

A STRUCTURED APPROACH TO INHERENT SHE IN PROCESS AND PRODUCT DEVELOPMENT

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The potential benefits of adopting Inherent SHE principles in process design have been recognised since the 1970s, following the pioneering work of Trevor Kletz and others. However, it has not proved so easy to realise these benefits in actual process design. Some reasons which have been put forward to account for this include cultural issues associated with the multidisciplinary nature of process development, and the lack of formal tools to support Inherent SHE ranking of process alternatives. This paper contains an introduction to a methodology which has been developed to facilitate the application of Inherent SHE principles throughout the design cycle, from initial identification of the need the develop a product, to equipment selection and preparation of a "base case" Process Flow Diagram.

Keywords: Decision-making, Inherent SHE, chemical process design, risk management.

INTRODUCTION

The increasing size and complexity of chemical plants in the 1960s and '70s, coupled with the occurrence of major accidents such as Flixborough, resulted in the development of such techniques as HAZOP (Hazard and Operability Studies), risk assessment and inherent safety as means to manage hazards and risks more effectively. By reducing the need for protective systems, it is widely believed that inherent safety can actually add commercial value to a project, unlike other tools which may simply provide a check that the design is "safe enough". However, although HAZOP and quantified risk assessment (QRA) are methods that are in common use today, the ideas of inherent safety (or, recognising the broader range of issues, Inherent SHE – Safety, Health and Environment) have not been so successfully adopted. Reasons given for this range from lack of awareness of the benefits to the lack of tools and methodologies to support assessment of process designs.

Principles such as *substitution*, *minimisation*, *moderation* and *simplification* are often used to capture the essence of the "inherently safer" (or "SHE-er") approach[1, 2]. Thus, for example, we would seek to substitute hazardous materials with less hazardous ones, minimise process inventories, moderate process conditions, and simplify processes and their operation. It is widely believed that the timely and effective use of these principles can make a process and plant cheaper to build and operate, as well as helping to improve safety, health and environmental performance. Research appears to confirm[3] that there is indeed a link between the inherent safety "score" associated with the reaction conditions, i.e. temperature, pressure and yield, and the total fixed investment associated with a plant. Recognising the range of benefits which can be gained from application of I-SHE principles, some companies, for example ICI[4], have made consideration of I-SHE a formal requirement. There is now also increasingly pressure from the regulators to consider I-SHE formally in the design process. In the UK, under the COMAH legislation, there is a requirement to demonstrate that a hierarchical approach to process design, including I-SHE, has been taken. In the USA, it is notable that the Worst Case Scenario element of Risk Management Programs (which are a requirement of the Clean Air Act) allows only the mitigating effects of passive measures to be considered – a clear driver for industry to adopt inherently safer processes.

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Given the range of benefits which can be accrued from I-SHE, why have the ideas not had more impact ? Some of the factors necessary for the successful adoption of I-SHE have been identified by Mansfield[5]. These include[2]:

i) *assuring management commitment and support, and their implications for training programmes, project organisation and other aspects of corporate activity*
ii) *introducing and maintaining awareness of the I-SHE principles and applications among the chemists and design engineers*
iii) *setting aside time in the development and design programme to identify and evaluate alternatives, recognising that this should save time later by reducing the need for changes*
iv) *providing opportunities for chemists, designers and plant operators to discuss ideas at all stages in the development and design process*
v) *actively encouraging lateral thinking and innovation*
vi) *addressing S, H and E aspects on an integrated basis, to establish the trade-offs and conflicts these can bring.*

Many of the decisions determining the basic process and unit operations are taken early in a project, usually before formal Hazard Studies are initiated. It is therefore important that I-SHE issues are considered at these early stages where the basic SHE characteristics of the process are determined. In practice, it can be difficult to ensure this happens. In contrast to HAZOP, which is generally "owned" and driven by a project manager accountable for delivery of a physical asset, the ownership of and accountability for the early stages of product development can be less clear. In the absence of clear ownership there is the risk of a business becoming committed to a process which is not as attractive with regard to I-SHE as it might have been if the SHE aspects had been actively managed at the outset.

