

ARE WE TOO RISK-AVERSE FOR INHERENT SAFETY? AN EXAMINATION OF CURRENT STATUS AND BARRIERS TO ADOPTION

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The inherent safety (IS) philosophy and its practice in inherently safer design (ISD) are described. The aim is to avoid or minimise hazards by substitution of benign materials, moderation of conditions and simplification of operations in process plant. This common sense approach is becoming common knowledge but it is not yet common practice, although some IS plant exists. Production trends in the industry together with an increasing aversion to taking risks with new ideas in the current competitive business environment are militating against further uptake of ISD. Such risk aversion can manifest in many forms including: process development traditions (particularly for fine chemicals and pharmaceuticals), project assessment methods and preoccupation with new product speed to market and protection of existing market share. There are no regulatory 'sticks' or incentives to overcome this risk aversion and no reason for the industry to improve its already good safety performance. The industry might not want to make too much of the undoubted benefits of IS, if this might result in pressure for costly revamps to existing plant.

Strategies for increasing uptake of IS may be described as by: persuasion, incentives and regulation. The economic benefits of IS are many and follow easily from the fundamentals of ISD but the industry is extremely reticent about acknowledging actual achievements. Other benefits might seem obvious but not to the industry, it seems. Incentives might need to be funded by government. IS has begun to appear in legislation in the USA and it behoves companies to anticipate future legislation by putting IS into practice now. In order that risks are not exported, a global industry-led body is needed to set global standards. This might particularly ease the uptake of IS, as might the education and encouragement of young engineers to use IS.

INTRODUCTION

Inherent safety (IS) is often described as common sense but according to Khan and Amyotte[1] in their excellent review of the field, it might not be common knowledge. We present some evidence that IS is common knowledge but that it is not yet common practice. We explore the reasons why this mature, common sense design philosophy has not yet been incorporated into mainstream design practice. The reasons may be ascribed in some measure to the inherent conservatism and risk-aversion of the process industries (PI), especially in the current competitive environment.

First, let us review inherent safety and its practical application in inherently safer design (ISD). Please skip the next section if you are familiar with these concepts.

INHERENT SAFETY (IS)

The traditional plant design philosophy and practice identifies hazards and then adds protective measures to control them. This method of secondary prevention reduces the *probability* of accidents. The alternative IS philosophy, or primary prevention, aims to use safer chemicals and operations to remove the *possibility* of accidents or minimise or reduce their consequences. In ISD hazards are identified early and then avoided or at least minimised, rather than controlled — so that accidents either cannot happen or their effects are minimal.

The principles of ISD were first enunciated by Kletz[2] after the Flixborough accident (28 killed) in 1974. His many books and papers have refined the concept and practice, see for example his 1998 book[3]. At first interest was limited, but the appalling loss of life at Bhopal in 1984 gave a greater impetus to discussion and a number of books and papers have appeared.

At Bhopal, between 2000 and 8000 (depending upon your information source) people died immediately, many thousands more have subsequently died and hundreds of thousands have suffered long-term health problems. The site has still not been cleaned up and there are many ongoing health problems that are believed to be caused by environmental pollution. The Bhopal disaster is the worst example of an inherently unsafe design, where a hazard has been realised. Methyl isocyanate killed so many people but it was an intermediate that should not have been stored and certainly not stored in such large quantities (40 tonnes). Furthermore, there is an alternative way of making the final product, carbaryl, which uses the same raw materials as the Bhopal plant[3]. The same feedstocks are reacted in a different order and methyl isocyanate is not produced. If this process had been used at Bhopal, there would have been no methyl isocyanate intermediate to escape and kill or maim so many people.

The International Process safety Group (IPSG) and the AIChemE Center for Chemical Process Safety (CCPS) have published a working definition of ISD. Hendershot[4] quotes four keywords:

- **Minimize:** use small quantities of hazardous materials, reduce size of equipment operating under hazardous conditions (high temperature, pressure).
- **Substitute:** use less hazardous materials, processes, conditions.
- **Moderate:** reduce hazards by dilution, refrigeration, process alternatives to use lower temperatures, pressures.
- **Simplify:** eliminate unnecessary complexity, "user friendly" plants.

Bungalows are inherently safer than houses, because they do not have stairs, which are the major cause of serious accidents in the home. Stairs are inherently unsafe, but they may be made 'safe' by lighting, fitting a handrail and child-gates, etc. It is important to distinguish between inherent safety and safety, because inherent safety is the more desirable quality. It is better to achieve safety inherently (live without stairs in a bungalow) rather than by modification (fitting a handrail, etc), because then unforeseen events (for example a rotten treadboard) cannot cause a problem.

Most chemical processes and the associated plant are safe enough but some are inherently safer than others. For example, large inventories of toxic and/or flammable materials are inherently unsafe, while small inventories and/or non-toxic and non-flammable materials are inherently safer – what you don't have can't hurt anybody. Problems in an inherently unsafe plant may escalate catastrophically, while in an inherently safer plant they should not arise but, if they do, they are self-correcting or escalate harmlessly. Therefore, it is almost self-evident that an inherently safer chemical plant is to be preferred over an inherently unsafe one, no matter how safe the latter is made by controlling the hazards. Inherent safety is best considered in the initial stages of the design[5], when fundamental decisions, which have a large impact on inherent safety and cannot be altered later, are made.

