

CHEMICAL ENGINEERING – AN INHERENT SH&E IMPERATIVE

David W. Edwards
Visiting Fellow, Department of Chemical Engineering, Loughborough University, Loughborough, LE11 3TU, UK.

The principles of Inherent safety and inherently safer design are briefly described and the extension is made to health and the environment to yield the concept of Inherently Safer, Healthier and Environmentally Friendlier (ISHE) design and production. Six current problems and threats to the Process Industries (PI) that can be related to Safety, Health and Environmental (SHE) performance are proposed. Society's perception of the SHE performance of the PI often does not do them justice and the social construction of this perception is examined. Even though sustainable production is ill-defined, there is a push towards achieving it. Legislators are being driven to enact ever more stringent SHE regulations for the PI and the nature of the risk assessment methods to be used might change radically. Some production with problematic SHE issues is being transferred from the Developed Countries (DC) to the Less Developed Countries (LDC), where the problems may be amplified. A change to production by batch processes in the DC has been commented on and this might be deleterious for SHE performance; although no evidence for the trend has been found. Finally, the decline in numbers of students of chemical engineering in the UK is noted. Even though the SHE performance of DC companies is very good, it could be better and it is claimed that ISHE design and production, which is defined as avoiding or minimising SHE impacts, is the way to achieve this improvement. It is claimed that ISHE can help alleviate/counter these problems/threats. However, achieving ISHE design and production implies a move away from the traditional business aim of maximising return on investment (ROI) subject to acceptable SHE performance to a new aim of optimum SHE performance subject to maintaining an adequate ROI. This fundamental shift of emphasis is necessary for the long term sustainability (including profitability) of the PI in DCs.

Inherent SHE, public perception, sustainability, risk assessment

INTRODUCTION

It has become common practice in the process industries to group Safety, Health and Environmental matters together for the purposes of organisation, responsibility or reporting. The abbreviation SHE or permutations of it are often used.

Inherent SHE, or ISHE, is that safety, health and environmental performance that exists in a plant as an intrinsic attribute of it. A chemical plant with good ISHE is characterised by a lack of hazards, both in the short and long term, to human life and health and to the environment. Whereas, most chemical plants have acceptable SHE performance, because defensive measures are added to control identified hazards, it is better to build plant with inherently good SHE, because this cannot be compromised.

In this paper I examine a number of current problems and threats to the chemical industry and suggest that a move towards production plant that are optimised for ISHE subject to the constraint of making an adequate return on investment is an imperative counter measure. But first some definitions and nomenclature.

DEFINITIONS, CATEGORIES AND NOMENCLATURE

I shall follow the IChemE definition of hazard and risk as stated by Jones[1]:

Hazard – a physical situation with potential for human injury, damage to property, damage to the environment or some combination of these.

Risk – the likelihood of a specified undesired event occurring within a specified period or in specified circumstances. It may be either a *frequency* (the number of specified events occurring in unit time) or a *probability* (the probability of a specified event following a prior event), depending on the circumstances.

We can distinguish two broad categories of damage, that might result from a hazard:

Acute – a short-term event, which is possibly severe or even catastrophic;

Chronic – effects that persist over (long) time and could be severe.

Then, safety (S) implies freedom from acute danger posed by plant hazards, health (H) is about minimizing chronic effects upon anyone who interacts with the plant or product and Environment (E) refers to avoiding acute events and minimizing actual chronic impacts caused by the plant or product. Safety and health are essentially local considerations, whereas impacts upon the environment must be considered both locally and globally. In this paper SHE means anything to do with any of these three aspects of a chemical plant and product.

In order to develop my arguments it is necessary to categorise. These categories are broad, might give rise themselves to some discussion and will overlap. The main categories and abbreviations are as follows:

Process Industries (PI) = those employing chemical engineers on development and/or production of products.

Developed Countries (DC) = USA, Europe, Japan, Australia and some parts of Asia.

Less-Developed Countries (LDC) = those which are not DC.

Hence, DCPI = developed countries process industries, etc.

