IChemE
www.icheme.org/journals
doi: 10.1205/psep.04241

0957–5820/05/$30.00+0.00

Trans IChemE, Part B, March 2005
Process Safety and Environmental Protection, 83(B2): 85–89

PROCESS INTENSIFICATION Safety Pros and Cons†

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One of the best ways of preventing accidents is to avoid hazards by inherently safer design. The adoption of such principles is now required by EU legislation. As many processes, particularly those in the chemicals, nuclear and oil industries, involve the production, handling and use of hazardous substances, process intensification (PI) is one way in which the inventory of such substances, and the consequences of a process failure, may be significantly reduced. PI, therefore, has the potential to be a significant factor in the implementation of inherent safety. However, conflict can arise between PI and some inherent safety practices. For example, certain PI technologies require higher energy inputs or to be operated at higher temperatures. The processes may be more complex or call for a more complex control system. For this reason, both the process (including the chemistry, where appropriate) and plant need to be considered together to reach a comprehensive understanding of the safety issues. This paper gives some examples of how process intensification has, or might have, improved safety. Some of the issues that need to be considered are also discussed. In order to promote the benefits of process intensification, and draw attention to safety considerations, HSE is co-sponsoring a process intensification network (PIN) in liaison with industry and the Department of Trade and Industry.

Keywords: process intensification; process safety; inherent safety.

INTRODUCTION

As all good safety professionals know, the best way of preventing accidents is to avoid hazards by inherently safer design. The adoption of such principles is currently required by EU legislation (for example, EC Framework Directive, 1990; CAD, 1998). Many processes, particularly those in the chemicals, nuclear and oil industries, involve the production, handling and use of large quantities of hazardous substances and process intensification (PI) is one way in which the inventory of such dangerous substances, and the consequences of a process failure, may be significantly reduced. There are also a number of business reasons for the uptake of PI, such as the possibility of producing new or better products and the ability to have smaller, local production plants rather than a large central one. The environment may also benefit. Consequently, there is much interest in its uptake and a number of companies and academic institutions are developing new intensified processes with the aim of them being, ultimately, adopted by the industry. However, in some cases, hazards may remain or new ones may be created in the development of such processes. This paper discusses the potential for PI to improve process safety, and some of the possible drawbacks, which should be considered in the light of the legal framework.

LEGISLATION

The principal health and safety legislation in the UK is the Health and Safety at Work, etc. Act (1974). It requires employers to reduce risks to employees, and others, 'so far as is reasonably practicable' (SFAIRP). The meaning of SFAIRP has been the subject of legal judgement in the UK Courts (Edwards vs. The National Coal Board, 1949), but essentially the risks have to be weighed against the costs (in terms of time, trouble and money) necessary to avoid them. The more recent term ALARP (as low as reasonably practicable) has a similar definition. Measures to reduce risk should only be ruled out if the sacrifice involved is grossly disproportionate to the benefits.

The requirement to assess risks is also embodied in a number of Regulations, which implement European Directives on health and safety matters. In particular, The Management of Health and Safety at Work Regulations (1999a, b) implement the EC Framework Directive (1990). These regulations require assessment of the risks created by work activities and the provision of suitable and sufficient measures to control them. Regulation 4 includes specific requirements to avoid risks by inherently safer design.

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More recently, the European Chemical Agents Directive (CAD) (1998) applies to all work places (including universities) handling dangerous substances. In Britain, the safety aspects of CAD are enforced through the Dangerous Substances and Explosive Atmospheres Regulations 2002 (SI, 2002; HSE, 2002. These specify that employers must:

- carry out a risk assessment of any work activities (including processes) involving dangerous substances;
- provide the necessary measures to eliminate or reduce the risks SFAIRP;
- provide equipment and procedures to deal with emergencies;
- provide information and training to employees.

