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Project Summary

Technology Assessment of Sequencing Batch Reactors

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The innovative and alternative technology provisions of the Clean Water Act of 1977 provide financial incentives to communities using wastewater treatment alternatives that reduce costs of energy consumption over conventional systems. To increase awareness and implement such alternatives, the U.S. Environmental Protection Agency's (EPA) Water Engineering Research Laboratory has initiated a series of assessments intended to evaluate both the current status and capabilities of these technologies. This report provides an analysis of one of these technologies, the Sequencing Batch Reactor (SBR).

The SBR is a fill and draw activated sludge system. Each tank in the SBR system is filled during a discrete period of time and then operated in a batch treatment mode. If tank volumes and aeration practices are properly designed, the SBR can simulate any conventional continuous flow activated sludge system. In a cost and energy comparison, the cost of SBR closely compared with that of the oxidation ditch and was roughly 20 percent less than that for the conventional activated sludge systems tested. As far as energy use is concerned, the SBR was 13.5 percent more efficient than the oxidation ditch and was the equivalent of the conventional activated sludge systems.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Technology Description

The SBR, a type of periodic process, is a fill and draw activated sludge system. Each tank in the SBR system is filled, one after the other, during a discrete period of time and then operated in a batch treatment mode. After treatment, the mixed liquor is allowed to settle and the clarified supernatant is drawn. The tank is then refilled after the remaining tanks in the SBR systems have been filled.

If the time required for a tank to fill is very long when compared with the time provided for batch treatment, the SBR behaves like a conventional completely mixed activated sludge facility. If the opposite is true, the SBR behaves like a nominal plug flow system. A properly designed SBR can simulate any conventional continuous flow activated sludge system. Each SBR tank carries out the functions of equalization, aeration, and sedimentation in a time sequence rather than in the conventional space sequence of continuous flow systems, where these functions are carried out in separate tanks. Because the relative tank volumes dedicated to, say, aeration and sedimentation can be redistributed easily by adjusting the mechanism that controls the time (and, therefore, share of the total volume) planned for either function, the SBR is flexible. By working in time rather than in space, the SBR can be either a labor-intensive, low-energy, high-sludge-yield system or a minimal-labor, high-energy, low-sludge-yield system.

Each tank in an SBR system undergoes one or more cycles (i.e., the time between one filling and the next) during each day. The cycle of a typical SBR tank is divided into five discrete periods—FILL, REACT, SETTLE, DRAW, and IDLE (Figure 1).

FILL: During FILL, either raw wastewater (screened and degritted) or primary effluent is added to the activated sludge remaining in the tank from the previous cycle. FILL ends either when the tank is

