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The Novel Use of Green Engineering Concepts in Teaching Separations

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Abstract

Green engineering concepts can be creatively and effectively integrated into the teaching of courses in separation processes. Through the support of the US Environmental Protection Agency (EPA), a Green Engineering Project has fostered efforts to incorporate green engineering into the chemical engineering curriculum. This paper focuses on the integration of green engineering concepts into the courses in the chemical engineering curriculum that cover separation processes (distillation, extraction, absorption, membranes, etc). The paper describes how the green engineering topics are "mapped" into a separations course and presents a sample of the novel types of problems that were developed for instructor use.

Green engineering is defined as the design, commercialization and use of processes and products that are feasible and economical while minimizing: generation of pollution at the source and risk to human health and the environment. Students need to be knowledgeable of the design and use of separation processes from a green engineering perspective. Using green engineering principles at the start of the design process can lead to processes and products of a sustainable future. Through the use of in-class examples, cooperative learning exercises, case studies and homework assignments, students can be learn these concepts without the faculty member using substantial additional class time.

Introduction

Green engineering was originally defined by the EPA as the design, commercialization and use of processes and products that are feasible and economical while minimizing: generation of pollution at the source and risk to human health and the environment [1]. In a recent conference this definition of green engineering was more broadly defined as transforming *existing engineering disciplines and practices to those that lead to sustainability. Green Engineering incorporates development and implementation of products, processes, and systems* *that meet technical and cost objectives while protecting human health and welfare and elevating the protection of the biosphere as a criterion in engineering solutions* [2]. As a result of this conference, nine green engineering principles were developed which engineers should follow to fully implement green engineering solutions:

1. Engineer processes and products holistic, systems thinking, and environmental impact assessment tools.
2. Conserve and improve ecosystems and human health and well-being.
3. Use life cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. Minimize depletion of natural resources.
6. Strive to prevent waste.
7. Develop and apply engineering solutions, being cognizant of local geography, aspirations and cultures.
8. Do not be limited by current or dominant technologies; seek fundamental and incremental change.
9. Create awareness in and engage communities and stakeholders.

In addition to these principles the conference participants felt strongly that there is a duty to inform society of the practice of green engineering. These principles were based in part on a previous paper giving 12 green engineering principles and examples of their use [3].

The need to introduce green engineering concepts to undergraduate students has become recognized to be increasingly important [4]. The U.S. Engineering Accreditation Commission - Accreditation Board for Engineering and Technology (ABET) chemical engineering program criteria require the incorporation of *safety and environment aspects* into the curriculum. Additionally all engineering students must have an *understanding of professional and ethical responsibility*. Students must demonstrate the *broad education necessary to understand the impact of engineering solutions in a global and societal context*. Programs must have a *major design experience incorporates engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political* [5].

Major chemical companies [6] such as DuPont [7], BP [8], Dow [9], Merck [10], Rohm & Haas [11] have adopted a green approach to move toward a sustainable future. In addition, professional organizations have taken up issues in sustainable development such as American Institute of Chemical Engineers Institute for Sustainability [12] and the Center for Waste Reduction Technologies [13] the American Chemical Society [14] and the Chemical Industry Council Responsible Care program [15]. A secondary factor in this drive is the news coverage given to governmental solutions to world environmental issues.

The most common method to introduce green engineering has been through a senior/graduate level elective course on environmental engineering, with emphasis on *end of the process* treatment. Courses have been developed that focus on methods to minimize or prevent waste streams from exiting chemical plants. These trends mirror those in industry, in which initial efforts were applied to waste treatment after the design work had been completed. Using green engineering principles not only are waste stream flows minimized, but the types of chemicals used in the process are examined to reduce their harm to humans and the environment. Efforts are now underway to incorporate aspects of green engineering throughout the curriculum.

