CONTROL STRATEGY FOR TOXIC POLLUTANTS

Jun Huang and Gang Yu
Department of Environmental Sciences and Engineering, Tsinghua University, Beijing, P. R. China

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Summary

Toxic pollutants are of great concerns due to their diverse effects on the health of human being and the whole ecological environment. It is important to adopt integrated strategies to control toxic pollutants, combining an environmental management system (EMS) with cost-effective techniques for cleaner production, waste treatment and remediation of contaminated media.

Pollution prevention should be regarded as the basement for the whole control strategy for toxic pollutants by adoption of approaches such as cleaner production, process integration, and product or process redesign, to minimize generation of toxic chemicals. Then cost-effective end-of-pipe techniques should be applied to minimize the input of toxics into the environment. For those environmental media contaminated by toxic pollutants, remediation techniques can be chosen based on cost-effective ratio.

1. Introduction

The presence of toxic pollutants in environmental media has always been a matter for great concern. This concern has become much more pressing with the intentional or unintentional release of an even larger variety of substances into the environment. A whole spectrum of difficulties has arisen in attempting to control the toxicity problem. Three major issues may be summarized as follows:

- Assessment of environmentally safe concentrations—most toxicity testing measures lethal concentrations but subtle sub-lethal effects may impair ecological success at concentrations well below those causing death. Chronic effects due to prolonged exposure or bio-accumulation, toxic interactions and geo-chemical cycles involving toxins all add further complications.
- Assessment of biodegradability—persistence of toxic pollutants in the environment is clearly undesirable but there are still difficulties in designing suitable tests to assess the biodegradability of newly synthesized compounds.
- Clean technology—the treatment of toxic pollutants may be technically difficult and expensive or in cases like metals consist of mere segregation. The current emphasis is therefore on developing clean technologies to avoid or reduce the production of toxic wastes.

Under these conditions, it is very necessary and important to adopt integrated control strategies for toxic pollutants. Above all, pollution prevention should be taken as the basis for other approaches to avoid or reduce the input of toxics to the environment. Secondly, cost-effective end-of-pipe pollution abatement techniques should be applied to related industrial process or other emission sources of toxic pollutants.

Thirdly, appropriate remediation methods are needed for those soils, surface water or groundwater contaminated by toxic pollutants in the past or by non-point emission sources where the responsibility is currently unclear.

2. Pollution prevention for toxic pollutants

A logical place to begin a presentation of the vocabulary of pollution prevention is with a discussion of the management hierarchy of waste containing toxic pollutants. It is well accepted that a wide range of solutions to environmental problems exists and that some solutions are preferable to others, so that there is a hierarchy of waste management alternatives.

2.1. Waste management hierarchy

According to the provisions in American Pollution Prevention Act of 1990, the elements of waste management hierarchy can be placed in the following order of preference:

- source reduction
- in-process recycling
- on-site recycling
- off-site recycling
- waste treatment to render the waste less hazardous
- secure disposal
- direct release to the environment

2.2. Pollution prevention (P2)

In 1990 the USA introduced the Pollution Prevention Act in which pollution prevention is defined as a 'source reduction'. P2 aims at reducing the amount of any hazardous substance, pollutant or contaminant entering any waste stream or otherwise released into the environment (prior to recycling, treatment or disposal). Recycling outside the production site and treatment were specifically excluded from the definition of P2.
Pollution preventions means 'source reduction', as defined under the Pollution Prevention Act, and other practices that reduce or eliminate the creation of pollutants through:

- *Increased efficiency in the use of raw materials, energy, water, or other resource, or*
- *Protection of natural resources by conservation*

Drawing an absolute line between prevention and recycling can be difficult. 'Prevention' includes what is commonly called 'in-process recycling', but not 'out-of-process recycling'. Recycling conducted in an environmentally sound manner shares many of the advantages of prevention, such as energy and resource conservation, and reducing the need for end-of-pipe treatment or waste containment… Some practices commonly described as 'in-process recycling' may qualify as pollution prevention.

The EPA definition therefore considers P2 to encompass the first two elements of the waste management hierarchy: source reduction and in-process recycling. Some experts and organization think this definition is somewhat too rigid. The Pollution Prevention Task Force of the American Petroleum Institute defines pollution prevention as

A multi-media concept that reduces or eliminates pollutant discharges to air, water, or land and includes the development of more environmentally acceptable products, changes in processes and practices, source reduction, beneficial use and environmentally sound recycling.

And another definition of P2 by Gottlieb is:

Pollution prevention is seeking to eliminate hazards in all environmental media along the production chain encompassing not only environmental releases but also occupational exposures and product use.

In current, a precise definition of P2 remains elusive. But usually it encompasses the first two or three elements of the waste management hierarchy for all wastes and emissions. Anyway, P^2 can be a solution to reducing environmental costs and liabilities, and at the same time improving production efficiency. It focuses on reducing wastes at the source rather than control or treatment after wastes have been generated.

2.3. Three levels of P2

In one of their books, D.T. Allen et al. classified P2 into three levels according to the scale involved: macroscale P2, mesoscale P2, and microscale P2.