METHODOLOGY

We introduce in this paper a methodology which has been designed to facilitate application of I-SHE design principles throughout process selection and development. The methodology builds on ABB Eutech's involvement in the EU-funded "INSIDE" (Inherent SHE in Design) project[6], and other experience gained working with chemicals manufacturers, and dovetails with existing hazard study procedures including the ICI 6-stage methodology. The methodology which has been developed is a four-stage approach which allows the principles of I-SHE to be applied in a structured way throughout the design cycle from process selection through to equipment specification. By employing guide words and guide diagrams reminiscent of HAZOP, together with other supporting tools, a multi-disciplinary team meeting at key stages in the design cycle can assess processes in a cost-effective fashion to gain the benefits of I-SHE improvements. The approach can be applied to completely new plant, or to modification of existing plants and processes. The scope of application is however limited to projects where there is the potential to make changes to the basic chemistry, or where significant changes can be made to the Process Flow Diagram. In all cases, the depth of the study and the tools employed can be varied to suit the project.

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STRUCTURE AND APPROACH

Process and product development is essentially a multi-disciplinary process in which accountabilities and responsibilities change as the project progresses from identification of a market and the need to develop a product for that market, to preparation of a "base case" process flow diagram (PFD). The ownership and focus of development move from marketing in the early stages through chemistry and process technology selection to detailed process design.

We distinguish four main phases in process selection and development, illustrated diagrammatically in Figure 1. Figure 1 also serves to emphasise that the greatest opportunities to incorporate I-SHE are at the early stages of the design cycle where there are fewer constraints – and less information available on which to base decisions. The four stages are outlined below.

Stage 1, Chemistry Route Screening

The purpose of activities at this stage is to:

- establish the business constraints and objectives of the project, in terms of timescale and cost, along with any SHE constraints on raw materials, intermediates or final product
- complete a preliminary screening of potential chemical routes so as to determine the most viable with regard to the project constraints and objectives, and nominate the most promising routes for further, more detailed, assessment

Stage 2, Chemistry Route Selection

A Chemistry Block Diagram is developed for each chemical transformation of interest. This shows flow rates along with all the reaction and separation stages, and is used to help the study team:

- determine the feasibility of the more promising chemistry routes from Stage 1, by ranking them in terms of waste generation
- select one or two routes for process design, taking into consideration cost and SHE benefits

Stage 3, Process Route Definition

A Process Block Diagram is developed and used to help the study team:

- consider the implication of proposed process conditions and inventory, with the aim of producing a process route optimised with regard to I-SHE

Stage 4, Process Route Development

A firm "base case" Process Flow Diagram is developed and used as the focus for study to:

- select appropriate equipment, taking into account opportunities to make the process more I-SHE

STUDY TEAM

The methodology requires that a team is established to guide process development throughout this cycle, but the make-up of the team will change to match the study's changing focus. Team members will include, at various stages, the Project Leader, Process Engineer, Development Chemist, SHE representative and a representative of the Business Manager. The Business Manager's role is to establish the business context and to help set the project constraints and objectives. The overall process is facilitated by a Study Leader, through a small number of focused meetings typically held at the start and end of each of the four stages. There is a strong emphasis on "off-line" activity, and the meeting overhead is small.

SUPPORTING TOOLS

Each stage of the Four-Step I-SHE Study Process is associated with a set of proformas and tools to support structured analysis of the options. Some of the tools are indicated in Figure 2, along with the stage with which they are associated. The relationship between Inherent SHE studies and Hazard Studies 1 and 2 of the ICI 6-stage Hazard Study Process is also shown. We note that Hazard Study 3 of the ICI process is the HAZOP study.

