



Inexpensive Denitrification  
via  
Side Stream Treatment  
by  
N-Removal over Nitrite



**1 ABSTRACT**

SHARON<sup>®</sup> is a very cost-effective treatment system for the total removal of nitrogen components, through nitrification/denitrification, from wastewater flow streams containing high concentrations of nitrogen. The system is used for the treatment of municipal wastewater side streams from both dewatered digested primary sludge and waste activated biosolids to achieve high total overall nitrogen removal. In addition it can be used to treat wastewater flows from sludge dryers and incinerators.

SHARON<sup>®</sup> is a high rate process for the removal of total nitrogen operating with minimal sludge retention time. Due to differences in growth rates of the bacterial species at the process design temperature (30-40°C) a selection can be made wherein the nitrite oxidizing bacteria can be washed out of the system while ammonia oxidizing bacteria are retained along with denitrifying bacteria. Using this metabolic mode of operation allows for a 25% reduction in aeration energy required for nitrification and a 40% reduction in the amount of BOD addition needed for denitrification. In addition since the process is accomplished in a side stream there are savings in mainstream reactor costs.

The process has moved beyond the development stage. Two full-scale SHARON<sup>®</sup> systems have been constructed at large wastewater treatment plants, a third plant (Zwolle) is currently being commissioned, and a fourth (Beverwijk), is under construction. SHARONs for Groningen (the Netherlands) and New York City (USA) are currently in the planning phase. The Utrecht plant has been in operation since 1997. The Rotterdam, Dokhaven plant has been in operation since 1999. The Zwolle plant will come on line soon. The pertinent data for the start-up and continuing operation of the Utrecht and Rotterdam plants are presented and discussed.

**2 KEYWORDS**

denitrification, nitrification, total nitrogen removal, side stream treatment, SHARON<sup>®</sup>

**3 INTRODUCTION**

This paper presents the performance results of the start-up and continuing operations of the SHARON<sup>®</sup> process at the Utrecht and Rotterdam, Dokhaven Waste Water Treatment plants in the Netherlands. The concepts for the SHARON<sup>®</sup> process were initially developed by Delft University of Technology, Water Board ZHEW, and Grontmij, a Dutch engineering and construction company. These concepts were pilot tested at Utrecht and Rotterdam; then they were implemented full scale. The full-scale operations illustrate that the claims for the SHARON<sup>®</sup> process have been successfully achieved.

**4 THE SHARON<sup>®</sup> PROCESS**

The SHARON<sup>®</sup> process [1,2] is a new and innovative process for total nitrogen removal which allows for nitrification/denitrification at minimal SRT values, resulting in a substantially smaller reactor volume than is currently required for conventional total nitrogen removal. In addition the process allows for both a savings of twenty five percent (25%) in oxygen transfer energy and forty percent (40%) in carbon feed for denitrifying bacterial growth as compared to conventional processes because of the unique metabolic pathway used (Figure 1). The pathway is conversion of ammonia to nitrite and conversion of nitrite to nitrogen, the chemical species nitrate is not produced or converted.

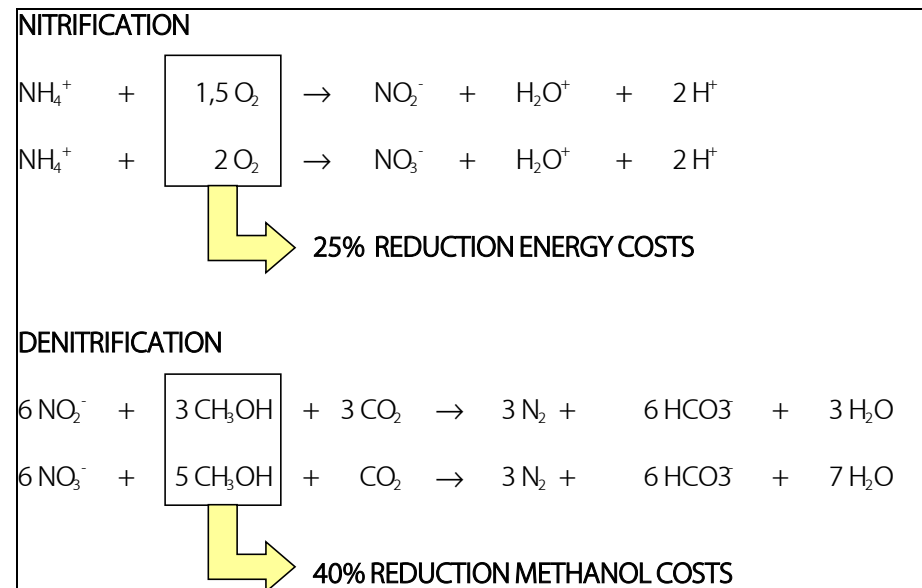


Figure 1 Biochemistry

The core concept on which the process is based is that at temperatures above 15°C, and especially between 30-40°C, the growth rates of the nitrifying bacteria are greater than the nitrifying bacteria. This allows for the design of a selector reactor where in nitroso-genera bacteria (nitrifying) predominate over the nitro-genera bacteria (nitrifying) (Figure 2). The nitrite produced is converted to nitrogen gas by denitrifying bacteria under anoxic conditions. This two step reaction can occur in either space or time (Figure 3).

