

**Challenges in Implementing Inherent Safety Principles in  
New and Existing Chemical Processes**

# White Paper



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## **Abstract**

This paper defines inherent safety and contrasts it with more traditional approaches to safety. It illustrates through analogies with common household examples the challenges faced in evaluating and implementing inherently safer designs. The first challenge is simply to measure the degree of inherent safety in a way that allows comparisons of alternative designs, which may or may not increase safety or may simply redistribute the risk. The second is that because inherent safety is an intrinsic feature of the design, it is best implemented early in the design of a process plant, while the US has a huge base of installed process plants and little new construction. Thirdly, in developing inherently safer designs, there are significant technical challenges that require research and development efforts with limited economic incentives. These challenges make regulation of inherent safety very difficult. We believe that a coordinated long-term effort involving government, industry, and academia is essential to develop and implement inherently safer designs. A similar approach has shown success in related areas such as green chemistry, energy conservation, and sustainable development.



## Challenges in Implementing Inherent Safety Principles in New and Existing Chemical Processes

### What is Inherent Safety?

Inherent safety is based on the use of technologies and chemicals with intrinsic properties that reduce or eliminate hazards. Inherent safety is based on concepts known for more than 100 years (Kletz, 1998) and is an approach to chemical incident and pollution prevention that is in some ways contrary to traditional accident prevention and mitigation methods. Traditional safety practices typically reduce risk by lowering the probability of an incident and/or mitigating the consequences of an incident. This approach alone, although extremely important and generally effective, does not reduce the hazards of serious chemical incidents because it attempts to control hazards rather than eliminate them. Inherent safety is especially important in today's world where terrorists may cause a chemical release by methods that bypass or defeat normal safety systems.

The concepts of inherent safety as applied to chemical process plant design has been discussed elsewhere (Mannan et al., 2002) and are summarized below:

**Intensification or minimization** consists of reduction of quantities of hazardous chemicals in the plant. "What you don't have can't leak".

**Substitution** is the use of a safer material in place of a more hazardous one. It may be possible to replace flammable substances with non-flammable ones or toxic substances with non-toxic ones. However, it is necessary to evaluate not only the substance but also the volumes required.

**Attenuation** or moderation is the use of a hazardous chemical under less severe conditions such as lower pressure or temperature. Thus chlorine and ammonia are stored as refrigerated liquids at atmospheric pressure rather than at high pressure at ambient temperature. The lower pressure results in lower leak rates and the lower temperature lowers the vaporization rate.

**Limitation of effects**, by changing designs or process conditions rather than by adding on protective equipment that may fail. For example, it is better to prevent overheating by using by using a fluid at a lower temperature rather than use a hotter fluid and relying on a control system.

**Simplicity**: Simpler plants are safer than complex plants as they provide fewer opportunities for error and contain less equipment that can fail.

Other principles such as, making assembly errors impossible, and avoiding knock-on effects are also inherently safer design concepts.

One of the most common accidents at home is falling on the stairs. A home without stairs, i.e. a one-story bungalow, is inherently safer with regard to falling on stairs than a two-story house. Even if the stairs are equipped with handrails, non-slip surfaces, good lighting, and gates for children, the hazard is still present (Kletz, 1998). Obviously the choice of an inherently safer house implies positive and negative consequences, which may include aesthetics, cost, and other types of hazards. An elevator could reduce the use of stairs but requires a large capital expense. During construction there would be significant hazards to the residents and construction workers and the stairs would still be necessary for emergency egress. Few families would conclude that installing an elevator is the best use of their resources.

### **Measuring Inherent Safety**

While inherent safety is based on well-known principles, difficulties have been encountered in adopting the principles as a routine practice by industry. One of the first problems encountered during application of inherent safety principles is the subjectivity involved. The principles are descriptive rather than prescriptive, hence they are subject to interpretation based on previous experience, knowledge, and personal perception. A consequence of the subjectivity is that a systematic methodology to measure inherent safety does not exist, and it is not currently possible to know how inherently safe a plant or an equipment item is because it is not possible to evaluate how well the principles have been applied. If we cannot measure how inherently safer the one story condo is with respect to the two-floor house, how can we choose the inherently safer option?

Several measurement and analysis tools have been proposed during the last few years, but in general they focus on specific aspects of the problem during a specific time in the plant lifecycle and are difficult to apply. Besides the lack of measurement methodology, inherent safety cannot be applied in the same way for existing productive plants as for new facilities during the design stage. Existing equipment and processes impose restrictions on changes towards inherently safer technologies that might be implemented in an operating facility. For instance it is not possible to turn a two-story house into a bungalow without an extremely expensive modification. However, other smaller changes can be implemented to obtain an inherently safer house even if not so safe as the bungalow. Some types of staircases are safer than others, e.g., short high steps are inherently more hazardous than long low steps. Very low single steps are easy to be undetected and cause accidents. Thus the possible solutions could be to avoid single small steps and to use staircases with low and long steps or (as suggested by Kletz) with frequent landings to reduce the distance and height of a possible fall.

