Session 3551

Building the Better Oil/Water Separator
An Environmental Engineering Design Laboratory

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Abstract

This laboratory was developed as an introductory Capstone Design module. The four-week laboratory requires students to apply process design, fabrication and performance evaluation concepts to one of the most fundamental unit operations of environmental engineering, an oil/water separator. Results of the laboratory have been used to identify areas in need of improvement in the overall engineering qualifications of individual students. Student performance in this laboratory is also being used as an assessment instrument to measure the achievement of objectives in Wentworth's environmental engineering program.

Working in teams, students are given the task of designing, building, operating and evaluating a system to treat a steady-state flow of wastewater with components of oil, water, dissolved and settleable solids. Treatment criteria consistent with regulatory limits are given including: water effluent limits for dissolved solids and oil and grease; water content in the retained oil phase; and oil content in the retained settleable solids phase. Few design boundaries are imposed upon the teams other than the requirement that the majority of the as-built system be constructed of materials available in the laboratory (such as 5 gallon buckets, flexible tubing, valves, clamps and variable speed pumps). Performance evaluation is similarly left open to interpretation and serves to promote the independent discovery of the merits of relevant standard methods of wastewater analysis.

This paper describes the design of the laboratory both in terms of how the laboratory is performed and in terms of how the laboratory fits into the scheme of Wentworth's environmental engineering curriculum. Results of student work are given in this paper to show design innovation and the application of engineering fundamentals. The paper also describes how the results of the laboratory are used in the Wentworth environmental engineering program self-assessment for ABET 2000.

I. Introduction

Wentworth Institute of Technology has both a long tradition and a continued commitment to experiential learning. The environmental engineering program at Wentworth is a laboratory-based program that focuses on process fundamentals. Typically, courses offered in the program consist of forty percent of contact time in laboratory and sixty percent of contact time in lecture. Upperclassmen in the environmental engineering program spend an average of 10 contact hours per week in the laboratory for engineering courses.

The environmental program at Wentworth is six years new. The first graduating class of the five-year program completed commencement exercises in May of 1998. Though most courses have been taught a few times, course curricula continue to evolve as the program develops and matures. Upon graduating its first class, Wentworth recently underwent an on-campus review of the program for accreditation under the ABET 2000 criteria. Based on preliminary results from this review, feedback from graduated students and the progam's IPAC, as well as the results of the program's own self assessment review, the program appears to meet its objectives in offering an undergraduate education which achieves the twelve Institute Learning and Competency Objectives, delivers graduates who have achieved the seven Engineering Program Mission Goals, and delivers an educational program consistent with its Environmental Engineering Program Philosophy and Academic Goals. Although weaknesses in certain areas were identified through that process, that was an objective of the process and those areas are being aggressively addressed.

For Capstone Design, students are given the opportunity to select and develop their own scope of work for their area of interest. Successful project proposals must identify actual stakeholders with an interest in the environmental engineering issue to be addressed. These stakeholders have taken an active (and appreciated) role in assisting students throughout the Capstone Design process and participate in an end-of-year assessment of both student projects and of the Capstone Design curriculum. Independent projects span the spectrum of environmental engineering interests including phytoremediation, hazardous waste facility design, storm water modeling and containment, landfill closure design, and fate and transport characterization and control for oil and hazardous material contaminated sites.