The next section examines progress towards ISD. Subsequent sections suggest the causes of the non-adoption of an IS approach to plant design. We look at the way process plant are developed and assessed for feasibility and the methods used, particularly in the early stages, when IS could have the greatest impact. We also examine legislative and other drivers, incentives and constraints that may or may not encourage the uptake of IS. Finally, some ways of overcoming these barriers are suggested.

CURRENT STATUS OF INHERENTLY SAFER PRACTICE

Even after 30 years of industry-wide acknowledgement that it is a good idea; even though the principles are well-founded and have been for a long time, with a number of excellent expositions of the philosophy and practice, inherently safer plant are the exception and the traditional approach to plant safety still predominates.

In bulk chemicals production, there has always been an economic incentive to optimise the production process. Continuous reactors offer better yields and more economic processing but often have smaller inventories per unit production; so they are inherently safer as well. Intermediate storage was not a big issue economically but it did give production flexibility. After the Bhopal disaster, when 40 tonnes of highly toxic methyl isocyanate escaped from intermediate storage and killed thousands of people, storage of toxics was drastically reduced industry wide. Some progress has been made with manufacture of toxics at the point of use, so that transport and storage are not required.

Nevertheless, distillation towers are often designed with trays, when it would be better to specify a usually smaller and cheaper packed tower, which is also inherently safer because liquid holdups are lower for packing than trays. Perversely, tray columns are often revamped for higher throughput, by replacing trays with packed beds according to McCarthy and Miller[6].

Plant revamps have also reduced inventories relative to production volumes. This is especially true when equipment is then operated at its maximum capacity and holding time design bases are superseded. An example of this is keeping the original reflux drums in the 'debottlenecked' plant[6].

However, there are still large inventories of toxic or/and flammable materials on many plants, held in reactor and other vessels, particularly distillation towers, and in storage.

Furthermore, the trend in the developed world chemical industry towards smaller scale production of fine chemicals is reversing some of the recent inventory reduction. Fine chemicals tend to be produced in batch mixer/reaction vessels, which have much larger (often many orders of magnitude larger) inventories per unit of production than continuous devices that have been designed to optimise mixing and heat and mass transfer. Butcher and McGrath[7] state that more than 50% of the value of the world's chemical production involves the use of batch reactors.

Most commentators agree that uptake of IS and ISD is not great or that it has not been reported as such. The most recently published paper to address this issue by Gupta and Edwards[8] presented the results of a wide-ranging survey of safety practitioners in industry, regulatory bodies and academia, that elicited 63 responses (36 industrial, 24 academic and 3 regulatory) from 11 countries.

IS AWARENESS AND PRACTICE

All survey respondents were aware of IS. This is an improvement over Kletz's last estimate of 70% awareness[9]. A surprising 70% claim to have used ISD, although the level of activity is variable. Only 15 of the respondents were known IS enthusiasts.

Products and processes that have benefited from the ISD treatment (in probable order of number of cases) include: polymerization, chlorine replacement, LPG storage, ammonia, nitrations, sulphonations, ethylene oxide, acrylic monomers, dyes and pigments, CO, fertilizers, uranium compounds, other organic specialties, offshore platforms, etc.

The responses to the survey question: 'reasons for not using ISD, even though you are familiar with it', may be roughly classified into three categories that are presented in Table 1.

If the equivalent numbers reported by Kletz[9] as hurdles to adopting IS are adjusted to take account of the increased awareness we get 29% for *conservatism in design and management* and 21% for *cost and time pressures on projects*. Then adding these two numbers yields a total of 50% for reasons characterised as CONSERVATISM in Table 1.

Table 1. Gupta and Edwards (consolidated) reasons for not using ISD

Reason	Number	Percentage
Unconvinced of benefits (including cost)/prefer traditional methods – CONSERVATISM	25	64
We are safe enough/no regulatory requirement	7	18
Lack of suitable ISD methods	7	18

So, we might say that the degree of conservatism has increased, from 50% to 64%. We might also use the term 'risk-aversion' instead of conservatism. The remainder of this paper will examine the reasons for this increased risk-aversion to inherently safer design.

GREEN CHEMISTRY

IS is very closely related to Green Chemistry, with its origins in the 1990 United States Pollution Prevention Act[10], which established source reduction as the highest priority in solving environmental problems. Green Chemistry has been defined by Anastas et al.[11] as "the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances".

There are numerous extant initiatives worldwide to promote Green Chemistry. However, uptake is believed to be poor. Evidence for this may be found in the numbers of companies applying for awards. For example, there were 10 applicants for the 2003 UK Green Chemistry awards and three awards were made. However, before this, awards were last made in 2000. Anecdotal evidence says that uptake is limited in the UK to some waste reduction and replacing very toxic solvents, in response to COMAH regulations. Very few new processes are being designed.

Uptake may be greater in the USA, where the Presidential Green Chemistry Challenge has a much higher profile. There were 72 nominations for the 1996 award; many of these processes and products also represent inherently safer technology according to Hendershot[12]. However, the USA chemical industry is much larger than that of the UK – turnover is roughly 5 times as great, so one would expect many more applicants for awards with a much higher profile.

