

Analysis on safe operation of urban gas pipeline

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Keywords: Fault tree, Safe operation, Minimum cut, Probability importance degree.

Abstract: Fault tree analysis (FTA) is a widely used method in the system safety analysis. In this approach, the logical relationship between accidents may occur and their various reasons is expressed in an arborescence, which is called fault tree analysis. By qualitative and quantitative analysis of the fault tree, the main reason for the accident can be identified. It can provide a reliable basis for determining the security countermeasures in order to achieve the purpose of predicting and preventing accidents. Combining with the survey of Chongqing City gas pipeline, the gas spill fault tree has been established. Do qualitative and quantitative research on the basic reasons for events in the fault tree, calculate the corresponding importance and accident probability, analyze the possible ways to accidents and finally the suggestions as to how the gas system could operate safely is made.

1 Introduction

The development of city gas industry is one of the important measures to use energy reasonably and efficiently, protect environment, prevent air pollution, promote production and improve the living conditions of people. With the implementation of many natural gas projects in our country, natural gas has gradually become the main source of city gas. Chongqing Yuchuan Gas Co., Ltd. is a subsidiary of China National Petroleum Corporation. Yu-chuan company mainly engaged in pipeline gas terminal sales, having 112,692 users, of which 116 industrial users, 286 collective users, 1199 commercial users, 111085 resident users and 6 CNG users. Although urban gas brings a lot of convenience to the city residents, it may lead to accident because of manage problems and improperly use. Especially with the extensive application of urban gas in industrial and civil areas, the number and density of underground pipe network are increasing. At the same time, fire caused by corrosion, damage and leakage, and poisoning frequently occur.

Fault Tree Analysis (FTA) is a system safety analysis method which is widely used. In this approach, the logical relationship between accidents may occur and their various reasons is expressed in an arborescence, which is called fault tree analysis. By qualitative and quantitative analysis of the fault tree, the main reason for the accident can be identified. It can provide a reliable basis for determining the security countermeasures in order to achieve the purpose of predicting and preventing accidents.

2 Construction of fault tree

According to Yuchuan company "2011 ~ 2014 production anomaly tracking table", there are 143 gas accidents during 2011~2014, of which 76 gas leakage accidents, accounting for 53.1%. The statistical results show that gas accidents are mostly gas leaks or accidents caused by leakage.

Table1. Yuchuan company gas accident statistics table

Years	2011	2012	2013	2014	Sum
Gas accident	34	25	36	48	143
Leakage accident	21	13	10	32	76
Proportion	61.8%	52%	28%	66.7%	53.1%

According to the principle of the top event of fault tree and the operation of natural gas pipeline network of Yuchuan Company, we select the "natural gas leak" as the top event.

Natural gas leakage includes outdoor gas transmission and distribution system leakage (extranet) and indoor gas supply system leakage (intranet). The relationship between them is OR. Figure 1 is to construct the fault tree after repeated analysis of the logical relationship among top events, intermediate events and the basic reasons. Table 1 is the basic events list of fault tree.

3 Fault tree analysis

A. Fault Tree qualitative analysis

The main task of fault tree qualitative analysis is to find out all minimal cut sets or minimal path sets of fault tree. Minimum cut set is an integrant set which cause the occurrence of top event. To some extent, the minimal cut sets can represent the level of system risk. When all basic events of a minimal cut set occur, the top event is bound to happen. In this paper, Boolean algebra method was used to solve the structure function of gas leakage fault tree diagram. The calculation result of all minimal cut sets is as follows.