INHERENT SAFETY, HEALTH AND ENVIRONMENT (ISHE)

ISHE is the extension of inherent safety to cover health and environmental impact as well. Those readers who are in a hurry and are familiar with inherent safety may skip this section.

The traditional plant design philosophy and practice identifies hazards and then adds protective measures to control them. This method of secondary prevention[2] reduces the *probability* of accidents. However, there is an alternative philosophy of **Inherent Safety (IS)** or primary prevention, where the *possibility* of accidents is removed, by the use of safer chemicals and operations. In the practical approach to IS, called **Inherently Safer Design (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[3] after the Flixborough accident (28 killed) in 1974. At first interest was limited, but the appalling loss of life at Bhopal in 1984 (3000 immediate deaths and many thousands more thereafter) gave a greater impetus to discussion and a number of papers have appeared, which are referenced in Kletz's latest book[4]. Kletz's many papers and books give an exposition of the principles of ISD, which he has distilled into the qualitative application of six keywords:

- elimination – avoid hazards,
- intensification – use less of a hazardous material,
- attenuation – use less extreme processing conditions or a hazardous material in a less hazardous form,
- substitution – use a safer material or operation,
- limitation – minimise the effect of an incident,
- simplification – reduce the opportunities for error and malfunction.

A good example, used by Kletz, is the bungalow, which is inherently safer than a house, because stairs 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 – they have to be, but some are more inherently safe 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 safe – what you don't have can't hurt anybody. Problems in an inherently unsafe plant may escalate catastrophically, while in an inherently safe 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 safe chemical plant is to be preferred over an inherently unsafe one, no matter how safe the latter is made by controlling the hazards. Also regulators, for example the Health and Safety Commission (HSC) and Health and Safety Executive (HSE) in the UK, are beginning to promote inherent safety and are pushing for inherently safe designs, for example with reduced inventories of hazardous materials.

ISHE can be considered on a number of levels. At the strategic level for example, if more than one product will satisfy a market need, we choose to make the one that has the best SHE performance and is made by the most ISHE process. At the most detailed level we may choose to use a particular type of gasket on our plant, in order to minimise emissions and leaks.

EVIDENCE OR LACK OF IT

This paper presents a personal, wide-ranging, subjective view of perceived problems facing the PI and the necessity for ISHE solutions. It is intended to be thought provoking and to throw up challenges. Such evidence as I have for the problems and solutions is referenced. However, there are many gaps and many of my arguments may be refutable by evidence to the contrary. If so, then please engage in the debate that needs to happen amongst the SHE and wider chemical engineering community.

THE PROBLEMS

PUBLIC PERCEPTION

Overall the safety and occupational health record of the DCPI is good. Environmental performance was poor in the past but has improved greatly in recent years. Legislation and inspection procedures have been in place for many years and the Industry has historically had a well-established "good neighbour" ethic, especially amongst the larger and more responsible companies – many of which have evolved hand in hand with their communities.

However, so far the PI have tended to adopt a 'we know what we are doing, let us get on with it' posture and, so far, the public has been happy to implicitly acquiesce – trading off employment and improved standard of life due to industrial production against this implicit permission to operate. Even so, it is debatable whether the public appreciates just how fundamentally their standard of life depends inextricably on the operations of the PI.

Recently, the public, who are becoming increasingly affluent but disconnected from industrial activity, encouraged by pressure groups and the media have become increasingly concerned about SHE issues. There is an emerging push towards sustainability, even though there is no consensus about what this means. However, it is undoubtedly true that the PI are large consumers of non-renewable resources and have a large impact upon the environment, whether by permit or unexpected incidents. The public are beginning to understand this and they also understand that many PI operations pose a risk of a large loss of life if the worst possible incidents were to be realised. Indeed a large onshore incident, with multiple loss of lives of people who are unconnected to the business of the offending facility, could sound the death-knell for the western process industries as we know them.

Familiarity, Control and Dread

It is helpful to consider other industries and social effects in trying to understand how public perception of the PI is constructed.