PROCESS INTENSIFICATION

Process Intensification (PI) had its roots in a desire to reduce the capital cost of large chemical plants, by making the equipment more efficient and hence smaller, preferably by orders of magnitude. The applicability of PI to the full range of chemicals production was recognised and process safety soon became a significant additional driver for PI. A favoured approach to inherent safety is intensification.

Process Intensification is being 'intensively' researched in Universities and other organisations. Many companies are promoting their intensified wares, for example reactors and heat exchange equipment. However, reporting of actual use for full-scale production is sparse. We believe that spinning disk reactors, which offer great operational and safety improvements, are under trial in a number of companies and that some might be in use for small-scale production but largely they languish in research laboratories. There is a lot of interest in the use of micro-reactors in fuel cells, where micro-heat exchangers are also finding application, and analytic equipment.

'Higee' equipment effects distillation in a rotating packed bed and it can reduce inventories by a factor of 1000. It was invented and proven in operation by ICI and has been available for 20 years. However, very few units are in use and most of these are in China. The poor uptake could be a consequence of the risk-aversion of the industry to high speed rotating equipment.

We now consider the reasons or barriers to the uptake of ISHE.

BARRIERS

PLANT DEVELOPMENT APPRAISAL

The undertaking of building and operating a process plant passes through stages in time. Starting with research or business planning, a project progresses through development, then design and construction, operation, may be some revamps and finally decommissioning. At each stage up to and including sanctioning of construction, the project is appraised for feasibility. Appraisals, particularly in the early stages, are mostly technical (can we make the product?) and economic (can we afford to build the plant and will we make an adequate return on the capital employed?).

The greatest improvement in IS can be made early on in the product and/or process planning/research/development/design/implementation undertaking. This is because major hazards can only be avoided by fundamental change to the product, raw materials, chemistry or production process. However, potential safety issues are not high priority for the people involved in the early stages of this undertaking. Production safety has traditionally been taken care of when the engineers become involved at a later stage. Most early concern is for materials that could cause serious difficulties for worker health and the environment.

We now examine why there is limited IS input in the early project stages, where perversely it could have the most benefit.

Early project Evaluation

Lack of IS Assessment Tools

One of the most mentioned reasons for not implementing ISD is the lack of tools for making the required analyses[8]. In fact there are a number of published tools, such as: Inset[13], Edwards, Rushton and Lawrence[14], Heikkila[15], Khan et al.[16], Koller et al.[17], Gupta and Edwards[18] but they suffer from some or all of the following:

- they are untried, usually due to lack of knowledge/technology transfer from academia;
- they are too complicated or inaccessible for application in a short timescale and with the limited resources available in the crucial early stages of a project, when hazards can be avoided;
- they do not address the economic aspects of process development.

According to Gupta and Edwards[8] 75% of their survey respondents were unfamiliar with such indices. Most academics and research organizations responding to the survey stated that they have had little impact on industrial practice.

Limited Resources For Early Feasibility Studies

Companies are continually evaluating both many ideas for business development and many new products. Only a few make it to production. The resources devoted to projects increase as the project progresses. This is because there is more work to be done as designs and cost estimates become more detailed. For instance, the bulk of safety-related work is done later in the project, after economic and technical feasibility has been demonstrated. The paucity of appropriate resources available at the start of a project does not permit IS analysis then. Therefore, IS options will not be considered further, because the safety benefits are not demonstrated and, as we shall see, traditional economic analysis is biased against IS plant.

Chemical and Engineering News 17 March 2003 published a letter from a process designer, Stanley S. Grossel, which clearly describes the problem:

"I have been working in the chemical process industries since 1950 (the last 9 years as a process safety/loss prevention consultant) and over this long period of time I have been involved in the process design of many chemical processes. Quite often, I have been given a technology transfer package and told to design a suitable plant. When I informed my management that the process was hazardous (it involved the use of very flammable, explosive and/or toxic chemicals), and that the process should be modified to be safer. I was then told that it was too late and that too much time and money had already been expended, and that I should use as many safety measures and equipment as necessary to make the process safer."

Stanley concludes that the concepts of ISD should be in the chemical engineering and chemistry curricula and that the priority is to increase awareness of IS amongst chemists, because they conceptualise and develop chemical processes. This comment is particularly apt in relation to the trend towards fine chemicals production.

Chemists and Batch Processing

It is widely perceived that there is a trend towards fine chemicals production in the West and that this has increased batch over continuous production. There are many reasons for batch production of fine chemicals but most are about getting a product to market as quickly as possible.

Many fine chemicals are produced in campaign runs in multi-purpose batch plant. In this case, the assumption is that a batch process will be used. Smaller companies, who might only be formulating products and producing them by mixing various ingredients do not have the staff resource to consider anything other than the stirred tanks that they have at the production site.

Chemical synthesis route discovery and product development is mostly done by chemists. They are generally most concerned to devise a viable route as quickly as possible; they do not focus on the safeness or the efficiency of the production process, which 'will be sorted out by the engineers'. They tend to target or assume that batch reactors will be used in the production process, because that is what is available in the lab (beakers with stirrers). There are not enough engineers with experience of scaling up processes working in laboratories to challenge this assumption.

