A REGULATORY GUIDE TO SEQUENCING BATCH REACTORS

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ABSTRACT

The Iowa Department of Natural Resources (IDNR) has been issuing construction permits for Sequencing Batch Reactor (SBR) treatment plants since 1981 under the new process evaluation provisions of the Ten State Standards and "Iowa Wastewater Facilities Design Standards." Although the need for supplemental design criteria had been perceived for some time because of the unusual start-up difficulties encountered, the need became immediately apparent by the failure of a new SBR facility in 1995.

The guidance presented in this paper for municipal treatment works is based on SBR design guidance from other states, comments received over a three-year period, and Iowa's experience within the frame work of adopted design standards for conventional processes. More than two tanks should be provided. Cycle time reliability shall be based on the design maximum-day flow. The sampling approach for each basin must consider both process control and compliance reporting.

KEYWORDS

Aeration; batch reactor; cycle time; decanter; mixing; reliability; scum; shall; should; solids.

INTRODUCTION

Iowa's first SBR facility, Grundy Center, was issued a construction permit on July 2, 1981. A total of 19 SBR facilities have been constructed in Iowa during the last 18 years. Two additional plants will be operational in the near future. Fourteen plants incorporated floating decanters in their design. The other

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seven use fixed decanters. Two facilities include continuous feed as the normal mode of operation. One plant is no longer being operated as a SBR facility because of a process failure.

IDNR design guidance and criteria for SBRs began development in the summer of 1996 with the helpful assistance of others who have had extensive SBR design and operations experience. The Department used available design guidance and criteria from the states of Michigan, Pennsylvania, Ohio, Minnesota, Tennessee and Oklahoma to prepare the initial draft. Comments from the Consulting Engineers Council of Iowa also were incorporated. Subsequent drafts dated April 1, 1997, November 7, 1997, July 20, 1998 and August 16, 1999 were distributed to all engineering consultants on the Department's mailing list. An interim draft also was distributed to the Consulting Engineers Council of Iowa, the Iowa Water Pollution Control Association, and interested equipment suppliers in April 1998. The guidance included in this paper has considered comments received to date. Correspondence regarding this has been retained in an IDNR file entitled "Con 11-19, Sequencing Batch Reactors." This file is available for inspection at the IDNR Records Center.

With the goal of providing continuity and reliability of treatment equal to that of other continuous-flow treatment processes, this guidance represents the State's best assessment of the fill-and-draw activated sludge technology for municipal treatment systems. We have referenced specific sections of Iowa's wastewater facilities design standards, the Ten State Standards and United States Environmental Protection Agency reliability criteria where applicable. This was done in part to help our technical staff understand the process and because formal design standards specific to SBRs have not been adopted by the Department's Environmental Protection Commission. Changes have been made as issues have arisen in our project review and regulation of these facilities. Through this and an extensive peer review, it is gradually being accepted as a standard of practice for design. This guidance may be updated periodically until formal design standards are adopted by the Commission. Updates may be posted on the IDNR web site. Current rules of the Environmental Protection Division, IDNR construction permit application forms and the "Iowa Wastewater Facilities Design Standards" can be obtained from the web site (http://www.state.ia.us/epd). The 1997 edition of the Ten State Standards by the Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers (GLUMRB) is available through the Health Education Services in Albany, New York (http://www.hes.org).

IDNR DESIGN GUIDANCE AND CRITERIA FOR SBRS

System Sizing and Reliability

1. Proposals will be reviewed, on a case by case basis, at the discretion of the Department under the new process evaluation provisions of IDNR Design Standard 14.4.3 (1987). In addition, system reliability shall meet the minimum requirements of IDNR 14.5.2 (1987). Power source reliability shall be in accordance with IDNR 14.5.3 (1987). See also IDNR 18B.2 (1984) and IDNR 14.9.1 (1987) regarding process selection and operating requirements.

2. More than two tanks should be provided.

3. Facilities for the equalization of flows and organic shock load (both high and low) shall be considered for each basin in accordance with GLUMRB 53.413 (1997). See IDNR 17.3.2.4 (1980), IDNR 17.3.4.4

(1980), IDNR 18B.4.1(5) (1984), IDNR 18B.4.4.1 (1984) and IDNR 14.4.5.5 (1987). See also IDNR 14.4.9.2 (1987) regarding selection of the design cycle time.