## **Evaluating and Comparing Design Options**

The cost of applying inherent safety to existing facilities may require significant financial resources but may also unintentionally cause an increase in risk if it is implemented without a holistic view of the plant. A chemical plant is a complex collection of intricate and interconnected equipment, pipes, vessels, and instruments containing a variety of chemicals. When a modification is made in one part of the plant, other areas will be affected, requiring other changes in other parts of the plant. If the safety impact of this cascade of changes into other areas is not understood during the evaluation of the original change toward an inherently safer plant, the final result could be a less safe plant! A common example is the possible substitution of a hazardous chemical substance, used in small amounts, by another one that is more benign but is required in much larger amounts. In this case it is difficult to evaluate which chemical is actually the inherently safer option, because aspects such as transportation, storage, and modification of the plant to work with the new chemical must be included in the evaluation. There must be a systematic assessment and minimization of all hazards together rather than one at a time to avoid the appearance of unidentified hazards. Application of inherent safety principles to operating plants is possible (Hendershot, 1997) but implementation is subject to constraints dictated by technical and economic factors.

The implementation of inherent safety for new plants is simpler and cheaper because the design exists only on paper since nothing has been built yet. However, since many inherently safer options may be available and because a systematic analytical methodology is not available, application of the inherent safety principles is still restricted. Also, inherent safety is not absolute, it is site and plant specific. For instance a two-story house may be safer than a bungalow when located in an area threatened by frequent flooding. Therefore, a solution that can be inherently safer for one plant may not be the best option for the same plant in another location with a different environment.

The application of inherent safety requires subjective judgment and tradeoffs among several factors. Furthermore, the selection and use of inherently safer technology does not guarantee by itself that a plant will result in safer operation among its complex and interrelated systems. For instance, a sick person with lung, heart, and digestive problems can take the best medicine for each sickness, however the interaction of those drugs may have catastrophic results rather than a positive therapeutic effect.

The objective of inherent safety is to remove or reduce hazards. The inherently safest case is the one with zero hazards, but this is a limiting and unachievable case. Everyday life is plagued with hazards that are intrinsic to our society. Removing all the hazards is not possible. The situation of a chemical plant is very similar, and therefore we can only aspire to design inherently safer plants. It will be necessary to apply other methods to control the remaining hazards. Therefore, it is still possible for incidents to occur but their consequences are reduced.

It may also be true that it is really not possible to judge which of two options is inherently safer. For instance solvent A is toxic but not flammable, solvent B is flammable but not toxic. There may be no “right” answer. Also, the answer may depend on one’s point of view. A plant can use chlorine from 1-ton cylinders or from a 90-ton rail car. To the operator who has to connect and disconnect cylinders several times a day the rail car is inherently safer. To a neighbor several miles away the cylinders are safer, they do not contain enough material to affect him.

When new knowledge about chemical hazards or new technology is available, our understanding of the inherent safety of a specific plant can change. An example of this change is the adoption of CFC refrigerant gases (Hendershot, 1995) that are not flammable or toxic compared with ammonia, which was previously used. It has been theorized (and widely accepted) that they destroy the earth’s ozone layer and our judgment of the inherent safety of CFC refrigerants relative to other materials are radically changed. Inherent safety is therefore a dynamic, subjective, and holistic concept that requires specific measurement and analytical tools to evaluate. However, these tools are under development and at present are not available for general use. Without these analytical tools it is very difficult if not impossible to impose restrictions, limits, and regulations to improve inherent safety.

Inherent Safety can also be misused when decisions are subjective and based on limited aspects without possibility of a methodical analysis. For instance, a plant requiring a specific raw material transported by rail can decide to improve the degree of inherent safety by reducing the inventory of that hazardous chemical. Changing the mode of transportation to truck results in a smaller shipment (and a smaller inventory) but it also triples the shipment frequency. Thus the total plant inventory is kept low but the remainder of the inventory is on wheels traveling from the supplier’s plant to the user’s plant. This example also shows an inherent safety complication that extends outside the plant boundaries and represents an incorrect application of inherent safety that cannot be detected without a measuring tool and without analyzing the plant as a global system. In this case it is inherently safer to maintain the large inventory inside the plant and, as suggested by Kletz (1998), keep it under control by using good design and operating practices that follow other concepts of inherent safety (e.g., keep the design simple to avoid errors).

## **Progress to Date**

We believe that many chemical plants have adopted the easiest and most obvious improvements, such as reviewing chemical inventories and reducing them when it is practical. This improvement is a natural outcome of the Process Hazard Analysis that has been required of most major facilities for the last 10 years.

Less hazardous solvents have been developed and are in use in some processes (Crowl, 1996). Plants using hydrofluoric acid can now use an additive that reduces the dispersion of this chemical during a release. These developments however, required substantial time and cost to develop, test,

and implement. Many significant advances are possible but they too will require research, development, and implementation over a long time period. As shown above, the development of methods to measure the inherent safety of various process options is an essential first step to the widespread implementation of inherently safer designs. The Mary Kay O'Connor Process Safety Center is currently developing a method to measure inherent safety using fuzzy logic mathematics.

## Moving Forward

Regulation to improve inherent safety faces several difficulties. One, there is not presently a way to measure inherent safety. Two, the complexity of process plants essentially prevents any prescriptive rules that would be widely applicable. At most it would seem that legislation could explicitly require facilities to evaluate inherently safer design options as part of their process hazard analysis, but inherent safety would be almost impossible to enforce beyond evaluation because of unavoidable technical and economic issues.

Government programs now support the research and development of concepts such as “green chemistry”, “solvent substitution”, “waste reduction” and “sustainable growth”, which are related to inherent safety. A similar approach involving industry, government, and academia can enhance the discovery, development, and implementation of inherently safer chemical processes.



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