CHEMICAL ENGINEERING TRANSACTIONS

VOL. 77, 2019

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Genserik Reniers, Bruno Fabiano
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ISBN 978-88-95608-74-7; **ISSN** 2283-9216

DOI: 10.3303/CET1977129

Achieving World Class Performance in Oil and Gas Industry Using Inherently Safer Design

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Hazard Identification, consequence evaluation, risk mitigation analysis, and management of effective safeguards are key to effective risk (safety) management. The high hazard industry, in its quest to achieve safer operations, has developed several risk assessment techniques that prescribe the addition of safeguards, usually safety systems, as the primary means to mitigate risk. This has led to complexity and not necessarily safer plants as evidenced by a trail of major process safety incidents.

High profile incidents with associated asset losses, increased public concern on safety issues and changes to regulatory expectations have driven the industry to consider inherently safer design (ISD) options. Chevron, on its journey to achieve world class operations, has adopted and deployed ISD principles during the execution of major capital projects (MCPs). As early as the alternatives generation stage of a MCP, projects rigorously evaluate options that allow for simpler and robust facility design.

This paper is based on the systematic application of ISD principles in offshore MCPs. The paper share examples of how ISD was applied in early MCP engineering phases and the benefits of the structured ISD application.

1. Introduction

An ‘inherently safer’ approach to hazard management is one that strives to avoid or eliminate hazards, or reduce their magnitude, severity or likelihood of occurrence, by careful attention to the fundamental design and layout. Less reliance is placed on ‘add-on’ engineered safeguard and procedural controls (Energy Institute 2014). High hazard industries promote a ‘hierarchy of control’s’ approach where inherently safer design is preferred above the other principles of engineered (passive and active) and procedural controls for prevention, control and mitigation. Inherently safer design (ISD) in process industries dates back to the 1970s and have formal origin in Trevor Kletz’s lecture titled ‘What you don’t have, can’t leak’. The concept got further developed over years and related rules of thumb have been developed including ‘Who is not there, can’t be affected’ (Nair, 2007), ‘What you don’t have doesn’t cost anything, won’t break down or won’t need maintaining’ (Energy Institute 2014) and ‘More is not always safer’ (Nair, 2017). In their paper at 7th Global congress on process safety, Amyotte et. al. analysed United States Chemical Safety Board’s investigation reports and identified that 36% of the incidents were related to failure to incorporate inherent safety in both incident prevention and consequence mitigation (Amyotte et. al., 2011).

Table 1: ISD fundamentals

Strategy	How?
Eliminate	Eliminate the hazard – material or activity
Substitute	Replace a hazardous material or process with an alternate that reduces hazard severity
Minimize	Use smaller quantities of hazardous substances or reduce inventory or energy to reduce the severity
Moderate	Use dangerous material in their less hazardous form or identify options with less severe conditions
Simply	Designing processes equipment and procedures to eliminate unnecessary complexity and potential human errors

Paper Received: 11 November 2018; Revised: 7 May 2019; Accepted: 22 June 2019

Please cite this article as: Nair S., Schnebele K., Attal H., Ogbeifun N., 2019, Achieving World Class Performance in Oil and Gas Industry Using Inherently Safer Design, Chemical Engineering Transactions, 77, 769-774 DOI:10.3303/CET1977129

The fundamental ISD strategies (Energy Institute 2014, CCPS 1996) are given in Table 1. Several examples where the typical design solution involved add-on safety features and how alternative ISD solutions were successfully applied are given in the sections below.

2. Systematic application in Major Capital Projects

Effective application of ISD principles on MCPs require a structured and multifaceted approach. Projects need to ensure broad stakeholder alignment and support, integrate ISD strategies into design philosophies and ensure basic ISD fluency among the design team. Finally, teams need to create a mechanism to identify, track ISD opportunities and advertise ISD application. The steps involved in systematic application is given in Figure 1 and explained below.

Figure 1: Steps for systematic ISD application

2.1 Role of leadership

Strong and visible leadership is a key condition for success. From the project conception phase, leaders should incorporate in development of goals and vision to deliver an inherently safer facility. Leaders at all level, including business, project and engineering must proactively engage the project team in the ISD vision and communicate the role it plays for project success.

One of the challenges that leaders must effectively overcome is the perceived notion that incorporating ISD is cost prohibitive, especially in a challenging economic condition. These concerns can be overcome during ISD launches when leadership provides examples where incorporation of ISD in early phases of projects had minimal cost impacts and lessons from missed opportunities which resulted in add-on safeguards. Incorporation of an ISD objective in each project team member's performance expectations have proven very effective way to engage the wider team.

