1972

STUDENT CONTEST PROBLEM

Each year the Student Chapters Committee of AIChE publishes a practical design problem to which the seniors in AIChE Student Chapters are invited to provide solutions. The first prize, the A. McLaren White Award, is $300, the A. E. Marshall Award carries with it $200, the third prize is $100, and there are usually three papers receiving honorable mention.

Winners of the first, second, and third prizes in 1972 were Donald S. Frook, University of Toledo; Daniel W. Tedder, Georgia Institute of Technology; and Timothy O. Bender, Michigan State University. James D. Bittner, Washington University, and Steven W. Goering, University of Colorado, received honorable mention. The awards will be made during the Annual Assembly at the Annual Meeting in New York on November 27.

A committee from General Foods Corporation, Tarrytown, New York, prepared the problem and judged the solutions. Members of the committee were Fredric Kleiner, chairman, and Lon Feldbrugge, Joe Su, and Ed Kelleher. The comments of the judges follow.

The 1972 Student Contest Problem, emphasizing an aspect of environmental control, was purposely selected for its relevance in today's industrial climate. As it was recognized that this subject matter is not offered in many chemical engineering curricula, the problem was structured to be less involved than some previous Contest Problems to allow the contestants sufficient time for background reading and familiarization with the subject before the actual working of the problem. Evidence that this time was well spent was borne out by the numerous references to the cited literature and to other related texts and articles and by the contestants' firm understanding of the fundamental technical material involved. In general, the judges were gratified by the overall quality of the solutions submitted.

The solution required a preliminary design and economic analysis of a conventional activated sludge wastewater treatment facility followed by a consideration of the merits of this approach versus some alternatives. While no solution was without errors or omissions, the better solutions recognized the need to provide for nutrient addition and the desirability of determining the respiration ratio of the waste material. These two considerations were weighted heavily by the judges in grading the solutions. Other important factors included the methods used to determine settling velocities in the clarifier, the recycle ratio chosen to minimize sludge production, the equipment sizes and costs, and an evaluation of this approach versus the alternatives. Computational errors were not severely penalized.

The contestants are to be commended for their interest, diligence, and many hours of effort put forth in dealing with this year's Contest Problem.

Problem

INTRODUCTION

Wastewaters from a food processing plant are currently being discharged into a city collection and treatment system, which established an allowable limit of 12,000 lb. biochemical oxygen demand/day from the food plant because the city system, in turn, must further decrease its received BOD loadings to levels suitable for discharge to local waterways. The food processor is currently being billed $80,000 annually by the city for wastewater treatment, which has been averaging 10,000 lb. BOD/day annually.

Because of stricter water quality standards, however, the city must further decrease the permissible BOD loading in its effluent. The decrease will require a capital expansion of current municipal treatment facilities and hence a substantial increase of $100,000 a year in wastewater disposal costs to the food processor for a 12,000-lb. BOD/day maximum loading. Subsequent food-plant expansion would further increase these water-pollution control costs.

To find the most economical means of pollution control, the food processor is evaluating three alternatives:

1. To continue to discharge all its wastewater to the municipal treatment system (12,000 lb. BOD/day maximum).
2. To provide a high-quality on-site wastewater treatment so that plant effluent may be discharged directly to natural waters.
3. To provide intermediate on-site wastewater treatment to greatly reduce the weight of current loadings before they are discharged to the city sewage plant for advanced treatment.

A conservative estimate of the annual costs for alternative 2 is $275,000.

As 90 percent of the total BOD loading from the food processing plant originates with a process for manufacturing prepared rice, alternative 3 may be achieved by treatment of the rice wastewater alone.

STATEMENT OF THE PROBLEM

As part of an overall study to evaluate potential routes to alternative 3—evaporation and incineration, aerated lagoons, and trickling filters among others—you are asked to prepare a preliminary design and economic analysis for a conventional activated sludge process to remove 80 percent of the influent BOD, for cost comparison with alternatives 1 and 2, and to recommend a course of action. The waste sludge generated in the process is to be dewatered by vacuum filtration and buried on the site.

To maintain an equal basis for the comparison of the alternatives, assume that the economic life of the process equipment will be ten years, or equal to the length of the new municipal treatment contract. The source of investment funds will be internal capital.

PROCESS DESCRIPTION, DATA

Rice production is on a 7-day-week around-the-clock schedule, with an average wastewater flow of 60 gal./min. from the cookers. Although the water temperature at the cookers is 200°F., the wastewater will lose heat in the pipes and will be delivered to the treatment site at 100°F.

After passage through a 20-mesh screen to remove suspended matter, the wastewater stream, in which the waste solids are of a colloidal and dissolved nature, was analyzed as follows:

Wastewater analysis	Concentration, mg./liter
BOD_5	12,500
COD	20,900
Total solids	13,850
Total volatile solids	12,900
Suspended solids	485
Phosphorus, as P	45
Nitrogen, as N	100

The pH of this stream was 6 4.

The elemental composition of the waste on a dry weight basis was

Component	Percent
Carbon	54.00
Hydrogen	7.85
Oxygen	37.45
Nitrogen	0.70

Batch tests on the rice wastewater, as summarized below, were performed in the laboratory for necessary design information on the removal rate of waste from the system, the amount of oxygen required, and the quantity of sludge produced. Organic concentrations in the waste were measured by the standard BOD test, and activated sludge concentrations were measured by a volatile solids determination. During the batch tests the amount of carbon dioxide that evolved from the system was recorded in cumulative fashion as cubic centimeters of CO_2 evolved (70°F., 1 atm.) per liter of system being aerated. Examination of the disklike spheroidal sludge particles resulting from the laboratory tests showed them to have a specific gravity of 1.005 and to be about 1.5 mm. in diameter.

Table 1. Summary of Batch Laboratory Data for Rice Wastewater

Aeration time, t, min.	Waste concentration as BOD, l, mg./liter	Activated sludge concentration s, mg./liter	CO_2 evolved c, cc./liter
0	10,800	19,300	
14	9,772	19,533	
31	9,329	19,737	
56	8,714	19,946	1,248
114	7,218	20,378	2,277
187	5,593	20,867	3,438
221	4,898	21,066	3,897
266	4,162	21,294	4,368
302	3,651	21,425	4,752
384	2,981	21,582	5,292
439	2,740	21,625	5,526
494	2,542	21,647	5,613

For design purposes a mixed liquor-suspended-solids concentration entering the aeration basin shall be taken as 2 percent by weight. The volume of sludge recycled in the process should be chosen to minimize the amount of sludge wasted from the system.

DESIGN CRITERIA

Assume that the following relationships are valid for this study:

$$\frac{ds}{dt} = c_1 \left[\frac{dl}{dt} - \frac{dl'}{dt}\right] \quad (1)$$

$$\frac{dl'}{dt} = c_2 \bar{s} \quad (2)$$

$$\frac{dO_2}{dt} = c_3 \frac{dl}{dt} + c_4 \quad (3)$$

$$\frac{l}{l_0} = 1 - 10^{-\left(\frac{kl_0}{s_0 t}\right)} \quad (4)$$

where

c_1, c_2, c_3, c_4, and k = constants

l = organic waste concentration

O_2 = dissolved oxygen concentration

s = activated sludge concentration

$\bar{s}$ = average sludge concentration

t = time

0 = initial value

$'$ = basic metabolic requirements

Note the following guidelines to be adhered to during the design of the process

1. The recycled sludge is to be between 10 and 30 percent by volume of the influent raw waste stream.
2. The sludge concentration of the recycle stream is to be between four and five times that of the mixed liquor entering the aeration basin.
3. The overall oxygen transfer efficiency in the aeration basin is 15 percent.
4. Because of the generally bulky nature of the activated sludge, base the clarifier design on 25 percent of the calculated settling velocity of the sludge particles.
5. As sludge filterability was not checked in the laboratory, assume a filtration rate of 0.1 lb./(sq. ft.) (hr.) of dry solids for each percent of solids in the feed, with the sludge being dewatered to a 100 percent increase in solids concentration.
6. Assume that the system design based on the information given is capable of handling normal shutdown periods and normal fluctuations in ambient temperature and BOD loadings.

COST ESTIMATION

Equipment costs not provided in the Appendix are available in standard textbooks.

Use the following cost information:

Electricity	$0.01/kw.-hr.
Operating labor	1/2 man/shift at $4/man-hr.
Depreciation	Straight line
Maintenance	5% of investment/year
Taxes	4% of investment/year
Insurance	1% of investment/year
Sludge cake disposal	$25/ton

REPORT FORMAT

Employ the following format for your report:

1. Introduction
   A concise statement of the problem, covering background and objectives.
2. Summary
   A brief description of the work performed in the study, including conclusions and recommendations.
3. Technical information
   A description of the proposed process, including a flow sheet detailing flow rates, concentrations, and equipment sizes. Calculation summaries of important operating and design parameters, detailing equations used and assumptions employed. A discussion of the analyses and considerations made. Summaries of equipment specifications and costs, capital investment, and operating expenses.
4. Appendix
   Calculations, graphs, an explanation of all assumptions made, and any details not included elsewhere.

GLOSSARY OF TERMS

BOD = Biochemical Oxygen Demand, also known as Biological Oxygen Demand. The amount of oxygen consumed under prescribed conditions during the biological oxidation of the organic matter in the wastewater.

BOD_5 = The 5-day BOD. A standard test to measure the quantity of oxygen consumed under prescribed conditions during the biological oxidation of the wastewater during the first five days.

COD = Chemical Oxygen Demand. The amount of oxygen consumed during the chemical oxidation of the organic matter in the wastewater.

Total Solids = The total dry-weight residue obtained after evaporation of the wastewater sample at 103°C.

Total Volatile Solids = The organic portion of the total dry solids present in the wastewater.

Suspended Solids = The material on a dry basis removed from the wastewater sample by filtration.

REFERENCES

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APPENDIX

Capital costs

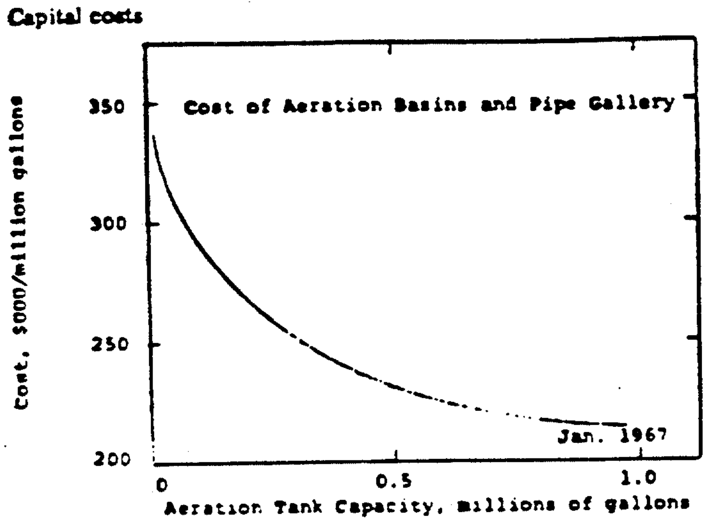

Figure 1

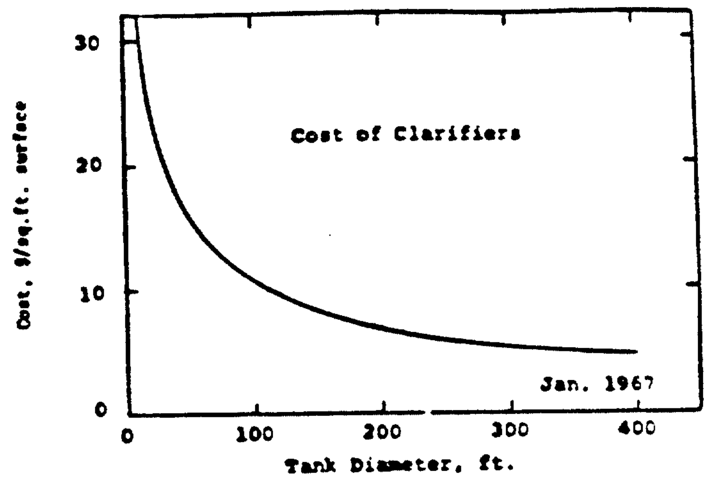

Figure 2

Wastewater treatment costs

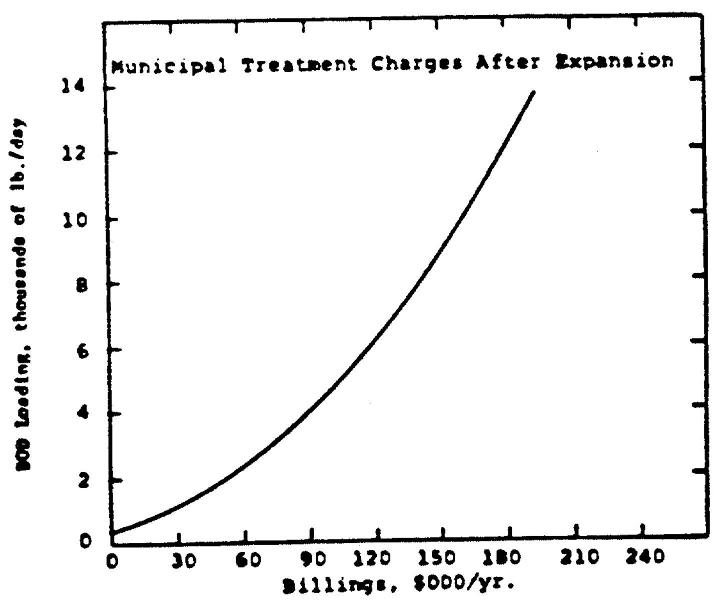

Figure 3