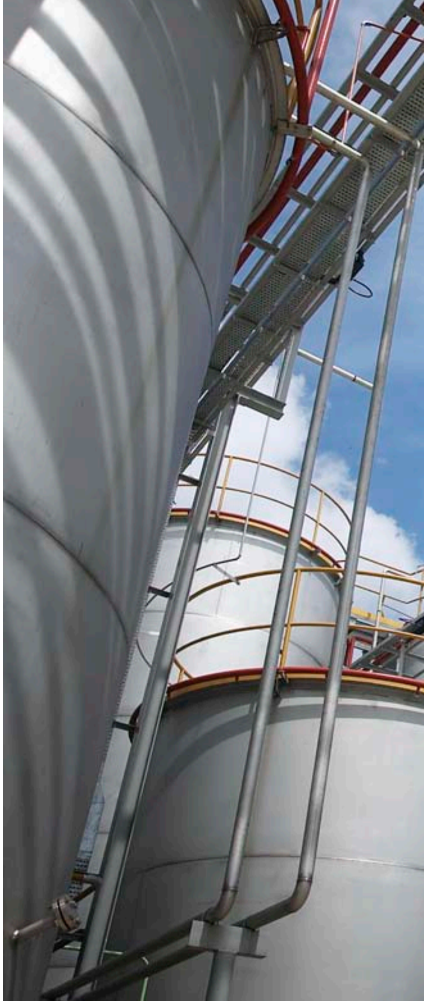

Inherently Safer Design

An Overview of Key Elements

By Dennis C. Hendershot

IN BRIEF
- Inherently safer design is a holistic approach to safer chemical manufacture.
- This overview examines key ISD elements such as minimize, substitute, moderate and simplify.
- A process's life cycle is also considered in context of ISD to further explain the most effective use of ISD as well as other risk mitigation methods and strategies.

Inherently safer design (ISD) is a philosophy for addressing safety issues in the design and operation of facilities that use or process hazardous chemicals. When considering ISD, the designer tries to manage process risk by eliminating or significantly reducing hazards. Often, the traditional approach to managing chemical process safety has accepted the existence and magnitude of hazards in a process, and incorporated engineering and administrative controls to reduce process risk. Where feasible, ISD provides more robust and reliable risk management, and has the potential to make the chemical processing technology simpler and more economical by eliminating the need for expensive safety systems and procedures.

However, when one considers the multiple risks associated with any technology, including chemical processing, it is unlikely that any process or plant design can eliminate all hazards and risk. A combination of ISD, engineering and administrative controls will always be required to adequately manage all process risks.

ISD addresses the immediate impact of single events (chemical accidents) on people, the environment, property and business. In a chemical processing plant, this generally means the immediate impacts of fires, explosions and the release of toxic materials. In many cases, an ISD also will be beneficial for other types of process risk, such as environmental risk, chronic health risk, or risk to consumers or product users. However, this is not always true. For example, a nonflammable solvent may be inherently safer in terms of fire and explosion risk, but it may be a serious environmental contaminant or it may pose a chronic health hazard.

While engineers recognize the potential benefits of ISD in managing other types of process risk, the main intent of ISD is to reduce the frequency and potential impact of chemical plant incidents—fires, explosions and acute toxic exposures. Therefore, application of ISD is one consideration in the selection of process and product technology, but the decision about what technology option is best overall must consider all risks.

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History of ISD

The concept of ISD is not new, nor is it unique to the process industries. Technologists have long recognized the value of eliminating or reducing hazards, applying ISD without calling it by that name; they simply considered it to be good design.

For example, when Stone Age cave dwellers decided to move to a cave higher above a river after a flood, they were practicing ISD by eliminating the risk of having their home flood. They could have stayed in the old cave and managed the risk in other ways, for example, by building a dike around the cave mouth (engineering control), or by assigning a family member to monitor the river level and warn everybody to move to higher ground when a flood was imminent (administrative control).

The term *inherently safer design* came into use in the process industries in the 1970s. Following a 1974 hydrocarbon vapor cloud explosion at Flixborough, England, Trevor Kletz, a senior safety advisor for ICI, questioned the need for such large quantities of flammable or toxic materials in a


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manufacturing plant, and the need for processing at elevated temperature and pressure (Kletz, 1978).