2.3.1 Macroscale P2

Macroscale studies of P2 are useful in identifying targets of opportunity for pollution prevention of toxic pollutants. At this level P2 utilizes three elements: waste inventories, industrial metabolism, and life-cycle assessment. Among these elements:

- **Waste inventories.** These can be used to grade P2 performance. It is essential that process designers be aware of the waste and emission data, their limitations and what the issues are in the continuing policy debate on measuring P2.
- **Industrial metabolism.** After the inventories come into being, the next step is to integrate waste generation data with production data, recognizing the huge numbers of waste generated annually could not be ignored as a potential source of industrial materials. The conversion of wastes from something undesirable into something of value eliminates the need for the release of many toxic pollutants into the environment and reduces the need for raw material extraction. Studies in this area have come to be called 'industrial ecology' or 'industrial metabolism'.
- **Life-cycle assessment (LCA).** A macroscale approach to identifying opportunities for P2 that is becoming increasing popular is to consider an individual product and trace the flows of energy, raw materials, and waste streams that were required to create, use and dispose of a product. A LCA consists of three components: (1) an inventory of wastes, emissions, and raw material and energy use associated with the entire life cycle of a product from raw material extraction to ultimate disposal; (2) an assessment of the environmental impacts associated with the wastes, emissions, and raw material and energy use; and (3) an improvement analysis where mechanisms for reducing adverse environmental impacts are sought.

2.3.2 Mesoscale P2

Once the targets have been determined from macroscale P2 studies, the design of cleaner processes and products can begin, this can be classified as mesoscale P2. At this level the issue of most importance is to adopt appropriate techniques for specific industrial process or even for unit operations based on the systematic analysis of waste audits and emission inventories. These P2 techniques include:

- equipment or technology modification;
- process optimization;
- reformulation or redesign of products;
- improvements in housekeeping, maintenance, training, or inventory control;
- increased efficiency in use of energy, water and raw materials.

2.3.3 Microscale P2

The former two levels of P2 are at the level and on the scale of entire industry sectors. While these process changes have been characterized as macro- or mesoscale, many of the approaches that have been described rely on a molecular-level understanding of chemical and physical processes.

For example, the synthesis of new catalysts that result in higher reaction yields and less wastes relies on an understanding of surface chemistry. The design of highly selective separation technologies relies on an understanding of adsorption and thermodynamics. The minimization of nitrogen oxide pollutants relies on an understanding of combustion physics and chemistry. In recent years, wide-ranging studies are contributing to a molecular-level redesign of some products and processes, such as systematically designing a substitute material with quantitative structure–activity relationship (QSAR)—a technique based on group contribution theory. Another example is molecular-level reaction pathway synthesis for reducing the use of toxic precursors and reducing the formation of unwanted by-products. Though there are currently still significant limitations to this field, it nonetheless shows promise in the systematic identification and evaluation of possible synthesis routes.

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Bibliography

A.H. Verschoor, L. Reijnders.(2000). *Toxics Reduction in Ten Large Companies, Why and How*. Journal of Cleaner Production. 8. 69–78. [This paper describes a survey of ten large companies. It explains why and how companies are reducing toxics (release and use) and to what extent they fulfil the requirements mentioned for substantial reduction of toxics.]

A.H. Verschoor, L. Reijnders.(2001). *Toxics reduction in processes. Some practical examples*. Journal of Cleaner Production, 9. 277–286. [This paper analyzes five cases of process modifications given by companies as examples of toxics reduction and concluded that to achieve toxics reduction, companies should develop a strategy, a program, goals and an evaluating procedure (which should also evaluate the risks)]

American Petroleum Institute (API). *Environmental Design Considerations for Petroleum Refining Crude Processing Units*. Publication 311, Feb. 1993. [This presents the definition of pollution prevention by the Pollution Prevention Task Force of the American Petroleum Institute]

D.T. Allen, K.S. Rosselot. (1997). *Pollution Prevention for Chemical Process*. Third Avenue, NY: John Wiley & Sons, Inc. [This presents the waste management hierarchy according to the provisions of the American Pollution Prevention Act of 1990]

Gottlieb R. ed. (1995). *Reducing toxics: A new approach to policy and industrial decision making*. Washington, DC: Island Press. [This presents one definition of pollution prevention]

P. Lecomte.(1999). *Polluted Sites: Remediation of Soils and Groundwater*. Brookfield, VT: A.A. Balkema Publishers. [This paper present a classification of techniques available in the environmental market, into five groups of methods]

Rich G. (1987). *Hazardous Waste Treatment Technologies: The choice Is Yours*. Pollu. Eng., 19(4). 71. [This paper tabulated efficacy data for representative treatment techniques: physical methods, chemical methods, thermal methods, biological methods]

Society of Environmental Toxicology and Chemistry (SETAC).(1991). *A Technical Framework for Life-Cycle Assessments*. SETAC Foundation for Environmental Education, Inc., Washington, DC. [This presents the technical framework of life-cycle assessment consisting three main components]

Wiley, C.(1998). *Pollution Prevention: It's Good Business*. Reinforced Plastics. 42(10), 26-27, 29-30. [This paper details the technologies available to help manufacturers to prevent waste before it is generated, and helps manufacturers to reduce costs and avoid future liabilities]

Biographical Sketches

Dr. Jun Huang is a postdoctoral researcher in the Department of Chemistry, Tsinghua University. He received an M.S. (2000) in environmental science from Nanjing University of Science and Technology and a Ph.D. (2004) from the Department of Environmental Science and Engineering, Tsinghua University. His current interests focus on analytic methods and behavior of persistent organic pollutants.

Dr. Gang Yu is a Professor and the Deputy Head, Department of Environmental Science and Engineering, Tsinghua University, Beijing, China. He received an M.S. (1989) degree in Environmental Chemistry from Nanjing University and a Ph.D. (1992) in Environmental Chemistry from the Research Center of Eco-environmental Science, Chinese Academy of Science. His current interests focus on persistent organic pollutants, including analytical methods, behavior in multiple media, disposal technology, remediation technology, and control strategy.