Inherently Safer Design: The Fundamentals

Dennis C. Hendershot
Center for
Chemical Process Safety

Build safety into your process by substituting less-hazardous materials and chemistry, minimizing inventories and equipment sizes, moderating operating conditions, and simplifying unnecessarily complex operations.

Elimination of hazards has always been a goal of engineering design in all disciplines and industries, including the chemical process industries (CPI). In the late 1970s, we began to call this approach to process risk management inherently safer design (ISD). Similar terms, such as inherently safer technology (IST) and inherently safer processes (ISP), have also been used.

In 1977, Trevor Kletz of ICI gave the Jubilee Lecture to the Society of Chemical Industry in England entitled, "What You Don't Have, Can't Leak" *(1).* Kletz suggested that the most effective approach to process risk management would be to focus on elimination of hazards where feasible, rather than relying on safety systems and procedures to manage risk. He asked whether process plants really needed large quantities of flammable or toxic materials, whether less-hazardous materials could be used, and whether it was really necessary to operate at hazardous conditions such as high temperature or pressure. He originally called this risk management approach "intrinsically safer," which was later changed to "inherently safer" to avoid confusion with the use of "intrinsically safe" to describe certain types of electrical equipment.

Although Kletz and others have acknowledged that it is not always feasible to eliminate hazards, they have emphasized that this should be the first approach to process risk management, rather than accepting the process hazards and immediately focusing on hazard management. Hazards can never be eliminated or reduced if the process designer does not challenge the need for hazardous materials and operating conditions.

Over the last 40 years, the philosophy of ISD has continued to evolve. Recently, new editions of the primary reference books on ISD have been published: *Inherently Safer Chemical Processes: A Life Cycle Approach,* by the Center for Chemical Process Safety (CCPS) *(2)*; and *Process Plants: A Handbook for Inherently Safer Design,* by Kletz and Amyotte *(3).* These books incorporate the latest developments in ISD based on decades of industrial experience.

What is ISD?

A frequently cited dictionary definition of inherent is something that exists "as an essential constituent or characteristic." Safety is built into the process or product, not added on. Hazards are eliminated or significantly reduced, not controlled, and the way they are eliminated or reduced is so fundamental to the design that it cannot be changed or defeated without changing the process. In many cases this will result in simpler and cheaper plants.

To understand what this means, it is necessary to define "hazard." The CCPS definition of hazard is "an inherent physical or chemical characteristic that has the potential for causing harm to people, the environment, or property" *(4).* For example, chlorine is toxic by inhalation. A hazard is a property of a material or the process operating conditions, and cannot be reduced or eliminated without changing the materials, process inventories, or operating conditions.

Every technology has multiple hazards. For a chemical process, hazards might include acute toxicity, flammability, corrosiveness, chronic toxicity, reactivity, adverse environmental impacts, and others. The statement that a process is inherently safer can only be in the context of a specific hazard, or possibly several hazards. It is unlikely that any technology will ever be inherently safer with respect to all possible hazards. Any change to a technology designed to reduce one hazard will also impact (increase or decrease) other hazards, and may even introduce new hazards. Design decisions must consider all process hazards.

Chemical process safety measures are frequently categorized as:

• *inherent* — eliminate or greatly reduce the hazard by changing the process to use materials and conditions that are nonhazardous or much less hazardous

• *passive* — minimize hazards using process or equipment design features that reduce either the likelihood or consequence of an incident without the active functioning of any device

• *active* — manage risk using process control systems, safety instrumented systems (SIS), mitigation systems such as sprinklers, and other active systems; these may prevent an incident, or reduce the consequences of an incident

• *procedural* — use operating procedures, safety rules and procedures, operator training, emergency response procedures, and management systems to manage risk.

While inherent and passive approaches are the most robust and reliable, a comprehensive process safety management program requires all of these strategies to address all the hazards of a process. These strategies are not discrete with clear boundaries, but rather represent general categories along a spectrum of process safety approaches. People may disagree about how to categorize a particular approach. For instance, is a high-pressure reactor capable of containing a runaway reaction an inherently safer design, or is it passive? This is not an important issue. If it is an appropriate design, it does not really matter what you call it.