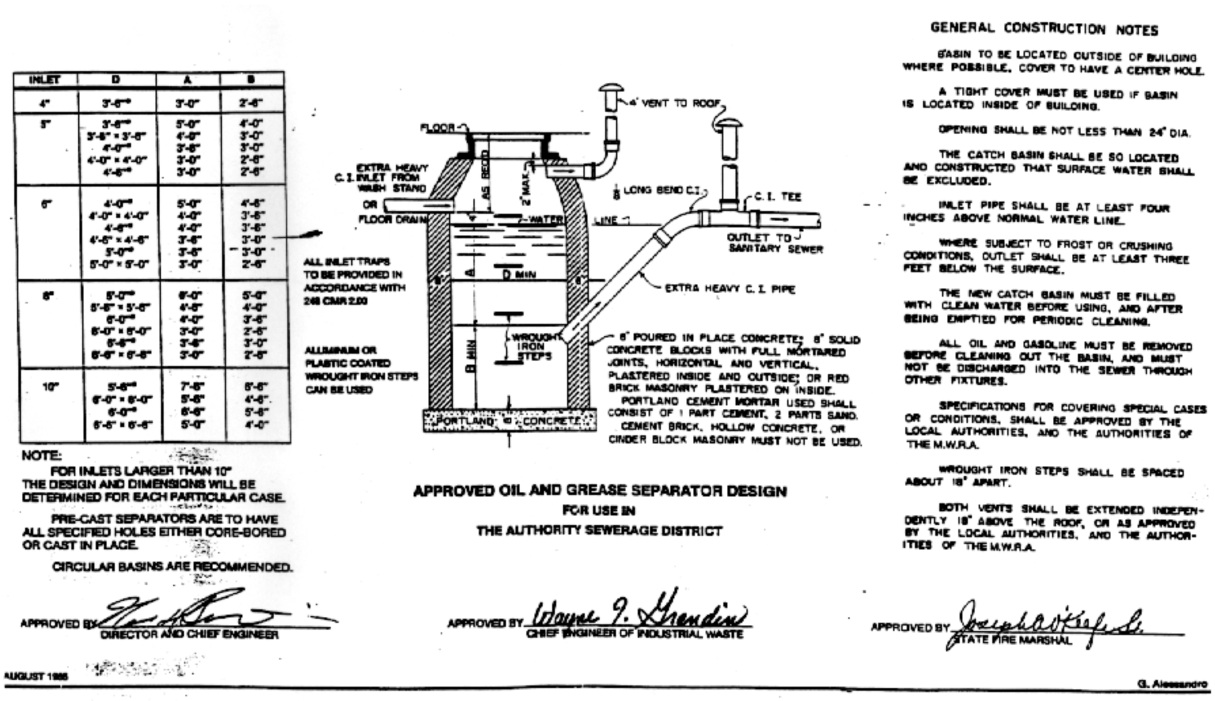
The Oil/Water Separator Exercise is presently given to Capstone Design students as a four-week assignment at the beginning of the fall semester. The objective of the exercise is to better prepare the students for completing their Capstone Project by first experiencing the design, construction and performance evaluation components of this fairly "simple" environmental engineering system. The exercise also allows design teams to experience the group dynamics associated with a team-oriented project.

II. Oil/Water Separators

Because of the widespread use of oils and other light non-aqueous phase liquids (LNAPL), the use of oil/water separators is common. Oil/Water separators are often used as pre-treatment unit operations and are designed to collect floating oil and grease, trap settleable solids and pass the aqueous phase of a wastewater stream. The simple design shown in Figure 1 has been used for many applications and is very effective provided emulsions and suspensions are not created in the waste stream and also provided the waste stream does not contain contaminants regulated at dissolved levels.

Figure 1

Massachusetts Water Resources Authority (MWRA) Separator Design[(1)]



INLET	D	A	B
4"	3'-6"*	3'-0"	2'-6"
5"	3'-6"* 3'-6" × 3'-6" 4'-0"* 4'-0" × 4'-0" 4'-6"*	5'-0" 4'-0" 3'-6" 3'-0" 3'-0"	4'-0" 3'-0" 3'-0" 2'-6" 2'-6"
6"	4'-0"* 4'-0" × 4'-0" 4'-6"* 4'-6" × 4'-6" 5'-0"* 5'-0" × 5'-0"	5'-0" 4'-0" 4'-0" 3'-6" 3'-6" 3'-0"	4'-6" 3'-6" 3'-6" 3'-0" 3'-0" 2'-6"
8"	5'-0"* 5'-6" × 5'-6" 6'-0"* 6'-0" × 6'-0" 6'-6"* 6'-6" × 6'-6"	6'-0" 4'-6" 4'-0" 3'-0" 3'-6" 3'-0"	5'-0" 4'-0" 3'-6" 2'-6" 3'-0" 2'-6"
10"	5'-6"* 6'-0" × 6'-0" 6'-0"* 6'-6" × 6'-6"	7'-6" 5'-6" 6'-6" 5'-0"	6'-6" 4'-6" 5'-6" 4'-0"

