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Challenges for Design Engineers in Sustainable Engineering

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Abstract. Very few industrial processes only produce the target product, but other materials not desired by the manufacturer are also obtained. These unwanted products constitute the residues of the processes and their discharge contributes to the overall environmental impact. The concept of preventing pollution is gaining increased importance, and certain industries that are particularly similar in nature, could benefit from PPP (Pollution Prevention Program) cross-fertilization. Implementing PPP sets important targets and benefits. A number of codes of good practice lead to PPP, both from a management and technical viewpoints. The fast development of technology and pollution standards implies important challenges for environmental engineers, environmental research and development. Although there is no general route to success, there are however a number of pollution prevention and waste reduction schemes that apply. These alternatives and procedures are illustrated in the paper. It is clear that environment-caring companies will be more readily accepted by their human environment. It is also evident that the engineer of the 21st century faces new and complex environmental challenges. Research remains the backbone of successful development.

1. Introduction

Increased consumption by population growth and rising standards of living as well as the expansion of the market economies lead to an increase in production. Natural resources are thereby increasingly depleted and wastes are discharged into the environment. As a result, the environment is strongly influenced and the international organizations are concerned with this global impact. The UN Brundtland Commission formulated principles of sustainable development, which “meet the needs of the present without compromising the ability of future generations to meet their own needs” [1, 2]. Sustainable development implies efficient allocation of raw materials, maintaining the environmental balance and guaranteeing social equality, opportunity and freedom. All three elements must be in perfect equilibrium. The industry must decisively contribute to these guidelines by using the environmental best available technologies (not entailing excessive costs).

Today's BAT (Best Available Technology) is no longer the BAT of tomorrow. Research and development constantly broadens the scope of environmental techniques, and developed technologies target more stringent pollution standards. There are unfortunately no industrial processes in which only the target product is manufactured, other materials not desired by the manufacturer are also obtained. These undesired by-products are formed in various ways: through impurities in the raw materials, due to the presence of a reaction medium (organic solvents/water), due to the presence of auxiliaries and/or catalysts, as a result of secondary reactions etc. They constitute the residues of the process and their discharge contributes to the overall environmental impact.



Residue reduction can be achieved by process redesign e.g. changing the chemical process by using new synthesis routes, using catalysts with higher selectivity, using bio-catalysis, replacing or eliminating auxiliaries that cause pollution etc. If residues are unavoidably formed, re-use is indicated either by in-house recycling or by external utilization. The concepts of preventing pollution and limiting wastes are gaining increased importance and form the backbone of a novel sustainable approach in environmental engineering: avoid or omit end-of -pipe technology by a reduction at its source [3, 4, 5].

The constraint imposed on processes by their natural, environmental and social environment are clearly defined and include: (i) yield and selectivity, quality control; (ii) waste limitation and management; (iii) flexibility and ease of operation, safety; (iv) low cost; and (v) efficient methods for design and scale up [6, 7].

In order to achieve these objectives, research remains essential.

2. The need and advantages of cross-fertilisation in research and development

Research and achievements in waste reduction and pollution prevention have been discussed in a rapidly expanding literature, mostly in the United States and Europe, and publications are numerous. Most publications present case study examples of successful waste reduction to illustrate its desirability and feasibility [7-9]. These studies may however not be useful to other companies in their waste reduction efforts. Furthermore, they are not a great help to those outside the industry in assessing the transferability and limitations of the techniques discussed. There are several reasons for the lack of usefulness.

- Firstly, few accounts go into enough detail to give a thorough understanding of why and how waste reduction was carried out. Often it is not clear what waste has been reduced, to what extent or by what method it was reduced, or what the costs and benefits were;
- Secondly, the number of cases reported in the literature is limited and the same examples appear over and over again;
- Thirdly, comparison between examples from one published source and another is difficult to make because there are no generally accepted definitions of wastes or reduction. Similarly, waste reduction definitions often include what is actually waste management. Examples of waste reduction in the literature may also include simple volume reduction (e.g. de-watering of sludge) with no reduction of its hazardous content.

An unfortunate limitation of waste reduction examples is that the generic opportunities are often not recognised. A reader notes the particular industry being discussed and if it is not his industry, he needs imagination to see that the waste reduction method might still be applicable. If the examples were redrafted to put them into functional or general terms it might be easier to transfer waste reduction measures across industries. Cross-fertilisation opportunities are numerous, and a few examples are mentioned below. There are obviously many more [7, 10].