ISD should be viewed as a spectrum of options in multidimensional space (Figure 1). The horizontal axis represents the ISD of the fundamental plant technology — the chemistry and unit operations. The vertical axis represents ISD characteristics of the components that make up the plant — including physical equipment such as piping, vessels, pumps, and instruments, as well as management systems, procedures, and people. Ideally, we want an inherently safer process and plant, and we want that plant to be built and operated with components that are also inherently safer.

It may not be feasible or even possible to develop an inherently safer process for a specific application (the horizontal axis in Figure 1). For example, it is difficult to imagine a process for manufacturing gasoline that eliminates flammability hazards. But that does not mean an engineer designing a process to manufacture gasoline need not think about ISD. Although the flammability hazard of the product cannot be eliminated, it is possible to reduce those hazards, for instance by minimizing process inventories, and using inherently safer equipment, procedures, and other systems (the vertical axis in Figure 1).

The philosophy of ISD applies at all stages in a process lifecycle. It is never too late for ISD to make potentially significant impacts.

CCPS *(2)* divides ISD strategies into four categories:

• *substitute* — use less-hazardous materials, chemistry, and processes

• *minimize* — use small quantities of hazardous materials; reduce the size of equipment operating under hazardous condition such as high temperature or pressure

• *moderate* — reduce hazards by dilution, refrigeration, or process alternatives that operate at less-hazardous conditions

• *simplify* — eliminate unnecessary complexity.

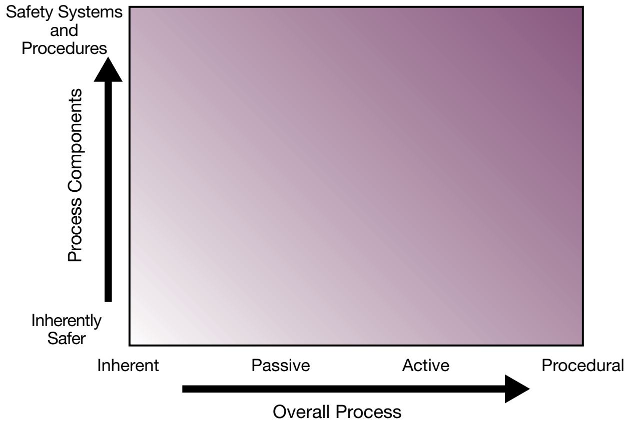
Others have used more and different categories to help designers identify ISD options, but those can be considered subsets of the four listed here.

ISD in practice

The philosophy of ISD applies at all stages in a process lifecycle, although the options available are different in different stages. The best opportunities for implementation of inherently safer basic chemistry and technology are early in product or process research and development, but it is never too late for ISD to make potentially significant impacts.

Basic technology. Consider ISD for technology selection, including the chemical synthesis route. Understand all hazards and ISD options relative to those hazards.

Preliminary design. Consider ISD for the specific unit



▲ **Figure 1.** Inherently safer design can be considered at the overall process level (horizontal axis) and for the individual components in a specific plant (vertical axis).

operations, for the processing steps required to implement a selected chemistry, and for plant site selection.

Detailed plant design. Consider ISD for the specific plant location on a site, and for detailed equipment and piping design. Think about the location and layout of the equipment, and the number of parallel systems and their sizes — for example, a single, large process train versus multiple smaller trains.

Detailed equipment design. Different designs for specific pieces of process equipment have different ISD characteristics, such as inventory of hazardous material. Also consider human factors and design of equipment to minimize potential for incorrect operation. The article by Maher, Norton, and Surmeli on pp. 43–47 discusses the use of ISD during the various stages of the design process.

Operation. Continue to think about ISD after the plant has been built. For example, develop inherently safer operating and maintenance procedures. Think about ISD when making changes, and look for ISD opportunities arising from technology advances — what was not feasible when the plant was built may be feasible today. The article by Edwards and Chosnek on pp. 48–52 discusses the application of ISD in existing plants in more detail.

