Expanding the Frontiers in Green Engineering Education

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Abstract

"Greening" the engineering curriculum is an important consideration for sustainable engineering education from fundamentals to design in the 21st century. This paper describes the latest advances in an educational project sponsored by the United States Environmental Protection Agency to integrate green engineering principles into the chemical engineering curriculum. This project has engaged faculty from engineering schools across the country to develop web-based instructional modules to allow for the seamless integration for green engineering principles such as risk concepts, green chemistry, mass and energy integration, life-cycle assessment into chemical engineering courses. Currently, faculty have contributed to chemical engineering core courses from material and energy balances to plant design. In addition, faculty have developed modules for multidisciplinary offerings such as freshman-level introduction to engineering and upper-level system dynamics and control. This paper will review some of the innovative modules developed and show how they can be used in the chemical engineering curriculum. This educational project's goal is to integrate green engineering concepts horizontally and vertically into the curriculum by taking existing courses and integrating topics as appropriate through examples, problems and case studies. Using green engineering principles at the start of the design process can lead to processes and products of a sustainable future.
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Introduction

The EPA originally defined green engineering as the design, commercialization and use of processes and products that are feasible and economical while minimizing the generation of pollution at the source and also minimizing risk to human health and the environment [1]. The definition of green engineering was more broadly defined in a recent conference. This definition of green engineering is 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]. Nine green engineering principles were developed as a result of this conference. Engineers should follow these principles to fully implement green engineering solutions:

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting 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, while being cognizant of local geography, aspirations and cultures.
8. Create engineering solutions beyond current or dominant technologies; improve, innovate and invent (technologies) to achieve sustainability.
9. Actively engage communities and stakeholders in development of engineering solutions.

A logical method for engineering professors to inform society is to first teach their students this subject in the classroom. Engineering students who are taught how to incorporate green engineering into their work, will help its implementation in industry and this will lead us to a sustainable future for all.

Strategy for Teaching Green Engineering

The need to introduce green engineering concepts to undergraduate students has become recognized to be increasingly important [3] The need to introduce green engineering concepts is being driven in part in the USA by its Engineering Accreditation Commission Accreditation Board for Engineering and Technology (ABET) criteria 2000. In Criterion 4 – Professional Component it states that "students must be prepared for engineering practice through the curriculum culminating in a major design experience … incorporating engineering standards and realistic constraints that include … economic, environmental, sustainability, manufacturability, ethical, health and safety, social and political." Discipline specific criteria, such as in chemical engineering, further specify that engineers must have "safety and environmental aspects" included in the curriculum.

Major chemical companies have adopted a green engineering approach to achieve a sustainable future. This is a more significant driver for teaching green engineering to students. Many of their future employers in the chemical industry have moved toward a sustainable future. Many of these companies are members of the Dow Jones Sustainability Index (DJSI) World & DJSI STOXX which totals 300 companies from 22 countries and was launched in 1999 [4]. For example, the leaders in chemicals, energy and food & beverages, industrial goods & services, non-cyclical goods & services sectors in 2004 were DuPont, BP, Unilever, 3M, Procter & Gamble, respectively[5].

The traditional and probably most common method of introducing aspects of green engineering has been through a senior and graduate level elective course on environmental engineering, with an emphasis on process treatment. Courses were developed that focus on methods to minimize or prevent waste streams from existing chemical plants in the 1990's. The educational progression mirrors the progression in industry. In industry initial efforts were applied to waste treatment whereas current efforts are aimed at reducing the total volume of effluent treated as well as the nature of the chemicals treated. Currently, many of the environmental and pollution prevention courses have been replaced by courses in green engineering, environmentally conscious chemical process engineering, and engineering for sustainable development. These courses are typically offered during the senior year and are optional engineering courses. These stand-alone courses are excellent in providing detailed coverage of the subject and are needed in the engineering curriculum. Students may get the impression that green engineering is either optional or something done at the end of the design process, since this course is usually both optional and at the end of their undergraduate education. Students may also get the impression that only one professor, the one currently teaching the course, knows about this subject matter which reduces the importance of this subject in the students mind.

A better method is to introduce these concepts throughout the curriculum [6]. This would better emphasize that engineers should be using green engineering and sustainability throughout the design process. Implementing this integrated approach, in which students see green engineering throughout their 4 years of engineering. This approach shows the high importance of this subject to the students and reinforces the need to employ this subject in industry. The faculty may agree to add this material, but its coverage becomes diluted and sporadic throughout the curriculum which is a drawback. Both of these methods of education should be encouraged and further development is needed.