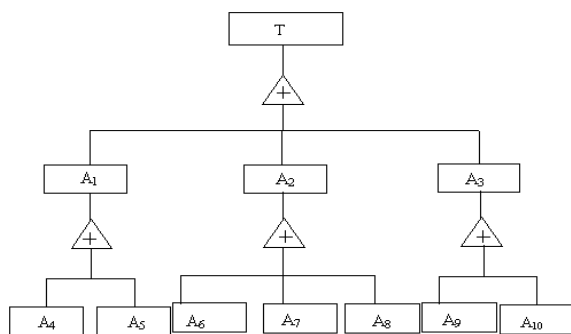


Fig. 1. Analysis diagram of gas leakage fault tree

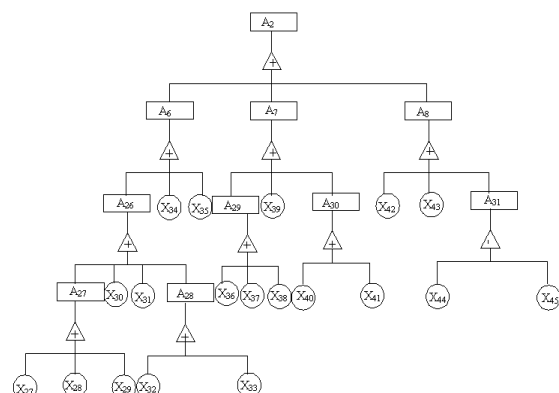


Fig. 2. Fault tree analysis diagram of Pipe network facility leakage

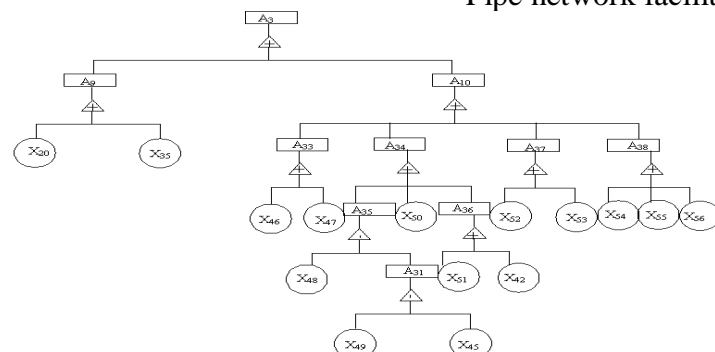


Fig. 3. Fault tree analysis diagram of gas equipment facility leakage

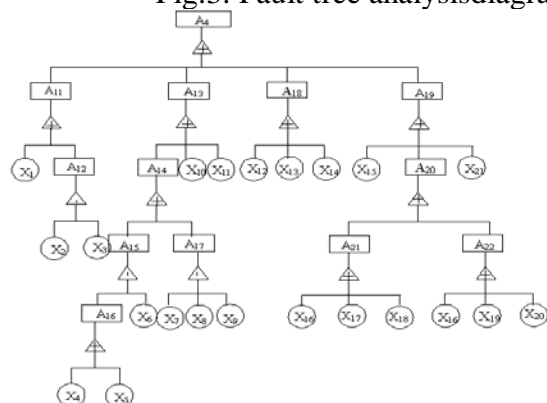


Fig. 4. Fault tree analysis diagram of the external city gas network leakage

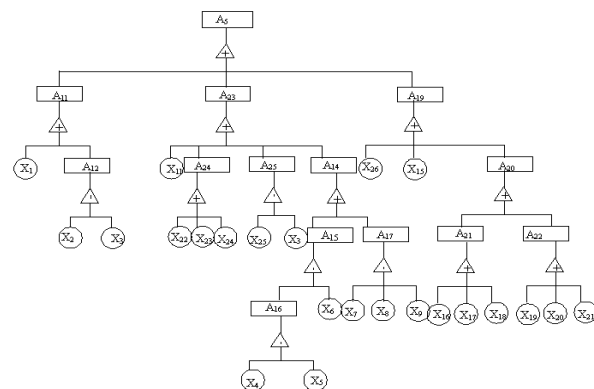


Fig. 5. Fault tree analysis diagram of the internal city gas network leakage

Table 2. Basic events of fault tree

Codes	Events	Codes	Events	Codes	Events	Codes	Events
T	Natural gas leak	A ₂₄	Hot melt defect	X ₁₀	Hot melt defects	X ₃₄	Poor sealing
A ₁	Pipeline network leakage	A ₂₅	Threaded connection leakage	X ₁₁	Flange connection leakage	X ₃₅	Third-party damage
A ₂	Facility leakage	A ₂₆	Poor equipment quality	X ₁₂	Tube wall thickness are poorly designed	X ₃₆	Ball valve junction leakage
A ₃	Gas equipment leakage	A ₂₇	Valve quality problem	X ₁₃	Geological changes	X ₃₇	Thread leakage at plug valve
A ₄	External network leakage	A ₂₈	Meter quality problem	X ₁₄	Road over load	X ₃₈	Other valve junction leakage
A ₅	Internal network leakage	A ₂₉	Valve connection leakage	X ₁₅	Fatigue cracking	X ₃₉	Regulator installed junction leakage
A ₆	Equipment failure	A ₃₀	Meter connection leakage	X ₁₆	Inappropriate selection of material	X ₄₀	Leakage at connection of flow meter and pipe
A ₇	Device junction leakage	A ₃₁	Illegal installation	X ₁₇	Stray current interference	X ₄₁	Leakage at connection of other instructions and pipe
A ₈	Illegal operation	A ₃₂	Outside anticorrosion failure	X ₁₈	protecting coating aging	X ₄₂	Operational error
A ₉	Anticorrosive coating failure	A ₃₃	Appliance quality problems	X ₁₉	Quality problems of the installation	X ₄₃	Illegal operation
