Environmental Engineering Design in Biological Process Engineering

Arthur T. Johnson
Biological Resources Engineering/University of Maryland

The Biological Resources Engineering Program at the University of Maryland educates students in the application of engineering to biological systems. The intention of the undergraduate program is to provide a broad and fundamental curriculum with a strong dose of biological sciences in addition to the required engineering science and design[1,2]. The program is ABET accredited.

After taking courses in general biology, organic and biochemistry, microbiology, and cell physiology, students may choose three biological science technical elective courses from among a list of hundreds of available courses. Depending on the student's interest, she may choose courses in air pollution, food chemistry, genetics, or kinesiology, for example.

This program is new, only two years old, and the total number of undergraduate students is approximately seventy-five. We anticipate the steady-state undergraduate enrollment to be twice the present number. Although we avoid requiring undergraduate students to choose their ultimate area of specialization, roughly half are interested in environmental engineering, forty percent are interested in medicine or biomedical engineering, and about ten percent are interested in a range of specialties including aquacultural engineering, agricultural engineering, microbial systems, and others.

Two of the major challenges to be met in this program are: 1) to provide a set of courses of sufficient utility to the range of student interests that they will be a useful foundation upon which to specialize further after graduation, either through graduate education or through on-the-job training, and 2) to make each required course contain something of interest to each and every student, no matter what his occupational specialty goal. The first of these challenges has required study, vision, and the establishment of a new set of courses rarely, if at all, seen in somewhat similar curricula. Included in this set are courses such as Biological Response to Environmental Stimuli (a black-box approach to biological input-output relationships), and Control Systems for Biological Engineers (a survey course on control strategies working with or within biological systems).

Technical material for the Biological Process Engineering course is based on the three transport processes of fluid flow, heat transfer, and mass transfer. Knowledge of these processes is important no matter what types of biological systems students are ultimately interested in. This course goes beyond transport processes, however, and emphasizes a generalized systems approach to the three named transport processes and other additional similar processes. Students in this course are introduced to effort variables (cause) and flow variables (effect). They become familiar with relationships such as resistance, capacity, and inertia[3]. They are taught about flow balances and effort balances before calculation details of the three major transport processes. The goal is to make students as familiar as possible with analogic thinking (seeing the common elements between disparate systems) before they are introduced to particulars necessary for specific applications.

Problems and examples in this course must reflect students' interests, as well. Thus, there must be some problems with medical overtones, some with clear connection to the environment or ecology, and others dealing with biotechnology. This mix is not normally found in programs of a more specialized nature.

There are three assigned design problems in this course, one each for fluid flow, heat transfer, and mass transfer. Each is expected to be completed in about two weeks. The short time is meant to reflect the real-life time constraints engineers often face after graduation. Each design problem is given verbally, without complete specification, to give students practice in posing questions and defining problems. Students are expected to research the topic, propose alternative solutions, give a completed design, and produce an acceptable design report by the required deadline. They are not expected to give the most thorough study to the topic, but the design report should be professionally well-done. Students are given two equally-weighted grades for each report: one for technical correctness and the other for communications skills.

A period of experimentation in the last few years has demonstrated that students need three design projects to learn how to complete designs of this nature. There are some students who are befuddled by a problem that is not completely specified or that may not have a single, simple answer or even a single, simple approach. These students oftentimes do not know how to begin the project, and they spend most of their time trying to figure out how to begin. Other students want to begin immediately by calculating the most minute of details, and often are caught close to the deadline with solutions that are not acceptable from some conceptual viewpoint. Both of these types of students begin to learn that going to the library and reading about the object of the design is a good way to clarify thoughts, formulate meaningful questions, and further define the problem. Some students require one design project to learn this; others require two. By the third design project, almost all know how to approach a design project of this type.

Design projects are chosen to exercise knowledge about fluid flow, heat transfer, and mass transfer. They are also meant to appeal to students' technical specialization interests. Thus, design project application areas are chosen from medicine, environment, and food or biotechnology. The particular matching of transport process with applications area changes every year. In recent years some design projects have been:

1. drying of wood chips to produce taxol
2. removal and immobilization of chlorinated hydrocarbons from wastewater
3. remediation of ecological effects of truck traffic across a salt marsh.
4. packaging of spices
5. complete wastewater treatment, including uv and constructed wetlands
6. freezing of hamburger
7. harvesting of cranberries
8. composting of swine waste
9 processing of surimi
10. mechanical analog to test artificial hearts
11. life support suit for toxic waste cleanup
12. bioremediation of underground gasoline tank leakage
13. ventilation system for rearing of test mice
14. delivery of genetic material to the respiratory system
15. yogurt processing

The range of topics is quite broad, and reflects the expectations that students completing this course will be able to solve almost any engineering problem involving biological systems. Appended to this paper are several of the design projects as assigned. Answers to detailed questions asked in class by the students may have further modified project requirements.

