree by calculation : $\{X_2', X_3', X_4', X_5'\}$, $\{X_6', X_7'\}$, $\{X_1', X_4', X_5'\}$, $\{X_2', X_3', X_8'\}$, $\{X_1', X_8'\}$, The success tree was shown as figure 3.

3.2.3 Basic Event Structural Importance Degree Analysis

Structural importance degree is defined as the analysis of the important degree of each basic event from the fault tree structure. When one basic event keep its state unchanged, there are three types of state that may change the top event：

$\Phi(0_i, X) = 0 \rightarrow \Phi(1_i, X) = 0$，$\Phi(1_i, X) - \Phi(0_i, X) = 0$
$\Phi(0_i, X) = 0 \rightarrow \Phi(1_i, X) = 1$，$\Phi(1_i, X) - \Phi(0_i, X) = 1$
$\Phi(0_i, X) = 1 \rightarrow \Phi(1_i, X) = 1$，$\Phi(1_i, X) - \Phi(0_i, X) = 0$

The first and third type can't explain how the state change of X_i will influence the top event, while the second type can explain the influence of X_i . While the basic event X_i makes its state change from 0 to1and other basic event keep their state unchanged, that is, if the state of top event change from $\Phi(0_i, X) = 0$ to $\Phi(1_i, X) = 1$, it can be said that the state change of the basic event X_i will determine whether the top event will happen or not. Make all these events add together then multiplied by a coefficient $\frac{1}{2^{n-1}}$， define this as structural importance degree coefficient(N is the number of basic events of the fault tree)[2][6]。

3.2.4 Basic event structural importance degree analysis result

We use the quadratic approximate formula to calculate the structural importance degree. The quadratic approximate formula is shown as below:

$$I_{\phi(i)} = 1 - \prod_{x_i \in k_j}\left(1 - \frac{1}{2^{n_j - 1}}\right) \qquad (1)$$

The result can be achieved according to this formula :

$$I_{\phi(1)} = I_{\phi(6)} = I_{\phi(7)} = I_{\phi(8)} = 1-\left(1-\frac{1}{2^2}\right)\left(1-\frac{1}{2^2}\right)\left(1-\frac{1}{2^2}\right)\left(1-\frac{1}{2^2}\right) = 0.6836$$

$$I_{\phi(2)} = I_{\phi(3)} = I_{\phi(4)} = I_{\phi(5)} = 0.4375$$

The liquid ammonia leakage fault tree structural importance degree coefficient sequence for basic events is shown as below：

$$I_{\phi(1)} = I_{\phi(6)} = I_{\phi(7)} = I_{\phi(8)} > I_{\phi(2)} = I_{\phi(3)} = I_{\phi(4)} = I_{\phi(5)}$$

It can be known from the result that: the basic event that incorrect operation of operator, the operators couldn't monitor the key defrosting measurement equipment and control the hot ammonia defrosting valve at the same time, the company couldn't do water defrosting operation according to procedures because of the water defrosting device is missing and the equipment in the company didn't repair all the year for liquid ammonia leakage accident are more important than others. By reducing the probability of these four basic events can reduce the probability of liquid ammonia leakage accident.

4. The Theoretical Risk Control System Model Of High-Rise Building Fire Accidents.

4.1 the theoretical risk control system model

There is a mutual effect relation between security and risk in the Security systems theory, it is shown as below:

$$S=1-D \qquad (2)$$

In this formula , S signifies for system security, D signifies for system risk
Shanghai Baoshan "8.15"Liquid Ammonia Leakage Accidents safety accident can be regard as a system and it can be divided into three parts which is the input, output and system model. The relationship between the input and output of the system was shown in the figure 5 as below:

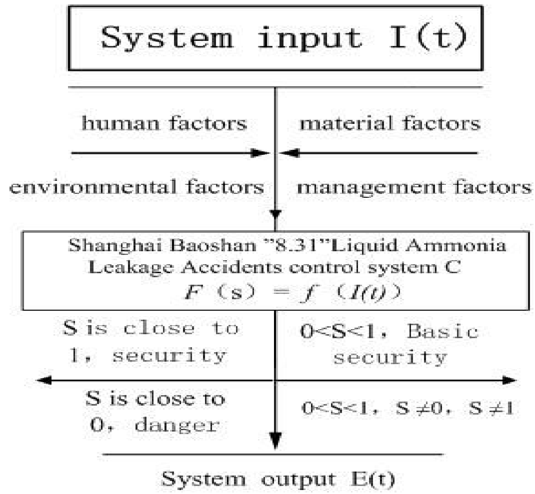

Fig.4 risk control system model

The above four system can be combined together to get an optimal output effect in order to make the system output to the best level[3].