Kletz (1978) suggested that industry redirect its risk management efforts toward elimination of hazards where feasible. Instead of devoting extensive resources to safety systems and procedures to manage the resulting risks, industry could try to identify process modifications that reduce or eliminate hazards. This could be accomplished, for example, by reducing the quantity of hazardous material, using less hazardous material or developing technology that operates in less severe conditions.

Kletz (1978) and others in the chemical industry established a set of principles for ISD and provided many examples of its implementation. In 1996, Center for Chemical Process Safety (CCPS) published *Inherently Safer Chemical Processes: A Life Cycle Approach*, which compiled information on industry thinking on ISD. In 2009, CCPS published a second edition of the book incorporating the latest developments on ISD based on more than a decade of additional industrial experience.

ISD Basics

What does ISD mean? *Inherent* means existing as an essential constituent or characteristic, something intrinsic. Therefore, something is inherent if it exists "as an essential constituent or characteristic." When something is inherently safer, safety is built into the process or product, not added on. Hazards are eliminated, not controlled, and the means by which the hazards are eliminated are so fundamental to the process design that they cannot be changed or defeated without changing the process.

Inherently safer design is a philosophy for addressing safety issues in the design and operation of facilities that use or process hazardous chemicals.

In many cases, this will result in simpler and less costly plants. If extensive safety systems are required to control major hazards, they introduce complexity, along with cost, both in the initial investment for the safety equipment as well as for ongoing operating cost for maintenance and operation.

Because ISD's goal is to eliminate or reduce a process's hazards, one must understand the term *hazard*. In this context, the definition from CCPS's (2008) *Guidelines for Hazard Evaluation Procedures* is used. According to this source, a hazard is "an inherent physical or chemical characteristic that has the potential for causing harm to people, the environment or property." Hazards are intrinsic to a material or its conditions of use. For example:

- Chlorine is toxic by inhalation.
- Gasoline is flammable.
- High-pressure steam contains a large amount of potential energy, from its elevated temperature and from the high pressure.

These hazards cannot be changed, except by changing the material or the conditions of use.

Chemical Process Safety Strategies

Chemical process safety strategies can be grouped in four categories: inherent, passive, active and procedural (Figure 1, p. 50). The first three can be characterized as engineering controls, while the last (procedural) can be characterized as an administrative control. In general, inherent and passive strategies are the most robust and reliable, but elements of all strategies are required for a comprehensive process safety management program when considering all hazards of a process and plant.

Inherent

The inherent approach to safety is, where feasible, to eliminate or greatly reduce the hazard by changing the process to use materials and conditions that are not hazardous or much less hazardous. These changes must be integral to the process or product, and not easily defeated or changed without fundamentally changing the process or plant design.

One example is substituting water for a flammable, and perhaps also toxic, solvent as a carrier for a paint or coating (e.g., using water-based latex paints instead of oil-based paints). Elimination of the flammable and/or toxic solvent is an inherent characteristic of the product and its manufacturing process. The hazard of fire or exposure to toxic solvent vapors is eliminated in the manufacturing process and throughout the manufacturing supply chain all the way to the product user.

Passive

Passive safety devices are engineering controls that minimize hazards using process or equipment design features which reduce either the frequency or consequence of an incident without the active functioning of any device.

For example, a batch process uses a chemical reaction that has a maximum possible pressure of 5 bar in case of a runaway reaction. If this reaction occurs in a reactor designed to contain a pressure up to 10 bar, the maximum runaway reaction pressure will be contained within the reactor vessel. The reactor contains the pressure because of its design and construction—the thickness and strength of the metal from which it is fabricated, the strength of the gaskets and bolts that hold it together, and its other physical components. This containment is robust and reliable; the reactor need not sense high pressure and take any action, and no moving parts are required to contain the pressure.