To steward the routine application of ISD, the project should have an ISD champion to help identify ISD opportunities, track the opportunities to action and communicate ISD application examples to wider stakeholders to improve overall fluency. During workshops, standing meetings, and model reviews, the ISD champion asks probing questions to challenge the design teams to consider ISD alternatives. The ISD champion provides broad support across the project but should have focused engagements with the process and mechanical engineering and operations representative's teams as most of the ISD opportunities lay in those functions.

2.2 ISD in design strategies

Projects must incorporate ISD strategies and concepts in early engineering design philosophies, specifically ones related to loss prevention and layout. The loss prevention philosophy should call to improve overall system performance by ensuring timely hazard identification, appropriate management and associated risk reduction. Application of ISD principles can be effectively implemented if hazards are identified and risks are understood while the design is in progress. The layout philosophy should call for segregation of hazardous areas from non-hazardous areas, orientation of facilities to take advantage of natural wind direction to promote enhanced ventilation, location of sensitive receptors upwind of hazardous emission sources, minimization of confinement and congestion, and location of equipment with the greatest potential for leaks in the best ventilated areas.

2.3 ISD awareness

Chevron developed an interactive ISD awareness training which introduces the fundamentals and assists the engineering design team practice on the application. The training is provided to project leadership, operations and engineering team members from both owner and engineering contractor. Participants work through the hazard management principles – elimination, prevention, detection & control, and mitigation and the hierarchy of risk reduction measures—inherent, passive, active and procedural. Emphasis is placed on strategies for identifying inherently safer options using industry incident case studies and ISD evaluation tools. One such approach is INherently SAfer design Evaluation (INSAFE), a Chevron process for systematic ISD review of a project design prior to detailed engineering. INSAFE, a focused brainstorming workshop to identify opportunities to reduce risk during the early design phase through the application of ISD strategies and is conducted by trained facilitator, technical scribe and a cross functional team (discipline engineers and operations representatives).

The facility is reviewed in section and when an ISD opportunity is identified, the team captures a brief discussion of the benefits and potential trade-offs to assist the team in further defining and assessing the opportunity for the facility lifecycle.

Examples of facilitator prompt questions include:

- For a section, how can number of potential leak paths be reduced with minimal impact to maintenance?
- How can equipment be made more resilient?

2.4 ISD demonstration

Demonstration of ISD application is crucial to communicate how ISD is adding value to a project. Projects develop an ISD Opportunities Register to document ISD opportunities and track them to closure. The minimum set of information in the Opportunities register include – (i) the hazard, (ii) ISD principle, (iii) description with benefit and trade-offs, (iv) the owner / responsible person for actioning the opportunity and (v) the implementation status. The owner of the ISD opportunity should be identified and Table 2 gives an example of the structure of an ISD Opportunities Register.

Table 2: ISD Opportunities Register - Example

Hazard	ISD Principle	Description (concern – options – benefit – trade-offs)	Owner	Status
Pressure	Substitution	Current design: Shut Down Valves located upstream & downstream of 1st stage inlet scrubber pump. Evaluate pump type for 1st stage inlet scrubber pump to eliminate instrumentation. Benefit: Simplify control for pump. Tradeoffs: Evaluate impact to operability.	A Other	Closed (Applied)
Temperature	Minimization	Current design: Process line from recovered oil pump to oil treater degasser provided in topsides design. Consider eliminating line from recovered oil pump to oil treater degasser. Benefit: Minimize corrosion, reduce topsides weight. Trade-offs: Evaluate operability issues related to recovered oil separator.	C Other	Pending

The opportunities status should be tracked periodically, and closure comments recorded with supporting documentation, as appropriate. on a frequent (weekly to monthly) basis. Communicate information from the project ISD Opportunities Register to a business unit or company-wide register to promote learning across projects and ensure examples are readily available for other project teams to consider.

3. ISD application examples

Application of some of the ISD strategies proves challenging in practice because high-hazard industries, like oil and gas, as the characteristics of materials (e.g. flammability) that make them hazardous are often what makes them valuable. Consequently, it may be undesirable to eliminate all hazards or reduce the hazard severity. This section lists examples from offshore oil & gas projects demonstrating how ISD strategies were incorporated to meet project vision to build an inherently safer facility.

Eliminate

(i) Elimination of high pressure gas handling hazard: Enhanced Oil Recovery (EOR) through gas injection, chemical injection or water injection is one of the strategic decision taken during concept select for offshore field development projects. In one greenfield project, prior to application of ISD, EOR by gas injection, was a preferred alternative for improved recovery of oil.

This process includes additional equipment, such as gas compressors for generating the high pressures needed and requires buy-back of flammable gas to the facility. Handling high flowrate of high pressure gas increases the risk to personnel on board which leads to addition of active and passive safeguards like high integrity instrumented protection system and blast resistant walls. Through ISD application, the project team eliminated high pressure flammable gas handling risk by electing not to pursue EOR by gas injection despite an expected reduction in total oil recovery.