In 1998 a program was initiated with funds from the Environmental Protection Agency. This program initiatives in green engineering were 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 titled, "Green Engineering: Environmentally Conscious Design of Chemical Processes" [7] by Allen and Shonnard was a designed for both a senior and graduate chemical engineering course and has a series of accompanying materials that can be employed throughout the curriculum. Efforts are currently underway to integrate green engineering concepts throughout the curriculum. These efforts include the development of instructor guides, case studies, homework problems and in-class examples. These green engineering course modules are the subject of this paper and can be found on the green engineering web site (www.rowan.edu/greenengineering) [8].

Curriculum Integration

One such example is Rowan University's chemical engineering program which has integrated green engineering starting in the freshman year and continuing through the senior year. We believe that green engineering concepts can be readily coupled with what is currently being taught in a chemical engineering curriculum. In the freshmen year at Rowan University starts with multidisciplinary projects [9] and case studies utilizing aspects of green engineering. During the sophomore year the chemical engineering students are required to purchase the Allen and Shonnard text [7] and use this in conjunction with all of their chemical engineering courses and with their projects. In Rowan University's multidisciplinary sophomore engineering clinic all engineering students participate in projects related to green engineering [6]. A summary of where green engineering activities can be incorporated into a chemical engineering curriculum is given in Table 1.

Faculty from schools has developed various materials for courses across the country (which are described in the next section). These materials and modules are available on-line (www.rowan.edu/greenengineering) as part of the ASEE/EPA initiative underway at Rowan University [8]. The goal of the initiative at Rowan University is to provide materials that can be readily adapted to currently existing courses. The materials that are provided consist of instructor guides to assist in mapping green engineering topics into various chemical engineering courses and provide homework problems, in-class examples and case studies for faculty to use. Green engineering modules prepared for core courses are available online. The site is password protected. Students do not have access to the homework problem solutions, but have access to the problem statements.

Table 1: Integration of Green Engineering in the Chemical Engineering Curriculum

Chemical Engineering Course	Green Engineering Topic
Freshman Engineering Clinic	Green Engineering Project Drip Coffee Maker Introduction to Environmental Regulations Introduction to Life Cycle Assessment
Sophomore Engineering Clinic	Life Cycle Assessment of a Product Environmental Regulations
Material & Energy Balances	Emissions Terminology/Calculations "Green" Material and Energy Balances
Mass Transfer/Equilibrium Stage Separations	Mass Separating Agent Risk Assessment
Material Science	Estimation of properties Life cycle assessment
Heat Transfer	Introduction to Heat Integration
Chemical Thermodynamics	Estimation of Chemical Properties
Separation Processes	Pollution Prevention Strategies Novel "Green" Separation Process Integration
Chemical Reaction Engineering	Pollution Prevention Strategies Green Chemistry
Process/Plant Design	Heat Integration & Mass Integration Flowsheet Analysis Life Cycle Assessment
Process Dynamics & Control	Pollution Prevention Modeling and Control
Unit Operations Laboratory	Green Engineering Experiments
Design for Pollution Prevention	Heat and Mass Integration Process Analysis
Senior Engineering Clinic/Senior Project	Real Industrial Projects in Green Engineering