However, the hazard (5 bar pressure) still exists, so some risk remains. For example, the reactor may be damaged, corroded, improperly constructed or contain a faulty gasket. Or, it could fail to contain the pressure from a runaway reaction even though it is designed to do so. The passive strategy would be considered less robust than an inherent strategy, which would change the process to eliminate or reduce the pressure from a runaway reaction.

Active

Active safety systems are engineering controls such as process control systems, safety instrumented systems and sprinkler systems. These systems are designed to sense a hazardous condition and take an appropriate action. Active systems may be designed to prevent an incident or to minimize its consequences.

For example, a tank might have a high-level interlock that shuts off a pump feeding the tank and closes all feed valves; such a system is designed to prevent a tank overflow. A fire sprinkler system is an active system designed to minimize the consequences of a fire; the system does not prevent the fire and may not even be activated unless a fire is detected.

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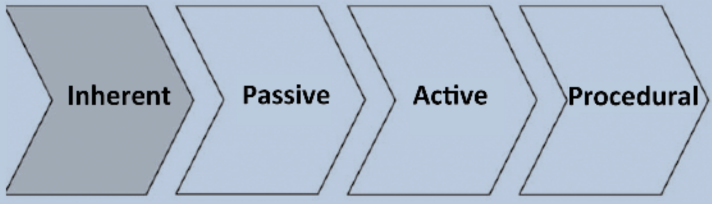
Procedural

Procedural safety systems are administrative controls; they include standard operating procedures, safety rules and procedures, operator training, emergency response procedures and management systems. For example, an operator may be trained to observe the temperature in a reactor and apply emergency cooling if it exceeds a specified critical value.

In general, for a high-hazard system, procedural risk management systems do not, by themselves, provide adequate risk management. Human reliability is not high enough, and people often cannot diagnose a problem, determine the appropriate action and take that action quickly enough. However, procedural safety systems will always be a part of a comprehensive risk management program. At a minimum, they will be required to ensure ongoing maintenance and management of the safety systems based on engineering controls.

Figure 1

Chemical Process Safety Strategies



Note. *Adapted from* Inherently Safer Chemical Processes: A Life Cycle Approach, 2nd ed., *by Center for Chemical Process Safety, 2009, Hoboken, NJ: John Wiley & Sons.*

Designing Inherently Safer Processes

CCPS (2009) has categorized strategies for designing inherently safer processes into four groups:

1) **Substitute.** Use less hazardous materials, chemistry and processes. For example:

•An alternate synthesis chemistry for acrylic acid manufacture by propylene oxidation eliminates the use of carbon monoxide, nickel carbonyl, anhydrous hydrogen chloride and acetylene used in an earlier process.

•Water-based latex paints eliminate fire, toxicity and environmental hazards associated with solvent-based paints.

2) **Minimize.** Use small quantities of hazardous materials or reduce the size of equipment operating under hazardous condition (e.g., high temperature, pressure). For example:

•Nitroglycerine can be made in a continuous pipe reactor with a few kilograms of inventory instead of a large batch reactor with several thousand kilograms of inventory.

•Loop reactors have been used to reduce the size of chemical reactors in many applications, including polymerization, ethoxylation and chlorination.

•A reactive distillation process for manufacture of methyl acetate reduces the number of major vessels and columns from 10 to three as compared to an older process where the reaction and distillation operations are performed in separate equipment.

3) **Moderate.** Reduce hazards by dilution, refrigeration or process alternatives that operate at less hazardous conditions. For example:

•Combustible solid was handled as a pellet instead of a fine powder, reducing the dust explosion hazard.

•Off-site risks were reduced by replacing anhydrous ammonia with aqueous ammonia for a neutralization application.

•Storage of monomethylamine under refrigerated conditions significantly reduced the hazard to the surrounding community by reducing the amount of material transported into the atmosphere in case of a leak from the storage tank.

4) **Simplify.** Eliminate unnecessary complexity and design user friendly plants. For example:

•Old piping was removed from a plant because of process modifications, making it impossible to accidently transfer material into a reactor through that piping because of either operating error or leaking valves.

•Confusing control system layouts, equipment on/off switches and equipment labeling in the plant were simplified to reduce the potential for error.