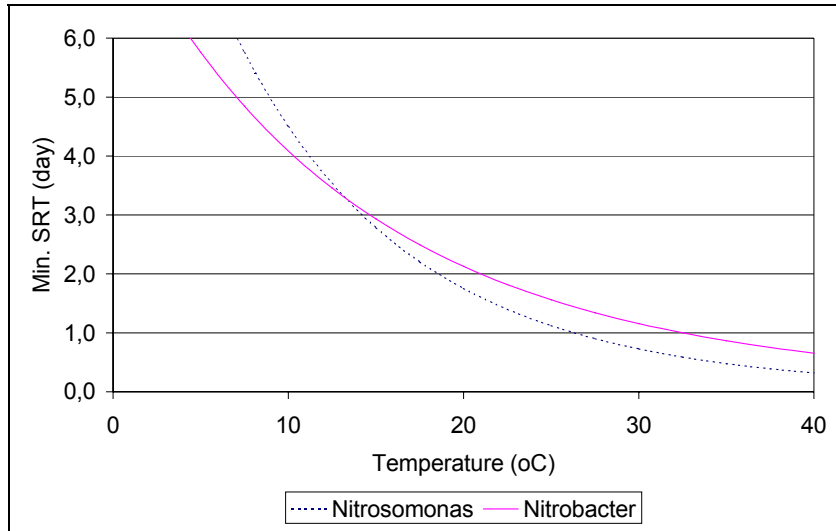


Figure 2 Growth rates

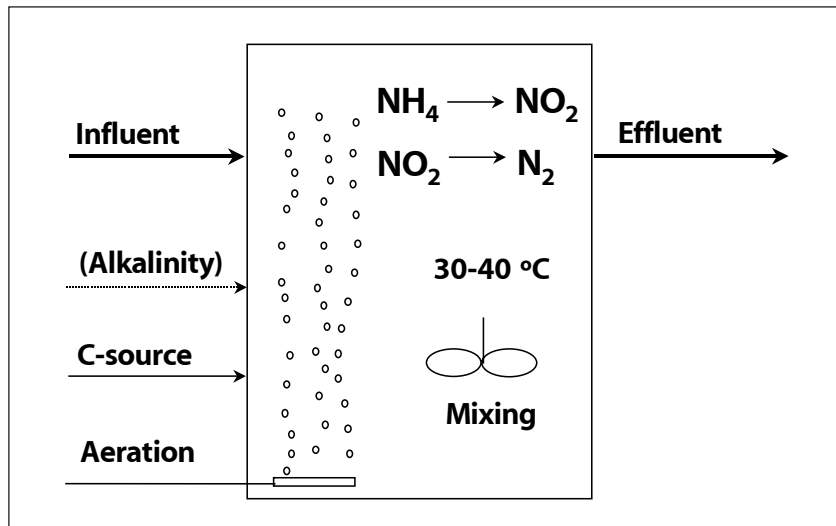


Figure 3 Reactor

## 5 SHARON® at UTRECHT

### 5.1 Design basis

The City of Utrecht is located in central Netherlands 25 miles Southeast of Amsterdam on the Amsterdam-Rijnkanaal. Utrecht is the fourth largest city in the Netherlands with a population of approximately 260,000. The city can trace its roots to Roman times.

The waste water plant is a two step ammonia removal plant. Both the aeration tanks and intermediate sedimentation tanks are covered. The thickened biosolids are treated by anaerobic digestion and then dewatered in centrifuges. The recycled centrifuge decant is treated by the SHARON® process.

The SHARON® process at this plant is a two-stage system with separate reactors for nitrification/nitrification and denitrification/denitrification (Figure 4).



Figure 4 Nitrification reactor (foreground), denitrification reactor (background)

That is the reactions are separated in space, two stages. The centrifuge's decant being recycled is pumped through screening unit and into the first reactor which is equipped with high efficiency jet-aerators (Korting) that provide both oxygen and mixing. The partially treated decant then flows to the second reactor which is equipped with a

mechanical mixer and recycled to the nitrification/nitrification reactor. The fully treated decant is then discharged to the head of the mainstream plant. A single building houses the PLC based control system, a heat exchanger, and blowers to provide air to the jet aerators for oxygen transfer and mixing in the nitrification/nitrification reactor. Methanol is contained in a buried storage tank and metered to the denitrification reactor. The design parameters for the plant are summarised in Table 1.

TABLE 1: DESIGN PARAMETERS UTRECHT, THE NETHERLANDS[3]

Parameter	
Flow design	35.0 m <sup>3</sup> /hr
Flow maximum	62.5 m <sup>3</sup> /hr
NH <sub>4</sub> influent	0.5-0.7 g/l
Nitrogen Load design	420 kg/day
Nitrogen Load maximum	900 kg/day
Reactor Size	
oxic	3,000 m <sup>3</sup>
anoxic	1,500 m <sup>3</sup>
Oxic Retention Time	2 days
Anoxic Retention Time	1 day

### 5.2 Startup

The Utrecht plant was started up in September of 1997 [3]. The decant influent flow during the first 160 days was highly variable, as would be expected, ranging between 0 and 900 m<sup>3</sup>/day. However the process rapidly attained stability and at twenty-one days after startup was attaining 95 plus % nitrification removal (Figure 5).

The startup was done using caustic soda to control pH in the reactors; at twenty-one days a switch was made to methanol. The methanol allowed denitrification/denitrification to occur and consequently since alkalinity was recovered the caustic soda addition was stopped. The progress of denitrification/denitrification can be observed by the falling nitrate and nitrite levels.

Nitrate concentrations fell from the 600mg/l level at twenty-one days to low levels by day eighty. The NO<sub>x</sub>-N level fell from over 600 mg/l to below 100 mg/l by increasing the amount of methanol dosed. Lower NO<sub>x</sub>-N levels are possible but not required to maintain a pH of approximately 7 in the reactor. The nitrate level remained under 200 mg/l and usually below 100 mg/l from the eighty day point out to one hundred and sixty days. Nitrite concentrations fell from 600 mg/l at the thirtieth day to very low levels after the eightieth day and remained very low. This occurred with the influent ammonia varying between 450 and 700 mg/l during the period (Figure 6).

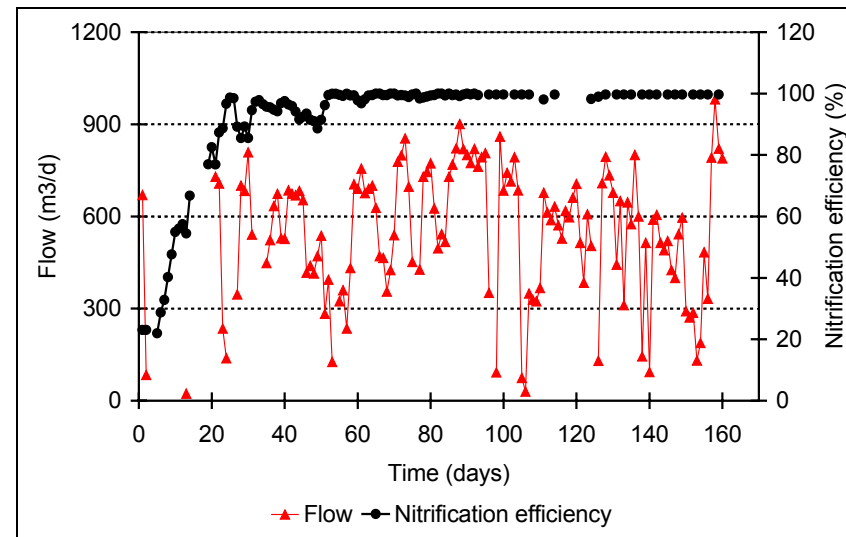


Figure 5 Start-up flow and removal efficiency

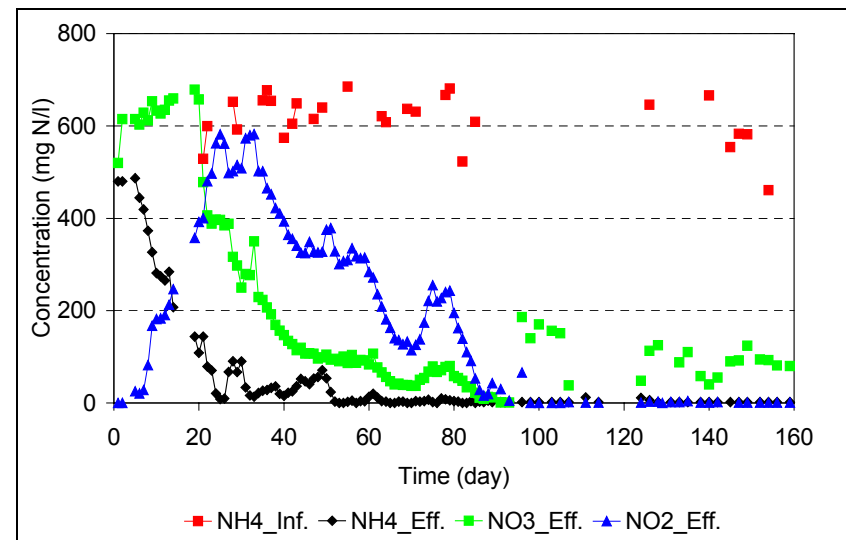


Figure 6 Start-up influent and effluent

5.3 Continuing operation

A review of a full year's operating data for 1998 shows very stable operation [3]. The influent ammonia varied from 400 to 750 mg/l during the period with a highly variable flow ranging from 0 to 1,375 m<sup>3</sup>/day (Figure 7). During this period the effluent ammonia averaged less than 5 mg/l, albeit with some peaks in the period from 50 to 100 days (Figure 8). The peaks were caused by insufficient pH control. The NO<sub>x</sub>-N concentration in the effluent was generally under 100mg/l (Figure 8).