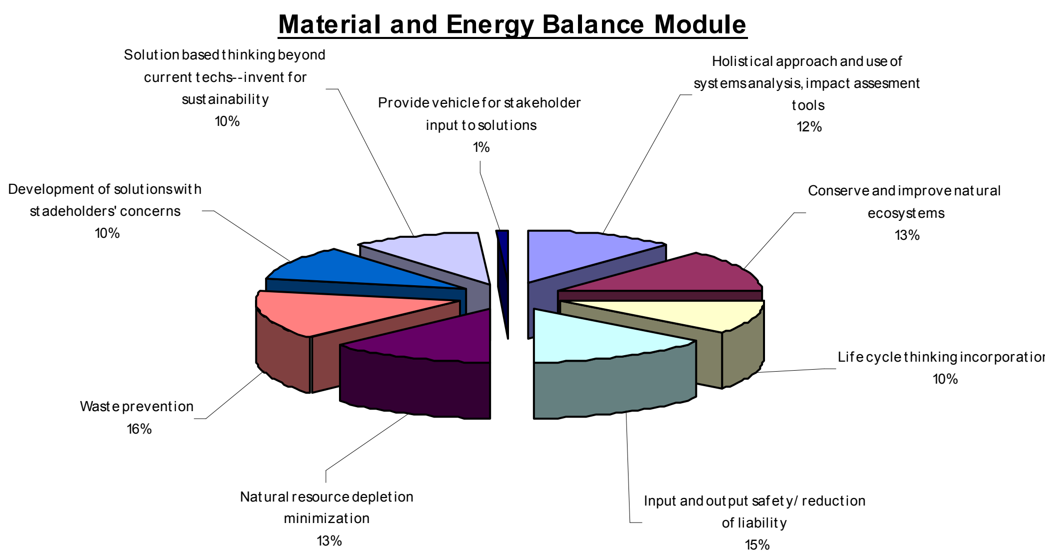
Green Engineering Modules

The following sections give examples from courses that have been developed for various courses by the corresponding faculty.

<u>Material and Energy Balances *(C. Stewart Slater, Rowan University)*</u>

This module is for introducing green engineering principles to the beginning student of chemical engineering, as the subject matter covered is introductory in nature [10]. Therefore, the green engineering principles covered in this section are introductory as well. This module covers the nine Green Engineering principles well and allows students to apply green engineering to their beginning education.
The following graph, (Figure 1) on the next page illustrates how this module maps the principles:

Figure 1: Mapping of the green engineering principles to the material and energy balance module



An example of how these topics "map" to various chapters of the widely used text by Felder and Rousseau [11] is shown in Table 2.

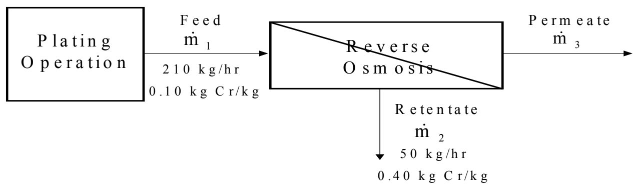
Table 2: Conceptual mapping of green engineering topics in a material and energy balance course.

Green Engineering Topic	Material and Energy Balance Topic (follows Elementary Principles of Chemical Processes, Felder & Rousseau, 3rd)
How green engineering is utilized by chemical engineers in the profession	Chapter 1: What Some Chemical Engineers Do for a Living
Unit conversions typically used in green engineering process calculations. Various defining equations used in green engineering	Chapter 2: Introduction to Engineering Calculations
Typical method of representing concentrations of pollutants in a process (%, fractions, ppm, etc)	Chapter 3: Process and Process Variables
Overall "closing the balance" of a chemical manufacturing process. Balances on recycle operations in green engineered processes Green chemistry in stoichiometry Combustion processes and environmental impact	Chapter 4. Fundamentals of Material Balances
Use of various equations of state in green engineering design calculations for gas systems. Pollutant concentrations in gaseous form	Chapter 5. Single Phase Systems
Representation and calculation of pollutant volatility using vapor pressure. Condensation calculations (gas-liquid equilibrium) for vapor recovery systems. Liquid-liquid extraction balances for pollutant recovery systems	Chapter 6. Multiphase Systems
Representation of various forms of energy in a green engineering process	Chapter 7. Energy and Energy Balances
Recovery of energy in a process - energy integration. Use of heat capacity and phase change calculations. Mixing and solutions issues in green engineering	Chapter 8. Balances on Nonreactive Processes
Energy use in green chemistry reactions, combustion processes. Overall integration of mass and energy balances in green engineering on a overall plant design basis	Chapter 9. Balances on Reactive Processes
Use of various simulation tools and specifically designed software for green engineering design	Chapter 10. Computer-Aided Calculations
Representation of mass and energy flows for transient processes with green engineering significance	Chapter 11. Balances on Transient Processes
Industrial cases studies of green engineered manufacturing processes	Chapter 12-14. Case Studies

Two example problems are given from this section that illustrate how green engineering principles can be applied to a material and energy balance course.

Example Problem 1: Electroplating Process

You have been hired as a process development engineer for Shiny Electroplaters and your first assignment is to look at the reduction of chromium discharge from its operation. The proposed process uses reverse osmosis as an environmentally effective separation process since it can be used for material recovery and recycle while it eliminates unwanted discharges from a chemical manufacturing operation.



a) The permeate quantity (kg/hr) and chromium concentration (mass fraction) being produced.
b) The potential uses for the permeate and retentate streams in a "green" process design.
c) The advantages this process posses over other pollution prevention techniques.