ISD & the Process Design Life Cycle

Process design starts with the selection of a potential product and a basic technology for a manufacturing process. As the technology progresses through process development, conceptual plant design, scale up, engineering and detailed plant design, plant construction, start-up, and ongoing operation and future modification, different choices and decisions are made by chemists, engineers and other technologists (Figure 2). The ISD philosophy applies at all stages, but the available options change.

The best opportunities for ISD implementation are early in product or process research and development. At this point, no commitment has been made to a particular technology; no resources have been expended on research and development that would have to be redone; potential customers have not committed to using products produced by a certain technology and developed their processes to fit this product; and no capital has been committed to build a plant to implement a particular technology.

As the process moves through the life cycle, it becomes more difficult to change the basic technology. However, it is never too late to consider ISD, although options for implementation may be more limited in an existing plant. To illustrate how ISD can be applied at various levels of process development and design, disinfection of drinking water is presented as an example process.

Selection of Basic Technology

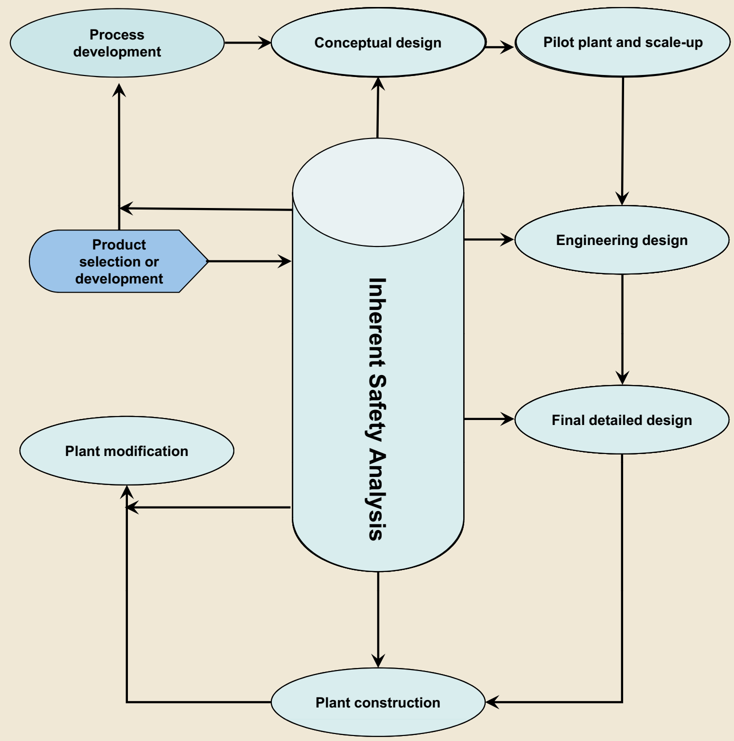
Water can be disinfected in many ways, including chlorination, ozone, ultraviolet light and radiation. These technologies have differing ISD characteristics relative to different hazards of concern. For example, chlorine is toxic and may produce hazardous chlorinated organic materials in water containing certain organic precursors. Ozone and ultraviolet light provide disinfection at the point of treatment, but do not have residual activity should the water be contaminated downstream of the treatment plant. To consider ISD for basic technology selection, the decision maker must understand all hazards of concern and the inherent safety characteristics of the available process options relative to those hazards.

Implementing the Selected Technology

Once the basic technology has been selected, many options for actual implementation of that technology may be available. Using the water treatment example, assume that chlorination technology is selected. The process designer now must decide how chlorination will be implemented. Options include elemental chlorine gas, sodium hypochlorite and solid chlorinating agents. Each option has specific ISD characteristics relative to various hazards of concern.

Figure 2

Inherently Safer Design in the Process Design Life Cycle



Note. *Adapted from* Inherently Safer Chemical Processes: A Life Cycle Approach, 2nd ed., *by Center for Chemical Process Safety, 2009, Hoboken, NJ: John Wiley & Sons.*

The designer also must consider factors such as economics, feasibility of the technology, state of development (proven technology, a new never-used process, somewhere in between) and other risks (e.g., environmental, chronic health).