Railway safety, measured for example by the number of deaths per passenger mile travelled, has improved from 1967 to the present. Privatisation has made no difference to this trend[5]. This is not the perception of the public, which demands increased rail safety at enormous expense (£11 million per averted fatality for Automatic Train Protection) and to the detriment of road safety, where, overall, accidents continue to kill far more people and where simple preventative measures are comparatively cheap (£100k per averted fatality on local roads).

Alcohol and nicotine cause orders-of-magnitude more deaths, disease and social problems than illegal drugs, yet there is disproportionate attention upon the damage done by the latter. Illegal drugs are perceived as a much greater threat to one's offspring than alcohol and nicotine, which are more dangerous yet are legally promoted in the youth market.

Even though there is no sound evidence that the MMR vaccine causes autism, many members of the public decline its use and subject their children to the dangers of mumps, measles and rubella and increase the risk of a potentially devastating measles epidemic.

It seems that peoples' fear of possible incidents is constructed from the following three factors:

The size (dread) – the larger the potential loss-of-life, the greater the fear of the causing agent;
Unfamiliarity – agents that are not familiar or are not understood are feared more;
Lack of Control - risks posed by agents that are imposed upon the public or where the public is not in control or even involved will be feared and resisted more than those where the public has some control over or is involved in some way with the causing agent.

Hence, large loss-of-life incidents always attract more attention, even though they are very infrequent. Contrast railway accidents – always on the news, with car accidents, which only make the news, if there is a large loss of life. Some people will not drive on motorways because reported crashes involve large loss of life, whereas statistically travel on motorways is safer than on other roads. Autism is an unfamiliar dread disease, whereas measles, etc are not. A drugs overdose and possible death is worse than being drunk or having a cough.

Both railways and cars are familiar. However, whereas alcohol and cigarettes and individual vaccinations are familiar, illegal drugs and MMR are not familiar to most parents. Most adults drive cars and so the risk of accident is perceived to be under their control, travelling on a train relinquishes control to the driver and the people and systems operating the network. Alcohol and nicotine are legal and so controlled but other drugs are illegal and uncontrolled. Table 1 presents these results and shows the comparison, where the accepted 'alternative' has more ticks compared to the unacceptable. People are willing to accept a higher level of risk from sources that are familiar, over which they have a degree of control and where the size of possible incident is small. The problem for the process industries is that the public is unfamiliar with process plant hazards, they have no control over these hazards but they believe that the effects are potentially very large.

SUSTAINABILITY

This single word has recently generated intense debate and activity. It is still not clear what it means but the concept became established after the publication of the 'Brundtland Report[6]' in 1987, which defined sustainability as: "meeting the needs of the present without compromising the ability of future generations to meet their needs". There is General Agreement that sustainability must satisfy goals in the economic, environmental and social arenas.

I believe that there is also a general acceptance that much industrial production is unsustainable and that some products must be substituted and production methods changed - particularly as the larger LDCs ramp-up production.

Put simply, the industry cannot be sustainable when driven by maximising profit/minimising cost, because minimum cost production will inevitably consume non-renewable material and energy resources with non-optimum efficiency. However, it must be said that the root cause of unsustainability is not industry, which only makes its profit by providing goods and services for consumers. It is they, or rather you and I, who are the root cause by consuming too much.

Table 1. Presence or absence of features in everyday hazards influencing peoples' perception

Hazard	Familiar	In Control	Small Effect
Railway travel	✓	✗	✗
Car travel	✓	✓	✓
Illegal drugs	✗	✗	✗
Alcohol/nicotine	✓	✓	✓
MMR	✗	✗	✗
Individual vaccines	✓	✓	✓

RISK ASSESSMENT AND REGULATION

Simply put, a hazard is the potential for harm of a situation and risk is the likelihood of an effect originating from a hazard. Risk Assessment is taken to include: hazard identification, event scenario assessment, consequence assessment, risk assessment, risk comparison and decision-making. At present, there is immense interest in Risk Assessment across industry sectors and countries. Indeed the European Union has a major project underway at the Joint Research Centre, Ispra, which is attempting "technical harmonisation on risk-based decision-making"[7]. Much of this interest is driven by the awakening public concern (described above) about SHE, which extends across most human activities and is not limited to the PI.