In 1998 the Environmental Protection Agency initiated a program in green engineering to develop a text book on green engineering; disseminate these materials and assist university faculty in using these materials through national and regional workshops coordinated with the American Society for Engineering Education (ASEE), Chemical Engineering Division. The textbook developed titled, "Green Engineering: Environmentally Conscious Design of Chemical Processes" [16] by Allen and Shonnard is a designed for both a senior and graduate chemical engineering course and has a series of accompanying modules that can be employed throughout the curriculum. The book is divided into three major sections: 1) Chemical Engineer's Guide to Environmental Issues and Regulations 2) Environmental Risk Reduction for Chemical Processes 3) Moving Beyond the Plant Boundary. For more information on the Green Engineering text see http://www.epa.gov/opptintr/greenengineering/textbook.html. Current efforts are underway to integrate green engineering concepts throughout the curriculum through the development of instructor guides, case studies, homework problems and in-class examples for various chemical engineering courses [17, 18]. This paper describes the efforts to incorporate green engineering into a separation processes course.

Green Engineering in a Separation Processes Course

Separation process topics covered can be applied in a green engineering way in an overall role in pollution prevention such as in the reduction of byproducts, waste minimization, emissions reduction, etc. The choice of the proper mass-separating agent from a green engineering standpoint for the particular industrial separation is a key criteria to be presented. Ultimately a separation course should present sound rationale for the "green" integration of separation technologies in a reuse/recovery mode where valuable material(s) may be recovered and reused in the overall process. These approaches should be applied in the discussion of design and application of the various separation methods to the system being purified, fractionated or concentrated. Separation processes courses also need to encompass a broad range of both traditional and novel unit operations such that a student can see the pros and cons in their application from a green engineering standpoint.

A series of problems were developed to accompany an instructor in a chemical engineering Separation Processes course who intends to integrate concepts of Green Engineering. The materials are developed around the "Green Engineering" text and can be used with any of the texts covering separation processes or mass transfer operations.

These problems can be used to accompany courses teaching separation processes in various courses. Some schools teach these topics in a Mass Transfer course covering some of the traditional separation processes of distillation, absorption, and extraction. At many schools these equilibrium staged processes are frequently grouped together in a course with suitable name. The problems can also be used to supplement courses in advanced separations or rate-controlled separations. Such as the membrane based operation problems developed for this module. Regardless of the type of course, text used, or curricular level, this module presents problems in many of the separation processes that can readily be integrated.

At Rowan a two semester sequence of separations courses are taught with the first being equilibrium staged (distillation, extraction, absorption, etc) and the second rate controlled (reverse osmosis, ultra/microfiltration, adsorption, crystallization, etc). When each of these processes is discussed a particular problem or case study can be employed showing an application for material recovery/reuse or related pollution prevention. For example, reverse osmosis applications in pollution prevention, reuse/recovery and mass integration in a variety of manufacturing processes can be described. Reverse osmosis use in electroplating industry to recover and reuse purified water and recover and reuse concentrated plating metals is an excellent example from an environmental and economic standpoint since both separated streams can be reused. For a more advanced topic, students can investigate the integration of a novel technology, membrane pervaporation, with a traditional separation, distillation, in azeotropic separation. A good design case here is replacing the entrainer benzene in ethanol-water separation with the pervaporation technique, since the potential release of benzene in the environment is removed. In the above cases, students can perform calculations to quantify the environmental improvements.

The problems can be used for in-class examples, cooperative learning exercises, homework or exam problems. The way the problems are grouped are by the separation process described. One to two problems have been developed for each separation process and the majority have multiple parts. Most require a quantitative solution, while others combine both a process theory, application, or design calculation with a subjective or qualitative inquiry. The problems take a topic from a particular separation process and then find a green engineering application or green engineering analog. The problem heading indicates the sections of the Green Engineering text that the material refers to. To view the full problem set with solutions, the reader is referred to http://www.rowan.edu/greenengineering.

It is envisioned that the instructor covering a particular separation process topic, like liquid-liquid extraction column calculations, would be presenting some in-class examples or cooperative learning exercise. Instead of a generic type calculation that has no green engineering significance, the instructor could use the problem developed in this module. Not only would the student get the active experience of solving a concentration type problem, but a new concept from the Green Engineering text can be introduced. In this case, the student would learn about the concept of how a separation process is used in the reuse and recovery of materials (process mass integration) in a chemical manufacturing plant. Most of the problems are written in way to introduce this concept to the student taking information from the Green Engineering text so that additional lecture activity on the green engineering topic is not needed. Although the instructor may wish to review the Green Engineering text section beforehand or assign reading of sections to students to accompany the problem.