The process was not upset by high influent suspended solids which at times reached concentrations of 30-50,000 mg/l and were often above 10,000 mg/l (Figure 9).

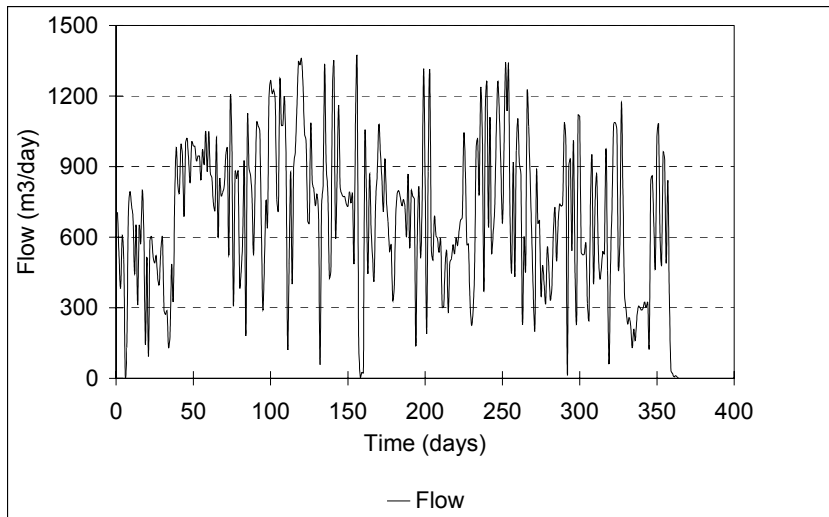


Figure 7 Continuous operation flow

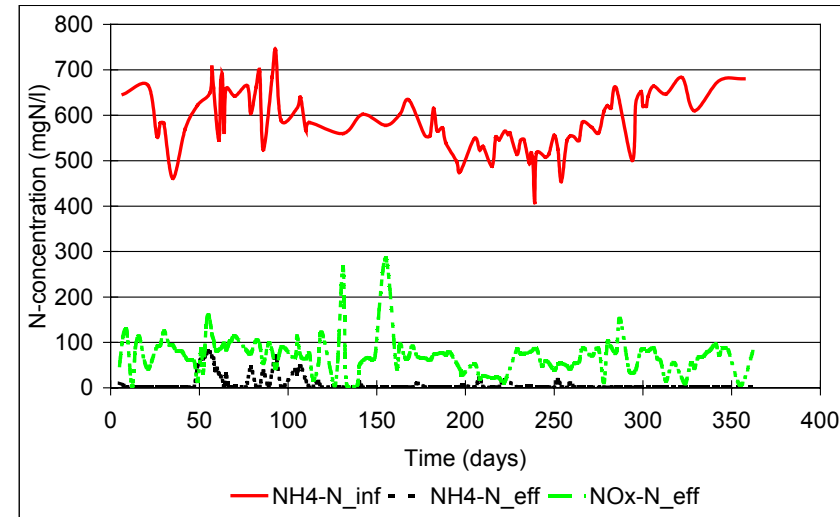


Figure 8 Continuous operation, influent and effluent

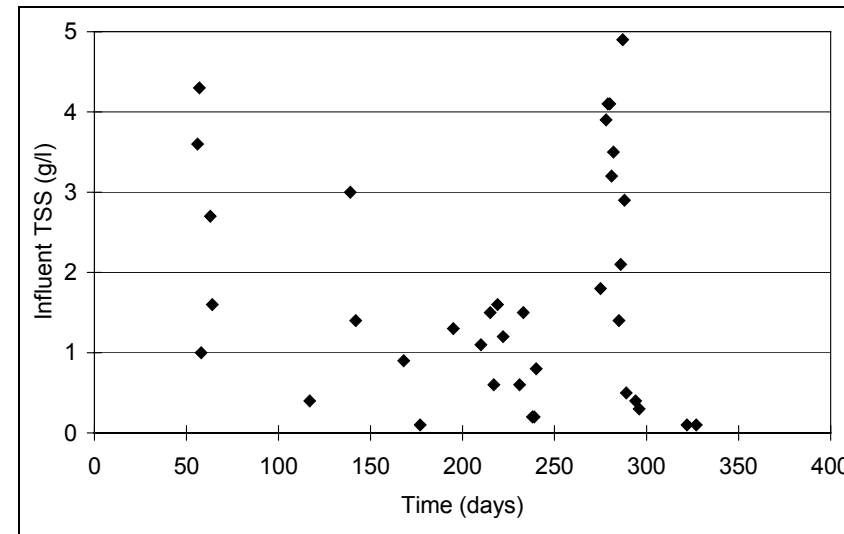


Figure 9 Continuous operation total suspended solids

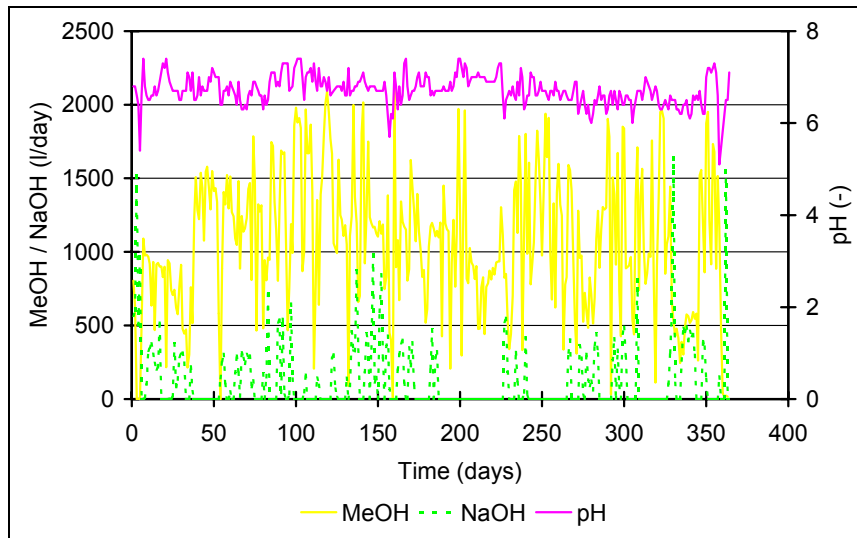


Figure 10 Continuous operation methanol and caustic soda dosing

The control of pH was done through recovered alkalinity from denitrification/denitratification caused by methanol addition in anoxic conditions. Occasionally supplemental sodium hydroxide, a backup pH control, is used in the case where insufficient methanol was dosed. (Figure 10).