4. The design F:M ratios and MLSS concentrations for SBRs should be similar to other conventional and extended aeration processes. For domestic waste, the F:M ratio provided to nitrify is typically in the range of 0.05 to 0.10 and not required to nitrify 0.15 to 0.4. Higher values may be accepted, if justified. The selected F:M ratio for each tank should account for the unbalanced loadings which may occur in the absence of proportional flow splitting (IDNR 14.4.9.2, 1987). The reactor MLVSS and MLSS concentrations should be calculated at the low-water level. See also IDNR 18B.4.1 (1984) and IDNR 18B.4.2 (1984) regarding basis of design, capacities and permissible loadings.

5. Solids management to accommodate basin dewatering shall be considered.

6. Cycle time reliability shall be based on the design maximum 24-hour wet-weather (MWW) flow (IDNR 18B.4.1, 1984).

a) The decantable volume and decanter capacity of the SBR system with the largest basin out of service for treatment facilities providing nitrification should be sized to pass at least 75 percent of the MWW flow on a continuous basis without changing cycle times.

b) The decantable volume and decanter capacity of the SBR system with the largest basin out of service for Reliability Class II or III treatment facilities providing secondary treatment should be sized to pass at least 50 percent of the MWW flow on a continuous basis without changing cycle times.

7. The added settling time before a discharge may begin shall be considered for systems with fixed decanters. The vertical travel distance for mobile decanters, specific to the equipment supplied, shall accommodate the required decant volume.

8. The low-water depth should not be less than 10 feet (3 m). See also IDNR 18B.4.3.2 (1984) regarding tank geometry.

The water depth of any basin where simultaneous fill and decant may occur shall not be less than 12 feet (3.7 m) at the end of the DECANT phase (IDNR 16.3.1, 1987). This low-water level may be reduced to 10 feet (3 m), provided the SBR is treating less than 340 lbs/day (150 kg/day) of BOD_5 and is followed by a 5-day pond. See also IDNR 14.5.2.1(2) (1987) under Unit Process Reliability Criteria A. Provisions for returning the holding pond contents to the treatment process are required.

Treatment facilities with fixed decanters, or any other system where the low-water depth cannot be adjusted quickly by the operator, should be designed to end the DECANT phase at a higher water level than other types (IDNR 16.3.4.2, 1987).

9. Downstream units shall be sized to handle peak discharge rates. See IDNR 14.4.7 (1987) regarding conduits. Flow equalization downstream of the SBRs may be necessary to dampen the flow.

10. Although the control systems may prevent multiple-tank decant for normal operations or to minimize the sizing of subsequent treatment units, system flexibility and outfall piping to allow the decant of at least two tanks simultaneously for SBR plants with more than two basins may be desirable if downstream facilities and the receiving stream are not adversely impacted.

11. The appropriate wasteload allocation must be determined to account for the high rates of intermittent discharge. Thermal shock also may be a concern for some fisheries.

12. Adequate consideration shall be given for expansion or modification of the plant in accordance with IDNR 11.2.8.2 (1979) and GLUMRB 53.6 (1997). Final settling tanks may be required for systems experiencing an inability to retain scum or other suspended solids violations. See IDNR Subrule 567 IAC 61.3(2) (1997) for general water quality criteria.

Decanter Design

Consider the following in addition to IDNR Chapters 18B (1984), 14 (1987), and 16 (1987).

13. System reliability and the instantaneous delivery of flow shall be evaluated in the design of decanter weirs and approach velocities (IDNR 16.3.4.3, 1987; GLUMRB 72.43, 1997). The decant method, sizing, and system configuration shall limit velocities at the inlet port or at the edge of submerged weirs throughout the DECANT phase so as not to cause or allow entry of floating material, vortexing or disturbance of settled sludge solids. The treated effluent from each reactor should be free of scum and have a suspended solids concentration no greater than 30 mg/l at any time.

IDNR construction permit application schedules H3, Mechanical Plant Reliability and L, Settling Tanks shall be included in the application for a construction permit.

14. The decanter(s) shall draw treated effluent from below the water surface and exclude scum.

15. An adequate zone of separation between the sludge blanket and the decanter(s) shall be maintained at all times during the DECANT phase (IDNR 18B.4.1, 1984). Floating decanters or similar mechanical devices which allow the treated effluent to be drawn near the water surface throughout the DECANT phase are recommended for added process control (IDNR 18B.2.3, 1984; IDNR 16.3.4, 1987). Fixed decanters should not be used in basins where simultaneous fill and decant may occur, or where the sludge may be difficult to settle (IDNR 16.3.4.2, 1987).

16. A means of excluding solids from entering the decanter during the REACT phase should be provided. Some of the mechanisms which have been used are as follows:

a) Mechanically closed when not in use.
b) Physically removed from the mixed liquor except during decant.
c) Air-filled except during the decant period.

Provisions shall be included to flush and recycle any trapped solids back to the SBR. Air-filled decanters should be designed to break suction at the end of the DECANT phase without air displacement from the atmosphere through the tank water.

17. Protection against ice build-up on the decanter(s) and freezing of the discharge piping and decant valve(s) shall be provided. See also IDNR 18B.4.3.6 (1984) and IDNR 16.5.4 (1987) regarding cold weather protection.

Tank Details

Consider the following in addition to IDNR 18B.4.3 (1984) and IDNR Chapters 14 (1987) and 16 (1987):

18. Rather than odd numbers, pairs of tanks are recommended for ease of operations or efficient use of equipment.

19. Flow division control facilities preceding the SBR tanks shall be designed for greatest operating and maintenance convenience, flexibility, continuity of maximum effluent quality, and ease of installation of future units (IDNR 18B.2.3, 1984; GLUMRB 53.6, 1997). See IDNR 18B.4.3.4 (1984), IDNR 14.4.9 (1987), and GLUMRB 53.7 (1997) regarding design requirements for inlet and outlet control.

For systems with four tanks, flow division control facilities should be provided which may distribute the wastewater flows to at least two tanks at all times (GLUMRB 53.43, 1997). See also IDNR 18B.4.1(5) (1984), IDNR 18B.4.4.1 (1984), and GLUMRB 85.7 (1997), 88.4 (1997), and 89.25 (1997).

See also IDNR 18B.5 (1984) and GLUMRB 92.4 (1997) for SBR systems with return sludge equipment.

20. All projects shall consider the means and frequency for removal of grit and other debris from the SBR basins (IDNR 18B.4.1(4), 1984). Adequate space for equipment access (possibly cranes) should be considered, especially if the tanks are deep. Most SBR plants in Iowa have incorporated finer screens (clear openings 0.25 inches (6 mm) or less) and grit removal systems as a part of preliminary treatment to minimize the accumulation. See also IDNR 18B.3 (1984) for other pretreatment considerations. Comminution, rather than fine screening, may be approved for an SBR plant, but it is strongly discouraged in the absence of primary clarification. See also GLUMRB 62.2 (1997) and 92.2 (1997).

21. Influent baffling using a baffle wall and adequate physical separation of the influent from the decanter shall be provided for any basin which may operate with a continuous feed during the SETTLE and DECANT phases. The baffling must direct the influent wastewater below the sludge blanket. Average horizontal velocities through each baffle wall opening should not exceed 1 ft/sec (0.3 m/sec) at design peak-hour flows. See also IDNR 18B.4.3.2 (1984), IDNR 16.3.2.4.2 (1987), IDNR 16.3.3 (1987), IDNR 16.3.4 (1987), and GLUMRB 72.4 (1997) regarding tank geometry, inlet structures and weir design.

22. A system separate from the decant piping allowing sludge to be wasted during the DECANT and/or IDLE phases of each process cycle shall be provided. The location point(s) in the SBR tank for sludge wasting should be removed from the decanter(s) if wasting may occur during the DECANT phase. See IDNR 17.2 (1980) for sludge thickening and conditioning requirements.

23. The capability to transfer sludge from each basin to the other aeration tank(s) shall be provided. If decant pumps are used for sludge transfer, all solids in the decant piping shall be flushed and recycled back to the SBR.

24. All sludge transfer and wasting pumps should be accessible for maintenance without dewatering the tank.

25. Entrainment by mixing shall not be the sole means of scum control. Scum removal facilities, such as telescoping valves or high-water overflows, should be provided. See also IDNR 16.4.1 (1987).

Prevailing winds should be considered in scum control. See also IDNR 16.3.6 (1987) regarding additional freeboard or the use of wind screens.

26. Each tank shall be provided with an overflow to the other aeration tank(s) or storage (OWPO 252, 1974). See also IDNR 14.4.9.1 (1987) and IDNR 14.7.2.2 (1987) for unit operation bypassing.

27. A means shall be provided to dewater each SBR tank in accordance with IDNR 14.4.8.2 (1987). Tank bottoms should be sloped towards a drain or sump.

28. Protection from uplift when empty shall be provided where high groundwater may occur (IDNR 14.4.8.2, 1987). Common walls shall be structurally designed for liquid on one side only (IDNR 18B.4.3.1, 1984). Maximum use of earthen bank insulation should be considered to minimize heat losses (IDNR 18B.4.3.6, 1984).

29. All SBR tanks shall have a freeboard not less than 18 inches (460 mm) (IDNR 18B.4.3.3, 1984).

30. Adequate site lighting shall be provided for the SBR tanks.

Aeration and Mixing Equipment

Consider the following in addition to IDNR 18B.4 (1984) and GLUMRB 92.3 (1997):

31. The aeration equipment shall be suitable for varying water depths and cyclical operation in a sequencing batch reactor based on experience with installations handling similar wastes and loadings. The aeration and/or mixing equipment also shall not produce flow patterns within the aeration tank which interfere with quiescent settling. The discharge pressure of the blowers must be established at the maximum water depth.

32. Provisions to easily remove aeration diffusers without dewatering the tank are recommended to permit maintenance and repair without interrupting operation of the aeration tank or inhibiting operation of the other aeration equipment (OWPO 213.7.1, 1974). If the aeration equipment cannot be serviced and/or replaced without dewatering the tank, a minimum of four SBR tanks should be provided. See also GLUMRB 92.332(f) (1997).

33. Oxygen transfer rates from the aerators based on average water depth between the low-water level and the maximum water level for the critical flow conditions, as defined in IDNR Chapter 14 (1987), shall be considered to provide a dissolved oxygen residual of 2.0 mg/l during aeration, IDNR 18B.4.1(8) (1984). Credits for oxygen recovery through denitrification may be approved on a case-by-case basis for only those systems designed to denitrify.

34. The blowers shall be sized to deliver the total oxygen demand in a shorter period of time than allocated to the FILL/REACT and REACT phases of the cycle if oxic and anoxic conditions are required during these phases (IDNR 18B.4.1, 1984).

35. Autonomy in mixing and aeration is recommended and shall be provided for all systems required to provide biological phosphorus removal or denitrification. The mixing system shall be sized to thoroughly mix the entire basin from a settled condition within 5 minutes or the REACT phase shall be increased.

Where biological phosphorus removal or denitrification is required, equipment reliability for anoxic mix shall be equivalent to that of aeration under IDNR 18B.4.4 (1984). See also IDNR 18B.4.3.2 (1984) regarding tank geometry.

36. Floating mixers shall be accessible, adequately moored, and protected from excessive icing. See also IDNR 18B.4.3.6 (1984) regarding winter protection.

Controls, Sampling, and Operations Manual

37. The motor control centers should be located for convenient operation of the facility. A location in close proximity to the process with a view of the batch reactors is highly recommended.

38. A programmable logic controller (PLC) programmed to meet the required effluent limitations for the design loadings with limited operator adjustment is recommended. All factors affecting the flow and organic loading for each cycle shall be considered, e.g., diurnal, first flush, industrial, etc., (IDNR 18B.4.3.4, 1984). In addition, a fail-safe timer control which cannot be adjusted by the operator allowing not less than 20 minutes between the REACT and DECANT phases shall be provided. Where automatic process control is used, a hard-wired backup shall be provided. Both automatic and manual controls shall allow independent operation of each tank.

39. An uninterruptible power supply (UPS) with electrical surge protection shall be provided for each PLC to retain program memory (process control program and last-known setpoints and measured process/equipment status) through a power loss.

40. Visual display and recording of instantaneous and totalized flow rates, both to the plant as well as discharge, shall be provided. See also GLUMRB 56.6 (1997) for other flow measurement considerations.

41. Dissolved oxygen and oxidation-reduction potential (ORP) monitoring and control shall be provided as necessary (IDNR 18B.2.2, 1984). See also IDNR 18B.4.4.1 (1984) and IDNR 18B.4.4.2(c) (1984).

42. Effluent composite sampling shall be representative and accurate (IDNR Rule 567 IAC 63.11, 1999). Adequate provisions for sampling and flow measurement also shall be included which will allow the operations of each basin to be monitored separately (IDNR 14.4.9.3, 1987; GLUMRB 56.7, 1997). All 24-hour effluent composites for compliance reporting shall be flow-paced and include samples collected at the very beginning and end of each decant event.

43. Tank Level Sensors - Pressure transducers and floats may be used. Bubbler systems will not be approved. Float systems shall be shielded from prevailing winds and adequately protected from freezing.

44. Annunciator panel to indicate the following alarm conditions as a minimum:

a) High- and low-water level in each tank.
b) Valve - failure of all automatically operated valves.
c) Decanter - failure.
d) Blower - low pressure, high temperature and failure.
e) Pump - high pressure and failure.
f) Mixer - failure.
g) Effluent - high turbidity.

45. Visual display in addition to flow measurement is recommended and should consist of:

a) Mimic diagram of process showing status of pumps, valves (including position), blowers and mixers.
b) Process cycle and time remaining.
c) Tank level gauges.
d) Sludge pumping duration or volume.
e) Air-flow rate and totalizer.

46. Control Panel Switches recommended for:

a) Pumps - hand/off/auto
b) Valves - open/close/auto
c) Blowers - hand/off/auto
d) Selector switch for tank(s) in operation/standby

47. A complete and comprehensive operation and maintenance manual shall be provided for the treatment facility in accordance with IDNR 11.6 (1979) prior to start-up. Formal training specific to SBR operations is highly recommended (IDNR 18B.2.2, 1984). The design engineer also shall be retained by the permit holder to provide technical assistance and modify the manual as needed during the first year of operation.

CONCLUSIONS

Some comments indicated this guidance may be overly conservative. With all respect, it must be understood in a continuous-flow plant, all conduits are designed to convey the maximum expected flow without flooding. Unit operations at a continuous-flow treatment plant would not normally be partially out of service simply because a hydraulic conveyance or treatment device has failed, causing a stoppage. If there is potential for a flow stoppage (as in pumping, screening or high-rate filtration), firm hydraulic capacity is required to assure continuity of service without the need for storage. Separation of unit processes from the same physical structure may also enhance reliability and treatment where a central collection and distribution point is provided, including proportional flow splitting before each unit operation. The organic loadings to duplicate units at a conventional plant are distributed and easily balanced. Return sludge allows an activated sludge treatment facility to operate biologically as one plant. Conventional clarifiers are reliably designed to provide thickening and solids separation for a wide range of flows and operating conditions. Although designed to remove sludge rapidly, most final clarifiers may be operated with an inventory of solids. Backup components, ease of expansion and operating flexibility for SBR facilities are important, especially where water-quality-based effluent limitations are involved. Those interested in the fill-and-draw mode of the activated sludge process should be aware of the potential for severe solids-management problems as has occurred at some facilities because of basin downtime. Additionally, the SBR process may be unable to treat wastes effectively if operated at less than the design cycle time for more than 24 hours. We believe SBR process selection should be based on the specific application and an appropriate design to assure a high-quality effluent with reliability.

Others have expressed concerns regarding the need for representative samples and more frequent sample collection from each basin to adequately monitor the process or compare performance with other facilities. IDNR field office staff will be providing technical assistance to assure representative samples are, in fact, being collected for compliance reporting in accordance with IDNR Rule 567 IAC 63.11 (1999). The required sampling frequency may be reevaluated by the Department under the provisions in IDNR Subrule 567 IAC 63.3(4) (1999). It also may be necessary to separately apply the 85-percent-removal criteria to the discharge from each basin.

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