EXAMPLE – I-SHE EVALUATION TOOL

Use of one of the tools, the I-SHE Evaluation Tool is illustrated below. The I-SHE Evaluation Tool is used to help highlight opportunities for improvement with regard to I-SHE, and can be applied at Stages 2, 3 and 4. The relevant process diagram (chemistry block diagram, process block diagram and process flow diagram respectively) is subdivided into appropriate units, and I-SHE guidewords applied in a structured way using a guide diagram to provide appropriate prompts for potential improvements. Thus at Stage 2, for example, with the focus on the chemistry block diagram and opportunities for waste reduction or elimination, the guide diagram takes the form shown in Figure 3.

So, the main reaction and separation stages of a chemistry route are established, and each of these "blocks" assessed in turn for opportunities to make the process "I-SHEer". Thus the guidewords "Eliminate / Substitute", are applied to raw materials, solvents, and waste streams etc in turn. The guideword "Minimise" is then applied, and the process repeated for all guidewords, and all process chemistry blocks. The study technique is conceptually the same regardless of the stage of the process, but the focus for evaluation, along with the prompts can change. The output of the evaluation is recorded in the study meeting on a proforma which also provides for actions to be assigned and monitored.

A similar approach is adopted for the other assessment tools, which include I-SHE ranking tools to enable tradeoffs between S, H and E to be established, and others which support decision-making regarding relative advantages of routes having different SHE characteristics.

CONCLUSIONS

In order for Inherent SHE to have the greatest impact on process development, the principles must be applied early on. In general, once formal hazard studies have been started, it is too late for major conceptual changes to be made to chemical processes and we are generally faced with the challenge of risk reduction rather than risk elimination.

Application of the ideas presented in this paper has been seen to have a real impact on process development, leading to processes which have a lower SHE impact as a result of:

- inventory reduction
- use of different solvents
- reformulation of catalysts to less toxic form

The methodology which has been presented here has been trialed on table-top exercises and is both straightforward to use and time-efficient. Adoption of this approach to process evaluation helps generate a "level playing field" when comparing different process routes and clarifying SHE issues. Thus, for example, the different requirements of different processes for on-site storage and for waste treatment are brought out in an integrated assessment of total SHE impact, instead of the focus being primarily on the core process. Use of such an approach should also help encourage early formation of project teams and so drive better communication between disciplines - leading to less misdirected effort and the consequent need for re-work.

Precise legislative requirements for Inherent SHE study under COMAH remain to be clarified, but one further advantage of this proforma-based technique is that can be used to demonstrate that a structured process has been adopted to justify the selection of the preferred route and process design.

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Figure 1 – Inherent SHE Study Process

