Chapter 1

Green Engineering: Introduction

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The field of engineering, especially chemical engineering, has led the development of environmental technology over the past two generations. The design and implementation of a wide range of treatment and control technologies ranging from smoke-stack scrubbers to water effluent treatment facilities has resulted in dramatic improvement in the quality of the air, water and land, especially in the past thirty years. As the approaches to environmental protection evolved to include pollution prevention, chemical engineering once again produced a wide range of technologies and process changes that allowed, not only the chemical industry, but all industrial sectors that use chemical processes to reduce pollution at the source. This again, resulted in large measurable reductions in releases of toxic substances to the environment.

Today, as environmental protection is continuing to evolve, chemical engineering is once again responding with the innovation and ingenuity that has become a tradition in this field for addressing environmental issues. *Green Engineering, defined as the design of systems and unit processes that obviate or reduce the need for the use of hazardous substances while minimizing energy usage and the generation of unwanted by-products*, is the next generation of environmental protection in chemical engineering. Using the wide array of technologies developed in the past and applying them in new ways to new problems, and inventing and developing new technologies, chemical engineers are not only preventing pollution but are also creating inherently safer chemical processes by reducing the presence of hazards wherever possible.

This book presents a number of the innovations that have been developed recently in the emerging area of green engineering. The chapters of the book are derived from presentations made at the Green Chemistry and Engineering Conference

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at the National Academy of Sciences, Washington, D.C. This conference was established to highlight the cutting edge science and engineering in this field being conducted in industry, academia and government.

Over the years, the Green Chemistry and Engineering Conference has had different themes. One of those themes was "Implementing Vision 2020 for the Environment". This theme was based on the document produced by the chemical industry to provide goals for the next twenty years, entitled "Technology Vision 2020: the U.S. Chemical Industry". Throughout this document, there was a common thread that was woven throughout the goals ranging from new chemical technologies to supply chain issues and this thread was the environment. Throughout all aspects of the chemical enterprise and all of the goals outlined in the report was the recurring and overarching recognition that the environmental impact of all activities must be among the fundamental considerations.

It is because of the ubiquitous need to consider environmental issues in all parts of the chemical industry that Vision 2020 was viewed as an appropriate theme for the conference. It was recognized that the science and technology of Green Chemistry and Engineering was, in real time, implementing or beginning to implement many of the stated goals of 'Vision 2020'. By developing new separation techniques, new syntheses, new reaction processes, etc., and doing it while engaging in fundamental protection of human health and the environment, Green Chemistry and Engineering was accomplishing, or at least beginning to accomplish, those challenges outlined in 'Vision 2020'.

Another theme of a Green Chemistry and Engineering Conference was "Global Perspectives". This conference emphasized the fact that the science and engineering that are the topic of the conference know no boundaries. By featuring presentations from industry, academia, and government, the conference illustrated that Green Chemistry and Engineering is being actively pursued in both the public and private sectors. By featuring talks from disciplines ranging from organic synthesis to biology to electrical engineering and many others, it was demonstrated that this area is not limited by disciplinary bounds. The industrial sectors represented as well spanned well beyond the traditional chemical industry into electronics, pulp and paper, and pharmaceuticals, to name a few. Finally, it was shown that green chemistry and engineering know no national boundaries by representatives from eleven nations around the world taking part in the conference. Therefore, in several ways, one can see that a global perspective can be achieved through the practice of green chemistry and engineering.

Each year an organizing committee with representatives from all parts of the chemical and chemical engineering enterprise convene to construct a conference that will represent some of the most recent, innovative and topical advances in green chemistry and engineering. Those organizations, American Chemical Society, American Institute of Chemical Engineers, Chemical Manufacturers Association, Council for Chemical Research, U.S. Department of Energy, U.S. Environmental Protection Agency, National Academy of Sciences, National Research Council, National Institute of Standards and Technology, and Organization for Economic Cooperation and Development, represent a breadth of essential elements of the discovery, demonstration, and commercialization of chemical technology. The fine work presented in this volume is a tribute to the work these organizations do in promoting, encouraging, funding, supporting and catalyzing the emerging area of Green Chemistry and Engineering.

Discussion

Green Processing

Source reduction has the highest priority in the Pollution Prevention Act's waste minimization hierarchy since it aims at solving environmental problems at the roots. Effective source reduction relies on a comprehensive and deep analysis of process operations and the development of new processes that reduce and/or eliminate the inherent hazard in processes and products as well as unwanted by-products and co-products. The research and development work presented in this section contributes to greener processing in several important areas of industrial manufacturing.

In the area of coatings, Dong et al. present their work as part of a wider effort to develop a new class of water-borne coatings. They target the use of hybrid miniemulsion polymerization with acrylic monomers in the presence of alkyd and oil-modified polyurethane resins as a replacement for solvent-based coatings.

Nikles et al. contribute to pollution prevention in the magnetic tape industry. Through their work, significant progress has been made toward identifying a binder materials package that enables solventless magnetic tape manufacturing and the subsequent elimination of air pollution from this process.