The influent temperature varied over the year between 20 and 30°C. The reactor temperature was raised to 38°C by means of biochemical heat production, there is no need to provide supplemental heat. The installed supplemental heat exchange unit operation has been discontinued as the required reactor temperatures are maintained through heat released by the reactions and the insulation of the reactors.

It was the choice of the operations group to maximize ammonia removal so there was partial denitrification via nitrate. The ammonia removal efficiency aimed for can only be achieved with anoxic retention time of more than 2 days and therefore the conversion is partially to nitrate and partially to nitrite. Thus there is only partial nitrogen removal via nitrite in this SHARON<sup>®</sup>. This is confirmed by the average ratio of COD/ N-denitrified which had a value of 3.3 g COD/ g N. In theory the minimal stoichiometric demand would amount to 2.86 g COD/g NO<sub>3</sub>-N denitrified or 1.72 g COD/g NO<sub>2</sub>-N denitrified. Considering biomass yield, the demand is expected to be between 3.5 and 2.2 g COD/g N removed.

Since installation of the SHARON<sup>®</sup> process the main stream plant has lowered the total nitrogen content in the effluent by 30%. During the first half of 1998 the total nitrogen content in the plant effluent dropped on average from 16 to 11 mg/l.

## 6 SHARON<sup>®</sup> at ROTTERDAM

### 6.1 Design basis

The City of Rotterdam is located in southwestern corner of the Netherlands on the banks of the River Meuse. Rotterdam is the second largest city in the Netherlands and the world's largest seaport. Its population is approximately 800,000. The city can trace its roots to medieval times. Its name, Rotterdam, comes from the dam built there in the 1200s in the river Rotte.

The waste water plant is a two step ammonia removal plant located in the old dock area on the south bank of the River Meuse. The aeration tanks, clarifiers, and administration building are installed in a filled in dock and are covered. The area has been landscaped and is covered with grass and serves as a park. The plant is surrounded by residential high rises (Figure 11).



Figure 11 Rotterdam mainplant (background) and biosolids (foreground)

The biosolids processing is done remote from the main stream plant but close by. The biosolids are thickened, anaerobically digested, and dewatered in centrifuges. The recycled centrifuge decant is pumped through in line screens to the SHARON<sup>®</sup> reactor.



Figure 12 Reactor left, methane storage background

The flow was initially heated in a spiral flow in line heat exchanger to the required reaction temperature. Since the initial period the reactor has been insulated and heat addition is no longer required. The design temperature is reached from the release of heat from biochemical reactions. The recycled centrifuge decant is treated by the SHARON<sup>®</sup> process which was installed in an existing thickener (Figure 12). The SHARON<sup>®</sup> process at this plant is a one-stage system with a single reactor for nitrification and denitrification. That is the reactions are separated in time, one stage with sequencing steps. The centrifuges decant being recycled flows into the reactor which is equipped with high efficiency jet-aerators (Korting) that provide both oxygen transfer for the oxic phase where ammonia is converted to nitrite, nitrification, and mixing for the anoxic phase where nitrite is converted to nitrogen, denitrification. In the oxic sequence step, nitrification, the surface is frothy from the turbulence created by the jet aerators. In the anoxic sequence step the air is turned off and the jets just pump liquid for mixing. The surface is broken only by rising nitrogen bubbles. The reactor is run with minimal mixed liquor solids. During the oxic phase the dissolved oxygen is held in the 1-2 mg/l range; pH is held in the 6.8 to 7.2 range and monitored through out the reactor. The pH of the reactor is controlled, only, by methanol addition, which allows denitrification and consequent alkalinity regeneration. Supplemental caustic soda addition was installed as a backup pH control. The trail gases are drawn through a piping manifold and exhausted. All process data outputs are sent to a PLC based computer, which monitors the operation and controls the

sequencing of the oxic and anoxic steps. Automatic control is used for influent flow and chemical addition, oxygen, methanol, and caustic soda. The fully treated decant is then discharged back to the head of the mainstream plant. The design parameters for the plant were as follows:

TABLE 2: DESIGN PARAMETERS ROTTERDAM, THE NETHERLANDS [4]

Parameter	
Flow design	31.5 m <sup>3</sup> /hr
Flow maximum	50.0 m <sup>3</sup> /hr
NH <sub>4</sub> influent	1-1.5 g/l
Nitrogen Load design	540 kg/day
Nitrogen Load maximum	830 kg/day
Reactor Size	
oxic/anoxic	1,800 m <sup>3</sup>
Oxic Retention Time	1 day
Anoxic Retention Time	>0.5 days

## 6.2 Start-up

The SHARON<sup>®</sup> at the Rotterdam Dokhaven plant was started up in 1999 [4]. The SHARON<sup>®</sup> reactor was filled with river water warmed to 30°C and seeded with waste activated sludge from the main stream treatment plant. The initial control of pH was by means of caustic soda addition. Over the first seven weeks of operation the nitrogen load to the SHARON<sup>®</sup> reactor was increased until the entire production of centrifuge decant water was treated. The start up period lasted five months. Sludge dewatering in the decanters was dependent on sludge production and storage in the sludge buffer tanks. Therefore the flow during that period varied from zero to 980 m<sup>3</sup>/day, the inlet ammonia concentration averaged 1,230 mg/l, with a maximum of 1,530. This was 1.25-1.5 times the design basis.

The start up period was longer than anticipated mainly due to dysfunction of pH and flow measurements. The ammonia in the influent was initially converted to both nitrate and nitrite due to oxic detention times higher than two days (Figure 13). Indeed oxic detention times ranged from 2-10 days in the startup period of week five to twenty (Figure 14). Methanol was dosed during the anoxic phase of the cycle. Once the cycle times were properly controlled, the C/N ratio decreased to 2.4 indicating the metabolic pathway utilized was principally via ammonia to nitrite to nitrogen (Figure 15). Once the process conditions were under control the total nitrogen removal efficiency steadily climbed. As the process stabilized the reactor temperature rose to its design point (Figure 16). The plot of the amount of nitrogen fed as compared to the amount nitrified and amount denitrified showed a steady upward trend despite the obstacles encountered (Figures 17 and 18).