If the problems are assigned as homework exercises, then the instructor can provide additional green engineering commentary in reviewing the solutions with the students. Alternately, the instructor may require the student to do additional reading from the green engineering text to accompany the homework exercise. It is encouraged that the instructor actively engage students in the learning process for both separation process concepts as well as the green engineering materials. The instructor may decide to use a selection of the problems developed in this module and mix them with other more general problems as listed or use all of the problems in the module.

In some problems, additional questions are asked that require the student to investigate the literature, go to a web site, or perform a more qualitative analysis of the problem. For example, the student may need to go to an EPA web site to determine potential hazards related to the release of the chemical being separated or find more environmentally benign solvents to use in the operation.

All of the problems have worked-out solutions and are set-up in an easy to follow way with units and calculations shown at all steps of the solution. The instructor can easily change the problems from year to year by changing process parameter values or chemical mentioned.

Instructor guides are provided to map topics from the Green Engineering Text to the various separation process topics. These are presented in tabular form for easy instructor use. Materials from the Green Engineering text are used in solutions and are referenced by the section number designated in the problem heading.

For more information on the EPA Green Engineering project the instructor is referred to the following web sites:

http://www.rowan.edu/greenengineering

http://www.epa.gov/opptintr/greenengineering/index.html

Additional materials from Drs. Allen and Shonnard that have been used at EPA supported workshops are available at http://www.epa.gov/opptintr/greenengineering/workshops.html.

Green Engineering Text Mapping to a Separation Processes Course

The following tables provide an instructor's guide showing the "Green Engineering" text (Shonnard and Allen) chapter by chapter and mapping of topics taught in a Separation Processes course covering various topics.

Table 1

Green Engineering Text Chapter	Green Engineering Concept	Separation Process Topic	Method to incorporate Green Engineering concepts
1.2	Role of ChE in assessing potential environmental impacts of product and process changes	Intro	Introduction to separation processes to show the role of ChE job related to green engineering and why knowledge of separation processes is important in process engineering.
1.5	Air quality issues	Intro	Discuss the sources of air pollution and how separation processes play a major role in reducing criteria air pollutants and air toxics.
1.6	Water quality issues	Intro	Discuss the issues related to groundwater and surface water contamination and how separation processes can be utilized.

1.9	Waste flows in the environment	Intro	Discuss the overall issue of waste generation and classification in industry and how separation processes play a major role in material recovery and waste minimization.

Table 2

Green Engineering Text Chapter	Green Engineering Concept	Separation Process Topic	Method to incorporate Green Engineering concepts
2.5	Risk assessment concepts for chemical exposure	Intro	Discuss the level of contamination associated with various chemicals which will show why separation processes are needed to reduce the levels of chemicals in the workplace or environment.

Table 3

Green Engineering Text Chapter	Green Engineering Concept	Separation Process Topic	Method to incorporate Green Engineering concepts
3.1 3.2 3.3	Environmental laws regulations	Intro Or any Process	During the introductory materials a discussion on how some applications of separation processes are regulatory driven. This may also be presented in a particular separation topic.
3.4	Pollution prevention concepts and terminology	Intro Or any Process	Discuss how separation processes are used in source reduction, in-process recycle, on-site recycle, off-site recycle, waste treatment, and direct release into the environment.
3.4 (and specifically Figs 3.4-1, 3.4-2, 3.4-3)	Pollution prevention concepts and terminology – 7 elements of waste management hierarchy	Intro	Use each of the figures mentioned about the "elements of waste management hierarchy" as example "box" diagrams that represent single-unit processes, multiple-unit processes, recycle processes, reaction w/ recycle processes as related to separation processes.