System analysis of a unit operation such as an oil/water separator is straightforward. Oil, water and solids enter the system in one stream. Solids and oil accumulate in the system at a rate governed by the size and geometry of the system. Water, with a lower content of oil and solids, exits the system. Material balances for the three influent stream components, i.e., oil, water and solids are given in Equations 1,2,and 3, respectively. In practice, oil/water separators serve their intended use when the concentrations of solids and oil in the output stream fall below design criteria levels. Often these levels are regulatory-based discharge limitations such as NPDES or POTW pre-treatment limitations.

Water Balance: Input Rate = Output Rate + Accumulation Rate (in LNAPL phase) Eqn. (1)

Oil Balance: Input Rate = Output Rate + Accumulation Rate (in LNAPL phase) Eqn. (2)
+ Accumulation Rate (in solids phase)

Solids Balance: Input Rate = Output Rate + Accumulation Rate (in LNAPL phase) Eqn. (3)
+ Accumulation Rate (in solids phase)

The sizing of an oil/water separator of the type shown in Figure 1 is straightforward. Design should be based on the wastewater flow rate (input) and the composition of the wastewater (i.e., oil, water and solids content). The volume of the vessel should provide for adequate retention time to allow phase separation and adequate settling. The diameter, height and location of the effluent pipe invert should be based on the rate of accumulation of oil phase and solids above and below the invert, respectively. As might be expected, short-circuiting of oil/water separators often occurs due to a failure to periodically remove accumulated oil and bottoms from these systems.

The basic design shown in Figure 1 is commonly used to separate oils and grease which possess low water solubilities. Without an additional post-treatment, the design would not be adequate to remove gasoline from a wastewater stream because of the relatively high solubility of benzene, toluene, ethyl benzene, xylenes, MTBE and other toxic constituents in gasoline. Also, the design would not be adequate for wastewaters that possess surface-active agents and/or mixing conditions conducive to the formation of emulsions. Water-in-oil emulsions may greatly decrease the "capacity" of the unit to collect LNAPL phase while oil-in-water emulsions enhance the solubility of oil components in the output stream. With regard to solids removal, the design is ineffective for wastewater streams with persistent flocs, such as flocs formed by iron bacteria, and other conditions that would prevent adequate sedimentation from occurring. Other chemical and/or physical unit operations may be used in combination with the above design, or as an alternative to the above design, to overcome these troublesome wastewater characteristics. More detailed descriptions of oil/water separator design can be found in environmental engineering unit operations texts such as Corbitt [(2)].

III. Design of the Laboratory

The four-week laboratory requires students to apply process design, fabrication and performance evaluation concepts to an oil/water separator. In the first week students are given a problem statement and a brief review of the design, operation and maintenance of oil/water separators, similar to the review provided in this paper. Design criteria are summarized in Table 1. During the first and second weeks, student groups design their systems. During the second and third weeks students build, operate and begin evaluating the performance of their systems relative to the performance criteria given in the problem statement. Actual construction must utilize equipment provided in the laboratory. Components provided in the laboratory are given in Table 2. Additional parts available in the laboratory could be, and in many instances were, used by groups. In the fourth week, students demonstrate their systems to faculty and prepare and submit a report summarizing their results and overall experience with the exercise.

Table 1

Design Criteria

Treated Wastewater	Oil and Grease content of less than 5 mg/L and contain less than 0.01% total dissolved solids
Sediment Phase	Less than 50% oil and grease and less than 30% water by mass
Processing Rate	At least 2.5 gallons per hour

Table 2

System Components

- 5 gallon bucket
- Tygon® tubing
- Master-flex® variable speed pump
- 1-100 mL/min flow meters
- assorted valves and fittings
- standard laboratory glassware and accessories
- the concoction: 2.4 gallons water, 0.1 gallons vegetable oil, 1 lb dirt*
- filter paper

* a predominantly sand and gravel mixture conveniently available in the Wentworth soils lab.