A ₁₀	Appliance leakage	A ₃₄	Management deficiencies	X ₂₀	Poorly designed	X ₄₄	Installation isn't in strict accordance with the procedures
A ₁₁	Quality problems	A ₃₅	Improper gas appliance installation	X ₂₁	Third-party of external network	X ₄₅	Hasn't checked after installation
A ₁₂	Construction quality defects	A ₃₆	Weak security awareness	X ₂₂	Pipes and fittings don't fit each other	X ₄₆	Quality problems brought by extended use of water heater
A ₁₃	External network connection leakage	A ₃₇	Appliance failure	X ₂₃	Hot melt equipment is not suitable	X ₄₇	The aging of stove
A ₁₄	Weld defects	A ₃₈	Appliance connection leakage	X ₂₄	Partial melting tumor	X ₄₈	Non-licensed journeyman
A ₁₅	Weld strength does not meet the requirements	X ₁	Pipe quality defect	X ₂₅	Thread defect	X ₄₉	Installation errors
A ₁₆	Welding process execution doesn't meet the requirements	X ₂	Nonstandard construction	X ₂₆	Third-part damage of internal network	X ₅₀	Inferior products into the market
A ₁₇	Excessive geometric imperfections in welding	X ₃	The project hasn't been examined whether it's qualified	X ₂₇	Ball valve quality problems	X ₅₁	Valve not closed
A ₁₈	Pipe base sink	X ₄	Incorrect heat treatment process	X ₂₈	Plug valve quality problems	X ₅₂	Water heater failure
A ₁₉	Fracture openings	X ₅	The actual welding process control is wrong	X ₂₉	Other valve quality problems	X ₅₃	Stove fault
A ₂₀	Corrosive opening	X ₆	Strength test is not found	X ₃₀	Regulator quality problems	X ₅₄	Leakage at connection of water heater and pipe
A ₂₁	External anticorrosion failure	X ₇	Welder qualification	X ₃₁	The gas reservoir quality problems	X ₅₅	Leakage at connection of stove and pipe
A ₂₂	Cathode protection failure	X ₈	Welding environment	X ₃₂	Flow meter quality problem	X ₅₆	Leakage caused by Stove and pipeline interface is not strong
A ₂₃	Internal network connection leakage	X ₉	Execution of welding process is wrong	X ₃₃	Quality problems of other instrument		