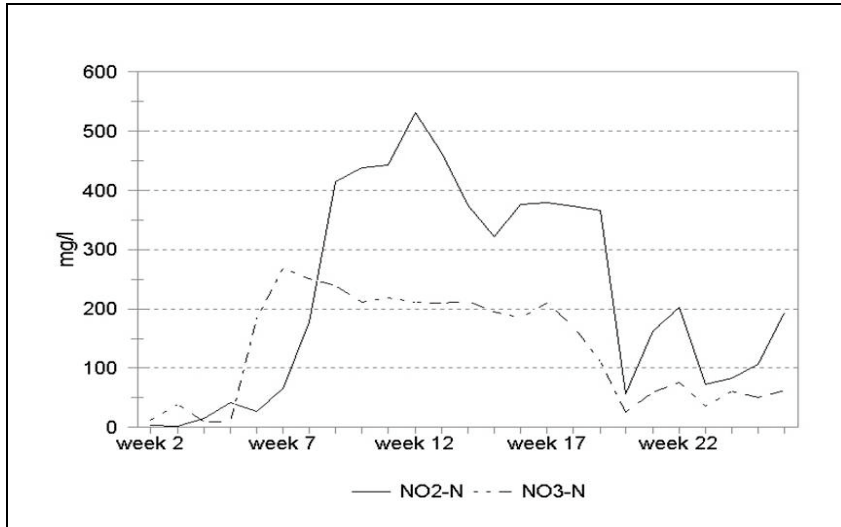


Figure 13 Start-up effluent NO<sub>2</sub> and NO<sub>3</sub>

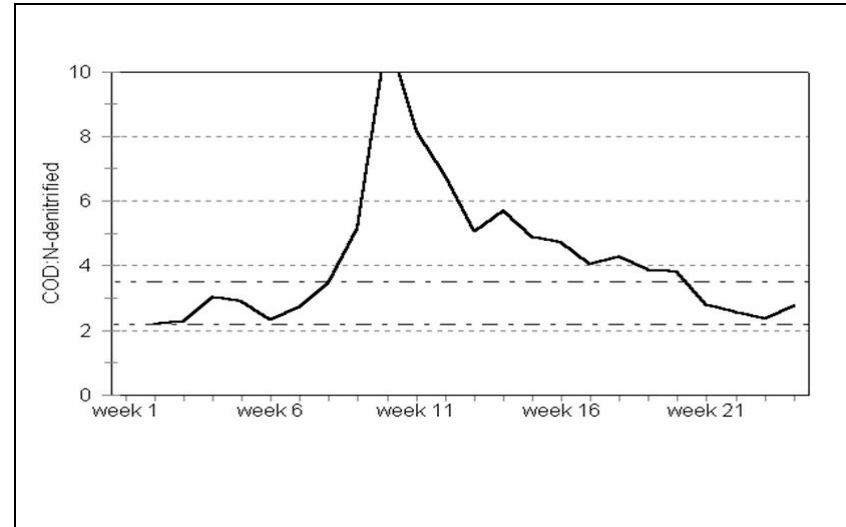


Figure 15 Start-up COD/N-removal

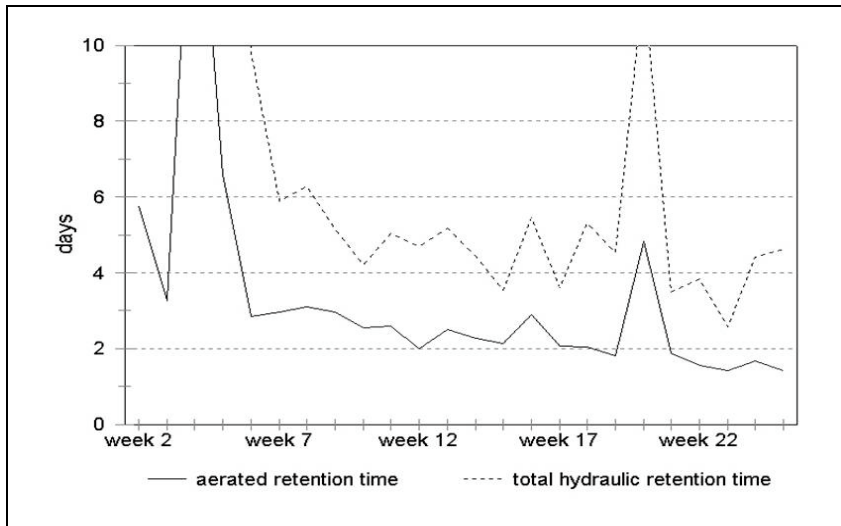


Figure 14 Start-up retention time

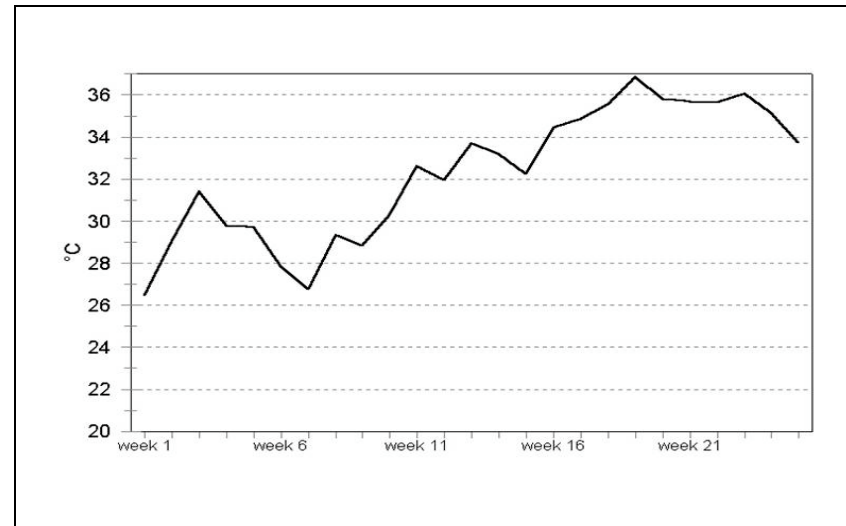


Figure 16 Start-up temperature

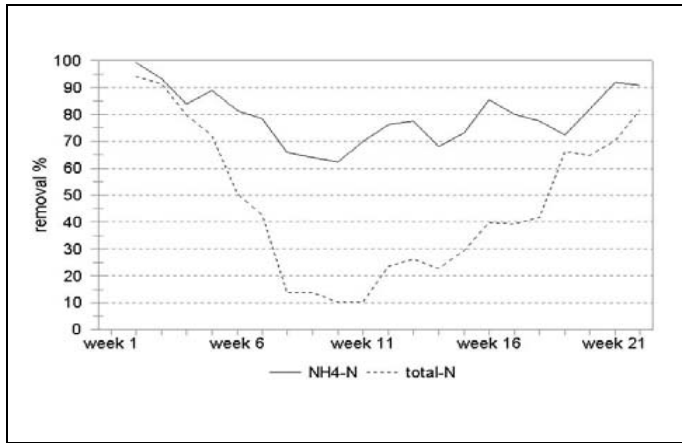


Figure 17 Start-up removal efficiencies

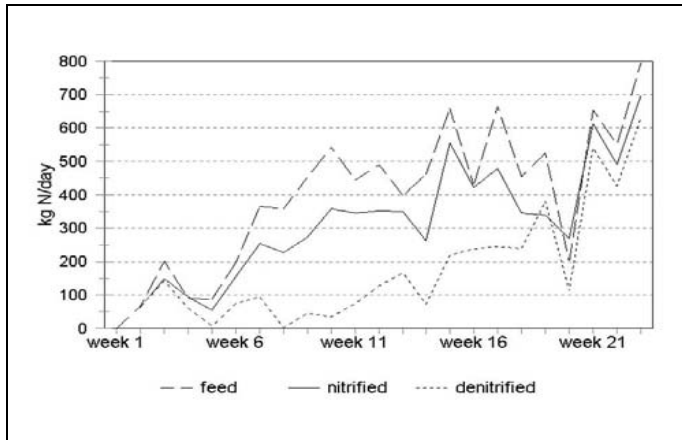


Figure 18 Start-up influent load effluent removal

### 6.3 Continuing operation

The results for 2002 show continued stable efficient operation [4]. The large fluctuations in feed nitrogen continued ranging from 200-750 kg/day in a random pattern (Figure 19). During the second half of 2002 denitrification efficiency was raised from 60-80% to approximately 90% by increasing the methanol dosage. During that period ammonia removal was on average above 95%. The influent ammonia nitrogen varied from 700-1200 mg/l and was above 1000 mg/l the majority of the time. Effluent concentrations stayed in the range targeted by the operations staff. Depending on the

process settings, effluent ammonia nitrogen concentrations ranged from 10-90 mg/l and averaged below 50 mg/l (Figure 19).