Such developments, coupled with the public image problem discussed above pose the challenge that the DCPI might be hampered by regulation, drafted to allay public concern, which, although well-meaning, is miss-targeted, because of lack of understanding of the fundamental science and the impact of technology. There is also the danger that future EU legislation will lump the PI in with other sectors and insist on inappropriate methods and standards of risk assessment.

Finally, the public wish for the 'no risk society' could result in many process operations being moved to developing regions of the world which already offer significant economic benefits. If this occurs not only manufacturing employment but design skills, teaching and research will move outside of Europe in the long term. For example, India already offers design services at lower costs than Europe. Although this may be socially desirable it could make other objectives such as Sustainability, which benefits from the close coupling of producer and user, more difficult.

GLOBALISATION AND WORLD DEVELOPMENT

Many LDCs have burgeoning chemical industries, unfortunately this is being achieved at great cost to their people and their environment. This can only get worse as the pace of relocation of hazards from the developed to the developing world accelerates – this being the short-term response of the DCs to their publics' perception of unacceptable hazards. Most large multi-national companies claim that they insist upon the same good SHE standards wherever they operate but this does not alter the fact that loss of life and environmental damage are much greater in LDCs than in the DCs. Indeed, if one travels to some LDCs you can feel the pollution – for example. If you look at accident reports and statistics for LDCs you will see that their safety and health performance is poor.

In the short-term the scale of human casualties and environmental degradation will increase in LDCs. You might say that sovereign states should look after their own people but we must accept that many environmental problems are global and affect us all.

DASH TO BATCH ?

Many commentators have remarked upon the changing emphasis of chemical production in DCs towards batch production. However, this flies in the face of better SHE performance. The key to ISHE production is to reduce inventories of hazardous materials, whereas batch reactors have much larger, often many orders of magnitude larger, inventories than a continuous reactor that has been designed to optimise mixing and heat and mass transfer. It seems that in the haste to bring new products to market as quickly as possible, good chemical engineering design is being ignored.

DECLINE OF ACADEMIC CHEMICAL ENGINEERING

The number of applications to and students taking up places on chemical engineering degree courses in the UK has been falling for the past 10 years. Figure 1 shows the most recent statistics. The commonly held view is that this is caused by the bad image of the industry amongst young people. There is certainly no shortage of well-paid jobs available for good students at the end of their courses. The situation with regard to post-graduate students is just as bad. It is very difficult to find UK PhD students.

So, even if we accept the arguments to follow that process plants must change radically, we will not have enough talented engineers to design this new generation of process plants.

THE SOLUTION – ISHE PLANT(S) ?

It is almost certainly true to say that current EU SHE practice is good and with the USA, probably defines the "current best practice" to which all others should aspire. The Industry is generally responsible in its behaviour and constantly strives to do better – most companies have well-established SHE programmes in place. Superficially it might seem that the industry is changing. Many large companies now produce SHE reports and the best of these are very good. If nothing else these demonstrate that large companies have high-minded visions and mission statements and that they are measuring and reporting performance. However, at best such documents report small incremental improvements in 'end-of-pipe' performance. I see no radical new plant, which is the only way to make significant, step-change improvements in SHE performance.

I believe that the problems identified above can be summed up in the phrase "the coming risk-tolerance crunch"[8]. This means that public tolerance of indirect risk is decreasing, while we are approaching a practical lower risk limit for engineered systems.The biggest challenge currently facing the PI is to ensure that it does not lose its permission to operate that is implicitly granted by stakeholders. This might happen if this 'crunch' comes when society perceives the SHE impact of the PI to be too negative, without manifest compensating benefits that they can understand. The only way to avoid the 'crunch' is by designing and operating ISHE plants.