E1={X1}; E2={X2, X3}; E3={X4, X6}; E4={X5, X6}; E5={X7, X8, X9}; E6={X10}; E7={X11}; E8={X12}; E9={X13}; E10={X14}; E11={X15}; E12={X16}; E13={X17}; E14={X18}; E15={X19}; E16={X20}; E17={X21}; E18={X22}; E19={X23}; E20={X24}; E21={X25, X3}; E22={X26}; E23={X27}; E24={X28}; E25={X29}; E26={X30}; E27={X31}; E28={X32}; E29={X33}; E30={X34}; E31={X35}; E32={X36}; E33={X37}; E34={X38}; E35={X39}; E36={X40}; E37={X41}; E38={X42}; E39={X43, X44, X45}; E40={X46}; E41={X47}; E42={X48, X49, X45}; E43={X51}; E44={X52}; E45={X53}; E46={X54}; E47={X55}; E48={X56}。

Generally speaking, the minimum cut sets which include less basic events are easier to happen. X2, X4, X5 and X25 were stored in a second-order cut set. X3 and X6 were placed in two second-order cut sets. X7, X8, X9, X43, X44, X48 and X49 exist in a third-order cut set. X45 exists in two third-order cut sets. The remaining events exist in the first-order cut sets.

According to approximate discriminant of importance:

$$I_i = \sum_{i=1}^{k_i} \left(\frac{1}{2}\right)^{N-1} \quad (1)$$

In the equation above, k_i is the number of cut sets which contain X_i ; N is the number of basic events in the cut set which contains X_i .

From the above, the structure importance of basic events which exists in first-order cut sets is biggest, X3 and X6 followed by. The importance of X2, X4, X5, X25 and X49 is relatively small. The structure importance of X7, X8, X9, X43, X44, X48 and X49 which exists in third-order cut sets is smallest. The resulting order of importance is as follows:

$$I_1 = I_{10} = \dots = I_{24} = I_{27} = \dots = I_{43} = I_{47} = I_{50} = \dots = I_{56} > I_3 = I_6 > I_2 = I_4 = I_5 = I_{25} = I_{49} > I_7 = I_8 = I_9 = I_{43} = I_{44} = I_{48} = I_{49}$$

Therefore, pipe defects, leakage at connection of stove and pipeline and quality defects of facilities occupy relatively important positions and they are the dominant factors whether the top events would happen.

B. Quantitative analysis of the fault tree

The main task of fault tree quantitative analysis is to calculate the probability of occurrences of top events. In quantitative probability calculation, assume that the bottom events are independent and the bottom events have only two conditions, which is normal or accidental condition.

At time t , the probability of occurrence of the minimum cut set j is:

$$P[k_j(t)] = P\left[\bigcap_{i \in k_j} x_i(t)\right] = \prod_{i \in k_j} F_i(t) \quad (2)$$

In the formula above, x_i is the bottom event of minimum cut set k_j ; $F_i(t)$ is the probability of x_i , which is the failure rate of component i .

The probability of occurrence of top event:

$$P(T) = \bigcup_{j=1}^N p[k_j(t)] \quad (3)$$

In the formula above, N is the number of minimum cut sets in the system. By statistics and analysis of gas accidents in Yuchuan Company in the past few years, the probabilities of occurrence of each basic event can be learned. They are shown as Table 3.