Example Problem 2: Ethanol process

Ethanol is considered a 'green fuel' since it can be made from renewable and sustainable resources and burns cleaner than fossil fuels. The process to produce ethanol can use a renewable resource such as domestically grown crops and thereby lessens the need for importation of crude oil. Since ethanol contains no carcinogenic compounds that are found in fossil fuels, worker exposure risk is reduced. In addition, when burned, ethanol generates fewer undesired byproducts compared to gasoline.
a) Investigate and draw the process flow diagram for the production of ethanol from corn. Suggest methods of mass and energy integration in this process to make it more environmentally efficient.
b) Calculate the higher heating value (HHV) and lower heating value (LHV) of ethanol (kJ/mol).
c) How does this compare to the HHV of fuel oil, gasoline at 44 kJ/g? What are other comparisons of fuel oil/gasoline combustion and ethanol combustion?
d) The use of hydrogen as a potential fuel of the future has received much recent attention. What is its HHV (kJ/mol) and what are the environmental issues and challenges related to its use?

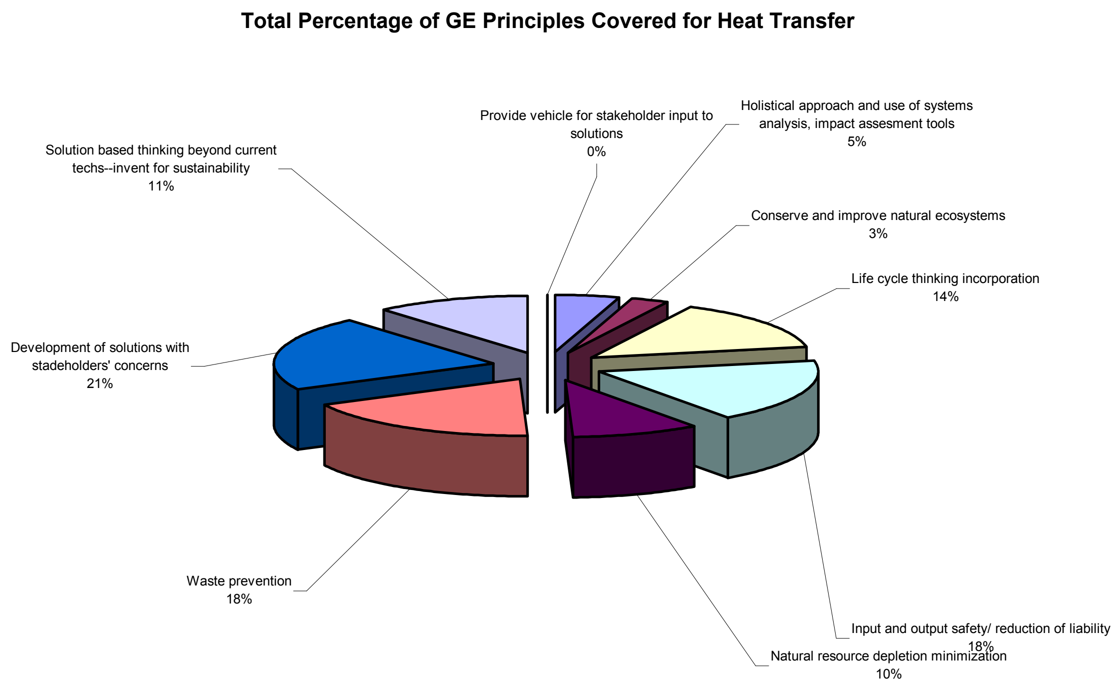
This section contains 25 problems that range from typical chemical engineering mass and energy balance problems and other environmental related mass and energy balance problems with chemical engineer themes, such as the problem for washing a car. The two examples above are typical chemical engineer problems. Example problem 1 shows students how other more recently invented processes can be used to decrease the amount of hazardous chemicals that would otherwise released into the environment. Example 1 also shows how the retentate can potentially be recycled back into the process. This would save both energy and money for the recovery of the chromium.

Example 2 shows how ethanol can be used as a fuel and the processing steps involved in making and purifying the ethanol. This problem like many other problems in this section is designed for students to research the selected compound. From the research the students can see that over 90% of the ethanol made in the world is made via a renewable route. This problem also shows how ethanol, a renewable fuel source compares to other fuel sources such as fuel oil and gasoline. Lastly, this problem addresses other renewable fuel sources such as hydrogen. Every renewable source has advantages and disadvantages and this problem asks students to address some issues related to hydrogen cells. The 3rd portion of this problem is to illustrate to the students to not just look at the end result, but to look at the entire process.