Cost Estimation And Economic Evaluation

There are two aspects to the impact of traditional economic evaluations on the uptake of IS. The first is that the methods used to estimate the costs and economics of proposed production plant do not show the advantages of IS plant. The following applies to the early stages of feasibility assessment of new production plant.

We estimate the capital required for designing and building the production equipment and ancillaries, offsites and infrastructure of a proposed facility in order to answer the question, ‘can we afford it?’ The cost of operating the plant is estimated in order to answer the question, ‘will we make an adequate return on our capital?’ Some elements of the operating cost are related to the capital cost estimate, usually by means of factors.

The cost estimates are used to compile a forecast for the cost of production (COP) of the product. The COP is used to calculate a return on investment (ROI), for a snapshot of the plant profitability, or a net present value (NPV) for a measure of the profitability over a number of years. The ROI and NPV are key numbers influencing the decisions whether to proceed with a project and the choice between alternative technology and/or plant designs.

Capital Cost Estimation

In the earliest project stages, simple correlations, derived from existing plant costs, are used to estimate the new plant capital cost from known data, such as its capacity, type (fluid, solid/fluid, etc), main reaction temperature and pressure, etc.

In later stages, up to the point that the investment and process choice decisions are taken, factored estimates are the norm. The cost of each major equipment item is estimated, again using correlations derived from historic data, then the costs of the surrounding and supporting ancillary equipment and infrastructure is taken to be a multiplicative factor of the item cost estimate.

Offsites costs are usually approximated as a percentage of the capital cost, with adjustments for existing site facilities. However, IS plant offsites should be lower because of the less severe conditions and simplicity.

Once the plant has been sanctioned, equipment costs are based upon quotations from suppliers but the costs of ancillaries are still estimated by factoring off the quoted prices.

Thus, capital cost estimates up to the point where the crucial design decisions are made are entirely based upon the costs of traditional equipment and plant designs — with the normal level of active safety devices. However, inherently safer plant and process designs require less of such protection systems — by definition. So, the estimated capital costs of IS plant will not show any advantage against the traditional alternatives, whereas in most cases these costs should be smaller.

Operating Costs Estimation

Operating cost estimates may be divided into two types: capital related and process-related.

Practices vary by company or even the person making the estimate but, in general, capital-related items include insurance and maintenance. Estimates for both of these items are made as fractions of the plant capital cost estimate. However, both of these numbers would be smaller for inherently safer plant, when compared to traditional plant with the same function. Maintenance will be less because there are less control systems and instrumentation to maintain on IS plant. Insurance premiums will be lower for IS plant because the hazards are smaller.

Raw materials usually account for the largest operating cost. Raw material and utilities consumption are process and equipment-related. Inherent safety has no direct bearing on the productivity of a plant. However, an inherently safer (often continuous) reactor design, which improves mixing and heat transfer and has reduced residence time, often gives better product yield. In this case the raw material costs can be significantly reduced. Similarly, utilities consumption might be significantly reduced by the smaller, more efficient equipment and less severe conditions that make the plant inherently safer.

Plant labour estimates are usually made by experience or are related to plant capacity, with an exponent less than unity. However, they are also related to the number and type of equipment items and amount of maintenance work. Therefore, they are less for IS plants, which might be simpler and will have fewer control systems.

In summary, in most cases all IS plant operating costs should be smaller but certainly no larger than those for conventional plant. However, this will not be shown in a cost estimate made using conventional methods and factors.

Cost of Production and Investment Appraisal

The consequences of lower capital and operating costs for IS plant would be that profits are increased and so ROI is doubly enhanced by a larger return on a smaller investment (which also puts less capital at risk). NPV is also improved by the greater surplus of higher profits over time over smaller capital employed. In the present macro-economic environment of historically low interest rates the NPV improvement is even more marked because the effect of discounting on future profits is smaller.

It is impossible to demonstrate the superior economics of IS plant, because the cost estimation methods use parameters and data derived from existing, traditionally designed plant. Consequently there is no economic incentive for choosing an IS design over a traditional alternative.

The second reason why traditional economic evaluation hinders uptake of IS designs is the lack of resources in the early project stages. This precludes estimators doing the extra work to show the economic advantages of IS plant. Estimators are naturally risk-averse and will not spend unbudgeted resources that might result in them recommending novel IS plant that might not work.

SAFETY: REGULATION, PERFORMANCE AND MEASUREMENT, COMPETITION

The individual reason for not adopting ISD most often cited amongst the respondents to the IS survey was the lack of regulatory requirements. However, IS is mentioned or implied in many regulations or related guidance documents. It is enforcement that is lacking.

Lack of Regulatory Enforcement

IS appears repeatedly as a recommended approach in guidance documents around safety and environmental regulations. Often the reference is implicit and the term inherent safety is not used. The following is a representative list.