Plant Design

At this point in the process life cycle, the designer must consider ISD for a specific plant design. Factors might include:

•location of the plant relative to surrounding population, in-plant occupied areas, sensitive environmental areas, etc.;

•general layout of equipment at the site;

•number of parallel systems and size of those systems (one large plant, or two or more smaller plants, for example).

If one assumes that the system's designers have decided that disinfection using gaseous chlorine is the optimum approach, ISD should be considered when determining, for example, where the facility is located, where the chlorine is stored and handled on site, and the number and size of the water chlorination systems.

Detailed Equipment Design

At this stage, the designer should consider ISD in the detailed design of each piece of equipment. A designer has many options, including heat exchangers, chlorine vaporizers and other devices that might be included in a water treatment plant.

The best opportunities for ISD implementation are early in product or process research and development. However, it is never too late to consider ISD.

Different equipment designs will have different ISD characteristics (e.g., inventory of hazardous material in the equipment). Also, the detailed layout of the equipment will affect factors such as the length and diameter of piping containing hazardous materials. Consideration of human factors in equipment design to minimize the potential for incorrect operation and human error will also result in an inherently safer plant.

Operation

Once a plant is built, ISD should be considered when developing operating and maintenance procedures. These must be clear, logical and consistent with actual human behavior. Ideally, the easiest way to operate equipment also should be the right way and the safe way to operate that equipment. Also, the plant should consider ISD options throughout the operational lifetime, particularly when modifications are made or if new technology becomes available.

ISD Concerns

ISD is not a magic bullet that will eliminate all potential risks associated with chemical processing. For example, it is often not possible to eliminate or reduce a hazard because the characteristic of a material or technology that makes it hazardous is the same characteristic which makes it useful.

•Jets typically travel at about 600 mph. This is what makes them useful. They can transport people halfway around the world in less than a day. But that speed also makes them hazardous. An airplane traveling at 600 mph has a large amount of kinetic energy that can cause major damage if it hits something, as well as likely killing all passengers on board.

•Gasoline is flammable and has the potential for a major fire. But its flammability is why gasoline is useful. It stores a large amount of energy in a small mass of material making it a valuable transportation fuel.

•Chlorine is toxic. This makes it hazardous to most life, including people and animals. However, this is what makes it useful for killing pathogenic organisms in drinking water so that people can drink the water safely.

For these and other hazardous materials or technologies, the important factor in attaining the technology's greatest benefits and managing the hazard is control. In some cases, alternative technologies that are less hazardous or are easier to control may exist.

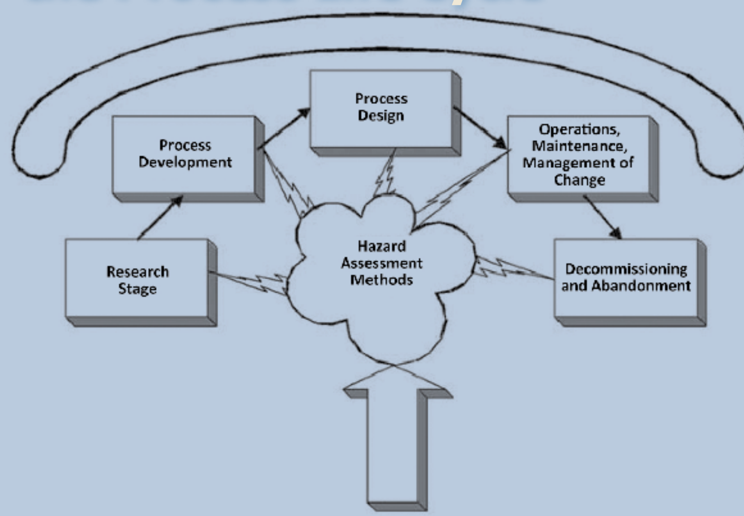
For many technologies, however, no inherently safer technologies exist; such technologies are not economically feasible; or other risks (e.g., environmental, chronic health) are important enough that society chooses to use a technology that is less inherently safe. In these cases, those involved must rely on engineering controls and administrative safety strategies to manage the risk. These strategies can be highly effective; travel by airplane is very safe despite the significant inherent risks of flying. This is because of the highly effective safety management systems in place in the air transport system.