Biological Process Engineering is a course that is a lot of work for students, but this challenge is offset by the payoff: students learn a great deal in this course and usually realize how valuable this is to them in their career goals. Rather than deal with a somewhat homogeneous group of students and with narrowly-focused course material, this course prepares students for a future that is less focused and more variable. Environmental engineering students who must consider the human angle, and biomedical engineering students who can see to the environment beyond neatly scrubbed operating rooms will certainly have a place in our future world. Some graduates have reported back that they were offered jobs after showing their design reports to interviewers. With such positive feedback, the way this course is taught will not soon radically change.

Example Problems

Traffic Across a Salt Marsh
(Mass Transfer)

A New England salt marsh is a harsh and diverse environment for both plants and animals. The low marsh area from beyond the water's edge to the mean high tide level is dominated by cordgrass, ribbed mussels, and fiddler crabs. The high marsh area, from the low marsh to the level of the monthly extreme high tides has salt meadow hay in the lower part and black rush in the higher. A combination of competition and predation keeps this marsh in ecological stable balance.

Although the low marsh seems to be a more difficult environment because its soil is waterlogged and constantly eroded by the tide, the high marsh is actually more difficult to restabilize after a disturbance. Bare areas in the high marsh allow sunlight to heat the exposed soil surface and to evaporate moisture. The soil becomes more saline. The soil salinity in large bare patches between salt meadow hay and black rush can become 30 times that under dense perennial vegetation. Closer to the sea, frequent flooding limits the accumulation of surface salt, and further into the black rush, rainwater dilutes any salty soil. Hypersaline soil prevents the germination of many seeds and slows marsh healing.

A client of yours, Investocorp, has a planned construction project that requires access across a portion of a high marsh in Rhode Island. Although the traffic will not require more than one month to complete, vegetation in bare areas left in the marsh could take years to become reestablished. The company cannot afford the regulatory and public-relations costs of such destruction. Investocorp is asking you to perform a feasibility study of using some kind of cover or coating on the high marsh areas damaged by traffic to allow quick reestablishment of native vegetation. Consider, in your report, 1) ways to minimize traffic damage, 2) the rate at which moisture is lost from the ground on bare earth compared to vegetated earth, and 3) how to provide an adequate local environment to germinate salt hay seed.

Toxic Material Removal
(Fluid Flow)

Resource Recovery, Inc., is a small firm dealing with disposal of toxic wastes. The company wishes to propose a disposal system to a large and well-known generator of toxic wastes. These wastes consist of water containing low levels of chlorinated hydrocarbons. RRI proposes to use activated charcoal to absorb the chlorinated hydrocarbons from the waste water. The charcoal will then be mixed with concrete in a solidification stabilization scheme that should allow disposal as a nonhazardous waste.

Waste water will be delivered to a tank capable of holding 190,000 Liters. From there it is pumped through a charcoal column in a tank 3.7 m high and 1.2 m in diameter. The cleaned water will then be stored in another tank for subsequent testing and either release or recycling through the charcoal.

The bottom of the charcoal tank must open to dump the contents into a waiting tank filled with at least 80 m^3 of fresh cement. There can be no charcoal remaining in the tank when it is dumped.

The concrete is pumped through a 7 m long pipe to 200 Liter drums that are filled ten at a time. When cured, the drums and concrete are removed to a landfill. The pipes are washed after use and the wash water is stored for later use in making more cement.

Design the system, including piping, pumps, and tanks.

Toxic Materials Cleanup
(Heat Transfer)

Super Fund, Inc., is a small company involved in the design and manufacture of protective equipment to be used in the cleanup of toxic materials. There is a new line of protective suits that needs to be designed for the company. As a biological engineer, you are being hired to design the new suits.