EU Publications
Chemical Agents Directive (98/24/EC),
http://www.bbp-facts.com/C-L/Legislation/98_24_Chemical_Agents_at_Work_Directive.pdf
Guidance on the Preparation of a Safety Report to Meet the Requirements of Council Directive (96/82/EC) (Seveso II), 1997.
http://mahbsrv.jrc.it/downloads-pdf/Safety-report.pdf
Guidance on Inspections as Required by Article 18 of the Council Directive 96/82/Ec (Seveso II), 1999,
http://mahbsrv.jrc.it/downloads-pdf/inspecf.pdf

HSE Publications
Assessing compliance with the law in individual cases and the use of good practice, *http://www.hse.gov.uk/dst/alarp2.htm*
Designing and Operating Safe Reaction Processes, 2000,
HSG 143, Health and Safety Executive, ISBN: 0 7176 1051 9
A guide to the Control of Major Accident Hazards Regulations 1999
HSE, L111, priced publication
Preparing Safety Reports: Control of Major Accident Hazards Regulations, 1999,
HSG190, priced publication
Reducing Risks, Protecting People; HSE's decision-making process,
http://www.hse.gov.uk/dst/r2p2.pdf
The Safety Report Assessment Manual,
http://www.hse.gov.uk/hid/land/comah2
Principles and Guidelines to Assist HSE in its Judgements that Duty-Holders Have Reduced Risk As Low As Reasonably Practicable,
http://www.hse.gov.uk/dst/alarp1.htm

UK Legislation
Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR).
http://www.hmso.gov.uk/si/si2002/20022776.htm

The respective As Low As Reasonably Practical (ALARP) and Best Available Technology (BAT) criteria in safety and environmental legislation should foster IS plant. However, crucially, there is no requirement for ISD and there is no enforcement of the recommended approaches.

Regulations focus on operating plant. For example, in Control of Major Accident Hazards (COMAH) Safety Reports ALARP is demonstrated for existing measures and any improvements are covered in the Action Plan. These will be incremental and will probably not offer radical IS improvements. The development money has already been spent and redesign for IS can be shown to have grossly disproportionate cost, so the existing measures are ALARP.

There is some evidence that older regulations, engineering standards and codes of practice, being very prescriptive, can preclude the use of IS approaches. For example, some pressure-protection regulations require relief valves even when the vessel can be designed to withstand the highest foreseeable pressure. The relief valve provides a potential source of leaks and failure and requires maintenance and venting.

Major overhaul of the current Seveso II legislation appears to be some time away. Therefore, it seems that lack of specific regulatory requirements will continue to be a reason for not incorporating IS into development/design practice for some time to come.

Enforcement of major hazard regulations engenders a ‘hurdle’ approach to compliance. Breaches of safety standards are punished by improvement orders, denial of permission to operate or closure in the worst case and fines are imposed for incidents. However, so long as the required standards are met, there is no penalty and thus no incentive for doing any better.

Moreover, safety is adequate in the process industries. The fatal accident rate for the chemical industry is well below that for construction, for example. Major accidents are sufficiently few that there is no significant pressure to improve safety. The last person to be killed offsite in the UK by a major hazard accident was in the mid 1950s. We believe that the last person to be killed offsite by a chemical accident was in the 19th Century. Chemical company management consider adequate health and safety performance to be ‘a given’.

Incentives for ISD

There might not be any regulatory incentives but other advantages of IS ought to encourage its adoption as a philosophy and practice.

One of the key incentives for IS should be its enhancement of corporate reputation. Companies with IS plant would be better able to counter societal opposition to facilities by demonstrating that there are no significant hazards or that they have been minimised, rather than by presenting low calculated incident probabilities of catastrophic events. Demonstration of corporate responsibility to large investors, such as pension funds, is facilitated by IS operations. Insurance premiums might be reduced for IS plant and production.

However, there is no requirement to communicate risk directly to the public and there is a flip side to use of IS in corporate ‘PR’. Even if some production is IS, much will not be so. Drawing attention to the IS ‘good guys’ might highlight the many non-IS ‘bad guys’ and result in pressure for bad guy revamps, which would incur extra costs for no immediate economic benefit. Safety performance is generally good and has been for some time. Companies might not want to give the impression that it is not as good as it could be by adopting IS. Highlighting safety performance carries great risk in the case of an accident, because the loss of reputation will be amplified by a “you told us that you were safe and now look what’s happened” reaction.

Similarly, reducing inventories of hazardous material, which is a key feature of IS, is a ‘no-brainer’ with respect to making chemical production facilities smaller targets for terrorists. However, companies might be nervous about acknowledging this fact, because it might pave the way for legislation such as the Chemical Security Act that again would force them to make expensive revamps for no immediate economic benefit.

Achievement of IS plant might conflict with measures implemented to secure environmental benefits. Given that there are no established methods for trading off safety, health and environmental benefits and concerns, companies would not want such added analysis and decision burden and would not want to revisit existing analysis.

For example, CFC refrigerants replaced hydrocarbons and ammonia as refrigerants because they have low acute toxicity and are not flammable. However, they cause environmental damage and have negative health impacts. So there is now a move back to using propane, which is flammable and ammonia, which is flammable and toxic.

Another example is heat integration around reactors. Plant energy consumption can be reduced by using hot reactor effluent to preheat the feed to the same reactor. However, if the reaction is exothermic this creates a feed-forward loop that will exacerbate the effects of a runaway reaction.

Because there is neither enforced requirement nor incentive for ISD, safety performance is demonstrated to be good enough. If this can be achieved without IS, then traditional approaches will be used. There is no incentive for having any less inventory than in the COMAH schedules for prescribed chemicals. A new way of measuring safety performance might help to change this.