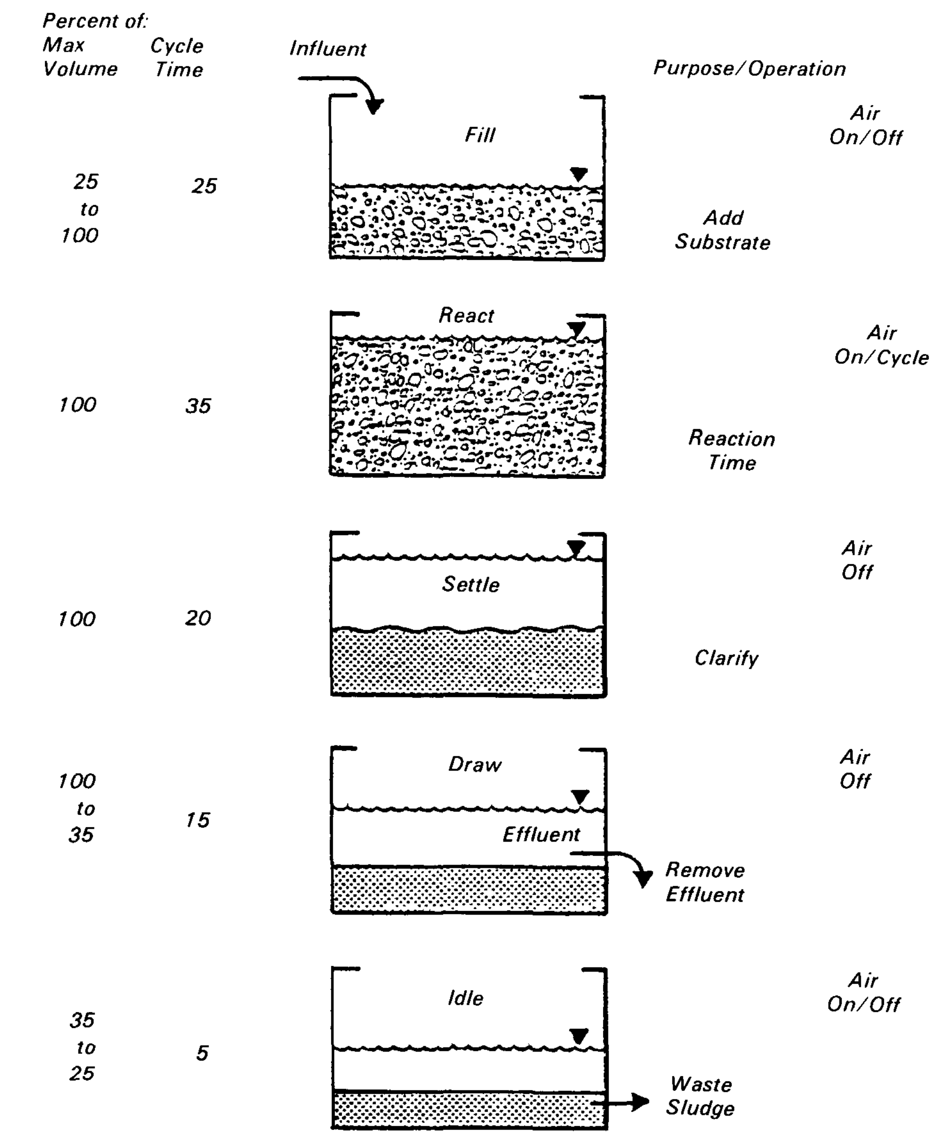

Figure 1. *Typical SBR operation for a complete cycle in one tank.*

full or when a maximum time for FILL is reached. The wastewater flow is then diverted to the next tank in the SBR system. Although FILL time is shown to be 25 percent of the total cycle time, a range of 40% to 60% would be more typical for a two-tank system and, in any event, would more or less depend on the extent of daily variations in the hydraulic flow rate.

REACT: Reactions begun during FILL are completed during REACT. Although the liquid level appears to remain maximum, sludge wasting can take place during REACT as a simple means to control sludge age, e.g., sludge age in days would be equal to the reciprocal of the fraction of the maximum liquid volume wasted each day. The total cycle time dedicated to REACT can actually vary from just greater than zero to more than 50 percent.

SETTLE: During SETTLE, solids and liquids separate. The time should be between 0.5 and 1 hour so that the sludge blanket remains below the withdrawal mechanism during DRAW and does not rise (because of gas formation) before DRAW is completed.

DRAW: During DRAW, the treated wastewater is removed. The percent of cycle time can range from 5 to more than 30. DRAW cannot be overly extended, however, because of possible problems with rising sludge.

IDLE: The IDLE period can be used to waste sludge from the system. Otherwise IDLE is simply that time that must be waited after DRAW for the last tank in the SBR system to be filled before the tank in question can be refilled, thus beginning a new cycle.

An SBR system consists of the headworks, one or more tanks, an aeration device, a mechanism to withdraw wastewater, and a control system. The influent sequences from one tank to the next and may be either pumped in or allowed to flow in by gravity. When using gravity flow, some device such as an adjustable weir or automatic valve must be used to divert the flow to one tank or the other.

Theoretically, there's no limit to the size of each tank, or the number of tanks used in the SBR system. The tank may be an earthen ditch, an oxidation ditch, a rectangular basin, or any concrete or metal structure. Virtually any aeration system (e.g., diffused, floating, mechanical, or jet) can be used although a system that separates mixing from aeration (e.g., as for the jet) and one that is not clogged by having mixed liquor settle on it once each cycle would likely be best. The withdrawal mechanism may be as simple as a pipe fixed at some predetermined level (with the flow regulated by either an automatic valve or a pump depending on the hydraulic grade line of the system) or, preferably, an adjustable or floating weir at or just beneath the liquid surface. As with the fixed mounted pipe, discharge from the weir can be regulated by an automatic valve or a pump. Level sensors and a timing device provide overall control of the SBR.

