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AN ANALYSIS OF MAJOR ACCIDENT IN THE US CHEMICAL SAFETY BOARD (CSB) DATABASE

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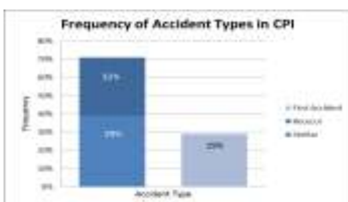
Graphical abstract



Abstract

Accident rate in the chemical process industry (CPI) is high and causing loss of lives, massive property and environmental damage. Continuous improvement on accident knowledge and understanding is vital for process safety. Thus, an initiative to study the latest trends of accident was taken by analyzing 75 completed investigation reports of US Chemical Safety and Hazard Investigation Board (CSB) accident cases occurred in CPI from 1995 to 2011. The result of the analysis shows that the CPI accepted the concept of Prevention trough Design (PtD). However, 71% of accident cases are similar due to incorrect corrective action taken.

Keywords: Accidents, corrective actions, chemical process industry (CPI)

Abstrak

Kadar kemalangan, *chemical process industry (CPI*) adalah tinggi dan menyebabkan kehilangan nyawa, harta benda yang besar dan kerosakan kepada alam sekitar. Penambahbaikan yang berterusan diatas pengetahuan tentang kemalangn adalah sangat penting bagi proses keselamatan. Oleh yang demikian, satu usaha untuk memahami trend terkini kemalangan telah dilakukan dengan menganalisa 75 laporan siasatan lengkap dari *US Chemical Safety and Hazard Investigation Board (CSB)* mengenai kemalangan yang berlaku dari tahun 1995-2011. Hasil kajian menunjukan bahawa CPI menerima konsep *Prevention trough Design (PtD)*. 71% punca kemalangan adalah sama dan disebabkan oleh tindakan pembetulan yang diambil adalah tidak tepat.

Katakunci: Kemalangan, langkah penambahbaikkan, industri pemprosesan kimia

1.0 INTRODUCTION

Fire, explosion, toxic release and a combination of those occurrences are common during major accidents in the chemical process industry (CPI) that cause loss of lives, property and environment damage, evacuation of nearest community and massive recovery expenses. It was claimed that accidents in the CPI are mainly caused by the occurrence of similar accidents not only within the same plant but similar accidents that occurred at other facilities with similar accident characteristics. This phenomenon is expressed into a high rate of accident occurrences which increase concern to all CPI players especially researchers.

Since the industrial disaster at Flixborough, Seveso and Bhopal, the culture of reporting abnormal events in CPI has been encouraged in collecting accident precursors by various voluntary institutions and firms around the world such as Failure Knowledge Database (FKD) from Japan, Major Accident Reporting System (MARS) managed by European Union, Major Hazard Incident Data Services (MHIDAS) by Health Safety Executive (HSE) in UK as well as Chemical Safety and Hazard Investigation Board (CSB) in US. However, there is no synchronization between existing databases since some of them might only focus on reported accidents while some are only gathering accident information as accident data service provider.

Based on knowledge hierarchy by Ackoff,[1] the current accident reports with analyses only give knowledge to CPI players instead of understanding and implementing efficiently the adequate accident corrective measures. A recent study found that only one third of accident cases are considered to provide lesson learned on a broader basis [2]. It shows that most accident reports are not informative and beneficial enough to CPI players in terms of learning from previous accidents.

Layer of Protection (LOP) is used in accident corrective action where it covers procedural, passive engineered, active engineered and inherently safer elements. However, industries prefer implementing Management Corrective Action (MCA) for all types of accident causes as MCA offered the fastest and cheapest accident solution [3-4] Until now, even though there are efforts in preventing occurrence of similar accidents in the CPI, accidents are recurring without control and there is a special factor that must be discovered and corrected by researchers to stop this trend. Because of that, in 2000's accident reporting awareness has been increasing among CPI players and provide massive opportunities for researchers to understand gaps that contribute to the occurrence of similar accidents.