Safety Performance Measurement

Industry safety performance focuses on audit of equipment and procedures and lagging indicators, for example the lost time accidents rate, which is decreasing.

There is no reward for removing or reducing hazards, when the hazard has never been realized and (in the UK) conventional QRA indicates that the risk is ALARP.

There are no measures of the proximity of a site to a major accident and its consequences. Development of a 'proximity measure' is difficult because many of the parameters that might be included have no physical meaning and the output is hopefully never correlated to actual events. However, such a metric could be used to 'incentivise' better safety performance and would favour IS.

Competitive pressures

Foreign ownership, devolved budgets and competition mean that, at present, companies have limited funds for R&D or process improvements. They look for pay-back of a year or less on any capital spent. Competition is such that they are concentrating on 'fighting fires' and 'staying in the game', looking no further than 3 months ahead.

Industry staffing levels have been reduced to save money. There is no reason why companies should spend their limited time and money on improving safety unnecessarily. One quote from the Gupta and Edwards IS survey[8] puts it thus: "First, I have to convince the management, then make the changes with a reluctant staff and then risk my job in case of failure to get the expected results. Why should I do this? If I am successful, the management will take the credit, otherwise my neck will be on the block."

Possible loss of market share is a key issue — it might never be regained. For example, one toll manufacturer suffered a fire and major release of chlorine. They had to replace the chlorine supply facility. Installation of onsite chlorine generation would have taken longer than rebuilding the existing plant: a large liquid chlorine storage tank and an evaporator. The plant was rebuilt as was, because this resulted in the shortest shutdown and the best chance of retaining existing customers, whereas onsite generation would have been inherently safer.

In the fine chemicals business the emphasis is on developing unique products, or ones that are at least differentiated from competing products. Then, the aim is to move to production as quickly as possible, to maximise profits before competitors catch up. It is more important to optimise the functionality of the product than the means of producing it. There is no time or resources for developing IS production processes as alternatives to the usual stirred pots. Fine chemicals are high-valued products, which are sold on performance and with bigger profit margins than traditional bulk chemicals, so there is not even an incentive to reduce the cost of production by process optimisation.

Inherently safer design of pharmaceutical processes is particularly problematical because of the long time required to find new drugs and then gain regulatory approval. There is a need to produce pilot quantities as soon as possible, so that the trials can commence. Therefore, this is done in standard equipment, that is batch reactors and separation processes. Regulatory approval fixes the production process as well as the molecule and so the pilot process is simply scaled up, to save time getting the drug to market and so make the most of the remaining patent protection.

Some industry insiders maintain that the risk of delaying production of a new product is the key reason why companies will not deviate from well-known and non-IS designs and methods.

WHERE DO WE GO FROM HERE

We have examined the barriers to the adoption of IS. It is our belief that the root cause behind all these barriers is the inherent conservatism or risk-aversion to new approaches of the industry. Thus we can summarize this as follows.

The industry is averse to the risk of making safety a key driver early in project development; they are either unaware of tools that could help in this area or not willing to use methods that are untried. In any case for various reasons the resources are not available for additional evaluation early in a project and there is the risk that earlier consideration of safety might delay project completion. Industry traditions, particularly in fine chemicals and pharmaceuticals of using batch production impose additional disincentives on deviating from the normal way of doing things. Traditional cost estimation methods do not credit IS designs with their due economic advantage but who will take the risk of adjusting the methods to produce keener estimates — in case they are wrong. Regulators will not enforce IS in existing legislation for fear of appearing to be penalising some companies with the burden of extra work to achieve regulatory compliance, when others are not. Companies might not want to use performance indicators to measure IS or to publicise IS successes, because of the risk of drawing attention to inherent unsafeness elsewhere in their operations.

Now we discuss ways to remove or get past these risk-averseness barriers. But first we must answer the question, why should we carry on. Simply, because in 30 years no one has made a compelling argument against or come up with a better approach than inherent safety. The concept is right, inherent safety will deliver:

- better safety performance;
- economic benefits;
- added value in other areas, notably security, reputation and regulatory compliance.

None of the barriers discussed are insurmountable. None of them represent infeasibility in the IS approach, just difficulties of implementation. A common thread running through all of these difficulties is the inherent conservatism of the industry. So, perhaps the most important barrier to overcome is the risk-averseness of the industry to trying something different. Put another way we must convince the industry to 'buy IS'. From our own personal experience this is difficult, because there are no compelling reasons to buy IS.

Safety is adequate in the process industries. The fatal accident rate for the chemical industry is well below that for construction, for example. Major accidents are sufficiently few that there is no significant pressure to improve safety. There is no legislation to mandate a specifically inherently safer approach. On the other hand (the carrot rather than stick), there is no reward for removing or reducing hazards, when the hazard has never been realized and conventional QRA indicates that the risk is ALARP. At the same time, industry staffing levels have been reduced to save money and competition is fierce. There is no reason why people should spend their limited time and money on something that they do not need to do.

When the probability of loss is already very low through conventional control, there needs to be a strong positive incentive for adopting ISD. Therefore, until there is a more visible body of knowledge and experience that ISD can make a significant positive contribution to competitive advantage and profitability, as well as offering significant reductions in hazard exposure in H, S and E, little will happen.

