Chemical Process Failure Likelihood Analysis for Chlorine Handling Facilities

Baek, J[1], Bae, S.J[2] ,Bartolucci, A.A[3] and Singh, K.P[2]

[1]Department of Safety Engineering, ChungJu National University, Republic of Korea
[2]Dept. of Biostatistics, University of North Texas, Forth Worth, Texas, 76107- 2699, USA.
[3]Dept. of Biostatistics, University of Alabama at Birmingham, Birmingham, Alabama 35294 - 0002, USA.
E-mail: jbbaek@cjnu.ac.kr

Keywords: Hazardous chemical, Failure Likelihood, Chlorine Facility, Chemical Process.

EXTENDED ABSTRACT

Hazardous chemical processes analysis in the various steps are very crucial and may have the big potential impact on environmental, occupational, and public health consequences. After the implementation European Union Seveso II Directive in 1997, it is highly recommended to perform Quantitative risk analysis to prevent major failure in storage, production, and transportation of chemicals. Center for Chemical Process Safety (CCPS), Environmental Protection Agency (EPA), United Nations Environment Programme (UNEP), International Atomic Energy Agency (IAEA), World Health Organization (WHO), and United Nations Industrial Development Organization (UNIDO) provide more recommendations for safety of major industrial facilities.

In this paper, Chemical Process Failure Likelihood analysis was used in chlorine handling facility. Typical components of these facilities consist of pressure cylinder, vaporizer, pipeline, measuring equipment and safety equipments. We estimated r failure rates of mechanical components based on likelihood analysis procedure. Human errors were also considered. It was estimated to have 5.73×10-5 Cl2 leak per year during the major Cl2 handling process. The probability of failure in Gas Nueturalization system was 4.11×10-2/demand. Thus, to prevent the gas leak, it is highly recommended to check gas tank surface, pipelines, and joints in a regulated interval.

1. INTRODUCTION

After the implementation European Union Seveso II Directive in 1997, regulatory guidance to perform Quantitative risk analysis to prevent major failure in storage, production, and transportation of chemicals has been issued. Center for Chemical Process Safety (CCPS), Environmental Protection Agency (EPA), United Nations Environment Programme (UNEP), International Atomic Energy Agency (IAEA), World Health Organization (WHO), and United Nations Industrial Development Organization (UNIDO) provide more recommendations for safety of major industrial facilities (CCCP, 2000).

As noted by Agency for Toxic Substances and Disease Registry (ATSDR 1998, 2001) chlorine can be harmful to eyes, the upper respiratory tract, lungs and other parts of human body when it is improperly released. It is widely used as a disinfectant and as a bleaching agent. The acute release of chlorine can led to sever adverse consequences including injuries and possible loss of life. Several studies reported that chronic exposure to chlorine caused respiratory complaints, inflammation of membranes of the nose, and other complains (Schmittinger et al, 1986, Horton et al, 2002). Use of liquid chlorine at chemical processing facilities has a potential for an unintended large releases involving equipments such as tanks, valves, and pipelines which may result in harmful health effects.

In this article, we employed fault three analysis to study the risk level associated with various accident scenarios for the chlorine facility and estimated the associated frequencies and probabilities.

2. DESCRIPTION OF THE FACILITY

There were 60 employees in the facility assessed in this study. Other buildings and residence areas in the vicinity of the chlorination process are a primary school (< 1000 meters), residence area 1 (200-500 meters; 300 people) and residence area 2 (500-1000 meters; 500 people). Outline of chlorine unloading and operation schematic process flow diagram is shown in Fig. 1.
IF a large chlorine release occurs from the facility, wind would disperse it to employees as well as the residences around the facility more than 500 meters away. In addition, the children at the primary school would also likely be exposed.
Possible incidents considered during the hazard and operability (HAZOP) study for this study include mechanical failure (erosion, pipe rupture, internal high pressure, pump fails, pipe breaks,…). Especially, the problem of storage tank can cause huge spillage of liquid chlorine.