2.0 FEEDBACK SYSTEM

An analysis recorded the number of death, injuries, exposures and evacuations as the result of recurring, similar and first accident involving the various CPI players such as contractors, fire fighters, paramedics, police, adjacent business workers, drivers, pedestrians and local residents. Recurrences of accident are those accidents that occur within the same company and might encounter several near misses previously. The management or company's organization usually lack in terms of the hazard identification process as they are targeting a due date or running out of time during massive work order. They also lack expertise and resources to identify hazard in the workplace as well as monitor and give consultation for wrong or unsafe condition in workplaces.

Similar accidents are accidents with the same accident characteristics that occur in a different company due to poor knowledge dissemination as well as poor hazard awareness and identification. In addition, standards, codes and regulations require further improvement. Finally, first accidents are accidents that occur for the first in the CPI due to unrecognized hazards and risks. It can be summarized that recurrence, similar and first accident are closely related to poor learning from previous accidents.

The existence of various reporting systems as a solution from poor learning from accidents through information and knowledge sharing is not as effective as thought. Some reporting systems only provide detailed description of accidents occurred and some of them are not an open access system to keep information confidential for the sake of companies' reputation. Besides, among all reporting systems, there is no information synchronization that can ease researchers in analyzing. Moreover, not all reporting systems are monitored and validated by professionals where information integrity can be questioned.

Experience feedback system by Kjellen [5] illustrated a cycle of learning from accidents triggered from accident occurrences in CPI that are analyzed and studied to generate knowledge before being disseminated to be implemented in tools and plant modification and design. It was claimed that current cycle of learning system is not sufficient enough in preventing accident occurrence due to poor input quality, lack of analysis, poor dissemination and insufficient use of information [6-7] The weakest link is information dissemination [8] as majority of research on experience feedback only related to accident investigation and not much on information dissemination [7].Therefore, the main challenge is to effectively disseminate accident information and translate the current knowledge into practice [9].

Accident information can be disseminated among the CPI through several approaches which are physical means such as reports and journals; electronic means like accident reports in database and development of accident based safety or design tools. Disseminating accident information through physical means is less effective compared to accident database which have a good data retrieving system [10-11]. However, both approaches represent lower level of information in knowledge hierarchy compared to analyzed knowledge and there is no such reporting system that provides information dissemination to all CPI players.

Generally, reporting systems only provide general accident information without solution to overcome the problems, recommendation for improvements and lessons learned from the accidents. The provided information does not help much in giving awareness to other companies about the risks and hazards that contribute to the accidents.

When companies are dealing with accidents, they have options to choose correction actions between using Management Corrective Action (MCA) or Engineering Corrective Action (ECA). MCA is a solution which manipulates human resources through training and work instructions while ECA is a corrective action of desired system such as system and plant design, additional technology and is inherently safer. It is a fact that companies prefer to use MCA instead of ECA due to fast results and easy implementation at any duration of time. However, the main concern is, this solution needs continuous effort and easily contributes to human error.

Even though there are multiple accident prevention efforts that have been proposed and implemented over the decades, similar accidents are still recurring. Corrective actions seemed to be not effective and factors contributing to the failure are poor learning from accidents, poor safety knowledge and poor dissemination of accident information which translated into the increasing accident rate globally. Thus improvement is required to make sure that there is no repetition on similar accidents in the CPI which should decrease the number of accident cases.

3.0 LAYER OF PROTECTION

Hazard can be managed by using Layer of Protection (LOP) as shown in Figure 1. LOP can be classified into four categories, listed in decreasing order of reliability: inherently safer (IS), passive engineered, active engineered and procedural. IS eliminates the hazards by managing materials and process conditions which are hazardous while passive engineered is minimizing the hazard by process and equipment design features which reduce either the frequency or consequence of the hazard without active functioning of any device. Both approaches are more reliable because they depend on the physical and chemical properties of the system rather than the successful operation of instruments, devices, procedures and people. In contrast, active engineered use controls, safety interlocks and emergency shutdown systems to detect and correct process deviations whereas procedural use operating procedures, administrative checks, emergency response and other management approaches to prevent incidents or to minimize the effects of an accident. IS and passive engineered are usually classified as strategic approaches where those are best implemented at the early stage in the process of plant design [12] Meanwhile, tactical approaches include the active engineered and procedural which tend to be implemented much later in the plant design process or even after the plant is operating and often involves much repetition, increasing the costs and potential for failure [13].