Heat Transfer *(Ann Marie Flynn, Manhattan College)*

This module was designed to introduce students to green engineering in the subject of heat transfer. Overall, the module is well organized, thorough in its treatment of the green engineering principles, and concise enough for incorporation into a heat transfer course via homework problems. This can be seen in Figure 2. An example problem is also given for this section

Figure 2: Mapping of the Green Engineering Principles For the Heat Transfer Module



<u>Example Problem 3: Attic insulation</u>

A homeowner has decided to renovate her home. Due to the rising cost of fuel her first priority is to insulate the attic. As of now, the attic has no insulation at all and the outer wall is made of brick (k = 0.72 W/m°C). The thickness of the brick wall is 5 cm.
The insulation will have a thickness of 11 cm. The homeowner has narrowed down her choice of insulation to either fiberglass (k = 0.036 W/m°C) or cork (k = 0.039 W/m°C). Once the insulation is installed, a 2 cm thick wall of sheetrock (k = 0.118 W/m°C) will be installed on the inside of the attic to cover the insulation. The average temperature outside in the winter-time is determined to be 10°C and the temperature inside the attic will be maintained at 21°C. Assume the inside wall temperature is equal to the room temperature. One wall of the attic is measured to be 7 m wide and 2 m long. The price of the fuel that operates the furnace heating the attic is $0.03/ MJ ($0.03/MW-s).

a.) *How much heat was lost through the attic wall before the renovations took place? What is the daily cost of the fuel without insulation?*

b.) *How much heat is lost through the attic wall when using:*

1. *Fiberglass insulation*
2. *Cork insulation*

What is the daily cost of the fuel for each type of insulation?

c.) *Assume the homeowner did these renovations herself and decided to use the fiberglass insulation. She wore gloves on her hands, but had no protection on her arms and nothing covering her mouth. The mass fraction of exposure chemical in fiberglass is 0.5. Assume she installed one section of the fiberglass every half hour for eight hours per day. What is the dermal exposure to her arms?*

d.) *What are the dangers of skin exposure and inhalation of fiberglass?*

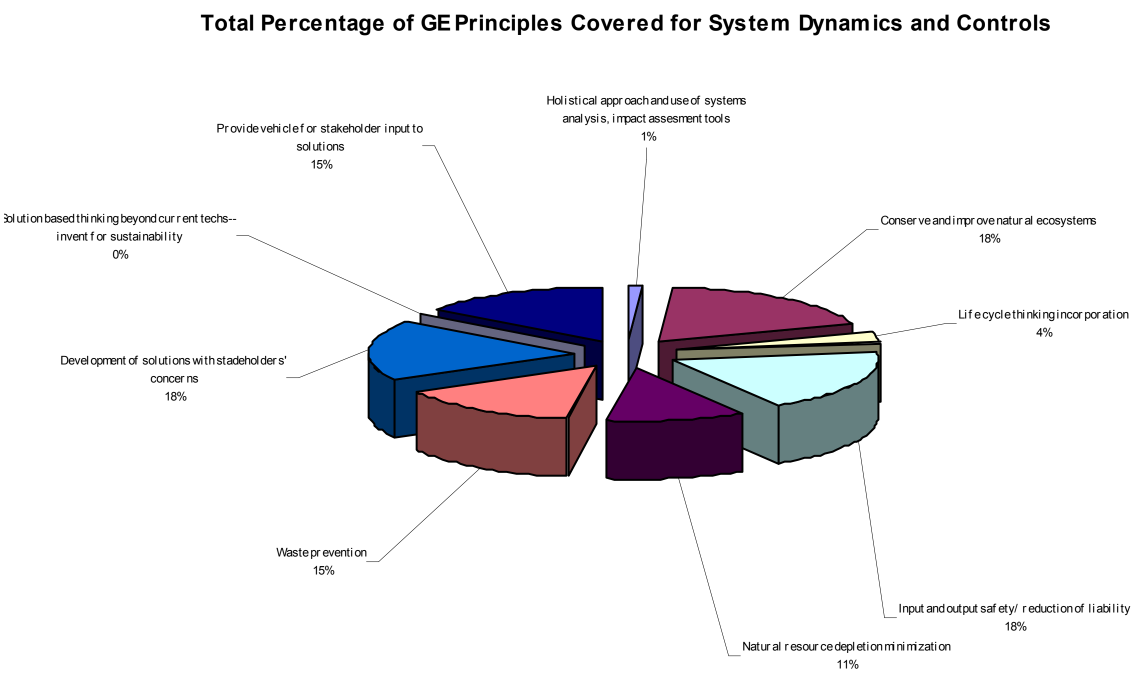
e.) *How much difference in heat loss would have occurred had she used the cork insulation instead?*

