DEMONSTRATION
OF
LOW TEMPERATURE NITRIFICATION
WITH A SHORT SRT

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ABSTRACT

The InNitri® nitrification process/flowsheet was developed to provide an inexpensive alternative for plants in the northern climates which need to upgrade their air or pure oxygen activated sludge process for year-round nitrification or nitrogen removal. In this process/flowsheet supplemental nitrifiers are added daily to the activated sludge process to replenish nitrifiers removed with the wasted activated sludge. The supplemental nitrifiers are grown in a separate small side-stream aeration tank using either ammonia available in the digested sludge dewatering liquid and in the digester supernatant or commercial ammonia. The paper presents a description of this process/flowsheet, the theoretical background and results of modeling, results of laboratory testing, and a cost evaluation to retrofit a typical wastewater treatment plant.

KEYWORDS

Activated sludge; low temperature nitrification; nitrification, supplemental nitrifiers; short solids retention time.

INTRODUCTION

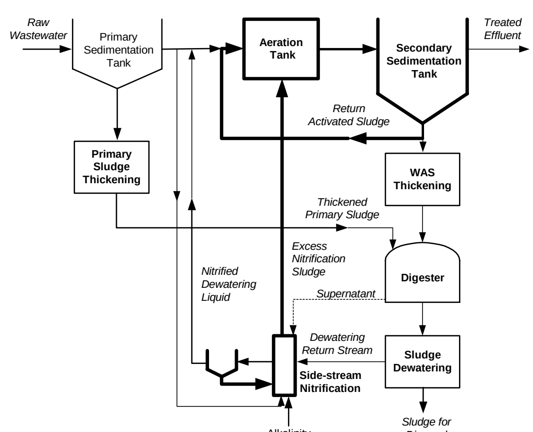
The ability of the conventional activated sludge process to nitrify is highly temperature dependent. At low winter temperatures, nitrification can be sustained only if the activated sludge process is operated at relatively high solids retention time (SRT) values (for example at least 15 to 18 days SRT is used for designing nitrification at temperatures around 10°C if an effluent ammonia concentration of 2.0 mg/l is required). If the activated sludge process is operated at substantially lower SRT values the growth rate of nitrifying bacteria (nitrifiers) is lower than the daily wasting rate of nitrifiers discharged in the excess activated sludge and nitrifiers are washed-out of the system causing nitrification to cease. Therefore, to upgrade existing activated sludge plants for winter nitrification usually requires substantial enlargement of the aeration tank to allow operation at higher SRT values.

This paper introduces InNitri®, a new nitrification process which allows nitrification at short SRT values, even at low winter temperatures and thus provides nitrification in a substantially smaller aeration tank than is currently required for conventional nitrification.

PROCESS FLOWSHEET DESCRIPTION

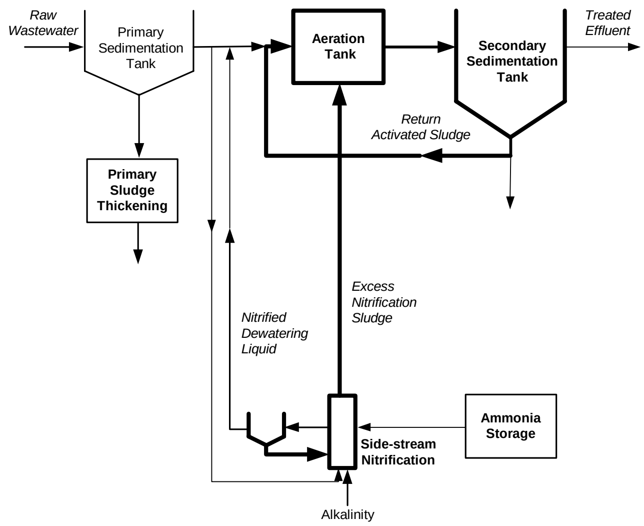
A schematic diagram of the InNitri® nitrification process/flowsheet is presented in Figure 1. **(See Figure 1. "Flowsheet with in Plant Sludge Treatment")** It consists of a typical secondary treatment plant (primary sedimentation, aeration tank, secondary clarification) with sludge thickening followed by anaerobic digestion and sludge dewatering. The upgrading of such a conventional plant to provide year-round nitrification using the short SRT nitrification process requires addition of a small aeration tank and clarifier for growing nitrifiers. In this system, the warm (typically 30 to 35°C) dewatering liquid containing a high ammonia content (between 300 to 900 mg/l) is mixed with a small portion of primary effluent (to adjust the temperature and provide BOD), and nitrified in the side-stream nitrification aeration tank. A portion of the resulting biological sludge, which contains a high percentage of nitrifiers, is continuously or periodically discharged into the main aeration tank and provides the main activated sludge process with supplemental nitrifiers.