3. METHOD

Fault tree analysis was used to estimate the frequency of occurrence of potential release incidents. Fault tree analysis (FTA) is a systematic failure analysis that focuses on undesired event called the "top event" and develops the underlying sequence of events that leads to the top events. The first step of fault tree analysis was to identify the undesired top events. FTA is a deductive methods that uses Boolean logic (AND, OR gates) to break down the causes of the top event and identify the causes and the logical relationships between the causes and the top event. A fault tree for this study was developed from each top event down to the basic initiating events. The FTA is a graphical representation of the relationship between basic events (Table 1) and the selected top event.
The Boolean equation can be analyzed to calculate the probabilities or frequencies of the intermediate events and the top event. If it is analyzed qualitatively, a list of the failure combinations that can cause the top event is generated. These combinations are known as cut sets

Table 1. Failure Data- Basic Event

Basic event	Probability	Frequency
B 1 / Gas Sensor Failure	3.00×10^{-4}	3.80
B 2 / Controller Failure	3.00×10^{-2}	1.62
B 3 / Suction Pump Failure	1.08×10^{-2}	
B 4 / Storage Tank Physical Defect	8.83×10^{-5}	
B 5 / Storage Tank Bad Welding	1.88×10^{-4}	
B 6 / Erosion of Storage Tank	1.00×10^{-3}	
B 7 / Connecting flange damage	1.88×10^{-4}	
B 8 / Leak detector failure (B2 Redundancy)	3.00×10^{-4}	3.80
B 9 / Pipe Erosion	1.00×10^{-3}	
B10 / Chlorine alarm system failure	3.30×10^{-4}	
B11 / Personnel did not detect the leak in five minutes	9.50×10^{-2}	
B12 / Failure to reopen the valve after Replacement	5.01×10^{-5}	
B13 / Malfulction of safety valve	1.18×10^{-3}	
B14 / Chlorinator pressure-regulating valve fail	1.12×10^{-4}	

Using the process information, equipment failure rate data, an estimation of the probability of the identified hazardous incident was calculated.
A minimal cut set (MCS; Table 2) is the smallest combination of basic events that, if they occur or exist simultaneously, cause the top event. A list of MCSs represents the known ways the top event can occur, stated in terms of equipment failures and associated circumstances.

Table 2 presents the minimum cut set of basic events under chlorine release scenario.

Table 2. Minimal cut sets of Basic events.

Number	Basic event	MCS Number
1	B2. B4	MCS 2
2	B3. B4	MCS 3
3	B2. B5	MCS 5
4	B3. B5	MCS 6
5	B1. B6	MCS 7
6	B2. B6	MCS 8
7	B3. B6	MCS 9
8	B2. B9. B11	MCS 17
9	B3. B9. B11	MCS 18
10	B2. B11. B12	MCS 26
11	B2. B7. B11	MCS 44
12	B3. B7. B11	MCS 45

Reliability databases on the basic event, failure rate, gate information were used on a fault tree evaluating processor to calculate gate probability and obtained minimum cut sets. Partial FTAs for an accidental chlorine release example in this study are shown in Figures 2 and 3.

Fig. 2) Fault tree for failure of chlorine release.

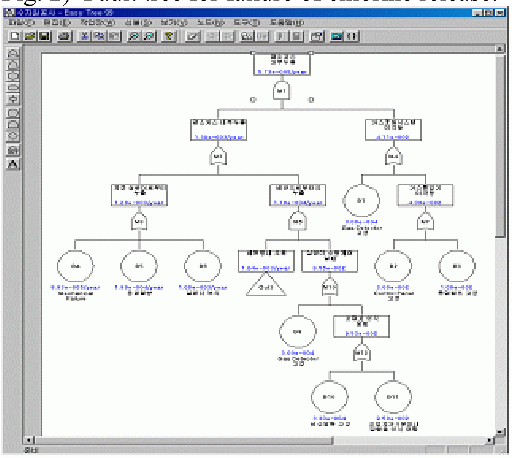
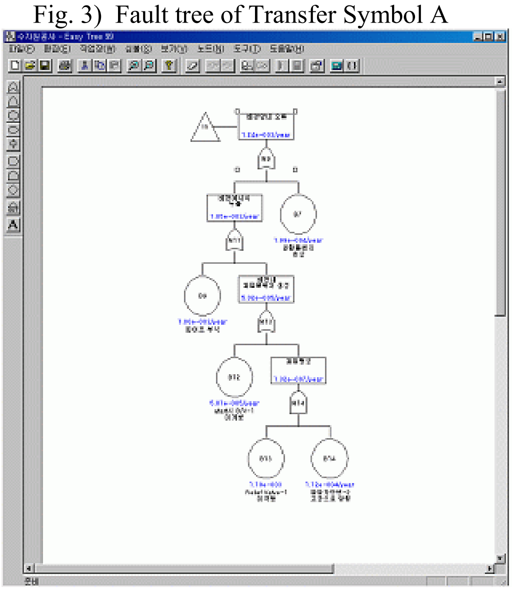