Table 4

Green Engineering Text Chapter	Green Engineering Concept	Separation Process Topic	Method to incorporate Green Engineering concepts
4.1	Roles and responsibilities of ChE's in environmentally conscious design and operation of chemical processes	Intro	Incorporate material into Intro by discussing ChE roles in selecting, designing and optimizing separation processes for the environment and responsibility to both employer and the public at large.
4.3; 4.4	Responsibilities for environmental protection and ethical issues	Intro	Incorporate material into Intro by discussing roles in designing separation processes for the environment and responsibility to both employer and the public at large.

Table 5

Green Engineering Text Chapter	Green Engineering Concept	Separation Process Topic	Method to incorporate Green Engineering concepts
5.2.1	Boiling point estimation	Distillation	Include the boiling point estimation in a distillation problem on flash distillation.
5.2.1	Melting point estimation	Crystallization	Include the melting point estimation technique in a crystallization problem
5.2.2	Vapor pressure of and chemical partitioning	Distillation	Discuss how vapor pressure is important in separation process design from distillation to condensation. A calculation of a solvent recovery operation can be used showing the use of the Antoine equation.
5.2.3	Octanol-water partition coefficient	Extraction	When discussing liquid-liquid extraction processes, show how there are various ways to describe organic transport between two liquid phases. The use of octanol-water partition coefficients unique role in modeling water-organic phase transport can be described.
5.2.5	Saturation concentrations in aqueous systems	Crystallization Extraction	The water solubility of chemicals can be used in showing the extent necessary for liquid-liquid extraction and crystallization operations.
5.2.6	Henry's law constant in describing chemical transport	Absorption	In the discussion of Absorption systems, the used of Henry's law and the Henry's law constant, (Table 5.2-12) that shows the classification criteria for organic partitioning between air-water phases and how this is used in environmental calculations.
5.2.7	Soil sorption coefficients in environmental partitioning	Adsorption	When adsorption on solid surfaces is presented an example on adsorption of organic contaminants from liquids onto soil can be used as the example.

Table 6

Green Engineering Text Chapter	Green Engineering Concept	Separation Process Topic	Method to incorporate Green Engineering concepts
6.2	Occupational exposure: recognition, evaluation and control	Intro Or any Process	This topic can be presented in the course Intro when the need for separation processes to reduce the concentration of undesired contaminants in the workplace. This topic can also be used with other Separations Topics such as their use in a manufacturing facility to separate a contaminant from laboratory/workplace environment (e.g., membrane process to reduce organic solvent vapors in air)

6.3	Exposure assessment for chemicals in the ambient environment	Intro Or any Process	This can be incorporated into the Intro when the role of separation processes in the reduction of chemical contaminants in the environment is mentioned. This topic can also be integrated into any specific separation topic such as the use of absorbers to reduce air pollutant emissions from a power plant.

Table 7

Green Engineering Text Chapter	Green Engineering Concept	Separation Process Topic	Method to incorporate Green Engineering concepts
7	Green chemistry	Not Applicable	

Table 8

Green Engineering Text Chapter	Green Engineering Concept	Separation Process Topic	Method to incorporate Green Engineering concepts
8.2.3	Threshold Limit Values, Permissible Exposure Limits, Recommended Exposure Limits	Any Process	The concept of Threshold Limit Value, Permissible Exposure Limits, and Recommended Exposure Limits can be integrated into a specific separation process topic in describing how the separation process is used to reduce the concentration of the contaminant in the environment.

Table 9

Green Engineering Text Chapter	Green Engineering Concept	Separation Process Topic	Method to incorporate Green Engineering concepts
9.4	Pollution prevention for separation processes	Absorption	The process of absorption can be profiled for its role in pollution prevention. Particular design heuristics and applications to particular industries or separations cases for green engineering design can be included. Table 9.4.3 from GE can be used as a discussion point when a particular unit operation is used in a problem.
9.4	Pollution prevention for separation processes	Crystallization	The process of crystallization can be profiled for its role in pollution prevention. Particular design heuristics and applications to particular industries or separations cases for green engineering design can be included. Table 9.4.3 from GE can be used as a discussion point when a particular unit operation is used in a problem.
9.4	Pollution prevention for separation processes	Extraction	The process of extraction can be profiled for its role in pollution prevention. Particular design heuristics and applications to particular industries or separations cases for green engineering design can be included. Table 9.4.3 from GE can be used as a discussion point when a particular unit operation is used in a problem.