- The application of coatings to metals, printing ink to paper, and finishes to textiles, essentially involves the commonality of laying down an organic material on a substrate;
- Utilising mechanical instead of liquid processes. Whenever liquids are used to transfer or remove material, it may be possible to accomplish the job by a mechanical means. For example, abrasive beads can replace a caustic solution to remove dirt or oxide on metal parts. Some types of plating can be done mechanically rather than with traditional electroplating methods. Paint can be removed by ultrasound, cryogenics or by bombardment with plastic or metal beads rather than by using solvents;
- Replacement of organic solvents leads to emissions reductions. There are a number of successful examples in many industries, of companies that have cut their costs and hazardous waste problems by changing from materials that contain large amounts of organic solvents, such as inks, to ones based with water. This approach competes in popularity with in-process

recycling of organic solvents, which is also widely applicable and on the rise, but the substitution approach is a better example of waste reduction. Very volatile organic solvents can be replaced by less volatile ones, e.g. MIBK (methyl-isobutyl-ketone) instead of MEK (methyl-ethyl ketone);

- In-process solvent recovery can be used by many industries as an alternative to replacement of organic solvents to reduce waste generation. It is attractive because, like end-of-pipe pollution control measures, it requires little change in existing processes. The widespread commercial availability of solvent recovery equipment is another attractive feature. Availability of equipment suitable for very small operations, particularly batch operations, may make in-process recovery of solvents financially preferable to raw material substitution for such firms, but for most companies the relative economic advantages on in-process recovery are less clear;
- Prevention or abatement of vapour losses can be practised in many industries;
- Process water is used in a wide variety of industries, and reduction techniques in one industry could be applicable to many others. Water is used to transfer heat, to transfer materials, as a solvent, as a medium for precipitation and for cleaning. Many technologies allow the use of closed-loop systems in which process water is recycled rather than being passed through the system a single time. In some locations, such approaches are attractive simply because they drastically cut water consumption. Moreover, this approach can eliminate the generation of large amounts of sludge in water treatment plants;
- There are certain industries that are particularly similar in nature and could benefit by cross-fertilisation, including the organic chemical manufacturing, and the petroleum refining industry; the non-ferrous metal, the inorganic chemical, and the mineral processing industries; the paint, printing ink, and adhesives manufacturing industry.

3. Important targets and benefits

The important targets relate to required improvements. They include expanding the pollution prevention skills of engineering students, enhancing the transfer of technology inside/outside company, improving the organisation, training and participation of workforce and promoting cross-fertilisation opportunities for pollution prevention techniques, e.g. non-ferrous metals, mineral processing, organic manufacturing, paint, ink, adhesives.

The benefits to industry of preventing, minimising or reducing pollution are important (see Table 1) and include:

- Economy. When wastes are reduced or eliminated, direct cost savings are realised, by reduced expenditures for pollution control equipment and lower disposal costs. Side benefits are also: significant improvements in energy and water conservation, and improved or more consistent product quality;
- Liability. Frequently the dominant cost savings come from reduced future liability for the pollution. Ever since passage of the "cradle to grave" responsibility for the wastes, waste producers have been subject to the possibility of unlimited liability for any harm caused by their wastes. This liability includes even future problems caused by wastes currently managed using the best available practices. Another important advantage is reduced liability related to workplace safety;
- Improving effectiveness. Pollution prevention reduces the risk inherent in managing the waste streams and residues that result from traditional control methods. For example: the most effective solution for lead, asbestos, PCBs and certain pesticides has been to ban their use. Prevention approaches also avoid the potential risk of control technology failure, and the problems associated with effective operation and maintenance;
- Avoiding uncertainty. Determining the fate of a pollutant can be uncertain. When there is an opportunity to eliminate risk, the public is often unwilling to accept the results of efforts to determine an acceptable risk level;

- Multi-media transfers. Pollution prevention avoids the inadvertent transfer of pollutants across media that may occur with end-of-pipe media-specific treatment and control approaches;
- Resource protection. Avoiding high levels of wastes/residues, limiting the use of resources, and assuring that the environments' capacity to absorb pollutants is not exceeded, pollution prevention protects natural resources for future generations;
- Improved image. Pollution prevention actions are generally looked upon favourably by the public. Public involvement can have an important effect on a company's activities;
- Energy considerations. Energy-saving techniques should be considered as pollution prevention, with resultant decreased pollution at the power plant.