This section contains 22 problems that range from typical chemical engineering heat transfer to typical everyday problems. These problems are adapted for Incropera & DeWitt [12], but can be used for other heat transfer books. The example above is typical chemical engineer problem for heat transfer. Heat transfer is a critical area for green engineering. Example problem 3 shows students how insulation cuts down the loss of heat from a house, but this approach can be used for pieces of engineering equipment also. An example of how insulation can be used effectively in chemical engineering is in distillation columns or quartz furnaces. This problem statement also addresses the factor of cost. Cost is sometimes a barrier for making a process more environmentally friendly. This problem addresses the trade-offs between cost, safety, use of renewable resources, performance of the product, and toxicity. In this problem, there is the issue that fiberglass can cause various hazards while cork does not, but fiberglass has lower thermal conductivity value; making it more suitable to use as insulation. Other problems in this section contain the heat transfer for incandescent bulbs and the comparison to fluorescent bulbs, different types of windows for home or office use, and insulation of an oil pipe. These types of problems enable students to numerically determine the heat loss for these problems and address the environmental concerns associated with these problem statements.

System Dynamics/Control *(Jim Henry, University of Tennessee, Chattanooga)*

The module was critiqued and there seems to be a relatively uniform spread of the various green engineering principles. The problems can be broken down into 5 sections and 24 problem statements. These sections are “Avoid Tank Spillage”, “Trouble in River City”, “Paint Spray Booth Pressure System”, “Filter Wash System” and “Aerator Mixer System”. This module has a unique feature of linking to a website where the student can run simulations for many of the problem statements and are interactive for the student. Most of the problems in this section allow the student to modify the various tuning parameters for the problems. The graph on the next page (Figure 3) shows the coverage of the various green engineering principles for this module.

Figure 3: Mapping of the green engineering principles to the process dynamic and controls module



An example problem for this section is given below for a sewage treatment plant.

Example Problem 4: Flow control for sewage treatment

Our POTW ("Publicly Owned Treatment Works") sewerage treatment plant in Chattanooga, TN, has a large filter press to filter out the sewerage sludge solids in order to send the solids to the city landfill. The filtrate water is then processed further before returning to the Tennessee River. The filter press operates in a repeating batch mode. Between batches, the filter media and plates must be washed. The manufacturer of the press specifies that the water flow rate to the washing nozzles have to be maintained between 7 and 10 lb/min.

The flow rate of the wash water is maintained by a variable speed centrifugal pump. The motor driving the pump is a variable-speed motor. The speed of the pump is under feedback control to maintain the desired flow rate to the washing nozzles. The controller is a proportional-integral controller. A diagram of the pump, washing nozzles and control system is shown below. Also shown on the diagram are 2 other "manual" or "auxiliary" wash lines that are used by operators in the plant to wash up spills when needed.