Every technology presents multiple hazards. Consider automobile travel. Hazards include the speed of the car (kinetic energy), flammable fuel, toxicity of exhaust gases, hot surfaces in the engine, a pressurized cooling system for the engine and electricity. For a chemical process, hazards might include acute toxicity, flammability, corrosiveness, chronic toxicity and reactivity adverse environmental impacts.

The statement that a process is inherently safer can only be made in the context of one hazard or perhaps several specific hazards. It is highly unlikely that any technology will ever be inherently safer with respect to all possible hazards. Any change to a technology designed to reduce one or more hazards will also affect other hazards, perhaps such that these hazards will be increased or new hazards will be introduced.

Chlorofluorocarbon (CFC) refrigerants provide an example of ISD conflicts. When first developed in the 1930s, CFCs were considered to be safer alternatives to existing refrigerants such as ammonia and light hydrocarbons (the term

Figure 3
Hazard Assessment During the Process Life Cycle



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inherently safer was not in use at that time). CFCs have low acute toxicity and are not flammable.

Toward the end of the 20th century, the adverse environmental impacts of CFCs were recognized, and their use has been significantly regulated or eliminated (EPA, 2010). However, CFCs are still inherently safer than many alternatives with respect to flammability and acute toxicity. Society has decided that the previously unknown hazard of adverse environmental impact is unacceptable and is willing to apply engineering controls and administrative procedures to manage the hazards associated with CFC replacements for refrigeration systems.

Different populations of potentially affected people may perceive the inherent safety of technology options differently. For example, suppose a process requires relatively small quantities of chlorine gas. A plant may have a choice between supply in 1-ton cylinders or 90-ton railroad tank cars. Neighbors of the plant would likely consider the 1-ton cylinders option to be inherently safer because it is unlikely that a leak would impact them at that distance.

On the other hand, plant operators would have to connect and disconnect cylinders 90 times for each one time they would have had to connect and disconnect a railroad car. Thus, operators would likely consider the rail car to be inherently safer because they would be affected by any release, even a small one. The operators would have a much higher frequency of relatively high-risk operations (connecting and disconnecting hoses that could contain chlorine).

Of course, these hazards can be managed with procedures, PPE and other safety management systems, but these are not inherent. Both the neighbor and operators are correct in their perception of the ISD characteristics of the chlorine supply options, but they are concerned about different kinds of incidents. The challenge for the system designer is to understand these conflicting requirements and make an intelligent choice, including consideration of the entire risk management system (inherent, passive, active, procedural).

It is also important to consider whether an ISD option actually reduces risk or transfers it somewhere else, perhaps increasing overall risk. For example, a plant might reduce the size of a hazardous material storage tank to reduce inventory and site risk. However, use of the smaller tank may require a change from shipment via railroad tank cars (typically about 300,000-lb shipments for many materials) to trucks (typically about 30,000-lb shipments) because the smaller tank cannot hold more than a truckload of material.

As a result, the site will receive 10 times as many shipments, and the material will be transported over the road rather than by rail. Depending on the specific characteristics of a particular plant location, road shipment may be more hazardous. While the site's risk is reduced, the overall risk to society may actually increase.