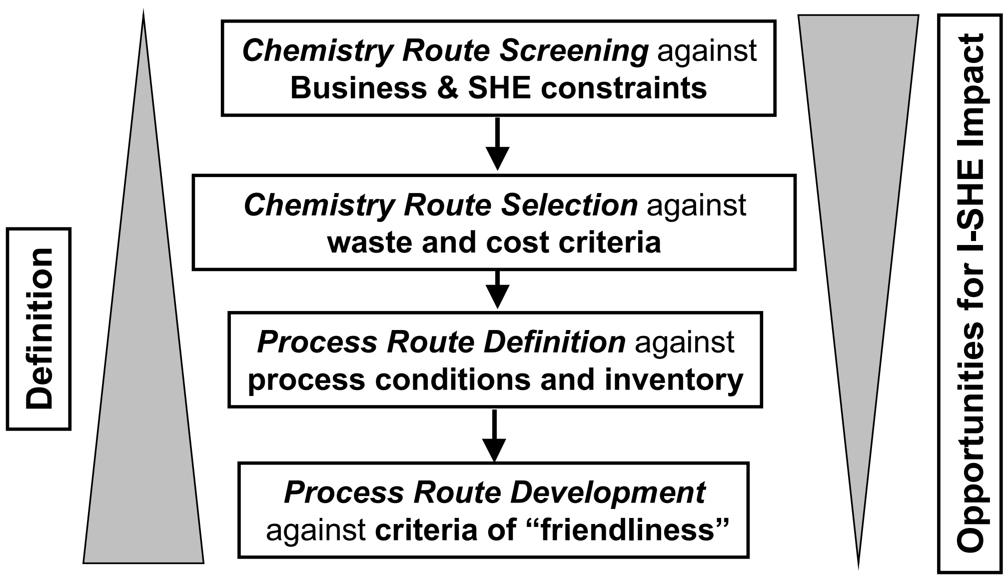

Figure 2 – Study Tools and Techniques, and Timing

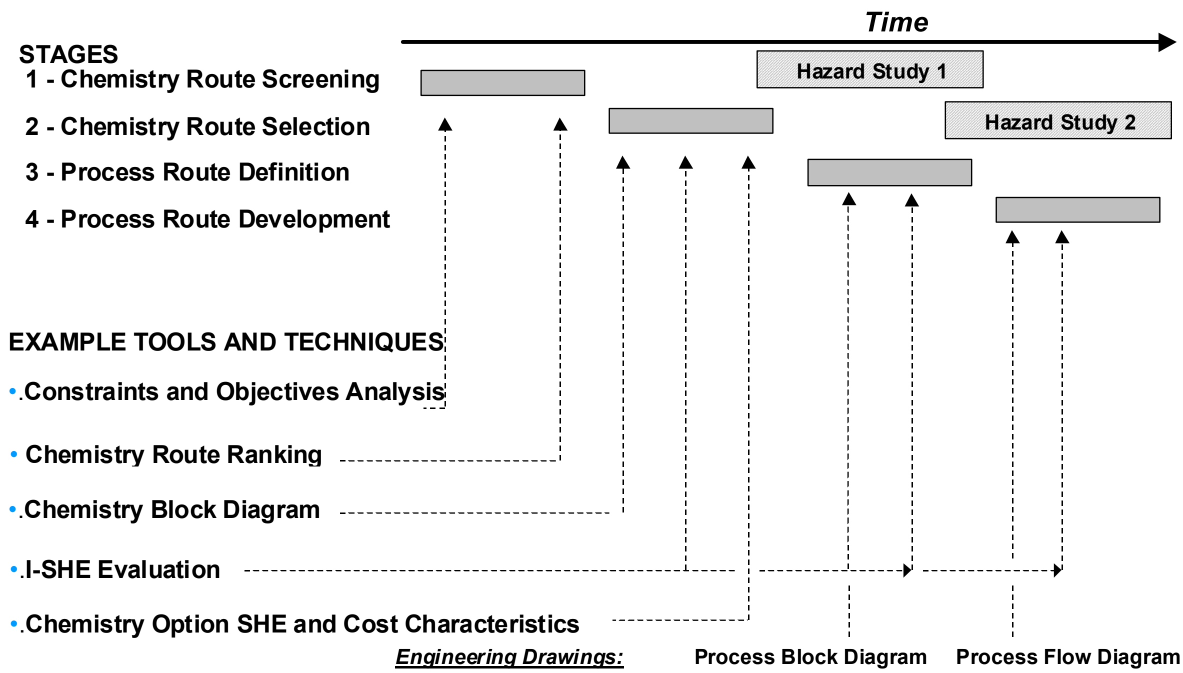

Figure 3 – Stage 2 Guide Diagram

Guide word	Meaning	Applied to	Prompts
Eliminate / Substitute	Remove the hazard or the material, or task creating it OR Substitute less hazardous materials and processes wherever possible	Raw materials Solvents Waste streams By-products Recycle streams Purge	*Is it possible to avoid a waste stream?* *Etc.*
Minimise	Minimise the amount of hazardous material that is in use or waste that is generated		*Is it possible to reduce the amount of waste produced, or to reduce the number of waste streams?* *Etc.*
Moderate	Moderate the process conditions of the hazardous materials		*Etc.*
Simplify	Simplify the process that is used		*Etc.*