Treatment criteria given are consistent with relevant regulatory limits. Industrial pretreatment limits within the Massachusetts Water Resources Authority (MWRA) jurisdiction for vegetable oil is 5 mg/L oil and grease[(3)] as measured by a gravimetric[(4)] or equivalent method. Depending on the waste stream, other analytical methods to measure "oil and grease" include infrared and gas chromatography techniques. For disposal of collected sediment in a lined solid waste landfill in Massachusetts, the total petroleum hydrocarbon (TPH) content of the sediment can not exceed 5000 mg/Kg[(5)]. For this laboratory, students were asked to assume oil in sediment was petroleum and not vegetable-based in nature.

Based on the design criteria and the "parts" made available to the students, it was understood that the design should provide for phase separation of the aqueous stream from solids and LNAPL. Students were encouraged to deviate from the basic design provided in Figure 1. Similarly, students were encouraged to consider alternative methods to measure whether treatment criteria were being met. It was hoped that the open-endedness of the laboratory would allow students to discover for themselves the effectiveness and limitations of both treatment techniques and measurement techniques.

IV. Assessment Methods

Program evaluation at Wentworth is a multi-faceted, continuous process consistent with the objectives of the ABET Criteria 2000 accreditation criteria. It involves a critical review of all aspects of every program on an on-going basis; a formal self-evaluation report at least once every three years; and periodic review of the program by interested stakeholders, including program faculty, other institute faculty, alumni, Industrial Professional Advisory Committee (IPAC) members, and others. The stakeholders most likely to see pedagogical problems first are the program faculty. Accordingly, the program faculty spends considerable amounts of time discussing successes and failures in every course in the program and constantly look for ways to improve the overall education delivered.

Program evaluation involves the comparison of student-centered Institute, engineering and program-specific goals and objectives to actual student performance. Wentworth has established twelve Institute Learning and Competency Objectives for students. They are:

1. Leadership Qualities
2. Analytical Thinking
3. Innovative Problem Solving Techniques
4. Team Building
5. Communication Skills
6. Decision Making Skills
7. Business Acumen
8. Application to Contemporary Societal Issues
9. Thorough Knowledge of the Design Process

10. Cooperative Work Experience
11. Ability to Work Efficiently
12. Life Long Learning Skills

The Wentworth Engineering Program Mission and Goals require that, upon graduation, graduates will:

1. have developed the engineering skills relevant to their desired discipline so that they can design, build, test, report and assess results for application to engineering processes, designs and projects appropriate to their discipline;
2. understand issues pertinent to their profession's ethics and standards and be able to incorporate these values into the engineering design process;
3. be prepared to seek professional registration;
4. be able to communicate their thinking and ideas effectively to members of the technical community as well as the general public;
5. have the desire to develop their skills and knowledge continuously through professional development, advanced graduate education and other appropriate creative activities;
6. understand and be able to solve for the needs of their clients and society at large; and,
7. have developed a sense of the marketplace in which their professional services are offered in order to advance and adapt to changes in their organization and professions.

Consistent with the Institute Mission, the Institute Learning and Competency Objectives, and the Engineering Mission and Goals, the environmental engineering program was established to achieve its own program-specific academic goals, based on a program-specific philosophy. In summary, the program philosophy is to prepare the student to provide useful contributions to the field of environmental engineering and to his/her employer beginning upon graduation, to secure professional registration, and to perform effectively in a variety of environmental engineering situations. The program seeks to graduate students who are flexible, able to work well with others as part of a team effort, capable of adapting to changing work place conditions and variable engineering demands, and capable of providing suitable engineering process designs to solve environmental engineering problems.

The program goals include, among other things, that at the end of the fourth year students will "be competent in the identification, selection, and use of the design concepts useful for simple to slightly complex engineering design projects". Upon graduation it is expected that students will, among other things, "be competent to design and evaluate simple environmental engineering projects with a minimum of supervisory oversight", "be competent to prepare and evaluate environmental engineering process designs, including fate and transport, and exposure processes", and "have a broad experiential background in data collection, analysis, interpretation, and evaluation, and in process design". The oil/water separator exercise at the beginning of the fifth year of study provides a unique and invaluable opportunity to re-evaluate how well each class has met the specified goals and it provides a clear road map for correcting deficiencies so that the graduation goals can be achieved for all classes.