Fig. 3) Fault tree of Transfer Symbol A



4. RESULTS

Results from the fault three analysis shown in Table 3 indicate that the estimated number of chlorine release is 5.73 x 10^{-5} per year. Approximately 1.28 x 10^{-3} /year chlorine release results from storage tank leak, pipe line leak of 1.18 x 10^{-4} /year. Furthermore, malfunction of neutralization system after chlorine leak is 4.11 x 10^{-2} / demand which is below safety standard of 1.0 x 10^{-2}/demand. Results from the cut set importance shown in Table 3 indicate that physical problems in pipeline, flange, and storage are the most crucial key factors of chlorine leak and accident.

Table 3. Cut set importance & Frequency of Minimum cut set

Minimal cut set	Frequency of cut set	Cut set importance
MCS 2	2.65×10^{-6} /yr	4.62
MCS 3	9.54×10^{-7} /yr	1.66
MCS 5	5.64×10^{-6} /yr	9.84
MCS 6	2.03×10^{-6} /yr	3.54
MCS 7	3.00×10^{-7} /yr	0.52
MCS 8	3.00×10^{-5} /yr	52.36
MCS 9	1.08×10^{-5} /yr	18.85
MCS 17	2.85×10^{-6} /yr	4.97
MCS 18	1.03×10^{-6} /yr	1.80
MCS 26	1.43×10^{-7} /yr	0.25
MCS 44	5.36×10^{-7} /yr	0.94
MCS 45	1.93×10^{-7} /yr	0.34

Top event frequency = $\sum Ci = 5.73 \times 10^{-5}$ per year

4. CONCLUSIONS

This study provides a basis for evaluation of the potential failure component. This study illustrates the use of quantitative risk assessment as a tool to select an appropriate ways to manage risk in a hazardous chlorine handling facility. Knowledge of the most important sources of risk in the plant provides important guidance for ongoing risk management. This process provides a basis for understanding of the potential effect of risk of malfunction of mechanical as well as human factors. Recommendations based on the analysis include a periodic inspection of all equipments in a facility including valves, pipelines, degassing, clocks, pumps, erosion of parts, pipe connections of proper material specification are strictly used where there is a chance of chlorine leakage.

7. REFERENCES

Agency for Toxic Substances and Disease Registry (1998). Alberton chlorine spill, Alberton, Montana. Phase I study report. Altanta: US Department of Health and Human Services.

Agency for Toxic Substances and Disease Registry (2001). Evaluation of residual respiratory and other health effects from a chlorine release near Alberton, Montata. Phase II study report. Altanta: US Department of Health and Human Services.

Center of Chemical Process Safety (1992), Guideline for Hazard Evaluation Procedures 2nd, 1992, 251-258

Center of Chemical Process Safety (2000), Guideline for Chemical Process Quantitative Risk Analysis, pp 297-330

Ernest. J. (1981) Reliability Engineering and Risk Assessment, Prentice Hall, Inc, pp44-102

Horton DK, Berkowitz Z, Kaye WE. (2002) The Public Health Consequences From Acute Chlorine Releases, 1993–2000. *J Occup Environ Med.* **44**:906–913.

Nuclear Power Engineering Committee (1984), IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear-Power Generating Stations

Occupational Health Guideline for Chlorine (1978), U.S. Department of Labor, pp 1- 3.

Schmittinger, P., Calvert, L., Asawa, T., Kotowski, S., Beer, H.B., Zeleft, E., & Breitschadt, R., (1986). *Ulmann's encyclopadia of industrial chemistry*, 5th edition, vol. A6, p399. Weinheim: VCH.

TNO, (1997) 30 years disaster statistics

Walter, R.J Practical Compliance with the EPA Risk Management, *AIChE*, 1999, pp 2-4

Fig. 1) The Pipe & Instrument Diagram of Chlorine Process