Bersin of Ulvac Technologies, Inc. describes a process methodology (ENVIRO™) that contributes toward eliminating organic solvents and acids in wafer processing. This technology uses deionized water to dissolve photoresist-ashing residues after plasma etching or ion implantation.

Lou and Huang introduce a novel approach for qualitative and quantitative analyses of clean electroplating operations. Using fundamental engineering principles and practical industrial experience, they developed a computer-aided tool to facilitate effective process analysis for waste reduction in electroplating operations.

Li and Paganessi of Air Liquide address the problem of using strong greenhouse gas, perfluorocompounds, in semiconductor manufacturing. They describe the development of a patented membrane-based recycle system that can capture and concentrate more than 95% of perfluorocompounds from the process exhausts.

Green Applications of Carbon Dioxide

The environmental benefits of using CO_2 as a solvent for processing are augmented by its tunability, the ability to control properties such as solubility, miscibility, rheology, viscosity, molecular density and reactivity. These special properties result in economic benefits as well. In this section, the use of both liquid and supercritical CO_2 are described in processing applications ranging from the synthesis of chemicals and building materials to the formation of solvent-free drug coatings for pharmaceuticals.

Hâncu et al. describe the environmental and engineering benefits of using supercritical CO_2 as the sole process solvent in several combined reaction/separation processes. In each of the processes described, the use of CO_2 resulted in benefits such as increased product purity, better throughput, and reduced energy input.

Subramaniam et al. describe the benefits of using supercritical carbon dioxide ($scCO_2$) to produce drug particles and as the fluidizing medium for substrate coating. Coating with $scCO_2$ allows the use of traditional organic-soluble coatings with complete solvent recovery and virtually no atmospheric emissions.

Hobbs and Lesser describe the effects of drawing fibers of poly(ethylene terephthalate) using a two stage drawing technique. Significant impacts were obtained by drawing fibers first in liquid CO_2.

Roger Jones of Materials Technology Limited describes a manufacturing process by which carbon dioxide is recovered from flue gas, made supercritical, and used to treat pastes derived from fly ash and other dusty wastes to produce several valuable building products. Examples of these products include a lightweight roofing tile that resembles a cedar shake and fiberglass-reinforced ceramic wallboard.

Environmentally Benign Catalysis

One of the principles of Green Chemistry is that "catalytic reagents (as selective as possible) are superior to stoichiometric reagents" (*1*). The chapters in this section illustrate some of the advancements and challenges of engineering and processing using catalysts.

Chuang et al. probe the mechanism of catalysis for oxidative carbonylation as an alternative, low-pressure pathway for isocyanate synthesis that does not require the use of highly toxic phosgene. They describe catalyst screening studies and estimate the economic viability of the process.

Robert Farrauto of Engelhard Corporation discusses the promise and challenges of three catalyst-based technologies for generating power with improved fuel efficiency and decreased emissions for vehicular and stationary applications. These technologies include the lean burn gasoline and diesel internal combustion engines, the proton exchange membrane fuel cell, and stationary power generation using catalyst assisted thermal combustion.

Marcus and Cormier of PQ Corporation (Zeolyst International) describe the intensive development and commercializaton of zeolites of aluminosilicate and other compositions in diverse areas due to their process and environmental advantages. They review the properties of zeolites, and some of the "green" application areas where zeolites are being used.

Flytzani-Stephanopoulos and Zhu describe a single-stage process of catalytic reduction of SO_2 to elemental sulfur as a promising new technology. This process is better suited to handle SO_2-laden streams generated in power plants and certain industries than the conventional multi-stage Claus process.

Ribeiro and. Somorjai explore the kinetics for the hydrodechlorination of chlorofluorocarbons over model palladium catalysts. This chemistry is important in the manufacture of many new compounds that use hydrodechlorination as an intermediate step.

Separations

One area of opportunity for new chemical science and engineering technology which will help meet the goals of the U.S. Chemical Industry's *Technology Vision 2020*, and facilitate movement towards sustainability, is the development of new separations technologies that eliminate the use of flammable, toxic volatile organic compounds (VOCs) as industrial solvents. Spear et al. describe a portion of their work in the area of separation science and technology geared toward replacement of VOCs in industrial scale liquid/liquid or chromatographic separations using water-soluble polyethylene glycol polymers. They also discuss the use of air and moisture stable, water immiscible, room temperature ionic liquids.

Harten et al. at the National Risk Management Research Laboratory (NRMRL) of the U.S. Environmental Protection Agency describe new separations materials and processes for removal and recovery of VOCs and toxic metals from waste steams and industrial process streams. Such separations technologies enable process lines to more closely approach zero emission through in-process recycling and reuse of resources that would otherwise be emitted to air, water, and solid wastes.

Conclusion

The chapters in the book serve to illustrate some of the examples of green engineering that are being researched and developed in academia, as well as being developed in industry. Also recommended to the reader is an accompanying volume entitled, "Green Chemical Syntheses and Processes" that provides a complementary treatment of the area of green chemistry that works together integrally with green engineering.

Literature Cited

1. Anastas, P.T. and Warner, J.C. (1998). *Green Chemistry: Theory and Practice.* Oxford University Press, Oxford.