Strategies to encourage IS may be classified as: persuasion, incentives and regulation. Beginning with persuasion, we must convince companies of the economic or other benefits.

ECONOMIC AND TIMESCALE BENEFITS

Economic performance and in particular profit drives most business and intuitively improving plant economic performance must offer the best incentive for IS.

Intuitively, again, IS plants should offer economic advantages because they are simpler, process less hazardous materials under less extreme conditions, etc. Unfortunately this hypothesis has not been confirmed by plant data. One person who is close to the fine chemicals industry has commented that speed to market is more important than reducing production costs, so demonstration of project timescale improvements would also help sell IS.

Given a belief that a product can be made, early project feasibility evaluation is almost entirely devoted to capital and production cost estimation and economic evaluation. The key to IS is to identify hazards early, so that they can be avoided. In order for this to happen, more or different resources (people, time and money) must be made available to a project at the start. Then IS analysis can be included and more process or plant options can be explored, with may be more time required for developing appropriate cost estimates for the IS options. The extra resources expended at the start of the project can be recovered in later stages, because an IS option will require less detailed design (of hazard control systems, for example). One practitioner has said that the more resources put in at the front end, the lower the cost and shorter the project timescale. He claims that this has been confirmed by an organization that benchmarks projects.

There are no **reported** cases of IS designs saving money or time, with relevant numbers to make the point. Commercial confidentiality does not allow this to happen. However, the economic case for IS can still be made in a number of ways:

- by qualitative argument,
- from the results of surveys and information from industry insiders.

Examples of qualitative arguments are:

- inventory reduction will generally reduce costs because smaller vessels cost less;
- simpler plant costs less because there is less equipment and ancillaries;
- avoiding hazards also avoids the costly hazard control measures.

These arguments apply equally to capital and operating cost, because reducing count, size and complexity of equipment, reduces utilities, labour, testing and maintenance costs. As Henry Ford succinctly put it: "what you don't fit costs you nothing and needs no maintenance".

A few examples of survey[8] and 'insider information' follow.

Capital costs of IS plant might be higher or lower but the lifetime costs are lower, because of lower operating costs. IS reviews can have instant payback.

Intensified reactors can be much cheaper, for example one specialist company quotes a continuous reactor producing three times as much product as a stirred tank, which has 65 000 times greater inventory, and where the entire intensified plant costs less than half the cost of just the stirred tank reactor of the conventional plant[19].

Industry insiders claim that SHE-related equipment represents 10–50% of the capital cost of conventional plant and that the potential savings are not appreciated because this equipment is seen as standard items that will inevitably be required. On operating cost, achievable IS reductions are 10% for maintenance and 20% for downtime. Payback is typically in less than 2 years for IS projects. IS in the guise of reducing equipment weight and unmanned operation has had significant impact offshore.

Such economic benefits are not apparent at the point that the major process decisions are made. This is because early economic estimates do not allow for the decreased capital and operating costs of IS plants. Therefore, in the absence of a compelling argument for doing otherwise, the conventional route will normally be chosen.

Therefore, the key economic arguments to win are that:

- more development capital should be spent in the early stages of a project, in order to identify and explore IS options and reduce project timescales;

- cost estimates for feasibility appraisal must be based upon parameters that are more realistic for IS plant and so credit IS designs with keener cost estimates.

DEMONSTRATE SOME OTHER BENEFIT

Plant Security

IS is a 'no-brainer' solution to better security on chemical plant. Clearly, the best way to remove/reduce the risk posed by terrorism is to not have a target or have a much smaller target, the target being the hazardous inventory. This is common sense.

Corporate responsibility and image

The high-level DTI Chemicals Innovation and Growth Team[20], which looked into the challenges facing the UK chemicals industry, concluded that the key challenge was its poor reputation amongst society at large.

Adoption of IS can help to improve the reputation of companies. It seems obvious that it is better to operate IS plants than to control large hazards. The public understand that low probability events can happen — people do win the lottery. The absence of hazards is far easier to communicate than acceptability of risk.

INCENTIVES

We have seen that there is currently no incentive for improving safety performance that is already good, by implementing measures that might degrade commercial performance. Therefore, Government should encourage and facilitate the implementation of IS designs. In the end this will require Government money in the form of grants or tax breaks on R&D targeted at bringing IS plant proposals to fruition. We need a method of reducing the perceived commercial risk of trying something new. This is already happening on a small scale with government-funded initiatives such as Crystal Faraday, which aims to promote and encourage firms to employ green chemistry and Britest, which develops the best processes and manufacturing strategy for member companies by using a set of proprietary methodologies. However, the level of funding of these two programmes is very small. A lot more money is needed.

More research is needed to develop methods for measuring safety performance. Government money will be required to make this happen.

The last of the methods to encourage IS is regulation.

REGULATORY COMPLIANCE

As we have seen, IS is not yet compulsory in most safety legislation but it is mentioned or described in existing regulations and guidance, where an IS approach is recommended. There is a trend towards regulation that focuses on reducing the size of hazards and the possible consequences, particularly to offsite populations, rather than reducing the statistical risk of harm. This trend favours the adoption of IS. Therefore, it is likely that it will appear, probably as IS, in future legislation. Bearing this in mind it behoves companies to adopt IS to ease current and future regulatory compliance. In terms of current EU legislation, reducing inventory of major hazard substances below thresholds might reduce regulatory compliance requirements.