Technically, human and organizational error are corrected by procedural approach; technical error is corrected by passive and active engineered approach while design and nature errors are corrected by IS approach. Common potential hazards in the CPI is best managed by IS but industries' current practice is to manage process hazards by using outer layer of LOP which is procedural approach even though it is already known that this approach is not the solid solution in preventing accidents from occurring or recurring.

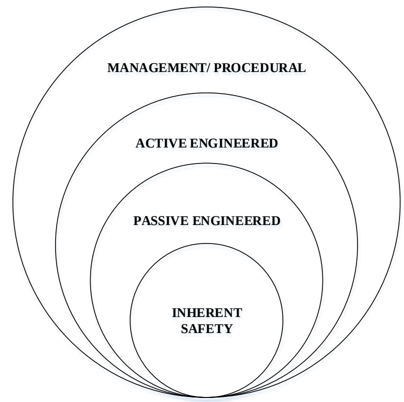


Figure 1 Layer of protection

4.0 CSB DATABASE

The accident analysis of year 2000s database demonstrated the efficiency of 1980s and previous decade technology and accident corrective action improvement taken. Therefore, the accident analysis on the current database is required to evaluate the effectiveness of previous improvement and to propose enhanced improvement for future technology and accident corrective actions. The US Chemical Safety and Hazard Investigation Board (CSB) databases are selected to be analyzed as it represents the current maturity in CPI [14]. High expectation of CPI maturity in generating accident reports and providing accident prevention recommendations by considering current issues in the CPI and the latest technology, modelling, knowledge and equipment is translated to the reliability of CSB accident database quality. CSB is believed to reach the matured level of development during the investigation as well as documented accident reports in all aspects including considering the application of LOP in accident prevention approach.

4.1 Analysis Methodology

In this study, 75 cases of loss accident that CPI related from complete investigated accident reports were extracted via CSB database from 1995 until 2011. Data mining is used in collecting accident details and research flowchart is expressed through Figure 2. For each accident detail, accident causes and accident corrective actions are recognized before those occurrences are transformed into percentage for better viewing. The primary purpose is to investigate and analyze the latest trend of accident causes and accident corrective actions using LOP in preventing accident in CPI while the correlation between those is then compared with the findings from previous studies using FKD.

In this analysis, accidents causes are classified into 5 categories namely design error, technical error, organizational error, human error and nature disaster. The description for each category is described and summarized in Table 1.

Table 1 Accident causes description

Accident causes	Description	Examples
Design Error	Errors during any design phase	Wrong material selection Poor plant design
Technical Error	Errors related to usage of equipment	Corrosion Equipment malfunction
Organizational Error	Errors related to management	No physical hazard analysis (PHA) No effective planning
Human Error	Errors related to human	Misjudgment Miscommunication
Nature Error	Errors related to nature activity	Flood Earth quakes