Table 1. Major benefits of preventing or reducing pollution [3, 4, 7]

Economic factors	Reduced expenditure for pollution control equipment
	Lower environmental taxes and disposal costs
	Energy savings, water conservation etc.
Improved efficiency	More efficient use of raw materials
	Resource protection, rejects/by-products reduction
Reduced liability	Cradle-to-grave responsibility
	Future problems caused by currently acceptable wastes
	Site clean ups, workplace safety
	Avoid uncertainty about fate of pollutant
Improved eco-image	Prevention is generally favourably accepted
	Positive towards "Right-to-know" public attitude

4. The challenges of the design engineer of the 21st century

4.1. Systems and media

Traditionally, environmental engineering has been dealing with ideal gases and mixtures of Newtonian fluids characterized by bulk properties. Novel processes are now increasingly concerned with complex media such as non-Newtonian fluids, ultrafine particles (PM 2.5), powders etc. Such complex media exhibit unusual behavior which cannot be accounted for by standard correlations.

The issue is: How to describe complex media and how to account for chemical and physical changes taking place in these systems. There is e.g. a need for new approaches to the description of matter on the micro-scale (i.e. 1 – 100 μm) [11].

4.2. Concepts, paradigms and methods

A certain number of “historical paradigms” constitute the core of all engineering design which makes use of specific concepts: unit operations, separation stages and transfer units, mass-heat and momentum analogies, reaction-transfer coupling, residence time distribution etc. The list must now be completed with new paradigms adapted to specific needs of environmental engineering, such as non linear dynamics...the formation and propagation of dynamic patterns is in its infancy and deserves further study (e.g. pulse jet cleaning of fabric filters, CFD-prediction of incineration, etc.) [12].

4.3. General source reduction

The 21st century engineer should firstly consider source reduction procedures and only thereafter focus his attention on pollution abatement by end-of-pipe technologies. Some relevant points of attention are summarized in Figure 1 [13-15].

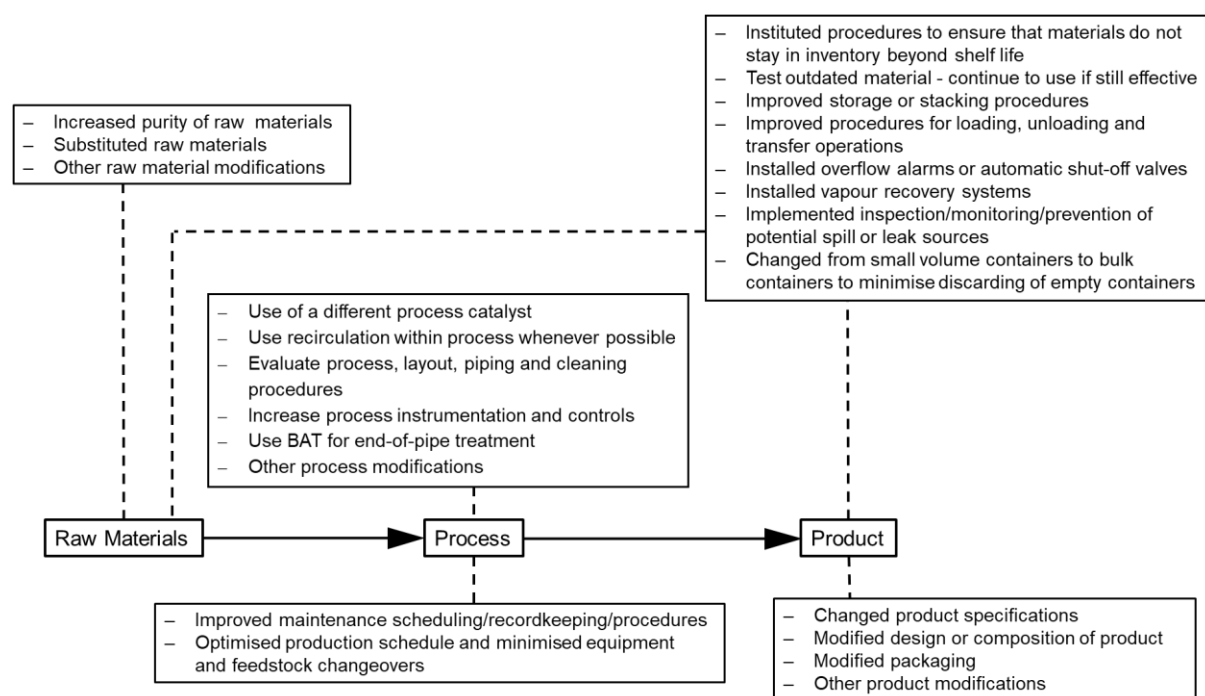


Figure 1. Overview of general source reduction procedures

5. Illustration of prevention schemes in the chemical industry

Although there is no general route to success and “no single solution fits all”, there are however a number of pollution prevention and waste reduction schemes that apply to chemical processes. These prevention alternatives and procedures are illustrated hereafter in Figure 2.