It is a requirement of the risk assessment that the risk from hazardous chemicals is either eliminated or reduced to a minimum. By preference, hazardous chemicals or processes should be replaced by less hazardous options. The onus is clearly upon the employer to consider process hazards and avoid them, right from the earliest stages in the process development. It is only once this has been done that companies should move on to further 'add on' safety measures to either avoid or control these hazards.

This has profound implications for both the process industry and researchers involved in developing new processes. However, the Chemical Agents Directive only exemplifies what has always been good safety practice. Politicians and the public alike are becoming increasingly aware of the hazards posed by industrial chemicals and are increasingly questioning whether safer options are available (Meacher, 1992; House of Commons, 2003).

PROCESS INTENSIFICATION—SAFETY BENEFITS

The safety advantages of process intensification are best expressed by Professor Trevor Kletz (1991) who put it quite simply saying, 'What you don't have, can't leak!' For hazardous processes, PI is one way that the inventory of such dangerous substances, and the consequences of a process failure, may be significantly reduced.

> As an example (Gupta, 2002), consider the worst-ever industrial disaster: The Bhopal Gas Tragedy. On 2 December 1984, 41 tonnes of highly toxic methyl isocyanate (MIC) leaked out of a ruptured storage tank at the Union Carbide pesticide manufacturing plant in Bhopal. Safety equipment had not been maintained. Over 3000 died and over 200 000 were left disabled for the rest of their lives. Some adverse genetic mutations were also passed on to the next generation. The reaction scheme in this batch plant produced MIC as an intermediate that was stored until a decision was made to produce another batch of the product. If a smaller continuous reactor could have been used instead of the batch one, it would have produced only a few kilograms of MIC that would have been internally consumed during the final stages of the process, leaving nothing to store. Even if this reactor had ruptured, only a few kilograms of MIC would have been released which, comparatively, would have done much less damage. This is the application of one of the main concepts of inherently safer design: *use less of* hazardous substances.

Further safety benefits may arise from PI, for example:

- In some cases the number of process operations can be reduced, leading to fewer transfer operations and less pipework (which can be a source of leaks).
- It may be easier to design a smaller vessel to contain the maximum pressure of any credible explosion, so that further protective devices such as emergency relief systems, are not needed (or the duties placed upon them are less onerous).
- Many incidents are associated with process transients such as start-up and shutdown. These are reduced during continuous (and intensified) processes.
- For exothermic reactions, the heat evolution should be much less variable than in batch reactions, and should be easier to control. Furthermore, the enhanced specific surface area of intensified plant makes heat transfer easier. Certainly, very few runaway reactions occur in continuous processes [although there have been some notable exceptions (Etchells, 1997)]

. In the UK, the HSE have been involved in encouraging companies to adopt more inherently safe designs. An example where PI was used to considerably enhance the safety of a process is given below.

> Case Study 1: A company was manufacturing an energetic material in tonnage quantities. The final stage was a batch evaporation stage. As the material became more concentrated, it became possible for it to detonate. Potential mechanisms for initiation were by overheating or by iron contamination. A number of precautions had been taken to prevent this occurring. However, because the vessel was constructed of mild steel with a glass lining, there was a danger that the glass lining might be breached during the evaporation stage and the mild steel come into contact with the energetic material. Part of the company's basis of safety was that, if this occurred, the breach would be detected, steam to the jacket would be shut off, cooling water applied, and the material dumped through the discharge pipe at the base. However, the company were unable to demonstrate to HSE that the safety system could work quickly enough before the vessel over-pressurized. The process was discontinued and replaced by a continuous wiped-film evaporator with only a few kilos of instantaneous inventory. Compatible process materials were selected and the process was operated remotely.

Other examples of the significant safety benefits of PI abound in the literature, for examples see Kletz (1991) and Hendershot (1995).

POTENTIAL PROBLEMS

Even though safety can benefit from process intensification, it is unlikely to be the main driver in most cases. Uptake will be based upon other factors such as reduced capital costs and better products. In some cases PI will allow new or better products to be produced commercially. In the drive towards newer processes, companies should be careful to ensure that new hazards are not created. Potential problems may include: