Freshman Engineering Design - Process Design and Siting of a Municipal Wastewater Facility

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Abstract

To bring "practical" engineering into the freshman year, a hands on lecture/laboratory chemical engineering introductory course was developed which meets twice a week for a total of 3 hours for seven weeks. The course was well received by students. In order to broaden the design experience and include concepts of manufacturing into the freshman course, an interdisciplinary Environmental Engineering course problem has been developed. This new course is team taught by a combination of Chemical and Civil Engineering faculty, meeting for 21 hours per week for fourteen weeks. The problem chosen was the siting and design of a municipal wastewater facility with the siting being the responsibility of the Civil Engineering faculty, and the process flowsheet, equipment design, and the process cost estimation addressed by the Chemical Engineering faculty. The course was enthusiastically received and the students particularly enjoyed working in teams to achieve their common objective.

Introduction

During the last five or six years the incorporation of design concepts into the freshman year has gained widespread acceptance in the United States. Spurred forward by the formation of numerous NSF sponsored Educational Coalitions the Freshman Engineering Design programs have become an integral part of the curriculum. The New Jersey Institute of Technology (NJIT), as part of the NSF sponsored Gateway Coalition, a consortium of ten engineering institutions, has instituted such a program and developed numerous discipline and interdisciplinary courses.

The basic intent of these programs is to move the traditional exposure to design concepts from senior year capstone courses into the entire undergraduate curriculum, beginning with entering freshmen. The overall objective is to introduce freshmen to the open-ended nature of design problems, to give students "hands-on" experience, to expose students to teamwork and the solution of problems by a team, and to teach students the importance of both oral and written presentation of their results.

NJIT Freshman Design Program

At NJIT, the program began about five years with Mechanical, Electrical, Civil, and Chemical Engineering modules. The Mechanical Engineering module was fourteen weeks for the

semester, while the other disciplines developed seven week modules. Students were required to take the Mechanical Engineering module and were assigned to two of the remaining three.

In Chemical Engineering, a module was developed which introduced freshmen to the senior Chemical Engineering Unit Operations Laboratory. The module was for seven weeks with two 80 minute periods per week. Students were first oriented to the nature of chemical engineering problems, the concepts involved in the manufacturing of hazardous substances, environmental issues, pollution prevention and pollution abatement. Students were divided into groups of three or four and immediately given hands-on experience in running the pilot plant size equipment in the laboratory, collecting data by measuring important parameters used in equipment design, reducing the data to meaningful correlations, and preparing a written report on their study and finally making an oral presentation. Simultaneously, the students were given instruction in the preparation of written and oral reports and worked with the Humanities Department for clear technical writing.

All students studied the simple calibration of a rotameter and in addition ran studies on pressure drop in pipes and fittings, pressure drop in packed towers, pressure drop in a fluidized bed and efflux time from cylindrical tanks.

Students were enthused, enjoyed working in teams and the hands-on experience most but disliked the oral presentation aspects of the course.

NJIT Pilot Studies

In the fall of 1996, running in parallel with the above program, a pilot section was introduced to expose some students to freshman design and manufacturing concepts and the interdisciplinary nature of engineering. Fourteen week modules were run in Mechanical and Industrial and Manufacturing Engineering (Lawn Sprinkler design), Mechanical and Electrical Engineering (Floppy Disk Drive), Electrical and Biomedical Engineering (Emergency Medical Service Field Radio), and Chemical and Civil Engineering (Wastewater Treatment Facility).

Wastewater Facility

The Chemical and Civil Engineering module focused on the siting and process design of a municipal wastewater facility. The course was coupled with a Humanities and Computer Aided Design component. The Civil Engineering Faculty guided the students, divided into groups of four, through the siting considerations of the design while the Chemical Engineering Faculty focused on the process design considerations. The course was for fourteen weeks, two hours ten minutes per week with a two hour ten minute CAD and software application class. The Humanities component met three hours per week for the semester.

Students were assigned to design and locate a municipal wastewater facility. The facility was to serve 45,000 households with an average of three people per household, and per capita water consumption of 80 gallons per day. The plant was to be located in central New Jersey between the south branch of the Raritan River and Highway Route 202 in the Township of Branchburg.

The influent stream had a BOD_5 of 250 mg/L and suspended solids of 250 mg/L and the effluent stream could not exceed a BOD_5 of 30 mg/L and suspended solids of 30 mg/L. As part of the course, the students were taken on a field trip to the Passaic Valley wastewater treatment facility in Newark, NJ, which serves a 100 square mile area in Northern New Jersey, and has a capacity of 330 million gallons/day. It services 36 municipalities with a population of 1.3 million and discharges the treated effluent into New York Harbor. This 156 acre plant is the largest wastewater treatment facility in the Eastern United States and processes about one fourth of the wastewater generated in New Jersey.

With this background the students were given a simplified process flow sheet and told to design and site the facility.

Civil Engineering Faculty (2) worked with the student groups on:

- Siting considerations (zoning, soil)
- Field reconnaissance trips to the proposed site area (photos)
- Environmental restrictions and regulations on the sites
- Political constraints on the sites (historical value, “not in my backyard” problem, etc.)
- Economic aspects of the proposed sites (property values)
- Site evaluation and selection

Chemical Engineering Faculty (2) guided the students on the process design aspects of the facility including:

- Process flow sheets of primary and secondary treatment
- Definitions used in design of wastewater treatment
- Discussion of the simplified flow sheet
- Material balance for process units
    - Flow rates
    - Composition of streams
- Size and quantities of process units needed
- Plant cost analysis
    - Plant construction cost
    - Annual operating and maintenance cost

Students were encouraged to seek help from local government agencies.

<u>Siting</u>

After careful consideration of all factors, the student groups located three to five potential sites and made a final recommendation based upon all of the factors cited.

Two of the four groups picked identical sites while the other two groups picked different sites. The students justified their choice based on all of the factors considered.

Process Design

Simultaneously, the students performed the necessary material balance calculations, determined the size and number of process units and performed a process cost analysis. Students relied on Sundstrom and Klei[1] for process calculations, Kawamura[2] and the Engineering News Record Index for process cost analysis and inflationary effects, and Water Treatment Federation, ASCE[3] for equipment size determinations.

Student results varied for the wastewater process design. Figure 1 shows a typical student flow sheet for the process with flows and compositions summarized in Table 1. Table 2 shows the quantity and size of units required. The plant cost estimates for the groups ranged from $6 million to $7.6 million. Operating and maintenance costs ranged from $450,000 to $500,000 per year and the size estimate was 30-35 acres.

Overall, the students found the project was too much work, but they enjoyed the effort, especially the team approach to the problem solution, and the close student-faculty interaction.

During the spring of 1997, two additional pilot groups in Civil-Chemical Engineering are studying the Siting and Environmental concerns of a new highway in New Jersey and the Siting and Process considerations in the manufacture of hazardous substances. The projects are about midway at this time and student reactions are similar to previous semesters.

References

1. Sundstrom, D. and Klei, H. E., "Wastewater Treatment", Prentice-Hall Inc., Englewood Cliffs, NJ, 1979.

2. Kawamura, Susumu, "Integrated Design of Water Treatment Facilities", John Wiley and Sons, Inc., New York, NY, 1991.

3. "Design of Municipal Wastewater Treatment Plants", Volume I and Volume II, Water Environment Federation, American Society of Civil Engineers, 1992.

4. Hanesian, Deran and Perna, Angelo J., "A Laboratory Manual For Fundamentals of Engineering Design", New Jersey Institute of Technology, 1995.

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Figure 1 and Table 1		Table 2	
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Anika Lewis	Vamsi Maddula	Ramzi Khalil	Bill Brzenski

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Biographies

DERAN HANESIAN served as chairman of the Dept. Chem. Eng., Chem., and Env. Sci. from 1975-1988 and is Professor of Chem. Eng. He came to NJIT in 1963. He received a bachelor of Chem. Eng. in 1952 and a Ph.D. in Chem. Eng. in 1961, both from Cornell Univ. Dr. Hanesian worked for DuPont from 1952-1957 and 1960-1963. He taught at the Algerian Petroleum Inst., Yerevan Poly. Inst., Armenia as a Fulbright Scholar, the Univ. of Edinburgh, Scotland, and Rutgers, the State Univ. of NJ. He was the recipient of the Robert Van Houten award for Teaching Excellence in 1977 at NJIT, the ASEE, Midlantic AT&T Foundation Award for Excellence in Instruction in Eng. in 1986, the John Fluke Award, ASEE, 1994, and the Outstanding Tenured Faculty Award, NJIT, 1994. He is a Fellow and Emeritus Member of the American Institute of Chemical Engineers and a Fellow and Life Member of the American Society of Engineering Education.

ANGELO J. PERNA received his B.S. ChE degree from Clemson University in 1957 and his M.S. degree from there in 1962. He received his Ph.D. from the University of Connecticut in 1967. He worked as a production and development engineer with Union Carbide Nuclear Company in Oak Ridge, TN, and taught at VPI, and the University of Connecticut. He is currently Professor of Chemical Engineering, Chemistry and Environmental Engineering at New Jersey Institute of Technology. In 1997, he received the NJIT award for Teaching Excellence in the Upper Division. He is a Fellow in both the American Institute of Chemical Engineers and the American Society of Engineering Education.

Figure 1

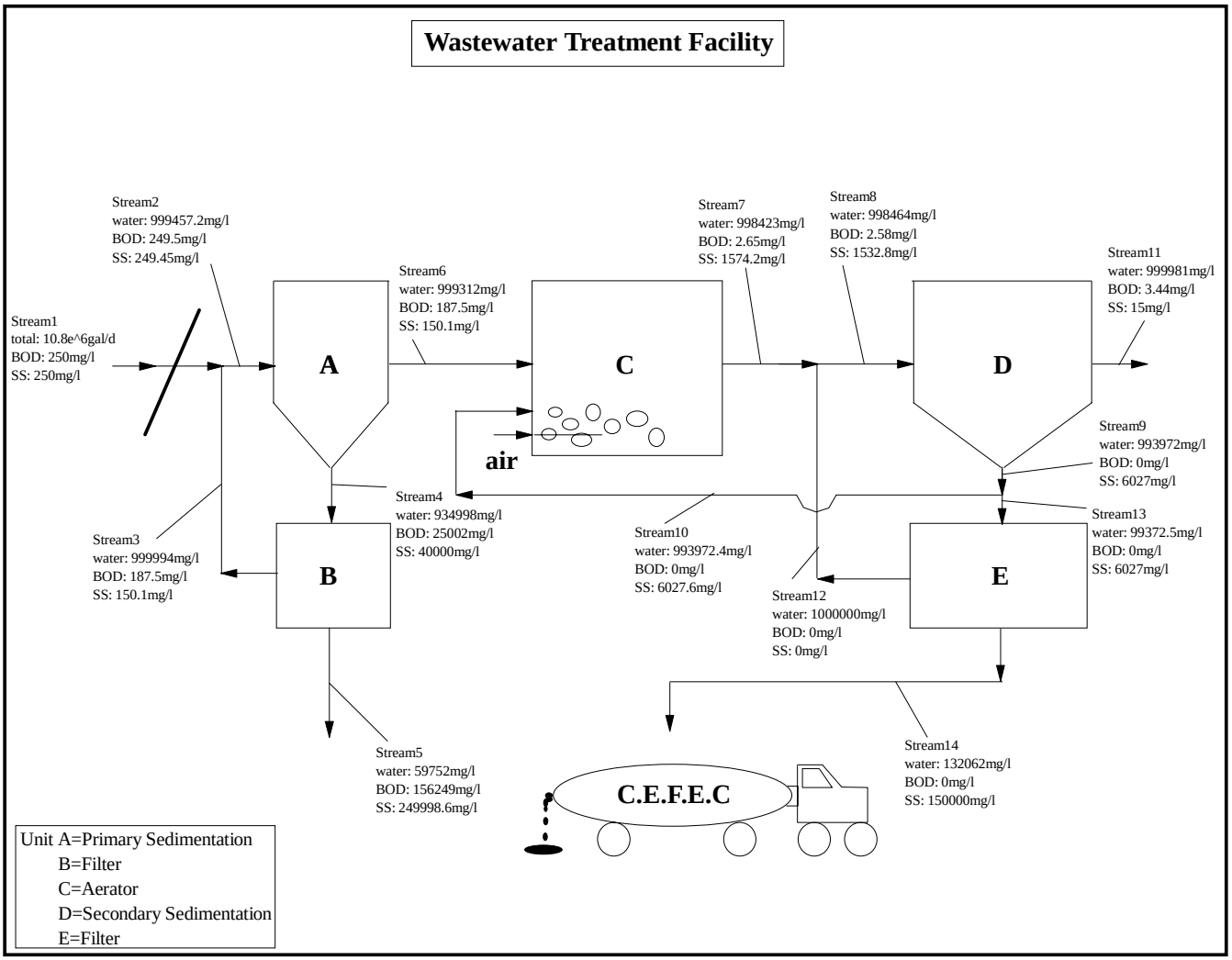
Wastewater Treatment Facility
Stream1
total: 10.8e^6gal/d
BOD: 250mg/l
SS: 250mg/l
Stream2
water: 999457.2mg/l
BOD: 249.5mg/l
SS: 249.45mg/l
Stream3
water: 999994mg/l
BOD: 187.5mg/l
SS: 150.1mg/l
Stream4
water: 934998mg/l
BOD: 25002mg/l
SS: 40000mg/l
Stream5
water: 59752mg/l
BOD: 156249mg/l
SS: 249998.6mg/l
Stream6
water: 999312mg/l
BOD: 187.5mg/l
SS: 150.1mg/l
Stream7
water: 998423mg/l
BOD: 2.65mg/l
SS: 1574.2mg/l
Stream8
water: 998464mg/l
BOD: 2.58mg/l
SS: 1532.8mg/l
Stream9
water: 993972mg/l
BOD: 0mg/l
SS: 6027mg/l
Stream10
water: 993972.4mg/l
BOD: 0mg/l
SS: 6027.6mg/l
Stream11
water: 999981mg/l
BOD: 3.44mg/l
SS: 15mg/l
Stream12
water: 1000000mg/l
BOD: 0mg/l
SS: 0mg/l
Stream13
water: 99372.5mg/l
BOD: 0mg/l
SS: 6027mg/l
Stream14
water: 132062mg/l
BOD: 0mg/l
SS: 150000mg/l
A
B
C
D
E
air
C.E.F.E.C
Unit A=Primary Sedimentation
B=Filter
C=Aerator
D=Secondary Sedimentation
E=Filter

Table 1

CENTRAL EAST FUTURE ENGINEERING CONCEPTS
CORPORATION (Group 3)

I. Material Balance
Primary Treatment

Stream	Total Flow Rate		Components					
			BOD5		SS		Water	
	GPD	lb/d	mg/l	lb/d	mg/l	lb/d	mg/l	lb/d
1	1.08E+07	9.01E+07	250	22518	250	22518	999500	9.00E+07
2		9.03E+07	249.5	22518.6	249.45	22518	999457.2	9.02E+07
3		189151	3	0.5674	0	0	999994.7	189150
4		225180	25002	5630	40000	9007.2	934998.7	210543
5		36029	156249	5629.5	249998.6	9007.2	59752	21392.3
6		90034000	187.5	16585.5	150.1	13510.78	999312	90003572
7		116859926	2.65	309.3	1574.2	183964.6	998423	116675652
8		120014306	2.58	309.3	1532.8	183964.6	998464.6	119830032
9		30296642	0	0	6027.6	182616.1	993972.4	30114026
10		27010200	0	0	6027.6	162806.7	993972.4	26847393
11		89901938	3.44	9.3	15	1348.5	999981.6	89900280
12		3154380	0	0	0	0	1000000	3154380
13		3286442	0	0	6027.6	19809.4	99372.5	3266633
14		132062	0	0	150000	19809.4	849999	112252.6

Table 2

Basis of Design & Unit Size
JRB&E INC.

Inflow Flow Rate
1. 10.8 MGD or 90,072,000 lb.'s/d
2. 250 mg/l BOD-5
3. 250 mg/l Suspended Solids

Effluent Components
1. 3.44 mg/l of BOD-5
2. 15 mg/l of Suspended Solids

Primary Sedimentation Tank. 1 Unit
1. Suspended Solids Removal - 40%
2. Biological Oxygen Demand Removal - 25%
3. Settled Solids Concentration - 4%
4. Detention Time - 4 hours .
5. Overflow Rate - 16m^3 / d-m^2

Dimensions
1. Length - 90 m
2. Width - 22.5
3. Depth - 3.37 m

Primary Vacuum Filter . 1 Unit
1. Cake Solids Concentration - 25%
2. 20 kg/m^2 -h filter rate
3. Filters 9,007.2 lb.'s/d of solid

Dimensions
1. Diameter - 5 m
2. Length - 6 m

Secondary Sedimentation Tank . 1 Unit
1. Suspended Solids leaving is 15 mg/l
2. Detention Time - 4 hours .
3. Removes no additional BOD-5
4. Overflow Rate - 16 m^3 / d-m^2

Dimensions

1. Length - 90 m
2. Width - 22.5 m
3. Depth - 4.5 m

Secondary Vacuum Filter. 1 Unit
1. Cake Solids 15% solid
2. 20 kg/m^2-h Filter rate
3. Filters 19,859.3 lb.'s/d of solid

Dimensions
1. Diameter - 5 m
2. Length - 6 m

Activated Sludge Reactor. 3 Units
1. Detention Time 7 hours
2. Sludge Life 120 hours .
3. Produces BOD concentration of 3.44 mg / l
4. Reactor Volume 420,900 ft^3
5. Recycle Ratio of .3
6. Generated Solids - 7697 lb.'s /d
7. Oxygen Needed - 1670118.7 L /d

Dimensions
1. Length - 122 m
2. Width - 9.1 m
3. Depth - 3.6 m

Design Calculations

Primary Sedimentaion
overflow 16m ^3 /d-m^2

Length = 90 meters
Detention Time 4 hours 90,035,000 lb/d = 40923.3 m^2 per day
Area needed = 40923.3 / 16 = 2557.7 m^2
V =qt (40923.3 * 4) / 24 = 6820.55 m^3
Total Volume = (90)(90/4)(D) D = 3.37 meters

1 tank 3.37 m deep , 90 m long , 22.5 m wide

Secondary Sedimentation
(120,184,817 lb/d / 62.3) / 35.3145 = 54630 m^3/d
54630 m^3/d / 16 = 3414.2 m^2

V=qt 54630 * 4 / 24 = 9105 m^3
9105 m^3 = (90)(90/4)D
D = 4.5 m

1 tank Length 90 m , Deep 4.5 , 22.5 m wide

Activated Sludge Reactor
V = 420,900 ft^3 * .028317 = 11919 m^3
11919 = (122)(9.1)(5)N
N= 2.15
Let N = 2 V = 2 * 122*9.1 * H
H = 5.36 m (to high)
Let N = 3 11919 = 3 * 122*9.1*H
H = 3.6 m
N = 3 Tanks Length = 122 m , Width = 9.1 m, Height = 3.6 m

Primary Filter
20 kg/m^2-h 9007.2 lb/d / 24 * .454 = 170.4 kg/h
170.4 / 20 = 8.5

Area = 3.14 * 5 * 6 = 94.2 M^2
1 filter Diameter = 5 m Length = 6 m

Secondary Filter
19859.3 lb /d / 24 * .454 = 375.7 kg / h
375.7 /20 = 18.8 m^2 area needed .

Total area = 94.2 m^2
1 filter , Diameter = 5 m , length = 6 m

Cost .
Index = 5671.91
6000000/4500 = x/5671.91 x = $7,600,000
for construction .
O&M
350,000 / 4500 = x / 5671.91 = $450,000

Sundstrum & Klie graphs of treatment facility costs .