9.4	Pollution prevention for separation processes	Leaching	The process of leaching can be profiled for its role in pollution prevention. Particular design heuristics and applications to particular industries or separations cases for green engineering design can be included. Table 9.4.3 from GE can be used as a discussion point when a particular unit operation is used in a problem.
9.4	Pollution prevention for separation processes	Washing	The process of washing can be profiled for its role in pollution prevention. Particular design heuristics and applications to particular industries or separations cases for green engineering design can be included. Table 9.4.3 from GE can be used as a discussion point when a particular unit operation is used in a problem.
9.4	Pollution prevention for separation processes	Distillation	The process of distillation can be profiled for its role in pollution prevention. Particular design heuristics and applications to particular industries or separations cases for green engineering design can be included. Table 9.4.3 from GE can be used as a discussion point when a particular unit operation is used in a problem.
9.4	Pollution prevention for separation processes	Ultrafiltration	The process of ultrafiltration can be profiled for its role in pollution prevention. Particular design heuristics and applications to particular industries or separations cases for green engineering design can be included. Table 9.4.3 from GE can be used as a discussion point when a particular unit operation is used in a problem.
9.4	Pollution prevention for separation processes	Reverse Osmosis	The process of reverse osmosis can be profiled for its role in pollution prevention. Particular design heuristics and applications to particular industries or separations cases for green engineering design can be included. Table 9.4.3 from GE can be used as a discussion point when a particular unit operation is used in a problem.
9.4	Pollution prevention for separation processes	Gas Permeation	The process of gas permeation can be profiled for its role in pollution prevention. Particular design heuristics and applications to particular industries or separations cases for green engineering design can be included. Table 9.4.3 from GE can be used as a discussion point when a particular unit operation is used in a problem.
9.5	Pollution prevention for separative reactors	Any Process	If the course is taught in conjunction with or following Chemical Reaction Engineering this topic would be suitable for inclusion.
9 Prob 1	Leaching process solvent selection	Leaching	This is an interesting problem in selecting a more environmentally benign solvent for leaching caffeine from coffee beans.
9 Prob 3	Energy efficiency in multiple separation processes	Extraction Distillation	This problem looks at the energy efficiency of using a process combining extraction and distillation.

Table 10			
Green Engineering Text Chapter	**Green Engineering Concept**	**Separation Process Topic**	**Method to incorporate Green Engineering concepts**
10.3 (Fig 10.3-3 and 10.3-8)	Process mass integration	4.7 10	Process mass integration can be incorporated into the overall mass balance on multiple separation processes and with computer-aided balance calculations. Show for example, GE Fig. 10.3-3 and 10.3-8, and do a balance with this process comparing the conventional manufacturing operation and that using water integration. Some complex optimization calculations can be performed on various separation processes although this topic may be more appropriately taught in a process/plant design course.

Table 11			
Green Engineering Text Chapter	**Green Engineering Concept**	**Separation Process Topic**	**Method to incorporate Green Engineering concepts**
11.3	Environmental fates of emissions	10	Computer-aided balance calculations can be used to show how to combine rates of input and output of emissions, bulk transport, etc in an overall process and how separation processes can be employed.

Table 12			
Green Engineering Text Chapter	**Green Engineering Concept**	**Separation Process Topic**	**Method to incorporate Green Engineering concepts**
12	Environmental cost accounting	Not Applicable	

Table 13			
Green Engineering Text Chapter	**Green Engineering Concept**	**Separation Process Topic**	**Method to incorporate Green Engineering concepts**
13	Life-cycle analysis	Not Applicable	

Table 14			
Green Engineering Text Chapter	**Green Engineering Concept**	**Separation Process Topic**	**Method to incorporate Green Engineering concepts**
14	Industrial ecology	Intro Or Any Process	Applicable to overall manufacturing processes – looking at overall material and energy flows and how separation processes are employed.