(ii) Elimination of asphyxiation hazard: Fire suppression is an important mitigative safeguard and can be achieved with multiple technologies, including water mist, chemicals or foams, and carbon dioxide (CO_2). Typically, some vendor packages choose CO_2 system and it endorses. However, the use of CO_2 for fire suppression introduces an asphyxiation hazard for personnel due to the potential for spurious activation of the CO_2 system in enclosed areas like equipment cabinets or electrical rooms. The design philosophies prohibited the use of CO_2 fire suppression systems in enclosures. By not allowing the use of CO_2 systems, the projects eliminated the potential asphyxiation hazard while still ensuring fire suppression can be achieved by other technologies.

Substitute

(iii) Substitution of flammable chemical: Hydrates, which occur due to the presence of water and gas in production fluids and the high pressures and low temperatures of the systems, can block flowlines and create operational and flow assurance concerns. The project planned to use a highly flammable chemical that is injected in the production flowlines to prevent hydrate formation. Storage and handling of the chemical introduced flammable hazards requiring designated area classification, therefore additional fire and gas detectors and fire suppression system. Through ISD application the design team substituted the hydrate inhibition system with a less hazardous (non-flammable) chemical. Risk reduction achieved without impact to production and saved cost of installing and maintaining the safeguards related to flammable chemical.

Minimize

(iv) Minimization of hazardous inventory: Initial project design specified storage of thousands of barrels of diesel in the hull to support power generation to meet facility availability targets. The estimated diesel storage required multiple pontoons of the hull and complex piping network for the diesel storage and handling. Through application of ISD minimization strategy, the project team was able to reduce the diesel storage needs by 75% through power use optimization effort and by choosing duel fuel alternative for power generation. The selected design option after considering trade-offs results in, significantly reduced risk and simpler design.

Moderate

(v) Moderation of hazardous drain system: Bilge water in the hull in the initial design was typically routed to the hazardous drain system on the topsides as the waste stream can accumulate small quantities of hazardous spilled material. By considering ISD strategies, the project segregated the non-hazardous bilge water in the hull through a dedicated hazardous drain system in the hull to collect hazardous spills and routed to hazardous drain system on the topsides. The hazards associated with the bilge system, which manages a large waste stream, have been moderated and the flows can be routed to the non-hazardous drain system.

(vi) An example of application of the moderation principle for an on-shore, greenfield liquified natural gas MCP is provided. Molecular sieve beds are used to remove water from natural gas prior to export and these beds must be periodically regenerated to remain effective. Regeneration can be done using a high pressure or low-pressure system options. Dewatering natural gas using sieve beds regenerated with a high-pressure system is a more energy efficient process but requires operation of the entire dewatering system at very high temperatures and pressures. The team selected a low-pressure regeneration system that allows the dewatering system to operate at much lower temperatures and pressures and the severity of a potential incident are reduced.

Simplify

(vii) Simplification with reduction in human performance dependency: Chemical injection into production flowlines or into the well-bore is a common operational activity to manage the impurities in the oil (e.g. hydrates, waxes) and provide other critical flow assurance functions. On one MCP, the proposed strategy for distributing chemicals consisted of using one pump and multiple valves to allow for multiple chemicals to be injected using the same piping configuration. The team identified that misalignment of the valves and inadvertent introduction of the wrong chemical was a credible concern. The design was reconfigured to provide dedicated pumps and piping networks to simplify the operations procedures and minimize the potential for human error.

(viii) Simplification by enhancing the design rating: Subsea production flowlines can be subjected to very high pressures during the initial phases of production in a reservoir or as the result of pressure buildup if subsea pumping is anticipated. High Integrity Protection System (HIPS), a complex and expensive instrument and control system, is often used for controlling pressure surges. A greenfield MCP elected to fully rate the subsea flowlines for the maximum expected pressures with incremental costs associated with the procurement and installation of thick-walled pipe. Through ISD application the risk was significantly reduced, and the complexity associated with maintenance of HIPS was avoided. In this example, the application of ISD provided a cost benefit for both Capital Expenditure and Operational Expenditure during the facility life.

(ix) Simplification through rationalization: During design of process systems, instrumented trips to shut down the process on detection of pressure, temperature or flow anomalies are common. To sustain the effectiveness of these safeguards, comprehensive inspection, testing and preventive maintenance is required. On one MCP, through a rationalization exercise, redundant and less effective instruments trips were identified and eliminated. Efficient optimization resulted in a less complex facility with improved production (e.g. reduced spurious plant shutdowns) and reduction in personnel risk exposure (less time at hazardous area for inspection and maintenance).

4. Challenges, Barriers and Pitfalls

This section addresses some of the familiar challenges in applying ISD strategies.