Because REACT, SETTLE, and DRAW take place after the flow has been diverted, the SBR system with just one tank would be quite unusual for a municipal waste situation but not all that uncommon for day schools, amusement parks, or industries that operate for 8 to 15 hours each day with little or no flow generated during the remaining hours. In a two or more tank system, the time for REACT, SETTLE, and DRAW in one tank must be less than or equal to the time required to fill the other tanks An SBR with three tanks is probably the practical limit for such systems. Although the total volume (sum of all tanks used) of an SBR decreases with the number of tanks employed, the incremental reduction is minimal for greater than three. In addition, the complexity of operation increases as the number of tanks increases. As a result, except under quite unusual circumstances, only one, two, or three tanks would be recommended.

Status of the Developed Technology

The retrofit plant in Culver, Indiana, served as the first full-scale demonstration plant for SBR treatment of domestic wastewater in the United States. At least four domestic waste plants are in various stages of design or construction: Juneau, Alaska; Sabula, Iowa; LeClaire, Iowa; and Poolesville, Maryland. An SBR-like facility was started up in July 1983 in Grundy Center, Iowa.

On the industrial side, Alphenrose Dairy owns and operates a two-tank fill and draw system in Portland, Oregon. A single-tank SBR was reportedly used in Ada, Oklahoma, to treat wastewaters from a vehicle maintenance area for a utility company. A single-tank SBR for a hazardous waste disposal site owned and operated by CECOS International, Niagara Falls, New York, began operation in June 1984, and Occidental Chemical Corporation has designed a similar system to treat its landfill leachates in the Niagara Falls area.

Process Capabilities

The only full-scale SBR performance data currently available is from the EPA-funded research project completed at Culver, Indiana.* Between May 1980 and May 1981, the Culver SBR produced average 5-day biochemical oxygen demand (BOD_5) and suspended solids (SS) concentrations of less than 10 g/m³ each:

	Raw Waste-water	Effluent North Tank	Effluent South Tank
BOD_5, g/m³	160 (152)	9⁺ (147)	10⁺ (144)
SS, g/m³	130 (153)	7 (258)	9 (258)

*( ) = number of observations
⁺Effluent BOD_5 measurements were conducted on prechlorination samples Post-chlorination BOD_5 effluent averaged 5 g/m³ (143 observations)

Nitrification

Because nitrification requires that the dissolved oxygen (DO) be greater than approximately 0.5 g/m³, the aeration time during FILL and REACT must be sufficiently long and the DO must be sufficiently high to allow both the enrichment of nitrifiers and the completion of ammonia-nitrogen (NH_4-N) oxidation. The following data are from those 5 months of the Culver study when nitrification was achieved, August to Decembr 1981:

	Raw Waste-water	Effluent North Tank	Effluent South Tank
NH_4-N, g/m³	20 (82)	1 1 (79)	1 0 (78)
SS, g/m³	150 (94)	5 (94)	6 (94)
BOD_5, g/m³	170 (59)	11⁺ (57)	10⁺ (59)

*( ) = number of observations
⁺Post chlorination BOD_5 effluent (August to December 1981) = 7 g/m³

Denitrification

Denitrification requires the DO to be less than approximately 0.5 g/m³, the presence of nitrite and/or nitrate nitrogen (the sum of these two is reported in NO_x-N), and a carbon source for energy. A mixing-only period of FILL with no oxygen supplied and the organics in the wastewater as the carbon source provides the best conditions for denitrification until the oxidized nitrogen supply, left in the residual liquid after DRAW, is exhausted. After all available NO_x-N is depleted, however, anaerobic reactions occur. To prevent these conditions after achieving denitrification, aeration during the later part of FILL can be instituted. The following denitrifcation data are also from August to December 1981:

	Raw Waste-water	Effluent North Tank	Effluent South Tank
NO_x-N, g/m³	2 0 (80)*	1 3 (81)	1 0 (81)
NH_4-N + NO_x-N, g/m³	22⁺	2.4	2 3

*( ) = number of observations
⁺Sum of averages of NH_4-N and NO_x-N

Controlling Microorganism Populations

The types of bacteria in SBR activated sludge can be controlled by the treatment plant operator who can easily relax or eliminate some of the selective pressures. For example, the treatment plant operator at Culver, Indiana, modified the aeration and mixing scheme in such a way as to encourage biological phosphorus removal and minimize nitrification and denitrification. During the subsequent 10-month period, effluent phosphorus concentrations averaged less than 1 g/m³ without addition of chemicals.

In every SBR cycle, microorganism selection pressures are quite severe—the mixed culture microorganisms are subjected to feast and famine as well as high and essentially zero DO conditions. Only a limited number of microorganisms can both survive and compete in this environment. In a conventional continuous flow activated sludge facility, population dynamics is largely influenced by the unsteady state nature of the influent wastewater. By way of contrast, the unsteady state nature of the SBR operation overwhelms variations in the wastewater and, thus, results in a more controllable system.