Required specifications are:

1. suits completely impermeable to liquids, gases, and vapors.
2. air supplied with hoses to a central hating/cooling unit located up to 10 m away from the position of the person working in the suit.
3. up to three suits to be operated from one heating/cooling unit.
4. suit is to be worn for up to four hours at a time.
5. suit should be able to be worn in a temperature range of -10°C to 35°C, in the sun or shade.
6. suits should be able to be cleaned of contaminants and resist abrasion during operation.

Work with our clothing people and recommend specifications for the central heating/cooling units. These specifications must include:

1. rate of airflow
2. charcoal filter capacity
3. maximum heating and cooling capacity
4. type and size of power to run the unit.
5. recommendations on techniques to control suit air for desired environmental conditions.

Waste Handling
(Heat Transfer and Fluid Flow)

Mr. Puerco Gordo is a wealthy hog farmer on the Eastern Shore of Maryland. He is installing a new manure handling system in his 28' x 270' building for 800 pigs. Two tanks of 300 gallons will dump each hour to flush the manure to a collecting trough, and from there the manure will pass over a screen to a sump. The liquid is to flow to a lagoon and the concentrated manure slurry will be pumped to a digester through a pipe located at least 10 feet above the ground to let machinery pass under. The manure handling system must work at all times, in all weather conditions. Specify:

1. pump
2. sump

3. pipe

Other information to be supplied in answer to questions:

distance from building to lagoon is 100 ft.
distance from sump to digester is 300 ft.
manure 9% T.S., concentrated manure 25% T.S.
0.2 ft^3/day/pig manure produced.

Waste Composting
(Heat Transfer)

A farmer wants to build a methane generator from some unused equipment he has on the farm. He proposes to use an old oil tank and some irrigation pipe with appropriate fittings. His chickens produce 1000 gal of raw manure per day, which he pumps through 4" irrigation pipe for a distance of 75 ft to a tank of 50,000 gallon capacity. The tank is surrounded by trees so that it is constantly shaded and never exposed to high wind. The tank is built on a structure to keep it 3 ft off the ground and has a radius of 10 ft. He can pump manure into the tank once per day with a 50 gpm pump. Digested manure is pumped to his land at the same time so that raw manure displaces digested manure. Average weather data is:

air temp = 65°F
wind velocity in tank area = 3 mph
wind velocity outside tank area = 7 mph
temp inside poultry house = 80°F

He pipes the methane back to his poultry house through ½" plastic pipe.

Inside the tank, heat is produced at a rate of 4 BTU/lb manure/day at a temperature of 90°F. The rate of heat production doubles every 10°F rise in temperature. Methane is produced at a rate directly proportional to the heat production, 0.125 ft^3/lb/day at 90°F.

Data for poultry manure is:

density = 60 lb/ft^3
solids content = 25%
thermal conductivity = estimated at .001 $\frac{cal}{cm\ C\ sec}$

Find: 1. What is the temperature of the manure as it enters the tank?

2. How much methane can be expected on a daily basis?

References

1. Johnson, A. T. and W. M. Phillips, 1995, Philosophical Foundations of Biological Engineering, J. Engr. Educ. 84:311-317.

2. Garrett, R. E., D. C. Davis, D. M. Edwards, A. T. Johnson, and G. E. Rehkugler, 1992, Improvement of Competencies of Agricultural and Related Biological Engineers, Report of CSRS USDA Agreement No 90-38411-5734, University of California, Davis, CA 956l6-5294.

3. Johnson, A. T., 1996, Biological Process Engineering: An Analogical Approach to Transport Processes in Biological Systems (book manuscript in preparation).

ARTHUR T. JOHNSON

Arthur T. Johnson received the B.A.E., M.S., and Ph.D. degrees in agricultural engineering from Cornell University in 1964, 1967, and 1969, respectively. He served in the U.S. Army in Vietnam, and worked as a civilian at Edgewood Arsenal, MD, before going to the University in 1975, where he is currently Professor in the Biological Resources Engineering program. His research interests are exercise and respiratory biomechanics, human performance, and convection heat transfer. He has actively promoted the establishment of undergraduate and graduate educational programs in biological engineering. Dr. Johnson has been actively engaged in professional societies, currently serving on the AIMBE Board of Directors and the ASAE Board of Directors. He is a Member of the Biomedical Engineering Society, the American Society for Engineering Education, and the American Industrial Hygiene Association.