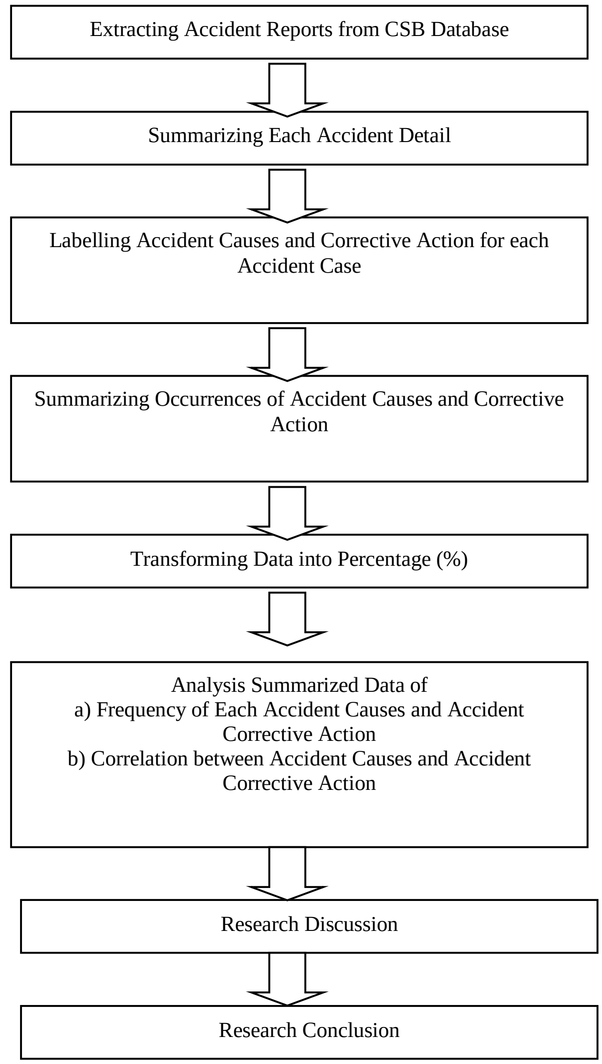


Figure 2 Research flowchart

5.0 RESULT AND DISCUSSIONS

This section will discuss in details on the findings of the analysis of the accident causes and the corrective action has been taken for future accident prevention for that particular accidents. The suitability of the accident causes and corrective action that has been chosen will also be analyzed in depth, since the corrective action taken has significant effect on possibility of recurrences of the accidents, if not appropriately chosen. The reoccurrences of similar accidents will also be analyzed.

5.1 Accident Causes

From the finding, organizational error (29%) is the highest contributor to accident causes followed by design (26%), technical error (23%) and human error (20%) while nature disaster (2%) constitutes the least of the accident causes. Human and organizational error reflected on the accident occurrence and near miss which are human and management related such as lack of process hazard analysis (PHA) and no effective planning. Design errors with 26% are mostly caused by wrong material selection, inadequate detection and protections as well as poor hazard identification during design phase. Technical errors which are the third most frequent accident causes mostly occur due to lack of supervision and poor documentation as well as lacking in understanding of purpose, operation and limitation of the unit operation. Human errors with 20% are mostly caused by inadequate knowledge and training, miscommunication and unintended actions while nature disaster that only contributes 2% are caused by poor prediction and lack of protection of extreme weather

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Figure 3 Accident causes contributors

An accident causation analysis by Viichez et al.[15] indicates that chemical accidents happened from the beginning of the century until 1992 caused by technical failures (33%) and human errors (24%) while Lees[16] found that 47% of chemical accidents are contributed by organizational errors, 29.2% by technical errors, 15.7% by human errors and 8.1% by design errors.

An analysis of major industrial accidents in Korea between 1988 to 1997 by Kang[17] shows that human errors contribute the highest percentage with 46.2% followed by technical, design and organizational errors. Kang[17] also concluded that during the past 10 years, many major accidents occurred in Korea due to lack of trained operators, mechanical integrity, inadequate new processes and chemicals, safety inspection, preventive maintenance, safety consciousness as well as inadequate safety measures and procedures.

In 2008, Gunasekera and Alwis[18] showed that chemical accidents that occurred from year 1997 to 2006 were caused by 35% of technical errors and 29% of human errors where accidents during process is the highest contributors (43%) compared to during loading, maintenance, transportation and storage.

Current research [12] verified that design errors contribute to 79% of chemical accident cases while the rest are only due to human and organizational errors in the operation stage and external factors.

Hence, it can be concluded that most of the previous study seem to agree with this paper's findings that there is significant error percentage from design and technical errors. Majority of other studies particularly Gunasekera and Alwis[18], Kang [17] and Viichez *et al* [15] also found that human errors as well has significant contribution to accidents occurrence as compared to organizational errors despite the finding of this paper that shows a more balanced errors percentage between the four categories of accident causes contributors; design, technical, organizational and human errors. But the differences in the findings of the accident cause contributors percentage is anticipated since different accident database is used in these studies.