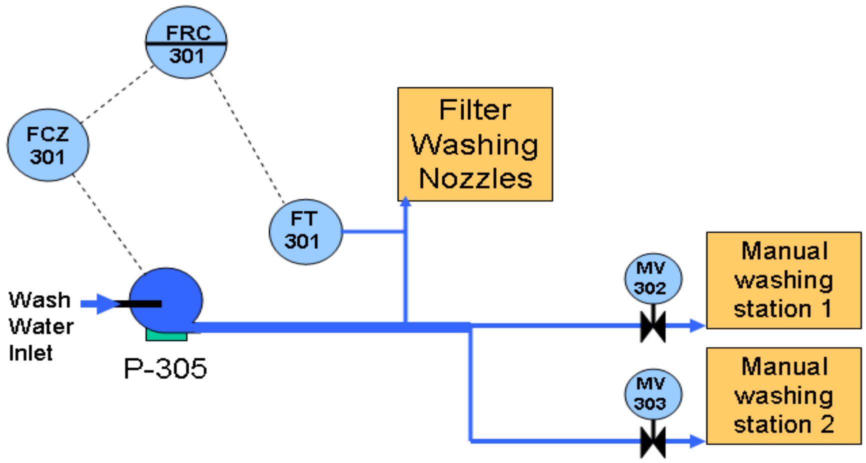
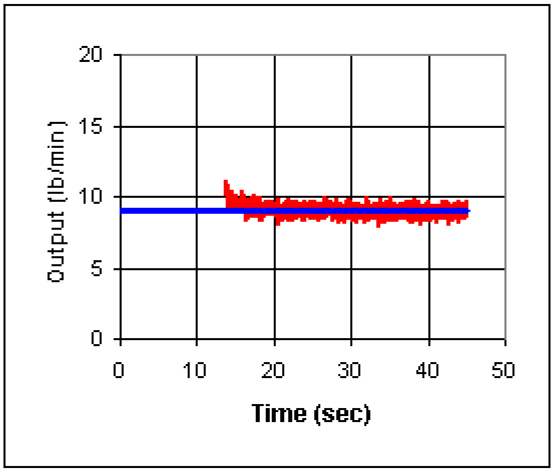


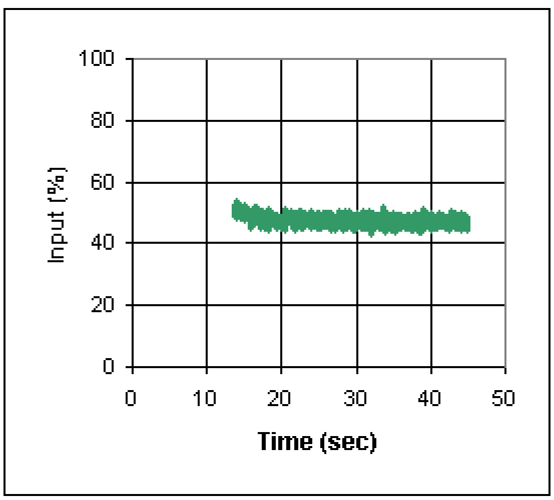
Figure 4*: Schematic diagram of the Filter Wash System*

Operational Situation:

Plant personnel have been happy with the system (including the control system) for years. Ever since plant start-up, we've been able to maintain the wash-water flow rate within specifications. Figures 5 and 6 are graphs of the wash water flow rate (sampled by FT-301) and Pump Speed (from FRC-301 output, expressed as %) under closed-loop feedback control for two recent periods.

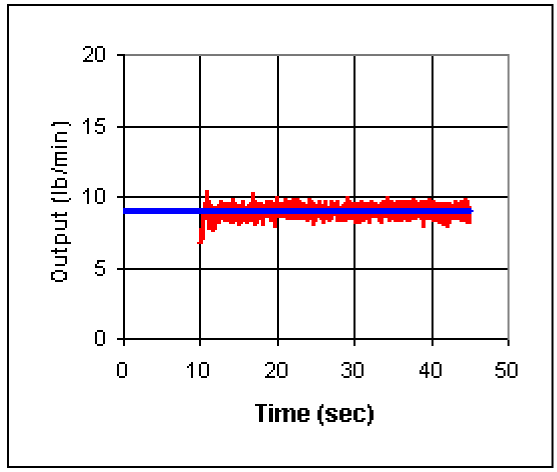


Flow (lb/min) at FT-301 vs time (sec)

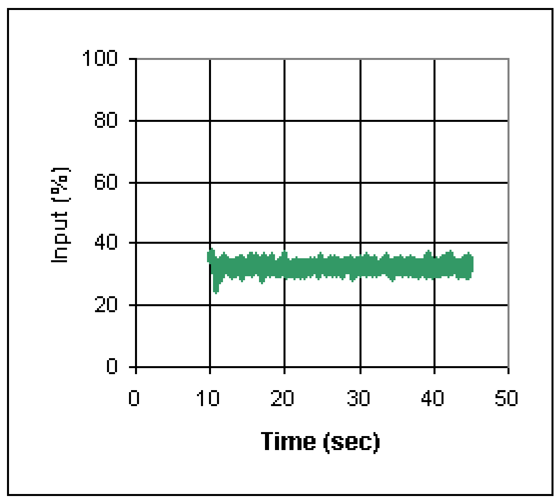


Pump Speed from FRC-301 Output

Figure 5. Performance while 2 auxiliary washing stations are in use



Flow (lb/min) at FT-301 vs time (sec)



Pump Speed from FRC-301 Output

Figure 6. Performance while 1 auxiliary washing station is in use

The controller tuning parameters were set by installation contractor and have not been adjusted. The value of Controller gain is 4.0 %/lb/min; the integral (reset) time value is 1.0 second.