One of Wentworth's primary program objectives is to teach its students how to design processes to solve environmental problems. The oil/water separator exercise is used in a "last-chance" feedback loop to identify areas of process design with which students may have difficulty in their Capstone Design projects. The process by which the separator design is developed by the individual groups, the creativity of the designs developed, and the successful evaluation of the results are the key elements of the feedback data. By analyzing the results of these projects, earlier courses can be strengthened, as appropriate, and weaknesses can be discussed with the class during the Capstone Design effort.

V. Results

Results of student work show design innovation and the application of engineering fundamentals. Figure 2 provides four examples of student designs. These process diagrams demonstrate an understanding of the design criteria by providing an accountability of each component in the waste stream. Each design is sufficiently different, suggesting groups worked independently and with a sense for innovation and creativity.

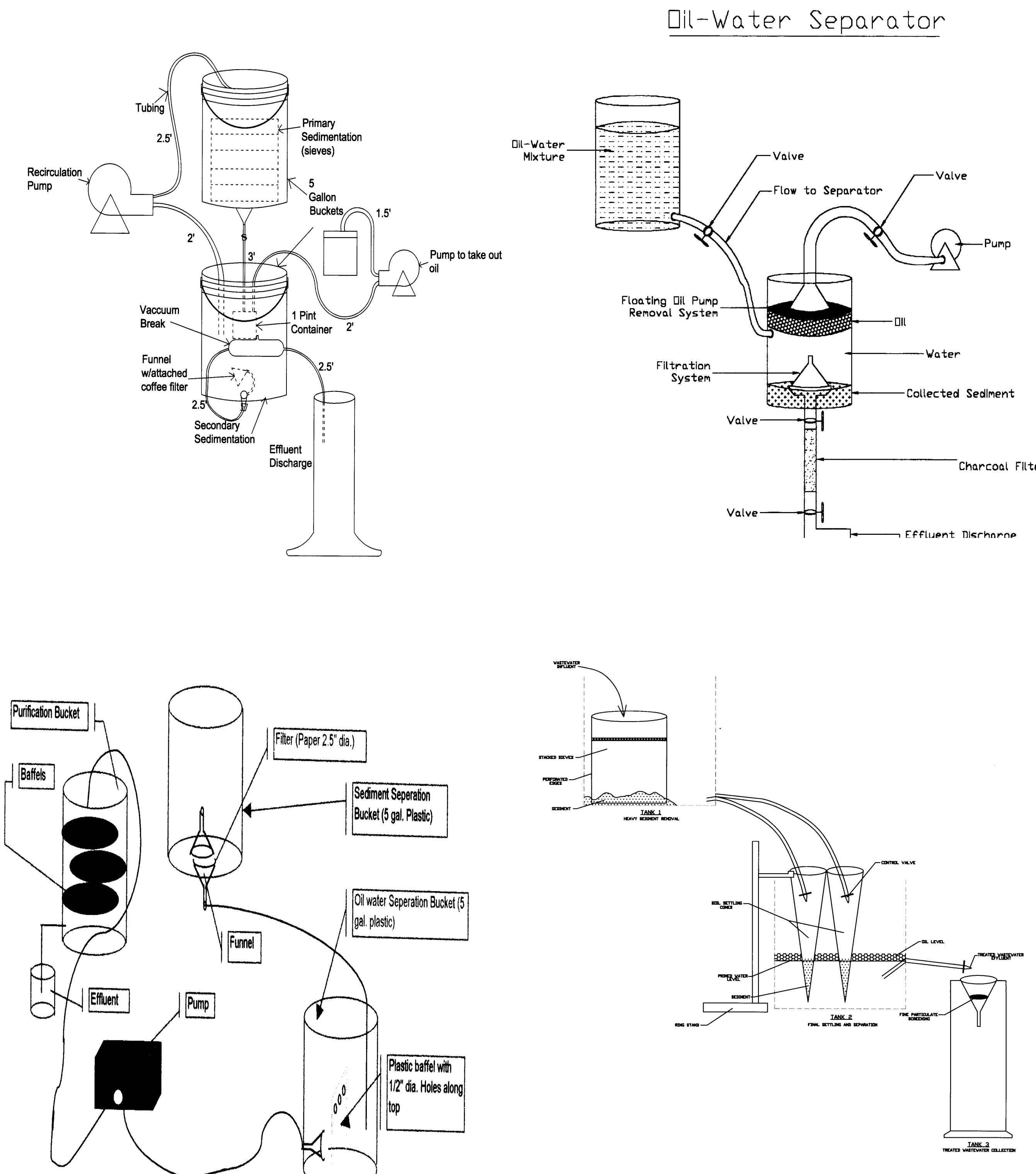
Overall, student work demonstrated an understanding of system design and competency in system analysis. With some exceptions, groups worked well together. Though students demonstrated creativity and an ability to take ideas from conceptual design to actual construction and operation, designs were expected to be more engineering based. In most instances, the design process followed a "this looks like it will work, let's try it" approach. Improvement in performance evaluation, data collection and data interpretation was also expected. Process description, including materials balances and process flow diagrams, was well done as well as the identification of regulatory issues, system objectives and comparison of results to performance criteria.