FIGURE 1
Flowsheet with in Plant Sludge Treatment



The same process can also be applied in plants without digesters, as shown in Figure 2. **(See Figure 2 "Flowsheet without in Plant Sludge Treatment")** In this case commercial ammonia is used instead of the dewatering return stream.

FIGURE 2



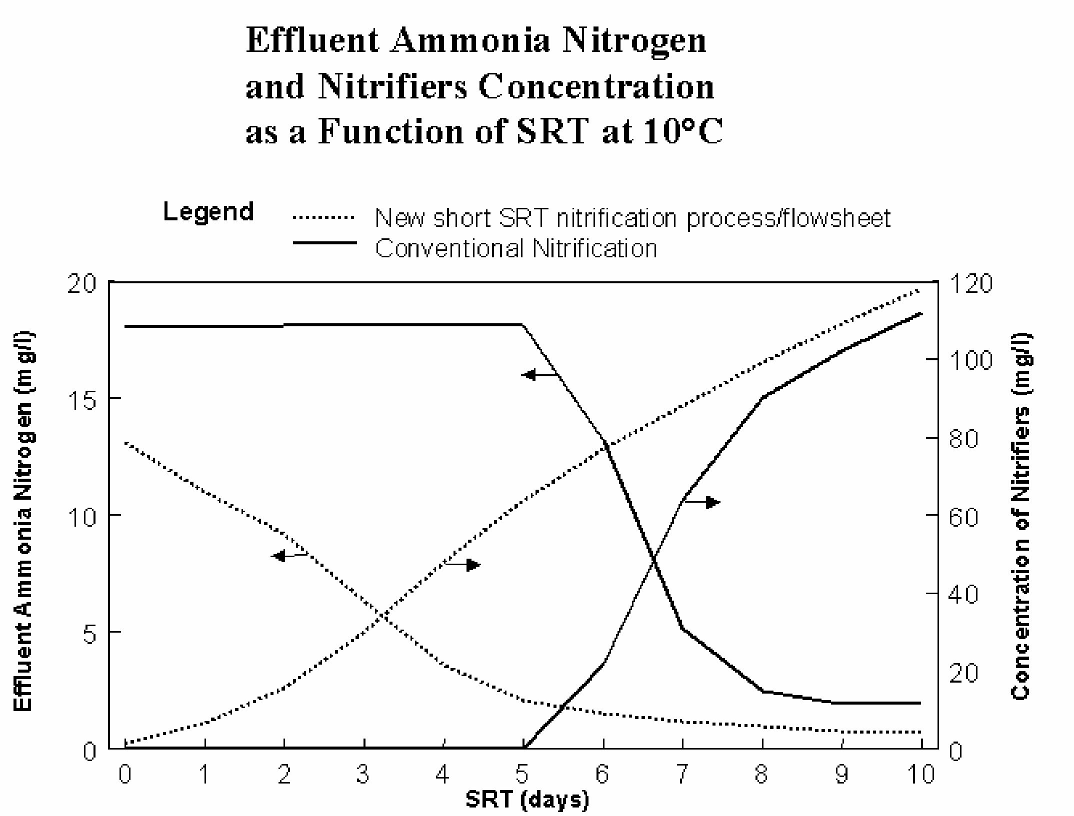
Flowsheet without in Plant Sludge Treatment

THEORETICAL BACKGROUND

To demonstrate the difference between the conventional nitrification process and nitrification with supplemental nitrifiers in the InNitri® process, KOS (1998) presented theoretical equations and results of modeling for a typical wastewater treatment plant. Modeling was carried out using the IAWPRC task group Activated Sludge Model No. 1. Figure 3 summarizes the difference for a complete mix steady-state aeration tank that has 6 hr hydraulic detention time, which operates at 10°C and receives an influent containing 25 mg/l of TKN and 25% of TKN is in the side-stream dewatering liquid. **(See Figure 3 "Effluent Ammonia Nitrogen and Nitrifiers Concentration as a Function of SRT at 10°C.")**

For conventional nitrification this Figure 3 shows that as the operating SRT is decreased, the concentration of nitrifiers also decreases and ammonia nitrogen in the effluent increases. The minimum SRT at these conditions is reached at an SRT equal to 5.4 days when the nitrifiers concentration equals zero and the ammonia nitrogen effluent reaches the maximum value. For an SRT below 5.4 days, the rate of nitrifier growth is lower than the rate of nitrifiers wasted in the excess activated sludge, and nitrification cannot take place. To achieve an effluent ammonia concentration of 2.0 mg/l, one would have to operate this process at the theoretical SRT equal to 8.8 days. In practice, the minimum safety factor between 1.5 and 2.0 would be applied, yielding the design SRT between 13 to 18 days.

FIGURE 3



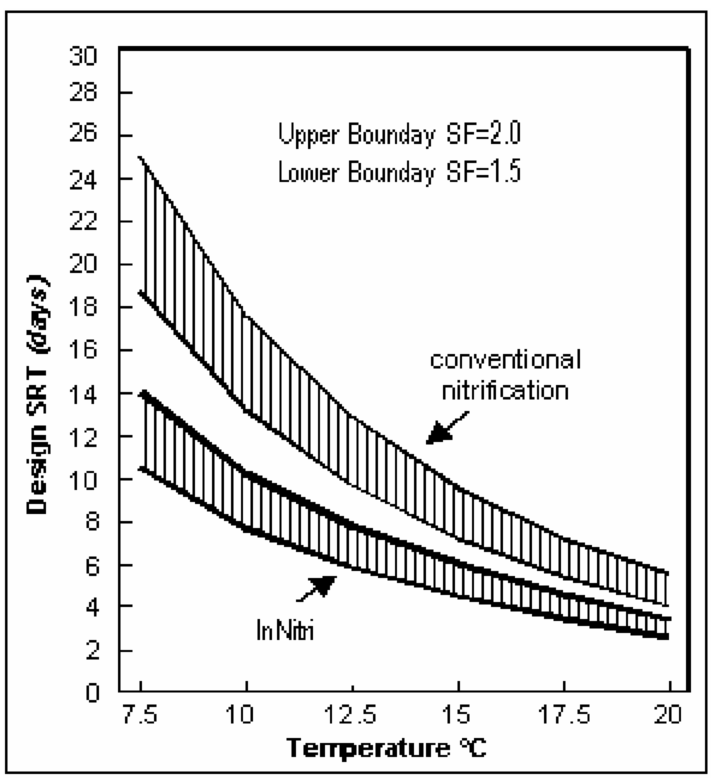
For the InNitri® process, where ammonia nitrogen from the dewatering liquid is first nitrified in the separate nitrification reactor, the concentration of nitrifiers is significantly higher at all sludge ages resulting in a much lower effluent ammonia concentration. In other words, to achieve the same effluent ammonia concentration, this new process/flowsheet can be operated at substantially lower SRT values. For example, to achieve an effluent ammonia concentration of 2.0 mg/l, the conventional nitrification would have to be operated at an 8.8 days SRT, while the new process/flowsheet would provide the same effluent ammonia if operated at an SRT of 5.1 days.

For design purposes, the safety factor of 1.5 to 2.0 is typically used in design for conventional nitrification yielding the design SRT between 13 to 18 days for 10°C temperature and a design effluent ammonia nitrogen concentration of 2.0 mg/l (SRT theoretical is 8.8 days, see Figure 3.). With this new process and the same safety factor of 1.5 to 2.0 a design SRT of 7 to 10 days is required to achieve a 2.0 mg/l effluent ammonia concentration at a winter temperature of 10°C.

Figure 3 also demonstrates that nitrifiers are present in the main aeration tank at all SRT values. Nitrifiers cannot be washed-out from the aeration tank even if operated at lower SRT values and so partial nitrification takes place even at extremely low SRT values. In other words this process/flowsheet does not have minimum SRT under which nitrification would not occur and therefore it will be much more stable and may not need as high a safety factor as conventional nitrification.

The above described example of modeling for a sewage temperature of 10°C was repeated at other temperatures from 7.5 to 20°C and results are summarized in Figure 4. **(See Figure 4 "Design SRT as a Function of Temperature")** Figure 4 compares the design range of the SRT values, using the safety factor 1.5 to 2.0, for the conventional and the InNitri® process/flowsheet. The comparison shows that the new nitrification process/flowsheet requires significantly lower design SRT than the conventional nitrification to achieve the same effluent ammonia concentration. For the case where the design effluent ammonia concentration is 2.0 mg/l the required design SRT for the new process/flowsheet is only about 60% of that required for conventional nitrification.

FIGURE 4
Design SRT as a Function of Temperature



LABORATORY TESTING

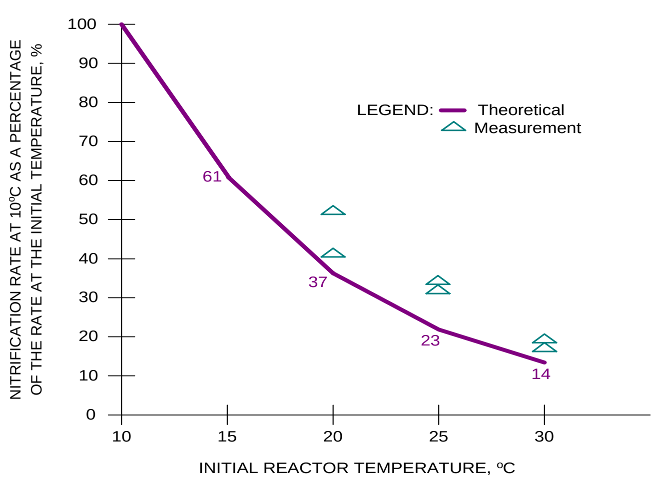
The theoretical considerations assumed that nitrifiers generated at higher temperature will slow down their nitrification reaction rate according to a theoretical factor of $e^{0.098\ (T-15)}$; where T=Temperature in degrees centigrade. To evaluate this effect a laboratory study was conducted at the Civil and Geological Department, University of Manitoba.

In this study three 2.4 l chemostat reactors were operated at 20, 25, and 30°C respectively. The reactors were operated at SRT=5 days and pH was controlled by automatic pH controller at 7.2 units. Reactors were fed batchwise three times per day and maximum nitrification reaction rates were determined by sampling from reactors in 15 minute intervals following feeding. Samples were quickly filtered and analyzed for ammonia nitrogen, nitrites and nitrates. On two occasions samples of mixed liquor from these reactors were quickly cooled down to 10°C, fed with the same ammonia source and the maximum nitrification rates were determined using the same procedure.

Figure 5 presents the nitrification rates at 10°C as a percentage of the nitrification rate at the initial temperature and compares them with the theoretical prediction using the $e^{0.098\ (T-15)}$ factor. **(See Figure 5 "Reduction of Nitrification Rates").**

The nitrifiers grown at 20°C exhibited 47% and 59% reduction of the nitrification rate at 10°C. In comparison, theoretical reduction is 63%. The nitrifiers grown at 25°C exhibited 66% and 67% reduction of the nitrification rate at 10°C. In comparison, theoretical reduction is 77%. The nitrifiers grown at 30°C exhibited 81% and 83% reduction of the nitrification rate at 10°C. In comparison, the theoretical reduction is 86%. This measurement showed that the measured reduction of the nitrification rates was slightly less than the theoretical ones.

FIGURE 5
Reduction of Nitrification Rates



COMPARISON OF PROCESSES

Brinjac, Kambic and Associates have completed an analysis for upgrading an existing facility for nutrient control. The existing facility can be considered typical of many of the plants designed to meet the original requirements of the Federal Clean Water Act. The existing facility is located in the Northeastern United States. It is the principal point source contributor of nitrogen to a river which flows to an estuary which is undergoing eutrophication.. The facility is site constrained with little room available for flow or process expansion. However the designers have to accomplish both of these tasks.

The results of the analysis are shown in the following Table 1.

Table 1
Summary of Costs For Total Nitrogen Control

COST ITEM	Conventional	InNitri	K-1	K-2	K-3	R-1	R-2
Construction	$ 7,851,386	$ 2,945,404	$13,698,404	$12,000,000	$ 6,000,000	$18,145,404	$14,500,000
TOTAL PROJECT (includes 20% Contingency and 10% Engineering, and Legal Fees	$10,599,371	$ 3,976,295	$18,826,295	$16,200,000	$ 8,100,000	$24,496,295	$19,575,000
Annual O&M	$ 541,635	$ 301,994	$ 542,029	$ 1,574,265	$ 1,233,628	$ 865,056	$ 1,785,866
Comments:	Design is 8 *mg/l* TN at 37.7 MGD	Design may meet target 8 mg/l TN at 37.7 MGD	Design is less than 8 mg/l as TN at 37.7 MGD	Design is less than 8 mg/l TN at 37.7 MGD	Design is 8-10 mg/l TN at 37.7 MGD	Design is 30 MGD and 8-10 mg/l as TN	Design is 30 MGD and 3-5 mg/l as TN
Cost per Pound of Nitrogen Removed[1]	$ 1.09	$ 0.50	$ 1.58	$ 2.32	$ 1.94	$ 3.44	$ 2.61
Percent Difference vs InNitri®	218	100	316	464	388	688	522

[1]Cost per pound of nitrogen removed is based on an assumed 1 mg/l residual ammonia-N in the effluent. Design flow with loading assumed to be 18 mg/l as TKN to secondaries provided removal calculations.

Evaluation Criteria:
Construction contingency @ 20% of construction cost
Engineering cost @10% of construction cost
Present Worth Period: 20 years
Interest rate: 8.75%

DEFINITION OF EVALUATED SYSTEMS

Conventional	Expands the existing facility to create a Modified Ludzack Ettinger process configuration for total nitrogen control.
In-Nitri®	Utilizes the existing facility retrofitted to a modified Ludzack Ettinger process with an InNitri side stream reactor to convert nitrogen containing recycle streams into supplemental nitrifiers for the MLE.
K-1	Utilizes the proprietary BioStyr process in conjunction with the existing facility in a split flow parallel treatment mode of operation for total nitrogen control
K-2	Utilizes the existing facility as a high rate first step followed by BioStyr in a series mode of operation for total nitrogen control.
K-3	Utilizes the existing facility with Actiflow supplemented with polymers in the primaries, the existing facility at high MLSS for nitrification, followed by BioStyr in a series mode of operation for total nitrogen control.
R-1	Similar to Kruger 1 with split flow to the existing facility modified to MLE and two parallel trains of BioStyr all operated in a parallel mode of operation for total nitrogen control.
R-2	Utilizes the existing facility as a high rate first step followed by BioStyr for nitrification with fluidized beds for denitrification all operated in series mode of operation for total nitrogen control.

Brinjac, Kambic and Associates have recommended that the facility proceed in implementing the InNitri® process for the following reasons:

- Lowest cost per pound of nitrogen removed
- Lowest capital cost
- Lowest operating cost
- Ability to implement future flow increases
- Minimal site excavation needed for implementation
- Amenability of construction sequencing to current plant operations
- Operational simplicity
- Washout protection for nitrifiers

CONCLUSIONS

The InNitri® process has been mathematically modeled using the IAWPRC task group Activated Sludge Model number 1. A comparison of the sludge retention time necessary for nitrification using InNitri versus conventional nitrification shows significant reductions in costs for low temperature wastewaters. Research at the University of Manitoba indicates that the transport of nitrifying sludge from a warm sidestream reactor to a cold mainstream reactor should pose no process problems. An evaluation of the process to upgrade an operating plant shows significant savings versus conventional and other advanced nitrification processes.

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(2) Private Correspondence with Ms. Melanie A. Head, student/researcher at Department of civil and Geological Engineering, University of Manitoba, Canada.

(3) Unpublished Engineering Feasability Study as of 12/June/2000 by Brinjac, Kambic and Associates, Inc.