Example Separation Process Problem

The following is an example of a problem and solution developed for Reverse Osmosis processes that maps to Green Engineering chapter 9.4.

Problem

Separation processes can play a key role in pollution prevention when employed in a recovery and reuse mode so that valuable components of a waste stream can be reused in the process for mass integration and provide economic benefits to the corporation. Recovery of these materials also lessens the burden on the environment. The use of reverse osmosis in recovering precious metals from a metals finishing plant is being examined for a future plant upgrade.

A new reverse osmosis membrane, CSS04, is to be evaluated for use in the separation of a process waste stream that has a total dissolved silver concentration of 27,525 mg/l and is at the temperature of 25 °C. The goal is the recovery of a silver concentrate stream and a purified water stream; both for reuse and economic savings. The density and viscosity of the waste stream may be considered that of water. A lab test employing a small rectangular membrane cell that accommodates rectangular membrane sheets measuring 4.3 cm x 11.0 cm was used in the studies. The cell holds one membrane sheet and operates using a cross-flow configuration. The applied pressure gradient measured across the membrane (feed side to permeate side), ΔP, was maintained at 750 psi. Feed flow rate to the unit was kept constant at 1.40 liters/min. The following results were obtained.

Permeate flow rate: 32.7 ml/min

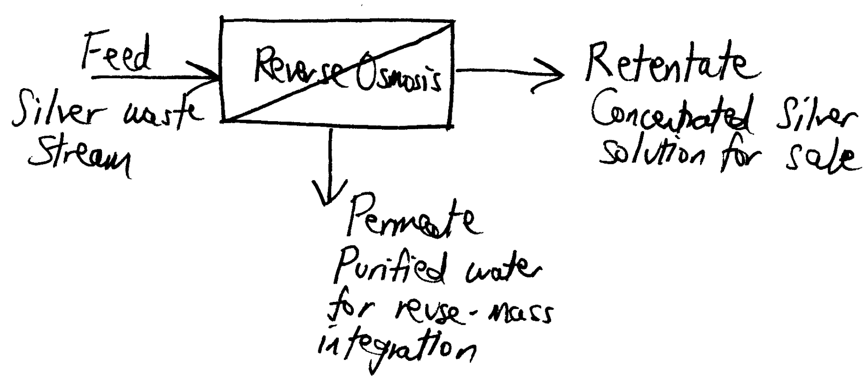
Permeate solute concentration: 287.5 mg/l

Assume no concentration polarization or fouling and that the feed concentration is kept constant with operating time. The following relationship exists for the osmotic pressure and solute concentration of the waste stream, $\pi_i/c_i = 0.0134$ *psi/(mg/l).*

Determine the following:

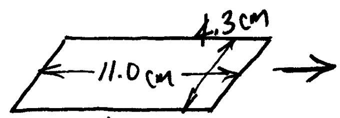
a) Solvent flux (kg/m^2*hr)*
b) Solvent permeability coefficient (kg/m^2*hr-psi)*
c) Solute flux (kg/m^2*hr)*
d) Solute permeability coefficient (m/hr)

Solution



New membrane, CSS04, tested

$Q_F = 1.40$ L/min
$C_F = 27{,}525$ mg/l



$\Delta P = 750$ psi

$Q_p = 32.7$ ml/min
$C_p = 287.5$ mg/l

$\pi/C = 0.0134$ psi/(mg/l)

Area = (4.3 cm)(11.0 cm) = 47.3 cm²

a) $$J_w = \frac{Q_p}{Area} = \frac{\left(\frac{32.7\ ml}{min}\right)\left(\frac{cm^3}{ml}\right)\left(\frac{1.0\ g}{cm^3}\right)\left(\frac{kg}{1000\ g}\right)\left(\frac{60\ min}{hr}\right)}{\left(47.3\ cm^2\right)\left(\frac{m}{100\ cm}\right)^2}$$

$$J_w = 414.8\ kg/m^2 hr$$

b) $$A_w = \left(\frac{J_w}{\Delta P - \Delta\pi}\right)$$

$$A_w = \frac{414.8\ kg/m^2 hr}{\left[750\ psi - 0.0134\ \frac{psi}{mg/l}\left(27{,}525 - 287.5\ mg/l\right)\right]}$$