Process Limitations

Two major limitations became apparent during the developmental stages of the SBR. (1) It is a noncontinuous flow system with no real operating counterpart in the United States. This significant liability has been partially overcome with the Culver demonstration. (2) SBR was perceived to have value only in small systems. Although a limit of 18,925 m³/d was considered reasonable for purposes of cost analyses in this assessment, the author believes that there are no theoretical or technical reasons for any upper limit. System selection should be based on a cost-effectiveness analysis for each specific application and the level of reliability and consistency desired.

Limitations of more concern include the freezing of scum (if present) during winter operating conditions, the possibility of high effluent SS of high mass loaded systems, and finally, the possibility of developing through improper operation an organism population that has a large number of filaments.

SBR Cost and Energy

Cost Considerations

A modular design was used to estimate costs for SBR's operating at four different average daily flow rates (Table 1). A two-tank system was used for the 379 m³/d plant, and three-tank systems were assumed for the remaining three daily flow rates. In all cases, size selection was based on a 50 percent draw-off volume and on a cycle with zero time in IDLE when using a peak flow, which is double the average dry weather flow. A three-tank system was used for the 18,925 m³/d flow with each tank composed of four equal sized modules. In all other cases, only one module was used for each tank.

*Full-Scale Study of Sequencing Batch Reactors, R F. Irvine and L. H. Ketchum, Jr., EPA/600/2-83/020, NTIS No. PB83-183186, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

Energy Requirements

Estimated energy requirements for aeration and decanting for each of the four SBR flow rates are:

Flow Rate (m^3/d)	Energy Requirements (kWh/yr)		
	Aeration	Decanting	Total
379	33.1×10^3	4.1×10^3	37.2×10^3
1,893	12.4×10^4	3.7×10^4	16.1×10^4
3,785	24.9×10^4	6.6×10^4	31.5×10^4
18,925	12.4×10^5	3.7×10^5	16.1×10^5

Cost and Energy Comparisons

A cost and energy analysis comparing the SBR with oxidation ditch and conventional activated sludge systems for flow rates of 379, 1,893, 3,785, and 18,925 m^3/d indicates similar costs for the SBR and the oxidation ditch, with the SBR being slightly less costly. Costs are roughly 20 percent less for the SBR than for the conventional activated sludge systems compared. The energy analysis showed the SBR to be 13.5 percent more efficient than the oxidation ditch and equally as efficient as conventional activated sludge. The unique fill and draw feature of the SBR permits its energy input to be widely varied without seriously impairing the effluent quality.

The full report was submitted in fulfillment of Contract No. 68-03-3055, Roy F. Weston, Inc., by Robert L. Irvine of the University of Notre Dame, under the sponsorship of the U.S. Environmental Protection Agency.

Table 1. *SBR Cost Estimates (in $1,000) for Four Average Daily Flow Rates*

Process Unit	*Flow Rates (m^3/d)* 379	1,893	3,785	18,925
Inlet control system	*$ 2*	*$ 3*	*$ 4*	*$ 20*
Contact chamber baffle walls	*2*	*4*	*5*	*24*
Aerators	*25*	*50*	*60*	*256*
Excavation, concrete, handrail	*70*	*150*	*250*	*840*
Microprocessors	*10*	*10*	*10*	*10*
Level control/monitor	*2*	*4*	*4*	*16*
Decant system	*9*	*16*	*18*	*90*
Subtotal (I)	*120*	*237*	*351*	*1,256*
*Noncomponent costs**	*30*	*59*	*88*	*314*
Subtotal (II)	*150*	*296*	*439*	*1,570*
Engineering, construction, supervision, and contingencies†	*45*	*89*	*132*	*471*
Total installed capital	*195*	*385*	*571*	*2,041*
Annual operation and maintenance	*13*	*24*	*40*	*148*
Present worth‡	*329*	*632*	*983*	*3,564*

**At 25 percent of subtotal (I), cost includes piping, electrical installations, instrumentation, and site preparation.*
†At 30 percent of subtotal (II).
‡Present worth computed at 7⅜ percent interest rate and 20-year life (PWF = 10.29213). Add present worth O&M costs to Total Installed Capital costs.

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The complete report, entitled "Technology Assessment of Sequencing Batch Reactors," (Order No. PB 85-167 245/AS; Cost: $11.50, subject to change) will be available only from:
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