ISD will not eliminate all risk associated with chemical processing. It may not be possible to eliminate or reduce the hazard because the very property of a material or technology that makes it hazardous is the same property that makes it useful (*e.g.,* gasoline, as discussed earlier). When dealing with hazardous materials or technologies, the important factor in attaining the benefits of the technology and managing the hazard is control. Engineers have recognized this ever since Kletz published his first article on ISD in 1978 *(1)*, and it cannot be stated more clearly than he did:

"I do not, of course, suggest that there should be any ban on plants which contain large quantities of hazardous materials, large inventories as they are often called. The development of alternative processes will take time and may often prove impossible. When large inventories are essential, I am sure that we can, by good design and operation, keep them under control. I merely suggest that, in designing new plants, we make a low inventory one of our aims. Usually in the past we have given no conscious thought to the size of the inventory; we have accepted whatever inventory was called for by the design. If we set out to reduce the inventory, we may find that in many cases we can do so."

ISD first and forever

So, how do we incorporate ISD into process design? First, start early in the lifecycle and never stop. Some companies perform separate ISD reviews, often using checklists to stimulate ISD ideas. ISD can be incorporated into the process safety management (PSM) activities — such as process hazard analysis, management of change, incident investigation, mechanical integrity, and others — that are normally done at every stage of the process lifecycle, from initial technology selection through detailed design and operation. The following articles explore various ways to do this. CEP

LITERATURE CITED

1. **Kletz, T. A.,** "What You Don't Have, Can't Leak," *Chemistry and Industry,* pp. 287–292 (May 6, 1978).
2. **Center for Chemical Process Safety,** "Inherently Safer Chemical Processes: A Life Cycle Approach," 2nd ed., American Institute of Chemical Engineers, New York, NY, and John Wiley & Sons, Inc., Hoboken, NJ (2009).
3. **Kletz, T. A., and P. Amyotte,** "Process Plants: A Handbook for Inherently Safer Design," 2nd ed., Taylor CRC Press, Boca Raton, FL (2010).
4. **Center for Chemical Process Safety,** "Guidelines for Hazard Evaluation Procedures," 3rd ed., American Institute of Chemical Engineers, New York, NY, and John Wiley & Sons, Inc., Hoboken, NJ (2008).

FURTHER READING

Amyotte, P. R., ***et al.,*** "Incorporation of Inherent Safety Principles in Process Safety Management," *Process Safety Progress,* **26** (4), pp. 333–346 (2007).

Center for Chemical Process Safety, "Final Report: Definition for Inherently Safer Technology in Production, Transportation, Storage, and Use," www.aiche.org/Conferences/Specialty/GCPS/IST.aspx, U.S. Dept. of Homeland Security, Chemical Security Analysis Center, Aberdeen Proving Ground, MD (July 19, 2010).

Clark, D. G., "Applying the 'Limitation of Effects' Inherently Safer Processing Strategy when Siting and Designing Facilities," *Process Safety Progress,* **27** (2), pp. 121–130 (2008).

Hendershot, D. C., "A Summary of Inherently Safer Technology," *Process Safety Progress,* **28** (4), pp. 389–392 (2010).

Hendershot, D. C., "What Does Inherently Safer Mean?," *Chem. Eng. Progress,* **106** (8), pp. 23–25 (Aug. 2010).

Mannan, S., ed., "Lee's Loss Prevention in the Process Industries," 3rd ed., Elsevier Butterworth-Heinemann, Oxford, UK, Chapter 32 (2005).

DENNIS C. HENDERSHOT (dennis.hendershot@gmail.com) worked for Rohm and Haas Co. for 35 years in process research, plant design and startup, and process safety, including management systems and tools and process safety support for new and existing facilities. He retired from Rohm and Haas as a senior technical fellow and was a principal process safety specialist for Chilworth Technology Inc. He was a member of the BP North American Refineries Independent Safety Panel, chaired by former Secretary of State James Baker. He is currently a staff consultant for the Center for Chemical Process Safety, and he edits the monthly *Process Safety Beacon*. He received a BS from Lehigh Univ. and an MS from the Univ. of Pennsylvania, both in chemical engineering.