Experience of IS Legislation

In the USA legislation enacted locally in Contra Costa County, California (CCC) insists upon inherently safer systems (ISS) unless evidence is presented that the financial impacts would be sufficiently severe to render the inherently safer system as impractical[21].

This legislation was prompted by a series of major incidents in CCC, which is near San Francisco, mostly involving refineries. We understand that this legislation has caused considerable problems for the 'major hazard' sites in CCC and that the County has issued a guidance document. It remains to be seen how this legislation will impact actual process design in this locale. Early reports indicate that hazardous inventories have been reduced, Cl_2 is now being generated in-situ for water treatment or else alternatives, such as ozone or UV, are used instead and aqueous ammonia is used instead of anhydrous. Major hazard sites are introducing procedures for implementing the ISS requirements of the ordinance.

Forthcoming Legislation?

The Federal USA (therefore with much wider applicability) Chemical Security Act of 2003 was first introduced in 2001 in response to '911'. It was withdrawn but has recently reappeared. It is sponsored by Senator Jon Corzine and co-sponsored by Hilary Clinton, amongst others. Some of this bill reads like excerpts from a Trevor Kletz book on ISD and is very prescriptive. Although it is ostensibly about protecting the public from unauthorised chemical releases, for example due to terrorist attack, some people think that this is a front for 'ultra-environmentalists' to further their anti-chemical industry agenda. This has 'drawn flack' from both supporters and opponents of ISD.

In response to this Democrat bill, Republican Senator Inhofe has introduced the Chemical Facilities Security Act. This bill deals with plant security only but it is rumoured that some Republicans want amendments to include IS.

Dennis Hendershot (2003), a well-known supporter of ISD, has commented on these proposed Chemical Security Acts: "Both bills are in committee. As anything in politics, whatever eventually emerges will probably represent some sort of compromise, and it will take a lot longer than anybody thinks it should. And I don't think that Corzine's bill shows an understanding of the complexity of ISD — any regulations written to enforce the provisions of the bill would be extremely difficult to write — how to deal with conflicts, what level of design are we talking about, anywhere from selection of the basic technology down to details of the equipment and control layout. I want engineers to think about ISD at all levels but I'm not sure I want regulators second guessing my choice of equipment layout or control panel design."

IS is on the regulatory agenda in the USA and if it is enacted there might cross the Atlantic.

AN INDUSTRY-LED APPROACH

There is always the danger that the risks associated with making chemicals will be exported abroad, where labour and raw material are cheaper. This has been happening in the bulk chemicals sector for a number of years now. Is it fair to let other people bear the hazards of maintaining our lifestyle? Of course, reputable companies will insist on the same safety standards as they would at home. But wouldn't it be better for everyone if these standards were raised for everyone by insisting on a new generation of IS plants, instead of using existing technology. To this end what is needed is a global standard for process safety based upon the IS philosophy. In such a global industry as the process industry this could work as a self-regulated system. Independent industry-funded bodies are set up to devise 'IS standards' and encourage/measure compliance. Eventually companies would have to adopt an IS approach because other organizations refuse to do business with firms that do not abide by the 'standards' and Governments deny them permission to operate.

EDUCATION

Many have commented about the need for IS education and training for engineers and other specialists, notably chemists, involved in product and plant development and design. A new generation of people in the industry who are knowledgeable and enthusiastic about IS will help break down the barriers. To this end University courses should be built around an IS ethos. Graduates should be imbued with the guiding principle of avoiding or minimising hazards in all that they do.

CONCLUSIONS

We have looked at the reasons why ISD has had limited uptake, despite the persuasive arguments in favour and almost universal enthusiasm for it. These reasons may be roughly categorised into those related to the way in which process plant development projects are appraised:

- inadequate early project evaluation, because of
    - lack of appropriate and tested IS assessment tools,
    - limited resources do not allow 'space' for IS,
    - development chemists are not sufficiently concerned with plant safety;
- inflexible economic feasibility assessment methods and
    - capital cost estimation,
    - operating cost estimation.

A further set of reasons are to do with safety performance and the associated 'carrots and sticks', there are:

- no enforced legislative requirements for inherently safer plant;
- no incentives for implementing inherently safer designs;

- no methods for measuring safety performance in terms of major hazards (avoided);
- competitive pressure and emphasis on speed to market make untried IS designs too risky.

Paradoxically, a common theme in these reasons is an aversion to the risk of new plant designs failing commercially, whereas the driving force behind the designs is reduction of risk to people.

Ways to overcome the resistance to inherently safer practice include persuasion by quoting successful examples but the industry must provide some. Government could help by funding initiatives to help firms invest the extra effort early in projects, so that IS options might stand a better chance of reaching fruition. Legislation insisting on an IS approach might intervene and so companies should take up IS, or else it might be foisted upon them.

Finally, perhaps the best way to encourage the uptake of the IS philosophy and practice is to educate young engineers and inspire them to lead the way. Young chemists and engineers, armed with ISD knowledge, are probably the most effective advocates and practitioners of ISD to overcome the inherent risk-aversion.

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