5.2 Accident Corrective Action

Figure 4 shows the preferred corrective action taken by the CPI. Obviously, in terms of accident prevention approach, procedural approach (44%) is the most implemented because it is the easiest to apply and is low cost even though it involves various parties such as ministries, employers and suppliers. However this approach requires gradual and continuous effort during the implementation. IS approach (20%) which is almost equal to active engineered approach (19%) is mostly applied in moderation strategy. In contrast, passive engineered with 17% is the last choice recommended because it needs a large investment.

Figure 4 Accident corrective action

In general, the analysis shows that the CPI preferred the Management Preventive Action (MPA) compared to Engineered Preventive Action (EPA). By definition, EPA is the contribution of Inherent Safety (IS), Passive Engineered, and Active Engineered while MPA is based on Management/ Procedural action. Table 2 shows the data on corrective action taken by the CPI that has been published previously.

Even though industries have been introduced to LOP in loss prevention, MPA is still used widely even when it is the less reliable approach compared to EPA. In general, the industry maturity in accident preventive efforts does not reflect much in the decision of strategies chosen. However, the gaps between applying the Management Preventive Action (MPA) and Engineering Preventive Action (EPA) has been narrowed where it is a good sign that CPI is heading to the application of proper or correct approaches in preventing accidents, in particular, the Prevention through Design (PtD).

Table 2 Comparisons of accident corrective actions used by the CPI

Paper	MPA	EPA			Total
	Procedural	Inherent Safety	Passive Engineered	Active Engineered	
Kidam et. al [4]	53	18	13	16	47
Amyotte et. al [3]	42	36	8	14	58
Jihan et. al (2014)	44	20	17	19	56
Average	46.3%	24.7%	12.7%	16.3%	43.7%

Table 3 Suitability matrix in accident prevention

Accident Causes	**Frequency**	**Inherently Safer**		**Active Engineered**		**Passive Engineered**		**Procedural**	
Organizational	148	29	20%	24	16%	24	16%	24	16%
Design	134	31	23%	22	16%	22	16%	22	16%
Technical	121	24	20%	20	17%	20	17%	20	17%
Human	104	18	17%	18	17%	18	17%	18	17%
Nature	8	1	13%	2	25%	2	25%	2	25%

5.3 Suitability Analysis of Corrective Actions Taken

In this paper, the contribution of design and technical errors to accident is significant i.e. 49%, however majority of the corrective action taken are based on procedural (44%) strategy. This fact is questionable and should be investigate further. The analysis is needed to verify the corrective actions taken by the CPI are suitable and effective to solve or lighten the problem i.e. accident causes. Therefore, a suitability study between accident causes and their corrective action for each accident cases are carried out.

Theoretically, it is logical that the human and organizational related errors are corrected by procedural approach, while technical and design errors are corrected by design changes and add-on engineered safety measures. In some cases organization and human failure also can be corrected by using design changes or add-on safety measures. However, any design or technical errors should be corrected by design changes for effective risk control. Based on this concept the suitability analysis is made and the result is shown in Table 3.

As seen in Table 3, it is clearly proved that there is an obvious unbalanced trend between accident causes and accident corrective action taken by the CPI. Analysis shows that the procedural strategy is mostly recommended across all accident cause contributors. It is interesting to notes that the majority of the design (40%) and technical (43%) errors being corrected by using procedural strategy. This is unacceptable since according to CCPS, the levels of reliability of the risk reduction strategy used is decreased from application of IS, passive engineered, active engineered and procedural. The most effective approach is IS where its application has a high potential in eliminating and controlling the hazard at source while procedural is less effective since the hazard remain and depend on human intervention. Correct application of the risk control strategy is vital to prevent similar and recurring of accident cases.