4.1 Designer mindset and reluctance to try something new

The biggest challenge is the mindset among facility designers, operators, regulatory authorities that the only way to make a plant safer is to add more systems to it. Risk assessments typically conducted reduce the identified risks through add-on safeguards (Dalzell and Chesterman 1997, Dalzell 2004, Khan and Amyotte 2002). This is also closely linked to the cultural factors such as a reluctance to change because “we’ve always designed it like this” or “we have always done it this way.” Designer may believe there is a lack of opportunity to apply ISD strategies for standardized or licensed technologies. Improving awareness of ISD benefits with examples through training, campaigns and workshops are effective means to overcome this barrier.

4.2 Single versus multiple debate

A systematic review during project engineering phase could optimize the equipment and inventory. Some difficult decision points where application of ISD principles could be valuable are listed below (Nair, 2017):

1. Single central processing versus multiple small/satellite facilities:
    1) Onshore: a combination like multiple well pads and satellite wells linked to a common processing facility could be an inherently safer option depending on offsite risk drivers;
    2) Offshore: multiple platforms and subsea processing could be a safer option compared to a single complex facility depending on the fluid characteristics, complexities and location. Separation of workforce/personnel from hazards (e.g. by bridge linked platform could be safer but may add operational complexities).
2. Single versus multiple decks for processing equipment layout: multi-deck layout or equipment spread over multiple elevations could be used in design to optimize pumping requirements whereas it may increase congestion and reduces separation between hazards from non-hazardous area;
3. Single equipment/vessel versus multiple equipment/vessel: reduction in the number of equipment can simplify the design and reduce potential leak paths but may impact reliability. Designers could also consider common spare and interchangeable design features versus parallel independent process streams;
4. Single stage facility development versus multi-staged development. Multi-staged projects could have quicker economic returns but may have increased risk due to construction workforce near operating facilities.

Risk based decisions supported by appropriate risk assessments can help in many cases mentioned above.

4.3 Cost versus benefit

It is commonly perceived that ISD application is cost prohibitive (Energy Institute 2014). Additionally, it is easier to quantify the contribution of a control and mitigation system rather than prevention. These barriers have perpetuated the over dependency on safety systems as a primary means of risk reduction. Cost benefit analysis of an ISD option may not factor reduced risk relative to a non-ISD option in the life cycle cost.

Inherent safety is a proactive approach for hazard/risk management and, considering the lifecycle costs of a process and its operation, an inherently safer approach is a cost-optimal option. Inherent safety can be incorporated at any stage of design and operation; however, application at the earliest possible stages of design (such as process selection and conceptual design) yields the best results (Khan and Amyotte 2002). Khan and Amyotte have also provided means of quantifying the benefits of ISD application.

4.4 Lack of application guidance

The conventional ISD application is primarily chemical and process industry focused. Finding real life examples of how to apply ISD in the upstream Oil & Gas industry and how to apply ISD in areas other than process engineering (e.g. subsea exploration, transport, station keeping, floating structure integrity) is challenging. Limited criteria and guidance is available on resolution of conflicts and trade-offs with reliability requirements and operational preferences. For example, multiple parallel streams may increase reliability but could increase the potential leak paths. Finally, demonstration of the consistent application is a challenge as ISD should be incorporated as a concept rather that a one-step risk assessment. ISD application may not be simple and clear for all opportunities and without careful screening and rigorous assessment, conflicts between options may not be resolved appropriately. It is also noted that potential opportunities to interface ISD concepts to the established risk assessments (e.g. Process Hazard Analysis, Quantitative Risk Assessments) should be utilized as appropriate. Industry guidance currently available (mostly related to chemical process industry but can be applied in other industries), CCPS, EI and INSET are listed for further reading.

5. Conclusion

This paper demonstrated risk management through a systematic application of the concepts of Inherently Safer Design through project design stages. It highlights the importance of project leadership and the relevance of approaching ISD as a concept rather than a one-time risk assessment activity. The relevance of ISD training for project personnel and the value of an ISD opportunity tracker is discussed. Examples in this paper demonstrate that the maximum value of ISD application is realized when applied early in the project (before the layout is finalized and decisions on choice of equipment / process is made). Though ISD application yields benefits, the paper discusses trade-offs that need to be considered. The authors recommend that a project define a clear ISD vision and engage leadership and design/engineering team in ISD strategies throughout the design phases to reduce capital expenditure, operational expenditure and realize risk reduction.

Acknowledgments

The authors would like to thank Chevron Leadership in Upstream Organization and Energy Technology Company for the opportunity to support ISD initiatives and guide the authors for successful demonstration in multiple projects. Note: Any views or opinions expressed in this paper are solely those of the authors and do not necessarily represent those of Chevron and its affiliates.

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