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INHERENT SAFETY BASED CORRECTIVE ACTIONS IN ACCIDENT PREVENTION

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Kamarizan Kidam[1,2], Markku Hurme[1], Mimi H. Hassim[1,2]
[1]Helsinki University of Technology; Plant Design, P.O. Box 6100, FIN-02015 TKK, Finland
[2]Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
kidam@cc.hut.fi, markku.hurme@tkk.fi, mimi@cc.hut.fi

1. Introduction and Research Approach

In this paper the enhancement of inherent safety by analyzing the accident cases is discussed. The research was conducted by studying 549 accident cases gathered from the Failure Knowledge Database, available from the Japan & Science Technology (JST) website (http://shippai.jst.go.jp/en/Search). 364 of the cases are chemical process industry (CPI)-related, and therefore worth further study. The aim of this paper is to study the corrective actions taken by the CPI to prevent similar accidents. Among risk reduction strategies commonly used include inherently safer, passive and active engineered, and procedural (Amyotte et.al., 2009). Based on the information gathered, the preferred risk reduction strategy taken by the CPI as a corrective action is analyzed. The actions taken using inherently safer strategy are the paper's interest. Therefore, the inherently safer corrective actions are further analyzed by using inherent safety keywords. This will give some information on how the ISD is being implemented in practice, or more specifically, the plant rebuilt or modified right after accident. The paper will then explore the potential of the inherently safer corrective action (based on the keywords) to tackle specific problems of chemical process plant operations, as listed in Table 1.

2. Result

The corrective action section of the accident report was analyzed to find out the risk reduction strategies used by the CPI to prevent accidents. It is found that the CPI normally takes several corrective actions due to multiple causes of accident. Here, the actions are classified according to the priority of risk management strategy: inherently safer > passive > active > procedural. Analysis shows that the corrective actions taken by the CPI is about equally shared between procedural (50%) and engineered (46%). In the engineered strategy, 17% of them are catagorized as an inherently safer, followed by active engineered (15%), and passive engineered (13%). 4% or 15 out of 364 cases are classified as unknown due to insufficient information. The contibution of the ISD concept during rebuilding or modification of the existing plant is significant. 62 cases of accident are corrected using an inherently safer strategy. In this study, the corrective actions are classified into 6 main inherently safer keywords, which are *minimization, substitution, moderation, simplification, limitation of effect* and *error tolerance.*

2.1 Inherently safer keyword

The inherently safer corrective actions taken by the CPI in the Failure Knowledge Database to prevent similar accidents are classified into: (a) mechanically stronger or robust component/ equipment *(error tolerance, 27%);* (b) safer process conditions *(moderation, 27%);* (c) substitution of chemicals and work method *(substitute, 21%);* (d) simplification of the piping system and unit operations *(simplify, 15%)*; (e) minimize the inventories of hazardous materials (*minimization, 8%)*; and (f) proper protective system to limit the consequences of accident *(limitation of effect, 2%).*

In the *error tolerance* keyword, the majority of the actions taken are to solve the problem related to the wrong material selection, corrosion/erosion issue, chemical reactivity/ incompatibility, and substandard equipment used. According to Taylor (2007), most of these problems are design errors or previously unknown. Special hazard such as reactivity or incompatibility of chemicals can directly or indirectly cause an accident. Typically they are contaminations of chemical that lead to unwanted/runaway reaction. Meanwhile, the *moderation* strategy used is changing the existing processes to an inherently safer process conditions by manipulating the temperature, pressure, concentration, and the physical state of the chemicals.

The main ideas of the *substitute* keyword are to lessen the likelihood and consequence of accident by using safer or compatible chemicals. Inherently safer chemical process plant also can be achieved through *simplification* of the process work unit by creating highly reliable system (no redundancy needed), simpler process plant (in-term of complexity and interaction between units), and design and use an equipment right for their purpose, not more than that (flexibility issue).

Analysis of the accident report in the Failure Knowledge Database discovers the true potential of the ISD initiative as an effective way to prevent accidents especially in plant rebuild or modification. Generally, the potential to apply the ISD concept at the existing plant can be ranked as follows based on the frequency of application in Failure Knowledge Database:

Error Tolerance & Moderate $>$ *Substitute* $>$ *Simplify* $>$ *Minimize* $>$ *Limit of Effect*

2.2 Cause of accident

The inherently safer corrective actions in Failure Knowledge Database are further analysed against causes of accident to see which inherently safer principles are typically used for accident prevention. The result is summaried in Table 1. Only selected causes of accident are discussed due to the limited space.

Piping system failure causes many major accidents in CPI. The best way to improve the integrity of the piping is by using *simplication* keyword (55%). This can be done by eliminating dead-end/no flow parts; removing of unnecessary valves, drain valves and by-pass lines; and changing piping fittings/attachments to a welded piping. Problems associated with dead-end or no flow piping are related to the localised corrosion (that creates leak in the pipe), accumulation of reactive material or residue settlement/deposits (that promote unwanted reaction, by-products or events such as fire and explosion). For existing plant, removal of the dead-end piping can be done during normal plant shutdown and this changes are permanent. Elimination and removal of unwanted piping components create a simpler and user friendlier piping system which qualtitatively reduces the likelihood of accident through low failure rate of the system and minimum human error/involment.