Excerpt From an ISD Checklist

No.	ISD Alternatives
2.2.1	Can alternate equipment with reduced hazardous material inventory requirement be used? Such as: •centrifugal extractors in place of extraction columns; •flash dryers in place of tray dryers; •continuous reactors in place of batch; •plug flow or loop reactors in place of continuous stirred tank reactors; •continuous in-line mixers (e.g., static mixer) in place of mixing vessels or reactors; •intensive mixers to minimize size of mixing vessel of reactor; •high-heat-transfer reactors (e.g., microreactor, HEX reactor); •spinning-disk reactor (especially for high-heat flux or viscous liquids); •compact heat exchangers (higher heat transfer area per unit volume, e.g., spiral, plate and frame, plate-fin) in place of shell-and-tube; •more hazardous material on the tube side in shell-and-tube exchangers; •use water or other nonflammable heat transfer medium, a vapor-phase medium or a medium below its boiling point; •wiped film stills in place of continuous still pots (distillation columns); •combine unit operations (e.g., reactive distillation or extraction in place of separate reactor with multicolumn fractionation train or extractor; installing internal reboilers or heat exchangers) to reduce overall system volume; •use of acceleration fields (e.g., rotating packed bed for gas/liquid or liquid/liquid contacting for absorption, stripping, distillation, extraction); •alternate energy sources (e.g., lasers, UV light, microwaves or ultrasound) to control reaction or direct heat to the unit operation.
2.2.2	Has the length of hazardous material piping runs been minimized?
2.2.3	Has hazardous material piping been designed for minimum pipe diameter?
2.2.4	Can pipeline inventory be reduced by using the hazardous material as a gas rather than a liquid?
2.2.5	Can process conditions be changed to reduce production of hazardous waste or by-products?

Note. *Adapted from* Inherently Safer Chemical Processes: A Life Cycle Approach, 2nd ed., *by Center for Chemical Process Safety, 2009, Hoboken, NJ: John Wiley & Sons.*

Implementing ISD

How are ISD philosophies incorporated into the design and operation of chemical processing plants? The best answer is to start early in the life cycle and never stop (Figure 3). The greatest opportunities for fundamental changes to processes occur early in the process life cycle, during initial process conception and early development.

At this stage, the researcher may have opportunities to select less hazardous raw materials and intermediates, or less hazardous chemical synthesis paths from among the many options that may be available. As noted, it is never too late to consider inherent safety.

One way to consider ISD at all stages in the process life cycle is to incorporate inherent safety considerations into the process safety management (PSM) activities normally performed at every stage in the life cycle, from initial technology selection through detailed design and operation. These activities vary in structure as the process moves from general technology reviews at early stages to detailed design reviews and other PSM activities later on. Some organizations conduct a separate inherent safety review at a relatively early stage of process or plant development, while others incorporate ISD considerations into the existing process safety review processes.

Clearly, the type of potential ISD improvements will differ at various life cycle stages. Early on, the designer has opportunities to change elements such as the basic technology, process unit operations and plant location. Later on, in detailed design, ISD opportunities will be more limited in impact and will include elements such as detailed piping configuration, user friendly operator interfaces and operating inventory in equipment. CCPS (2009) has published a checklist that is useful in identifying ISD opportunities at various stages in the process life cycle. The sidebar on p. 53 presents an excerpt from this checklist, which is more than 30 pages in length.

Also, ISD philosophy can be considered when determining how to respond to an identified hazard from any PSM activity, including process hazard analysis, management of change, incident investigation and routine walkaround safety inspections. The team conducting the PSM activity is challenged to consider ways to eliminate or minimize hazards, rather than accepting that the hazard exists and focusing its efforts on controlling that hazard.

The team should ask the following questions, in this order, once it has identified a hazard:

1) Can the hazard be eliminated?

2) If not, can its magnitude be significantly reduced?

3) Do the alternatives identified in questions 1 and 2 increase the magnitude of any other existing hazards or create new hazards? If so, consider all hazards in selecting the best alternative.

4) What engineering controls and administrative controls are required to manage the hazards that inevitably will remain?

Designers and PSM activity teams often skip directly to the fourth question, identifying systems to manage hazards whose existence is accepted and believed to be unavoidable. This may be true in many cases, but no team will ever eliminate or reduce a hazard unless its asks whether this is possible. A PSM team should challenge itself to eliminate or reduce hazards; only if this is not possible should it shift to designing systems to manage risk from hazards that cannot be eliminated.

Acknowledgment

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Some Inherent Safety Myths

Several misconceptions (or myths) are commonly expressed during ISD discussions. Consider these few:

•**Myth 1: ISD will eliminate all hazards.** It is unlikely that any process or material will ever be completely hazard free. One can only speak of ISD in the context of a specific hazard. It may be possible to describe a process as inherently safer with respect to the hazard of exposure to a volatile and toxic material, but that says nothing about other hazards (e.g., thermal stability, runaway reaction potential, flammability). Also, any change to a process or technology, even one intended to reduce a particular hazard of concern, can introduce a new hazard or increase the magnitude of a hazard other than that which the change is intended to reduce.