5.4 Recurrence and Similar Accidents

Issues on incorrect risk reduction strategy used by the CPI to prevent accident might be the basic reason why accidents keep on happening worldwide and is worth for further study. According to Mannan *et al.*[20] in the CPI similar accident recur every 5 year interval. Therefore, a specific study on this issue is made to verify whether incorrect corrective action taken resulting reoccurring of similar accident in the CPI.

As seen in Figure 5, the similar accident can be categorized in two categories i.e. (a) accident happens within the same company and (b) in different company but with similar operation. Analysis of the 75 major accident in the CPI shows that there are significant number of similar accident occur in the US which is 58 accident or 71% in overall. Out of 58 accidents, about 26 cases (32%) of accident recurrence within the same company while 32 cases (39%) happen in similar operation at different company. Only 29% accidents are caused by unique causes.

In-depth analysis shows that the main factor that causing the reoccurring of similar accident are related to neglecting previous near miss incident as well as ineffective correction action taken. In general, the CPI failed to notice the importance of near misses incident as an indicator to major accident. Large majority of the corrective action recommended where based on the outer layer of protection such as retraining, procedure review etc. although the accident are caused by technical or design errors. Large majority of the recommendation are made without proper investigation and risk analyses. Therefore, less reliable and easy to implement corrective actions were recommended without considering design changes and engineered add-on safety measures. In this condition, the hazard still in the process and the likelihood of accident is high due to fragile safety barrier chosen.

At the same time, the management or company organization usually overlooked the need for hazard identification process because they are happy with the current safety performance and focusing on routine daily operation issues. They also lacked of system to continuously identify and monitor process and personal hazards in the workplace. Hence, the process safety being compromised which resulting a thinner operational safety margin that increase the likelihood of process failures.

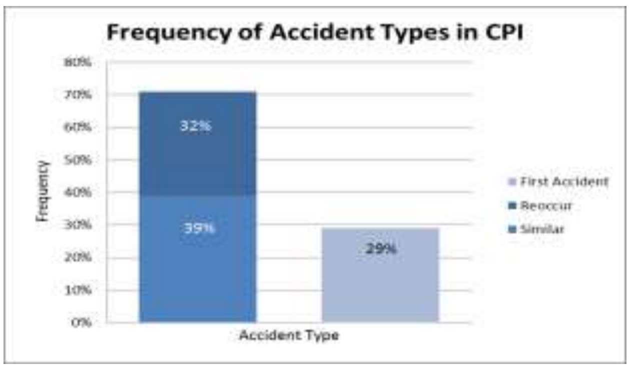

Figure 5 Frequency of accident types in CPI

6.0 CONCLUSION

Analysis of latest 75 major accident cases from CSB database is successfully carried out. The main objective is to see the latest trend of the contributor to accident in the CPI. The latest trends and concluding remarks of the analysis are as follows:

(a) The contributor to accident is balance between technical/design (49%) and organizational/human (49%) failures.
(b) The concept of PtD is well accepted by the CPI since the majority of corrective actions taken are based on EPA (56%).
(c) The application of IS to prevent accident is still slow but improved.
(d) CPI failed to foresee the near-misses incident as indicator to major accidents.
(e) CPI chooses and applied incorrect risk reduction strategy as corrective action to prevent accident.
(f) 71% of accidents in the US are similar caused.

In conclusion, the analysis found that the majority of accident in the US is similar; known caused and can be prevented by proper utilization of accident knowledge. Therefore, it is recommended that the experience feedback system in the CPI could be enhanced to improve learning from accident. Accident data should be compiled and continuously analyzed to generate new accident knowledge for a better understanding of accidents. Accident knowledge should be shared and disseminated efficiently throughout CPI. A better understanding of accident and correct application of risk reduction strategy could reduce the accident rate in the CPI.

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References

(1) Ackoff, R. L. 1989. From Data to Wisdom. *Journal of Applies System Analysis*. 16: 3-9.
(2) Jacobsson, A., Sales, J. & Mushtaq, F. 2010. Underlying Causes and Level of Learning from Accident Reported to the MARS database, *Journal of Loss Prevention in the Process Industries*. 23(1): 39-45.
(3) Amyotte, P. R., MacDonald, D. K. and Khan, F. I. 2011. An analysis of CSB investigation reports concerning the hierarchy of controls. *Proc. Safety Prog*. 30: 261–265. doi: 10.1002/prs.10461
(4) Kidam, K., Hurme, M. and Hassim, M. H. 2010. Inherent safety based corrective actions in accident prevention. In *Proceedings of 13th International Symposium on Loss Prevention*. Bruges, Belgium, Jun 6-9th. 2: 447-450.
(5) Kjellen, U. 2000. *Prevention of Accidents through Experience Feedback*, CRC Press, London.
(6) Kletz, T. A. 2009. Accident Reports May Not Tell Us Everything We Need to Know, *Journal of Loss Prevention in the Process Industries*. 22(6): 753-756.
(7) Lindberg, A. –K., Hansson, S. O. & Rollenhagen, C. 2010. Learning from Accidents – What More Do We Need to Know? *Safety Science*. 48(6): 14-721
(8) Lindberg, A. –K. & Hasson, S. O. 2006. Evaluating the Effectiveness of an Investigation Board for Workplace Accidents. *Policy and Practice in health and Safety*. 4(1): 63-79
(9) .Bell, J., & Healey, N. 2006. The Causes of Major Hazard Incidents and How to Improve Risk Control and Health and Safety Management: *A Review of the Existing Literature, Health and Safety Laboratory/Health and Safety Executive*. UK. (HSL/2006/117).
(10) He, G., Zhang, L., Lu, Y. & Mol, A. P. J. 2011. Managing Major Chemical Accidents in China: Towards Effective Risk Information. *Journal of Hazardous Materials*. 187(1-3): 171-181.
(11) Tauseef, S. M., Abbasi, T. and Abbasi, S. 2011. A. Development of a New Chemical Process-Industry Accident Database to Assist in Past Accident Analysis. *Journal of Loss Prevention in the Process Industries*. 24: 426-431.
(12) Kamarizan Kidam and Markku Hurme. 2012. Origin of Equipment Design and Operation Errors. *Journal of Loss Prevention in the Process Industries*. 25: 937-949
(13) Bollinger, R. E., D. G. Clark, R. M. Dowell, R. M. Ewbank, D.C. Henershot, W. K. Lutz, S. I. Meszaros, D. E. Park and E. D.

Wixom. 1996. *Inherently Safer Chemical Processes: A Life Cycle Approach, New York*: Center for Chemical Process Safety of American Institute of Chemical Engineers.

(14) U.S CHEMICAL SAFETY BOARD. 2013 Completed Investigation.[Online] Washington D.C.: CSB [Accessed: 17 July 2013]

(15) Juan A. Viichez, Sergi SeviUa, Helena Montielt~t and Joaquim Casalt. 1995. Historical Analysis of Accidents in Chemical Plants and in the Transportation of Hazardous Materials. J. *Loss Prey. Process Industry*. 8(2): 87-96.

(16) Lees, F. P. 1996. *Loss Prevention in Chemical Process Industries.* London: Butterworth.

(17) Soon Joong Kang. 1999. Trends in Major Industrial Accidents in Korea. *Journal of Loss Prevention in the Process Industries*. 12: 75–77.

(18) M.Y. Gunasekera, A. A. P. de Alwis. 2008. Process Industry Accidents in Sri Lanka: Analysis and Basic Lessons Learnt. *Process Safety and Environment Protection*. 86: 421–426.

(19) Centre of Chemical Process Safety (CCPS). 1998. *Guidelines for Design Solutions for Process Equipment Failures*. Hoboken, NJ:Wiley.

(20) Mannan, M. S., Prem K.P., and Dedy Ng, 2010, Challenges and Needs for Process Safety in The New Mellinium, In *13th International Symposium on Loss Prevention and Safety Promotion in the Process Industries.* Bruges, June 6-9, 1: 5-13.