$\underbrace{\quad}_{364.98\ psi}$

$$\boxed{A_w = 1.077\ kg/m^2 \cdot hr \cdot psi}$$

c) $$J_s = \frac{J_w C_p}{C_w} = \frac{\left(414.8\ \frac{kg}{m^2 hr}\right)\left(287.5\ \frac{mg}{l}\right)}{\left(10^6\ \frac{mg}{l}\right)}$$

$$\boxed{J_s = 1.193 \times 10^{-1}\ kg/m^2 hr}$$

d) $$J_s = B_s\, \Delta C$$

$$B_s = \frac{J_s}{\Delta C} = \frac{1.193 \times 10^{-1}\ kg/m^2 hr}{\left(27{,}525 \frac{mg}{l} - 287.5 \frac{mg}{l}\right)\left(\frac{kg}{10^6 mg}\right)\left(\frac{1000\ l}{m^3}\right)}$$

$$\boxed{B_s = 4.38 \times 10^{-3}\ \frac{m}{hr}}$$

Assessment and Future Plans

The Rowan initiatives have been assessed in several ways. We have used course evaluations with specific questions, student focus groups (drawn across the four years), senior exit interviews, alumni surveys, employer/internship surveys and student portfolio reviews. Our broad goals are program assessment (for ABET) and assessment for specific curriculum initiatives and projects like this one. We have had very positive responses from students related to green engineering curriculum initiatives. For example, a student focus group indicated that environmental issues were being covered very well in our engineering clinics, but they would like to see more in other courses. This helped confirm our more thorough course integration plans as mentioned above. Assessment of student portfolios in our "capstone" senior plant design course indicated that students were quite capable of designing a process by incorporating engineering standards and realistic constraints that include economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political considerations.

Future plans are to have modules developed for various chemical engineering courses and disseminate them through the web site (http://www.rowan.edu/greenengineering). This web site is developed for both student and faculty use to provide news and updates on EPA and Green Engineering activities, software, and provide information on the student paper competition.

Conclusions

The engineer, as the designer of products and processes, also has a central role in designing chemical processes that have a minimal impact on the environment. We as educators can prepare our students to use the risk assessment tools of green engineering to design new processes and modify existing processes. As a result, green engineering could become a central component of a separation processes course. A mapping of green engineering topics to a separations course shows many topics can be included. Our student assessment results have been very positive and show that integrating green engineering concepts leads to enhanced student preparation in this important area.

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Biographic Sketches

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Robert P. Hesketh is Professor of Chemical Engineering at Rowan University. He received his Ph.D. from the University of Delaware and B.S. from the University of Illinois. Dr. Hesketh has made significant contributions to the development of inductive teaching methods and innovative experiments in chemical engineering. He has done research in the areas of reaction engineering, process engineering and combustion kinetics. He is the recipient of the 2002 Robert G. Quinn Award, 2001, 1999 and 1998 Joseph J. Martin Award, 1999 Ray W. Fahien Award, and 1998 Dow Outstanding New Faculty Award.

Mariano J. Savelski is Assistant Professor of Chemical Engineering at Rowan University. He received his Ph.D. from the University of Oklahoma and B.S. from the University of Buenos Aires. His research is in the area of process design and optimization with over seven years of industrial experience. He has applied his expertise to food processing and green engineering technologies. He is the recipient of the 2000 Lindback Foundation Faculty Award.

Stephanie Farrell is Associate Professor of Chemical Engineering at Rowan University. She received her Ph.D. from the New Jersey Institute of Technology, M.S. from Stevens Institute of Technology and B.S. from the University of Pennsylvania. Dr. Farrell has developed innovative classroom and laboratory materials in biomedical, food, and pharmaceutical engineering areas. She is the recipient of the 2003 ASEE Middle Atlantic Section Outstanding Teaching Award, 2002 Ray W. Fahien Award, 2001 Joseph J. Martin Award, and 2000 Dow Outstanding New Faculty Award.

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