In addition to these schemes, some more general targets must always be kept in mind, e.g.:

- Implement a rigorous preventive maintenance scheme;
- Establish a waste stream inventory;
- Apply adequate painting because external corrosion can be a major cause of plant deterioration.

6. Conclusions

The concept of preventing pollution is gaining increased importance.

There are certain industries that are particularly similar in nature and could benefit from PPP (Pollution Prevention Program) cross-fertilisation, including e.g. the organic chemical manufacturing and the petroleum refining industry; the non-ferrous metals, the inorganic chemical and the mineral processing industries; and the paint, printing ink, and adhesives manufacturing industry.

In implementing a Pollution Prevention Program (PPP) there are important targets and benefits. There are also a number of codes of good practice that lead to a PPP, both from a management and technical viewpoint. The fast development of technology and pollution standards implies important challenges for the environmental engineer, and for the environmental research and development.

Although there is no general route to success, there are however a number of pollution prevention and waste reduction schemes that apply. These prevention alternatives and procedures are illustrated in Figure 1 and Figure 2. It is evident that environmentally-caring companies will be more readily accepted by their human environment. The engineer of the 21st century hence faces new and complex environmental challenges. Research remains the backbone of successful development.

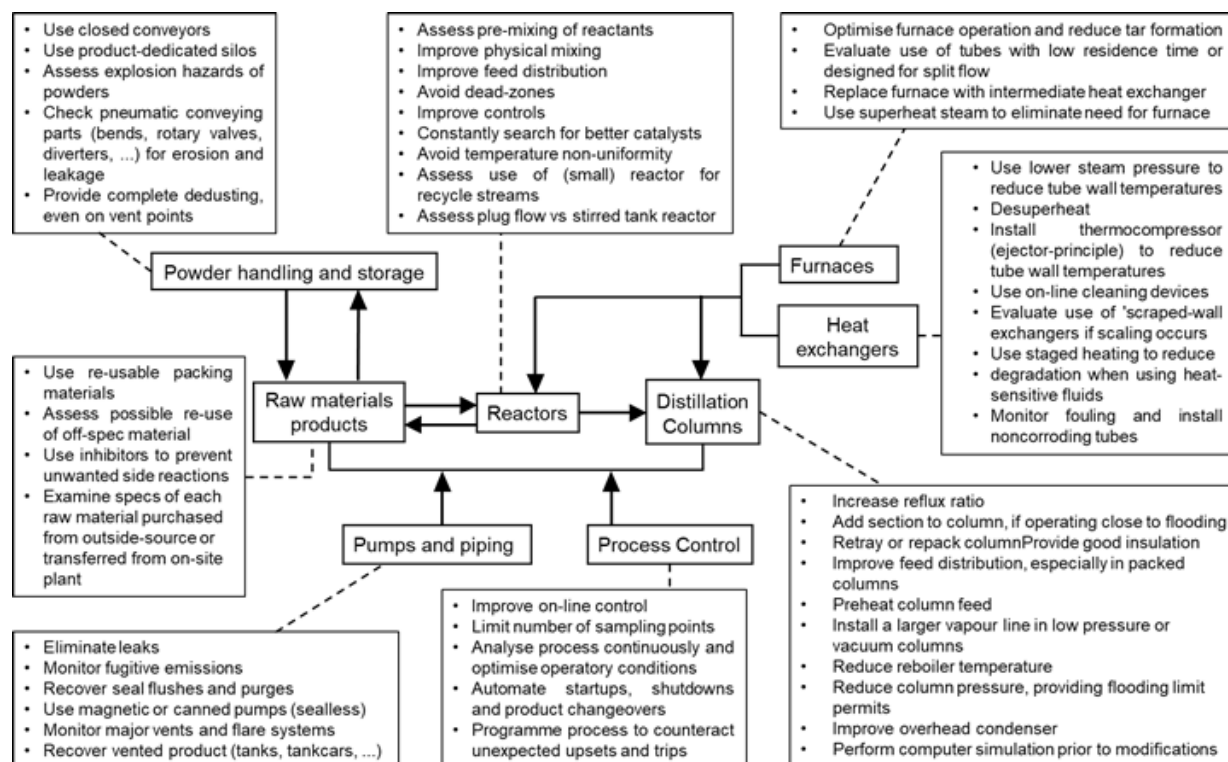


Figure 2. Overview of prevention alternatives and procedures

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