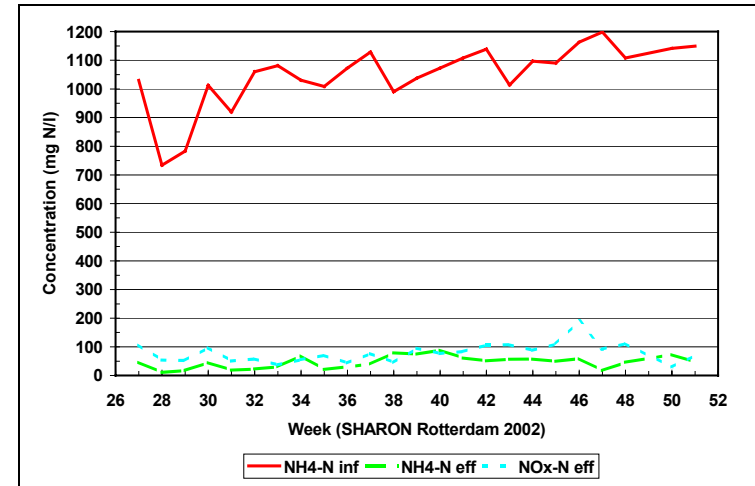


Figure 19 Continuous operations influent effluent

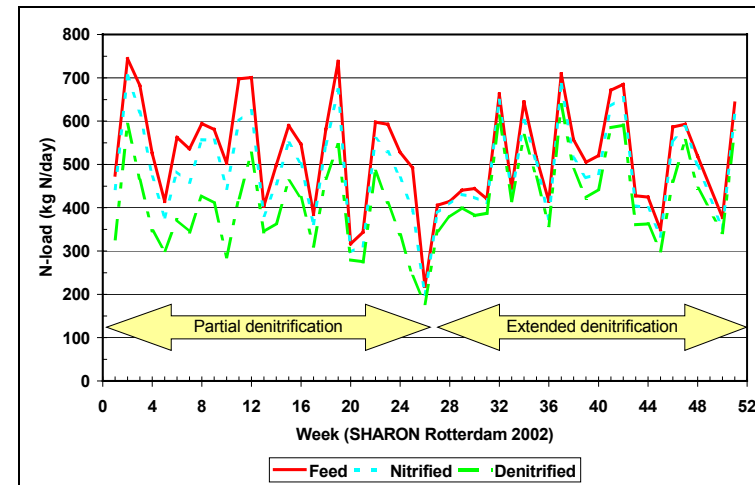


Figure 20 Continuous operations influent and effluent fluctuations

The Rotterdam SHARON® system is controlled to remove nitrogen via nitrite which requires an oxic hydraulic retention below 2 days. At an oxic hydraulic retention time of

approximately 1.5 days the COD/N ratio as methanol consumed illustrates clearly the metabolic pathway from ammonia via nitrite to nitrogen (Figure 21).

From 1999 through 2000 the SHARON<sup>®</sup> process had a very beneficial effect on the main stream effluent lowering the effluent ammonia from an average 6.2 mg/l to 2.1 mg/l and total nitrogen from an average 7.5 mg/l to 3.9 mg/l (Figure 22)

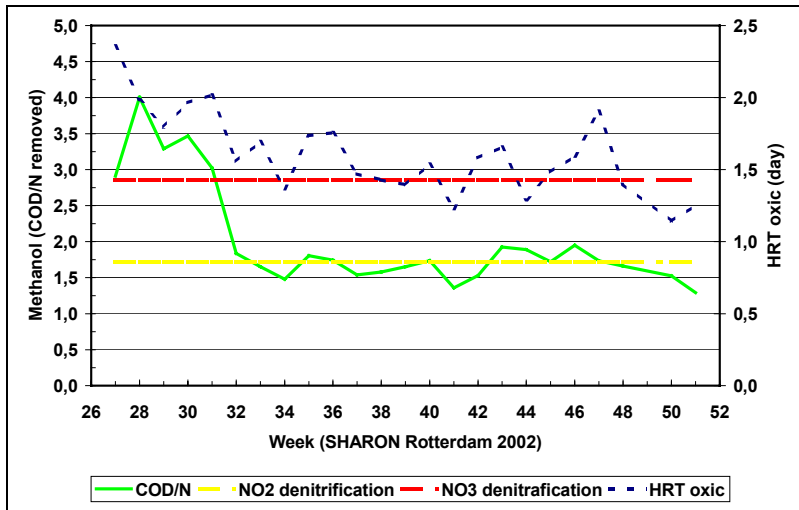


Figure 21 Continuous operations COD/N-removal nitrite pathway

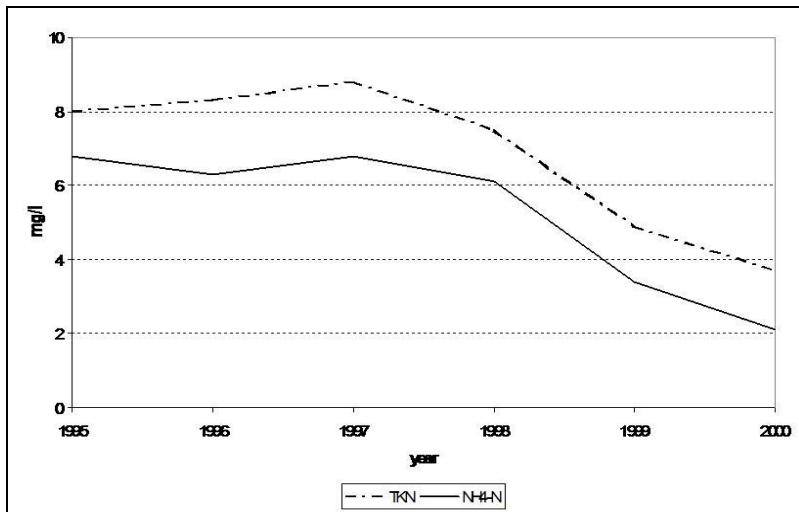


Figure 22 Continuous operation 1995 - 2000 effluent

## 7 OTHER FACILITIES

The success of the operations at Utrecht and Rotterdam has led other Waterboards in the Netherlands to a decision to implement the SHARON<sup>®</sup> process. For the City of Zwolle in northeast Netherlands located on the river IJssel which flows to the IJssel Meer, the City of Beverwijk in northwest Netherlands, and the City of Groningen in the northern Netherlands the construction of a SHARON<sup>®</sup> was tendered for a bid. The systems at Beverwijk (Figure 23) and Zwolle (Figure 24) are being constructed. The SHARON<sup>®</sup> at Zwolle is currently being commissioned. The SHARON<sup>®</sup> at Beverwijk will be operational soon.

SHARONs for the city of Groningen and New York City are currently in the planning stage. We believe, as others learn of this remarkable cost effective process for side stream treatment of high strength nitrogen bearing recycle streams, the reference list will grow.



Figure 23 SHARON<sup>®</sup> Beverwijk (1.200 kg Nkj/d)



Figure 24 SHARON® Zwolle (410 kg Nkj/d)

## 8 CONCLUSIONS

- The SHARON® process, which preferentially selects Nitroso-genera bacteria and removes total nitrogen by means of a hitherto unutilized metabolic pathway, has been successfully demonstrated full scale at two facilities for a number of years. The hitherto unused metabolic pathway is partial oxidation of ammonia to nitrite and then reduction of nitrite and followed by reduction of nitrite to nitrogen.
- The ability to select Nitrosomonas and other Nitroso-genera bacteria over Nitrobacter and other Nitro-genera bacteria has been proven.
- Demonstrated N-removal efficiencies over 90% are achieved.
- Control of the process pH by the production of alkalinity generated by denitrification has been proven.
- The production of heat in the SHARON® reactor due to the rapid conversion of high nitrogen concentrations is in most cases sufficient to allow designs without ancillary heat input from external sources.
- The hitherto unutilized metabolic pathway, partial oxidation of ammonia to nitrite and reduction of nitrite to nitrogen, has been proven to provide the anticipated savings of both a 25% reduction in aeration power consumption and capital cost and also a 40% reduction in COD chemical addition operating and capital costs.

The SHARON® process in full scale operation is very stable despite wide fluctuations in influent flow and total suspended solids.

The SHARON® process improves significantly mainstream nitrogen effluent quality.

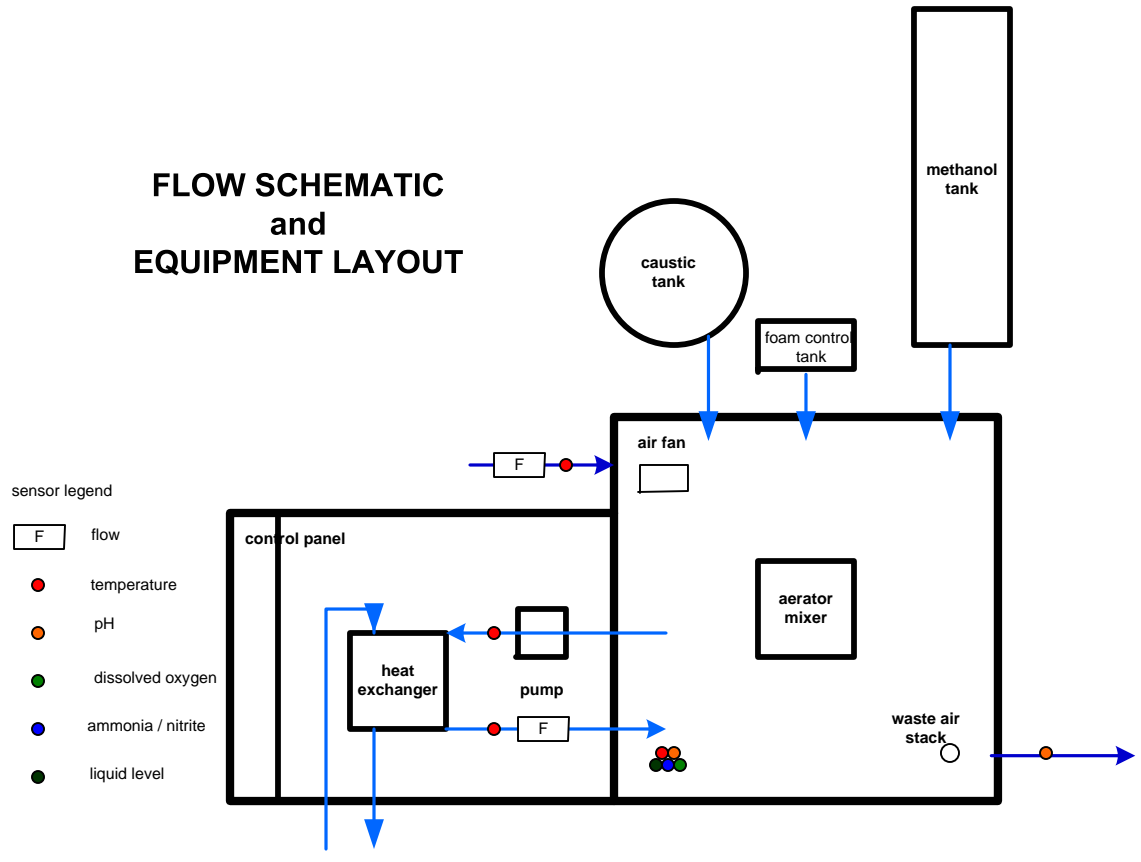
## 9 ACKNOWLEDGEMENTS

The authors wish to thank the Dutch Foundation for Applied Water Research (STOWA) and The Delft University of Technology (TUD) for sponsoring the initial research on this process; the operations personnel of the Utrecht and Rotterdam WWTP for sharing the performance results of their SHARON® system's operation.

## 10 REFERENCES

- [1] European Patent no. EP 0 826 639 B1, 19 August 1997; Biological Treatment of Waste Water; Joseph Johannes Heijnen, Marinus Cornelis Maria van Loosdrecht, assigned to Grontmij.
- [2] US Patents 5,863,435 and 6,183,642; 26th /January /1999 and 6th /February /2001;
- [3] Overview: Full Scale Experience of the SHARON® Process for the Treatment of rejection water of Digested Sludge Dewatering; R. van Kempen, J. W. Mulder, C. A. Uijterlinde, and M. C. M. van Loosdrecht; Water Science and Technology: VOL 44 NO 1 pp145-152 © IWA Publishing.
- [4] Full Scale Operation of the SHARON® Process for the Treatment of Rejection Water of Digested Sludge Dewatering; J. W. Mulder, M. C. M. van Loosdrecht, C. Hellinga, and R. van Kempen; Water Science and Technology VOL 43 NO 11 pp127-134 © IWA Publishing and the authors.

# FLOW SCHEMATIC and EQUIPMENT LAYOUT



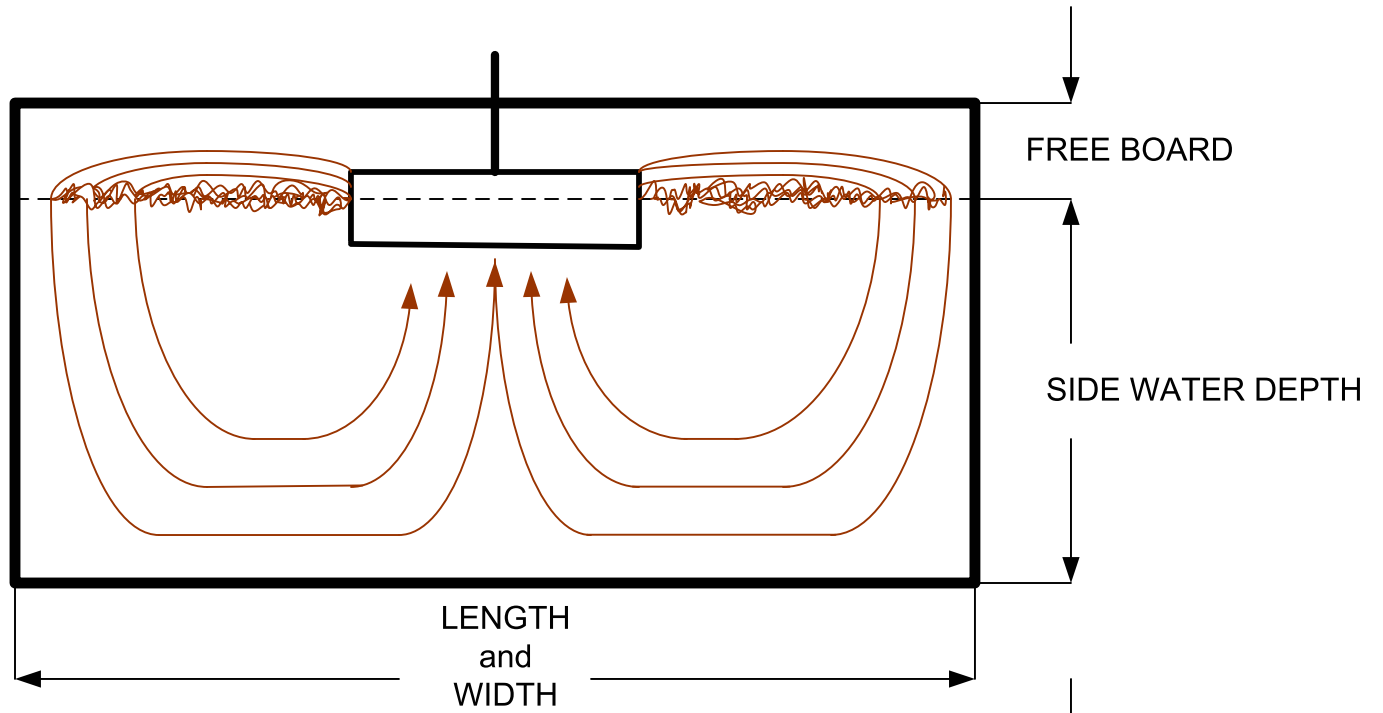
sensor legend

- F flow
- temperature
- pH
- dissolved oxygen
- ammonia / nitrite
- liquid level

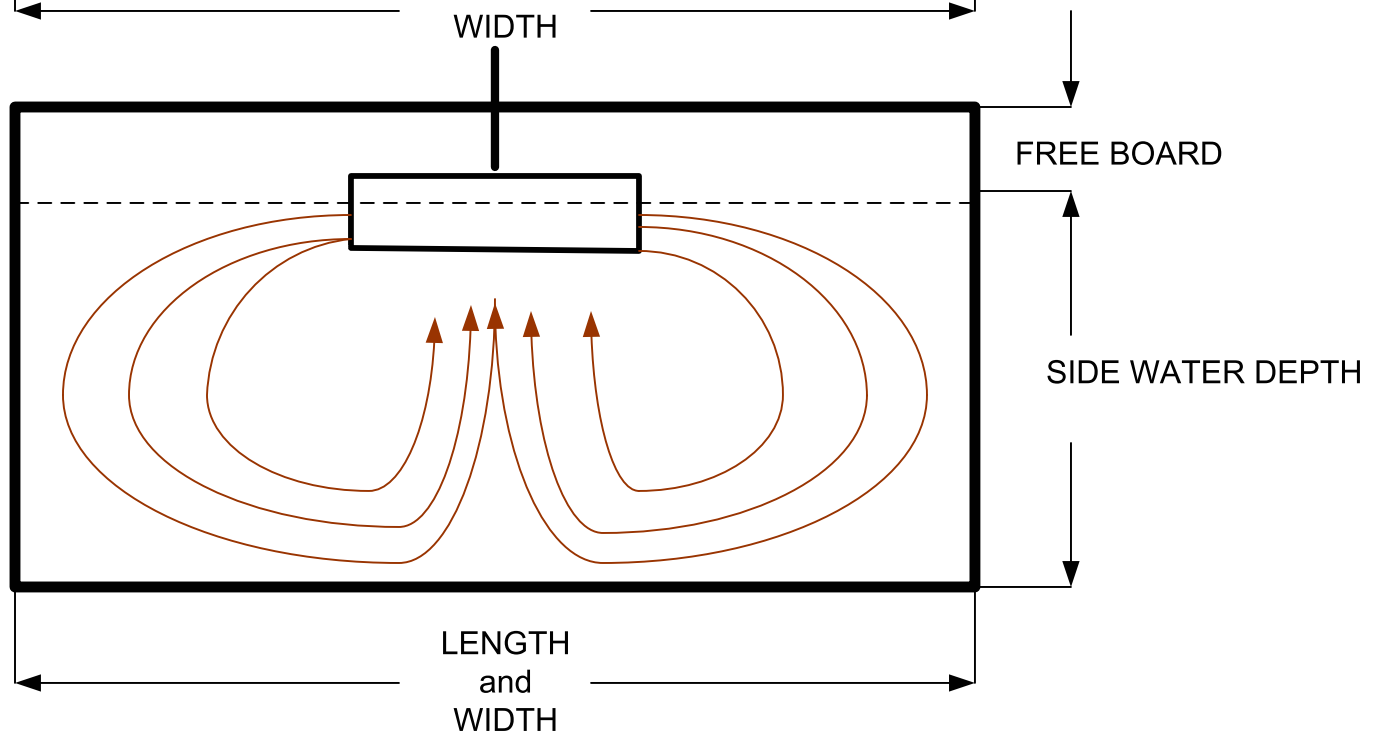
heating or cooling water  
dependent on ambient conditions  
many locations may require neither

**OPERATION of SHARON REACTOR  
OXIC and ANOXIC PERIODS IN TIME**

**OXIC MODE of OPERATION  
@ full rpm  
approximately 90 minutes**



**ANOXIC MODE of OPERATION  
@ 20% of full rpm  
approximately 30 minutes**



# **SHARON PROJECT**

## **SCOPE OF SUPPLY/WORK OF MIXING and MASS TRANSFER TECHNOLOGIES LLC**

**Budgetary Proposal for Cost Evaluation**

**Process Design (Consultant Review and Approval)  
(Patented Design)**

**Specification and Plan Development (Consultant Review and Approval of M2T2 submittals)**

**Bid Tendering to General Contractors**

**Detailed Engineering / Equipment Submittals (Consultant Review and Approval of M2T2 Submittals)**

**Procure and Supply of Equipment to Implement Process (Inspection by Consultant's PM)**

**Instruments and Controls (Consultant Review and Approval of M2T2 Submittals)**

**Assistance to Contractor during Installation of Equipment, Instrumentation, and Controls**

**Checkout of Installation and Certification**

**Start-up and Hands-on Training of Operators**

**Mechanical Warranties, Process Guarantees, and Patent License to Operate**

**Performance Testing (Consultant Approval of Performance)**

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