It could consider to make dimensionless processing to actual values of the indicators of each subsystem in system output operations. The premise of dimensionless processing is to given the upper and lower limits (x_{max} and x_{min}) of each actual situation. It can set upper limit and lower limit as 1 and 0, 1 on behalf of the security state and 0 on behalf of the unsafe state to each indexes. The value has been dealt with was on behalf of X, more big the value X is ,more good the security situation is. The formula is shown as below: $X=\frac{x-x_{min}}{x_{max}-x_{min}}$, the data x is on behalf o of the most primitive indicators, x_{min} represents the index that the actual value when the indicator is on the situation most unfavorable to system, while x_{max} represents the index that the actual value when the indicator is on the situation most favorable to system. Then compare the different value. It can consider the whole system is in a state of insecurity when most indicators after dealt with make the result close to 0 and the whole system is in a state of security when most indicators after dealt with make the result close to 1[5][9].

System input I (t) includes four part which are human factors, material factors, management factors and environmental factors. Human factors and material factors have a higher weight than management factors and environmental factors. It can be known from the analysis that human factors and material factors work together make the liquid ammonia leakage accident happen. Management factors and environmental factors do not lead the occurrence of accident directly, but they perform a very obvious effect on the ammonia spread and people escape. It can play a great role in reducing the personal property losses lead by liquid ammonia leakage accident if the two factors can be effectively control. These four factors work together made the system output E(t) finally output a result that state 0 which lead a heavy property losses.

5. The Result Analysis and Countermeasures

From the fault tree analysis, it can be known that to prevent the liquid ammonia leakage accidents that may cause great losses of property. The operator should obtain evidence and take safety education before they go to work. It is mainly from two aspects which are human factors and material factors to control the hazard basic event happen, especially large events with important degree coefficient. For example, incorrect operation of operator, the equipment in the company didn't repair all the year and so on. Relevant countermeasures should be taken as follow in order to prevent great losses of property caused by the liquid ammonia leakage accident.

01. Company management and special operations people should obtain evidence and take safety education and training before they go to work. The equipment in the company should be repaired regularly in order to make equipment in a stable state.

02. It is important to improve construction supervision environment and establish the security system in order to prevent and control liquid ammonia leakage accident from the source; It is necessary to implement the responsibility system for safety in management factors.
03. The administrative departments should strengthen the safety training of operators and production line workers. Workers without professional certificate should be prohibited to get work. The individual quick freezing machine should be inspected strictly before they are put into operation.

6. Conclusions

The fault tree model of the safety system engineering is used to analyze the liquid ammonia leakage accident and four angles of the accident are got which are human factors, material factors, management factors and environmental factors subsystem then make sure how these factors influence the total system state. Then the fault tree is drawing step by step and the minimal cut set, the minimal radius set and the basic event structural importance degree of the fault tree are obtained. Why liquid ammonia leakage accident lead great losses of property be known by according to the risk control system model and conclusions can be drawn from the calculation and analysis:

1. As one of the most important research methods of safety system engineering, FTA plays an important role in safety design, safety management and safety controlling. It is feasible and reliable to use fault tree method in the research of ammonia accident.
2. The safe production responsibility system, safe production regulations and safe technology operating rules should be committing; The company should identify major hazards according to the national standard and relevant laws. And equip with necessary emergency rescue equipment according to the security warning marks.. From the risk control system model can we know that indirect reason such as management factors and environmental factors should be controlled very strictly.
3. It is very hard to put out the ammonia when the liquid ammonia leakage accident happens because of the characteristics of liquid ammonia leakage accident. So it is important to take preventive measures in high-rise building and it can be found that people should choose important event to monitor in order to prevent and reduce the high-rise building fire accident probability from the risk control system model and FTA model.

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