ISHE DESIGN & PRODUCTION

This may be 'sloganised':

Neither you nor your environment can be hurt by anything that you do not have.

Risk is the likelihood of a hazard occurring and strictly speaking it is either a probability or a frequency, however there is currently a movement towards including the size of hazard in its definition. In either case, bearing in mind the comments about a practical lower limit for engineered systems, the only way to further reduce risk is to remove the hazards – or to reduce them, if the size is a factor. Therefore, we should develop products and achieve production plant that are: safe, have no long term adverse health effects and are not damaging to the environment, by not including agents (materials, operations) that could be detrimental in these areas or by minimising the inventories (amounts in plant) or instances of such agents. This is ISHE design.

This implies a fundamental and far-reaching change in the orientation of the process industries. Whilst it is important for the long term development of the industry that it retains its profitability (otherwise shareholders will disinvest), the industry must recognise that further improvements in safety, health and environmental performance together with 'Sustainable Development' are essential for the future. In the long-term the emphasis in the PI must evolve away from pursuing the current business objective of optimising economic performance subject to satisfying SHE constraints, towards a new objective of optimising SHE performance, subject to being able to generate or raise sufficient capital and making adequate returns on the capital employed.

In the long-term I believe that such a shift will guarantee economic survival. DCs currently have a great technological and consequent economic advantage but this will not last as the developing world catches up. We must provide the leadership to do things better in terms of SHE. This will provide the added value for the future and differentiate our products and production methods, so that we can still sell those products and the production technology in a world market that is increasingly aware of SHE issues.

Now I will address the problems identified above in turn.

PUBLIC PERCEPTION

ISHE production plant are the key to convincing society that there is no threat. Ideally, if there are no hazards then there is no risk. If the hazards have been minimised, then we can do no better, given that the product has a place in human activity.

In terms of the headings Familiarity, Control and Dread:

Familiarity can be engendered by better communication of what we do, how we do it and the benefits that society reaps from our activities. At a local level, is it not possible to engage ordinary people in design and development? This is done for consumer products, so why not for products of the PI?

An element of **Control** could also be given to society by the above engagement.

Addressing the **dread** factor is more problematic, but ISHE plant would minimise this response. There is a wealth of research in this area being done by social scientists – much of which is unknown to the engineering community but we must draw on this work. Some scientists and engineers claim that the public does not understand probability and so cannot be trusted to make rational decisions about major hazards, where the probability has been reduced to As Low As is Reasonably Practicable (ALARP). I believe that the public understands probability well and fully appreciates that an event with a miniscule probability can still happen today or tomorrow or in their lifetimes. The only way to demonstrate to an increasingly sceptical public that an activity has acceptable risk is to remove or reduce the size of hazard to an acceptable level.

SUSTAINABILITY

I have said that I do not believe that this concept has even been defined yet and may be it is not possible. You can only know if an activity is sustainable with hindsight and then it still cannot be projected into the future. However, if we take Sustainability to mean enduring, then clearly it must not stop. For production this implies not only continued economic viability and sufficient raw materials, which can only be assumed, but also avoiding events that might result in termination, such as high profile safety, health and environmental incidents – particularly those with deaths. The only reliable way to avoid such events, particularly over the long term, is to remove the hazards by designing ISHE plants. There is also the imperative to ensure that the public does not perceive the risk to be too high, even though we might not believe that it is, because, otherwise, they might shut us down anyway – as a precaution. This must be achieved by better communication and engagement as mentioned above.

Furthermore, such communication must be a dialogue, because it is the public as consumer that drives resource consumption. For example consumers buy bigger and bigger vehicles in the face of mounting concern about the environmental impact caused by cars. So, there are obligations on both sides and we must make the point that activities will only be sustainable if society does not demand products that are unsustainable, or consume too much of products that otherwise might be sustainable.

We must embrace sustainable production and lead the way – even at the expense of reduced profitability, because it is unreasonable to expect LDCs to embrace sustainable production methods if we do not. The dialogue aspect then is even more pressing, in order to educate the coming consumers of the LDCs. If they consume at our rate, then we are all doomed by a rapidly exhausted planet!