Table 3. Probability of basic events in gas system

Event	Probability	Event	Probability	Event	Probability
Leakage caused by pipeline facility corrosion	0.0001	Poorly designed	0.0003	Leakage at screw thread of cocks	0.0065
Leakage at pipeline welds	0.0002	Geological changes	0.0001	The project hasn't been checked whether it's qualified	0.0060
Third-party damage of external network	0.0003	Road over load	0.0003	Tank leakage	0.0003
Leakage caused by nonstandard installation of valve	0.0001	Inappropriate selection of material	0.0001	Leakage caused by poor gasket performance	0.0001
Leakage caused by quality defects of pressure regulator	0.0003	Leakage caused by fatigue cracking	0.0003	Leakage caused by insufficient attachment strength	0.0001
Leakage caused by pipecorrosion	0.0002	Leakage caused by quality defects of pipe material	0.0003	Leakage caused by poor seal	0.0005
Leakage caused by aging hose	0.0052	Leakage at flange joint	0.0003	Explosion caused by welding fire	0.0001
Leakage at weld	0.0018	Leakage caused by valve quality defects	0.0013	Leakage at pressure regulator	0.0006
Leakage caused by flow meter quality defects	0.0002	Leakage at valve joint	0.0020	Leakage at pressure regulator junction	0.0008
Leakage caused by aging stove	0.0055	Leakage caused by hose damage	0.0009	Leakage at hose junction	0.0035
Leakage at connection of water heater and pipe	0.0093	Leakage at connection of screw thread	0.0032	Leakage caused by stove defects	0.0024
Installation staff is not eligible	0.0010	Leakage at connection of flow meter and pipeline	0.0108	Leakage caused by extended use of water heater	0.0074
Hasn't checked after installation	0.0003	Leakage at connection of stove and pipeline	0.0054	Faults in stove installation process	0.0017
Leakage caused by cock quality defects	0.0073	Leakage caused by gas appliance quality defect	0.0010	Improperly closed valves	0.0107
Staff fail to work in accordance with procedures	0.0010	Leakage caused by water heater failure	0.0009	Leakage caused by third-part damage of internal network	0.0063
Non-standard construction	0.0010	The installation process is not in strict accordance with procedures	0.0052	Leakage caused by pipeline quality defects	0.0001
Leakage caused by incorrect heat treatment	0.0001	Leakage caused by ball valve quality defects	0.0079	Instruments quality defects	0.0003
Hot melt defects	0.0001	Leakage at ball valve joint	0.0065	Leakage at instrument junction	0.0005

Inserting the corresponding probabilities of basic events, the probability of natural gas leakage while running in Yuchuan Company can be calculated:

$$P(T) = \bigcup_{j=1}^{48} p[k_j(t)] = 0.0965 \quad (4)$$

According to the importance analysis, pipe defects, gas appliance failure and damaged pipe fittings are the main reasons for gas leakage. Corresponding probabilities of basic events can be got after further analysis. It is shown as Table 4.

Table 4. Probabilities of main intermediate events

Symbol	Event	Probability	Symbol	Event	Probability
$P(A_2)$	Probability of pipe network facility leakage	0.0380	$P(A_4)$	Probability of leakage at external city gas network	0.0024
$P(A_3)$	Probability of leakage at gas appliance	0.5090	$P(A_5)$	Probability of leakage at internal city gas network	0.0066

As can be seen from the table above, leakage at gas appliance is the most important factor for gas leakage while gas system is running. Leakage caused by facilities also cannot be neglected. However, leakage at city gas network is relatively small. In other words, these events should serve as the main basis for accident prevention. Gas company should pay close attention to these factors in order to ensure safety.

4 Conclusion

Based on fault tree analysis, in order to prevent fire and explosion caused by natural gas leakage and improve the level of safe operation of natural gas network in Yuchuan Company, several suggestions are proposed as follows:

- (1) Improve the construction of emergency organization system. It is recommended to build a rescue organization hierarchically and by region according to the current emergency rescue and protection work leading group, to bear the scope of their respective jurisdictions.
- (2) Improve the emergency response management mechanism. Yuchuan company has established a contingency management system. It is suggested that Yuchuan Company will further improve the rules and regulations, such as plans, systems and methods, and standardize the operation procedures and standards. Monthly inform the gas rescue rate, pipe network leaks self-examination rate, hidden trouble rectification and so on, and sum up lessons.
- (3) Improve the information construction of gas pipeline network. Transform urban natural gas pipeline network by new technology such as GIS and SCADA. Establish urban gas pipeline network information system and computer-aided scheduling system, so as to improve the safe operation of natural gas levels.
- (4) Strengthen the construction and training of rescue personnel. It is suggested that the company should focus on strengthening the knowledge level of the relevant personnel in the rescue skills, safety awareness, organization and coordination, professional level, actual combat experience and other aspects.

Acknowledgement

In this paper, the research was sponsored by Science and technology research Project of Chongqing Education Commission (Project No. KJ1501337) and Key project Fund Project of Chongqing University of Science and Technology (Project No. CK2016Z22).

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