Many accidents occur because of inappropriate material selection againts process worst case scenario such as unforseen process deviation by chemical reactivity and external contaminations. Most of the process designers design a process based on an ideal condition and sometimes they overlook the physical property of chemicals and other operational factors (Taylor, 2007). Based on the analysis, the right keyword to tackle this problem is

Table 1: Inherently safer corrective actions based on causes of accident in Failure Knowledge Database

Causes of Accident	Error Tolerance	Moderate	Substitute	Simplify	Minimize	Limit of Effects	Total
Piping System	2	2	1	6			11 (18%)
Material Selection	3	3	1	1			8 (13%)
Corrosion	3	1	3	1			8 (13%)
Contaminations	2	2	1		1		6 (10%)
Mass Transfer	1	3			2		6 (10%)
Substandard Equipment	3	1			1	1	6 (10%)
Flow Related	2		2				4 (6%)
Management/Procedural		2		1			3 (5%)
Knowledge Based			3				3 (5%)
Heat Transfer		2					2 (3%)
Fabrication	1		1				2 (3%)
Storage/Handling		1			1		2 (3%)
Layout			1				1 (2%)
Control System							0 (0%)
Total	17 (27%)	17 (27%)	13 (21%)	9 (15%)	5 (8%)	1 (2%)	62 (100%)

error tolerance and *moderation*. Material selection should be based on the result of the risk based analysis that considers the worst case scenario of the overall processes. The basis of the safe operation of chemical process is safe design with acceptable operational safety margin. However, for extrem process conditions (and worst case conditions), the wider safety margin and proper material selection (chemically and mechanically) are very important for safe operation. The construction materials should be physically robust and resistant to process deviations. For example stainless steel is better than mild/carbon steel, cast steel valve is better than cast iron valve, and metal pipe is better than hose.

Similarly for corrosion issue in CPI, resistant or robust construction material with proper provision on maintenance and pipe replacement, is the way to prevent accident. However, the inherently safer approch to control corrosion is by choosing a less or non-corrosive raw materials during process development. During plant design, special considerations are needed on compatibility analysis between process fluids (including utilities) and construction material, as well as the impact on possible contamination or process changes such as more corrosive feed stock, changing heat transfer media, increasing process temperature etc. Detail studies are also required during abnormal activities such as emergency, maintenance, cleaning, shutdown, startup, plant modification etc..

Flow related accidents involves e.g. fluid transfer (i.e. overflow), fluid movement (i.e. high speed and vortex), and flow distribution (i.e. wetted/unwetted process area creating hot spot). Basically, accidents related to the fluid flow can be reduced by better management and design. Accidents such as overflow is directly related to the poor management. In the plant design, *error tolerance* and *substitution* keywords can be applied for safer and robust design. For piping system, based on the inherently safer corrective action in the Failure Knowledge Database, in many cases, CPI normally will replace the construction material of piping towards more reliable, resistant and mechanicallly robust piping system, as well as strengthening the flow velocity management in piping.

Moderation keyword can be best applied to any accident caused by heat transfer. In practice, process conditions are fixed during route selection or process screening at early stage of plant design and rarely being changed after that. However, a number of accident cases in the Failure Knowledge Database are corrected using *moderation* keyword such as using warm water instead of steam especially for low temperature services. Heat source should be carefully selected and designed just enough as required by the process. The designers prefer to over-design the heating/cooling capacity of equipment for flexibility reason, without seriously consider the impact on the plant operations. Also, a number of accidents are reported due to incompatibility of process fluid with heat transfer media. Based on the result of the accident analysis, the reactivity and incompatibility analysis is still lacking especially at process development and early stage of plant design.

3. Discussion and Conclusion

The analyses of the corrective actions in the Failure Knowledge Database have been carried out. It is interesting to note that the corrective actions taken by the CPI are balanced between procedural and engineering approaches (50% : 46%). Also, the analysis reveals that the contribution of the inherently safer strategy as a corrective action to prevent similar accident is significant (17%), even though it is done at later stage of plant design (i.e. plant modification right after the accident). Majority of the corrective actions taken are related to mechanically stronger(27%), safer process conditions(27%), substitution of chemicals and work method (21%), and simplification the piping system and unit operations (15%). Furthermore, the analysis finds out that certain inherent safety keywords such as e*rror tolerance* and *moderation* have a larger potential to be applied at the existing plant. Based on this, in general, the potential to apply six selected ISD keywords in the plant rebuilding/ modification after accident are proposed and ranked accordingly.

In the second part, where the causes of accident are considered, the analysis shows the relationship between causes of accident and inherent safety keywords. It is clearly indicates that some causes of accident can be prevented using specific ISD keywords. For example, piping failures are much related to the complexity of the piping system, and it can be corrected by *simplify* keyword, or in other word, by designing a simpler piping system. In additional, application of ISD can solve several technical problems at an existing plant such as mass transfer, corrossion, heat transfer, and flow related issues.

In conclusion, the study gives understanding on how ISD is implemented in practice and provides general ideas on the relationship between cause of accidents and inherent safety keywords. Based on this study, some of the accidents can be avoided if the ISD keywords are implemented at early stage of the plant design in a right way. The presented ISD keyword analysis gives a basis for development of practical inherent safety application methods for process development and design.

4. References

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