RISK ASSESSMENT AND REGULATION

In the future risk assessment for the PI will be driven to focus more on the human risk receptor, rather than just the inanimate risk source (the chemical plant), which has been the engineer's focus. Social scientists have many competing approaches to tackling the same problems, but a common theme is the focus on the human risk receptor. Furthermore, they seem more willing to tackle difficult, vague risks, that engineers would shy away from because there is no obvious method for quantification. They are often more concerned with understanding the drivers behind risk and perceptions of it than quantification.

The PI should engage with the social science community with the aim of moving towards a new or synthesised approach to risk assessment and management that can integrate 'soft', people-centred aspects with 'hard', numeric quantification. Such a new approach is vital for the chemical industry, where, I believe, the single biggest threat is from misinformed public opinion and misplaced regulation.

The Control of Major Accident Hazard Regulations (1999)[9] apply where a dangerous substance as listed in the Regulations is present in a quantity equal to or exceeding the entry for that substance. Therefore the obvious way to avoid these regulations is to ensure that any quantity of a hazardous substance is less than the prescribed threshold. This coincides with the key feature of ISHE design – avoid or reduce inventory of hazardous materials.

Regulation happens when it is deemed necessary. A good way to avoid excessive regulation is to anticipate future regulation, which as well as demanding new methods of people-focussed risk assessment is likely to encourage ISHE design. Indeed, inherent safety is already mentioned in the latest EU regulations and are a feature of the Contra Costa County Ordinance Code Chapter 450-8, Section 450-8.016(D)[10] (California, USA). Therefore, in order to secure a 'lighter touch' from regulators, the PI should engage in ISHE design now.

GLOBALISATION AND WORLD DEVELOPMENT

LDCs can only improve their SHE performance if they know how to do it. Therefore it behoves the DCs to share their good practice. In the long term this is good for business as well. DCs cannot compete with LDCs that have lower people and raw material costs and which also place a lower value upon human life and the environment. Their thresholds must be raised by encouraging and sharing good practice.

DASH TO BATCH

When I started work on this paper, this was to be a key theme. However, I can find no production data that either confirms or disproves a move from manufacture by continuous processes to batch production. If this is a trend, then we must assemble some data on production levels and also on reportable incidents in relation to production method.

DECLINE OF ACADEMIC CHEMICAL ENGINEERING

Having just left academia, I can say that this is happening and that it is deeply worrying. Although there is some recent evidence that admissions are stabilising at a new lower level, we must take action now to ensure that the previous downward trend is reversed to an upward one. Otherwise, we will see the closure of more Departments.

I believe that action has to be taken at the programme level to make chemical engineering degrees more relevant to young people and the present and future needs of industry. Programmes must emphasise SHE matters and particularly ISHE, but also more material related to the PI as a business and its interaction with society should be included. Chemical engineering curricula are already extremely crowded with 'hard' science and engineering and some of this must go, in order to make way for the new material. This would also have the benefit of making the subject less difficult, which I believe is a big disincentive to prospective students. Nowadays computer tools for technical calculations are all-pervasive – not all chemical engineers need to be able to do their sums with a pencil and calculator. Of course they need to understand the results and when they are at odds with reality but more important is the ability to be able to deploy these results in business and social contexts. For those engineers wanting to follow a career with the emphasis on technology, masters courses can be provided to enhance their more broader-based basic chemical engineering qualification.

CONCLUSIONS

It is now common practice in the PI to consider SHE issues together and this is the correct approach, because they are clearly related and interact – progress will only be made by considering SHE performance holistically. The concept of inherent safety and inherently safer design has been around for a long time and is widely acknowledged as the ideal for production plant, however its philosophy and practice must be extended to encompass the totality of SHE. There are now many imperatives for the PI to embrace ISHE and implement such design in its production facilities.