One can cite many examples of "no good deed goes unpunished" cases in which a change intended to improve safety resulted in a new hazard or increased the risk of a different existing hazard. For example, an explosion suppression system installed on a grinder for a plastic inadvertently activated because of a water leak into the grinder and caused the grinder to explode because of the discharge of fire suppressant gas into the grinder while it contained wet material (Dowell & Hendershot, 1997). In another case, a vent system installed to collect and treat toxic vapor emissions caused a release of hydrogen cyanide from a storage tank by an unanticipated mechanism (Dowell & Hendershot).

•**Myth 2: Because an inherently safer technology represents "the best" approach to managing a particular hazard, one must always implement that technology.** This is not true because other hazards and risks may need to be considered; in addition, the societal benefits of a technology may justify the robust application of engineering and administrative controls (passive, active and procedural strategies). For example, people can eliminate the risk of airplane crashes, whether caused by accident or by terrorist activity, if they stop flying airplanes. Thus, if safety were the only objective, this would be "the best" approach.

However, eliminating crashes is not the only objective. People also want to travel from New York to Los Angeles in 5 hours instead of 5 days, and at a reasonable price, along with many other design objectives of the air transport system. The objective of society is safety, not necessarily inherent safety. An appropriate combination of active, passive and procedural safety management strategies can be extremely effective, as demonstrated by the safety record of commercial airlines.

•**Myth 3: ISD is only applicable at early stages of process research and development and plant design.** ISD applies at any stage in a plant life cycle. While the greatest benefits accrue from selection of inherently safer basic technology, one can point to many examples of significant improvements in inherently safer operation of existing plants. Following the 1984 toxic gas release tragedy in Bhopal, India, many process companies reported major reductions in the inventory of highly toxic materials in storage. For example, Wade (1987) reported reductions of hundreds of thousands of pounds of hydrogen cyanide and chlorine. Another plant eliminated bulk storage of liquid bromine, using bromine cylinders instead, and significantly reduced the hazard for plant neighbors (Hendershot, Sussman, Winkler, et al., 2006).

•**Myth 4: Plant operating personnel contribute little to ISD.** One can cite many examples of ISD improvements suggested by operating or maintenance personnel. While plant operators cannot be expected to suggest a safer chemistry for the process, they are familiar with the detailed mechanical functioning of the plant and its equipment. Who is in a better position to identify situations in which complex systems set up operators for error than the operators who use those systems every day?

For example, a start-up procedure that requires an operator to walk up and down the stairs three times to manipulate valves in the correct sequence (and an incident could occur if executed in the incorrect sequence) can be made safer by locating the valves so that an operator must walk up the stairs only once during the start-up; by automating and interlocking the valves so that they cannot be opened in the incorrect sequence; or (inherently safest if possible) by eliminating the valves through a piping or process technology change (CCPS, 2009).

•**Myth 5: There is a "best technology" that is always inherently safer for the manufacture of a particular product.** "Best" technology for inherent safety may be highly dependent on local factors, such as plant location and environment, proximity of population, significance of other hazards in a particular plant environment, and practicality of other engineering and administrative controls at a particular location. For example, single floor houses eliminate the risk of injury from falling down the steps; however, if one lives in a flood plain, perhaps a second floor is a good idea.

Conclusion

Chemical manufacturing process designers and operators should consider ISD options throughout the process life cycle, from initial conception through research and development, plant design, construction, operation, modification and eventual shutdown. Usually the best opportunity to implement ISD occurs early in research and development before significant resources have been expended in process or product development, and before a plant has been built.

However, it is never too late and ISD should be considered throughout the process and product life cycle and economic footprint. This means consideration of raw materials, the manufacturing process, transportation, storage at all stages in the supply chain, end use and the safety consequences of changing technology (demolition of old facilities and construction of new ones). All hazards must be considered so that informed decisions can be made about conflicting goals and impacts. **PS**

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