As a result of the evaluation of these student designs both individual and class strengths and weaknesses were identified. Capstone Design lecture topics involving identified strengths were covered in less detail than originally planned in the course syllabus. Weaknesses identified in the class were reviewed in more detail than originally planned in subsequent weeks in the course. As this paper is being written in the second half of Capstone Design, it is too early to determine how well students have responded to efforts to correct the weaknesses identified as a result of the oil/water separator laboratory. However it is expected that these improvements will be measured by higher quality Senior Design Project Reports submitted prior to graduation.

Results also indicate the need to improve the laboratory design itself. A better review of the gravity separation theory and the design process for this laboratory is warranted. Examples of previous student work and a critique of the merits and limitations of these designs will be included in the review. A fifth week may be added to the laboratory to allow more time for system design and system testing. Other modifications being considered include the creation of a different oil-water-solids concoction to force more critical thinking to design and the use of different building materials for the student groups to use in constructing the oil/water separators.

Figure 2

Process Diagrams (6)



VI. Conclusions

Though a “simple” unit operation, this oil/water separator laboratory incorporated all of the topic areas Wentworth values in its environmental engineering program. Improvements to the laboratory are planned for the Fall, 1999, semester to address some of its identified shortcomings and to improve its value to beginning Capstone Design students. The possibility of expanding the use of the laboratory to a newly developed freshmen level introduction to environmental engineering design course is also being considered. Maintaining the laboratory at both the freshmen and fifth year level may provide a valuable means to measure student development and serve as a technique to evaluate whether the program is achieving stated goals in preparing students for an engineering career.

Bibliography

(1) MWRA O/W Separator Design, Commonwealth of Massachusetts, Massachusetts Water Resources Authority, August, 1985.
(2) Corbitt, R.A., *Standard Handbook of Environmental Engineering*, McGraw Hill, 1989
(3) 310 CMR 7.00, Commonwealth of Massachusetts Industrial Wastewater Regulations
(4) Standards Methods for the Examination of Water and Wastewater, 19th Edition, APHA/AWWA/WEF, 1995
(5) “Reuse and Disposal of Contaminated Soils at Landfills”, Commonwealth of Massachusetts DEP Bureau of Waste Prevention Interim Policy #BWP-94-037, 1994
(6) Reichenbacher, S.J., Mullen, T., Leahy, J.E., Nabozny, S.J., Rackleff, C., Ruehrwein, J.R., Sparks, A.J., Lafferty, S.M., Claise, M.E., Griffin, B.R., Blodgett, S.D., Fox, P.W., Anzalone, R.J., Palie, C., Lacasse, J.E., Lochran, J.W., Troy, C.D. *Compilation of Oil/Water Separator Final Reports*, Wentworth Institute of Technology, October, 1998

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