Unfortunately, with a recent improvement in operating procedures and equipment upgrades, we frequently have no need for either auxiliary washing station to be used. When neither auxiliary washing station is in use, our operators tell us that the wash-water flow rate is very erratic. The objectives of this assignment are

1 -- to observe the operation and behavior of the recommended design of a proportional control system
2 -- to observe the effect of the value of the proportional feedback gain, K_c
3 -- to observe the response to a closed loop controlled system to a set point change
4 -- to determine the ultimate gain and ultimate period for the closed-loop system
5 -- to tune the controller for critically damped response, quarter decay and at the limit of stability
6-- to observe the response of the closed-loop system to one or more disturbances

Process Dynamics and Controls is also an integral part of green engineering. Steady state or pseudo steady state processes are important in improving the efficiency and conserving resources for processes. Having a process "in control" is critical in meeting many EPA requirements, such as the amounts of pollutants in air and water, decreasing the amount of waste in a process, and not producing hazardous by-products in a reactor. Example problem 4 was designed to the show how various tuning parameters affect the flow rate for the pump over a period of time. When a controller has improper tuning parameters, it will operate inefficiently which will lead to an increase in operating energy for the controller and also a waste in material. For this problem, improper tuning parameters will lead to the controller over adjusting the pump flow rate frequently, a waste of water due to rapid flow rate fluctuation, and possibly improper cleaning of the filter. This example problem covers some of the green engineering principles described by Allen and Shonnard [7] such as waste prevention and conservation of natural resources.

Summary

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 the engineering curriculum. This paper presents some methods currently being used to teach green engineering within engineering programs. Examples in which green engineering is integrated throughout a curriculum as well as examples problems used in several chemical engineering courses are presented.

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References

1 U.S. Environmental Protection Agency, Green Engineering web site - http://www.epa.gov/opptintr/greenengineering/index.html

2 Ritter, S. K., "A Green Agenda for Engineering: New set of principles provides guidance to improve designs for sustainability needs," July 21, 2003, **81** (29) *Chemical & Engineering News* pp. 30-32.

3 Bakshani, Nandkumar, and David T. Allen. "In the States: Pollution Prevention Education at Universities in the United States." Pollution Prevention Review 3, no. 1 (December 1992): 97-105.

4 Press Release, Zurich, 4 September, 2003, "Results of the DJSI Review 2003," http://www.sustainability-indexes.com/djsi_pdf/news/PressReleases/DJSI_PR_030904_Review.pdf

5 Dow Jones Sustainability Indexes (DJSI) –Annual Review 2003, Zurich, Switzerland, 4 September 2003, http://www.sustainability-indexes.com/djsi_pdf/publications/Presentations/DJSI_PRT_030904_Review.pdf

6 Hesketh, R.P. C. S. Slater, M.J. Savelski, K. Hollar, S. Farrell, "A Program to Help in Designing Courses to Integrate Green Engineering Subjects," *International Journal of Engineering Education* , 20(1), 113-123, 2004

7. Allen, D.T., D.R. Shonnard, *Green Engineering: Environmentally Conscious Design of Chemical Processes*, Prentice Hall, Englewood Cliffs, NJ (2001).

8 Green Engineering Education Modules, Rowan University, www.rowan.edu/greenengineering

9. Hesketh, R.P., K. Jahan, A.J. Marchese, C.S. Slater, J.L. Schmalzel, T.R. Chandrupatla, R.A. Dusseau, "Multidisciplinary Experimental Experiences in the Freshman Engineering Clinic at Rowan University," *Proceedings of the 1997 Annual Conference of the American Society for Engineering Education* (1997).

10 Slater, C. S. and R. P. Hesketh, "Incorporating Green Engineering into a Material and Energy Balance Course," *Chemical Engineering Education* 38(1), pp. 48-53, 2004

11 Felder, R. M., and R. W. Rousseau, Elementary Principles of Chemical Processes, 3rd, John Wiley & Sons, New York, 2005

12 Incropera Frank P., DeWitt, David P., Fundamentals of Heat Transfer, 5th, John Wiley & Sons, New York, 2002

Biographic Sketches

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