Study of public response to everyday hazards, leads to the scenario that the negative public perception of the hazards posed by the PI is constructed from three factors: unfamiliarity with the production methods and many products, lack of control over these hazards and fear of the potentially large consequences of serious SHE incidents. ISHE production plant are key to convincing the public that the PI have a place in our society – absence of hazard is the most convincing argument for permission to operate.

Sustainability is as yet not precisely defined and it may never be so. However, ISHE plants might endure for the long term because there can be no reason – large SHE incidents, particularly with loss of life – to shut them down. If they do not consume non-renewable resources and are economically viable in the long term, then their production is sustainable.

The PI must try to synthesise new methods for risk assessment from the traditional 'hard-science' based numeric quantification and presently unfamiliar 'soft' people-centred approaches employed by social scientists. This and the ISHE approach to production might then head off the danger of new, all-encompassing regulation placing infeasible constraints upon the industry.

The DCs must share their good ISHE practice with the LDCs and help to educate their people. In the long term this will safeguard the viability of the DCPI, because the DCs can only trade and compete with others who share the same attitudes about SHE.

A move towards batch production in DCs has been claimed but the reported statistics do not confirm this trend. If it is a trend we must consider the negative consequences for ISHE production.

The continuing decline in numbers of chemical engineering students must be reversed. Curricula must emphasise ISHE and the place of engineering and engineers in wider society. So that new products and processes are developed that take account of their impact on society.

I have stressed throughout the paper that the SHE performance of the DCPI is very good but it must attain new heights and this can only be achieved by ISHE plants. Moreover, I believe that plants must have optimal ISHE and that this implies that SHE performance becomes the objective function that drives our activities, subject to generating sufficient profit; rather than maximising profit subject to adequate SHE. The adoption of this new aim requires a leap of faith, with no guaranteed return – but, that is the scenario with most innovative projects.

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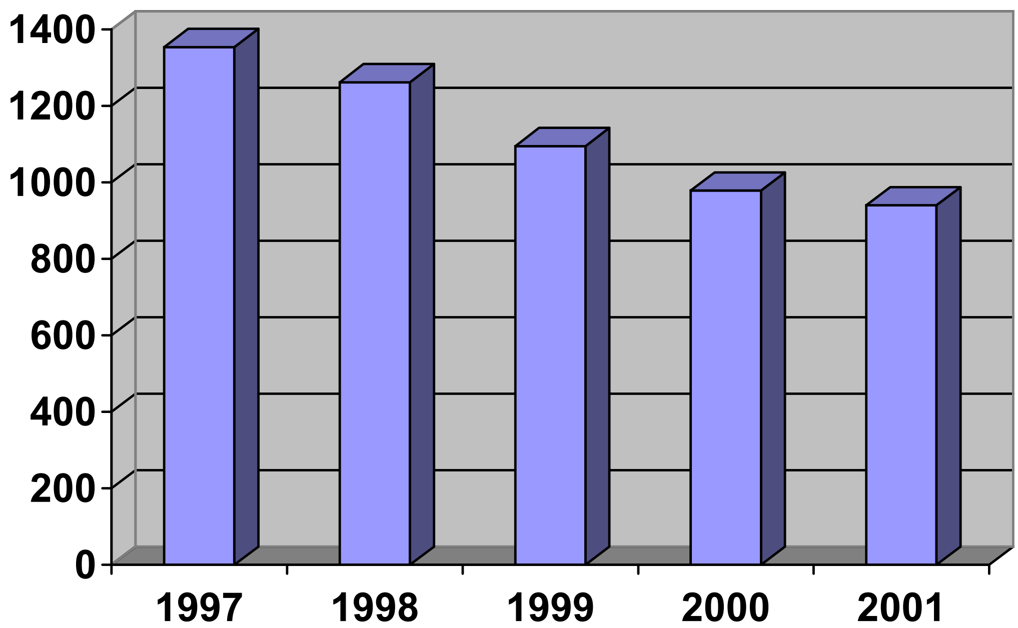

Figure 1. Number of chemical engineering students entering UK degree programmes