# EVALUATION OF ANOXIC - AEROBIC TREATMENT FOR NITROGEN REMOVAL FROM WASTEWATER

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## ABSTRACT

**Nitrogen removal can be achieved by biological nitrification-denitrification processes. In order to avoid investment into new treatment plants, existing activated sludge reactors could be adapted to nitrogen removal. A comparison of 4 different reactor configurations was carried out using an activated sludge pilot plant. Conventional activated sludge, contact stabilization, pre-denitrification, and step feed with large volume final settler, were the processes investigated. According to the results obtained, step feed system proved to be the most effective process for both nitrification and denitrification, if denitrification in the final settler could be achieved without disturbing solids settling in the settler.**

***Keywords: Activated sludge, Nutrient removal, Nitrification-Denitrification, Step feed.***

## INTRODUCTION

A lot of attention has lately been drawn to the increasing problems in our aquatic ecosystem caused by discharge of nutrient compounds such as nitrogen and phosphorus.

In municipal wastewater's nitrogen is present principally in the form of amino compounds (organic nitrogen) and ammonia. In the activated sludge process nitrogen is removed wholly or partially from wastewater by biological activities of the microorganisms, through: 1) incorporation into the sludge; and 2) reduction of nitrate (or nitrite) to nitrogen gas when nitrate (or nitrite) serves as electron acceptor. Only a minor part of the influent nitrogen is removed by incorporation in the sludge (about 20-30 %). Nitrogen removal by reduction of nitrate is known as dissimilative reduction of nitrogen or denitrification and involves the reduction of nitrate or nitrite, present in the wastewater, to gaseous nitrogen which escapes to the atmosphere. The removal of nitrogen is a consequence of biological redox reactions wherein biodegradable organic material serves as electron donor and nitrate -nitrite serves the same function as oxygen i.e. as electron acceptor.

Nitrate readily replaces oxygen as electron acceptor because the pathway for the transfer of electrons from organic substrate to the final electron acceptor is similar, but the presence of dissolved oxygen acts as a strong inhibitor on denitrification as it prevents the formation of the enzyme necessary for the final electron transfer to nitrate. For the removal of nitrogen from municipal wastes, the presence of nitrate is essential condition for denitrification, in other word nitrification is a prerequisite for denitrification. Moreover, absence of dissolved oxygen and presence of bacterial mass that can accept nitrate and oxygen as electron acceptor are other two essential conditions for denitrification, an environment that satisfies these conditions is called anoxic.

In order to remove nitrogen, several activated sludge tank configurations have been proposed. Four different processes for nitrogen removal have been tried during this research project. The major aim of this work was to evaluate nitrogen removal in the following processes : a) conventional activated sludge system; b) contact - stabilization; c) pre-denitrification; d) step feed system.

## NITROGEN REMOVAL IN THE ACTIVATED SLUDGE SYSTEM

The major part of nitrogen that could be removed in the activated sludge system is a result of 2 reactions:

### 1. *Nitrification*

In the nitrification reaction, ammonia is oxidized to nitrate in two steps where nitrite is the intermediate product. The conversion of nitrite is the rate limiting step in the reaction and therefore the nitrite concentration in the reactor is normally very low. The overall stoichiometric reactions are as follows [1]:

$$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + 2\ H^+ + H_2$$

$$+ (58\text{-}84)\ \text{Kcal / mol}\ NH_4^+ \qquad (1)$$

$$NO_2^- + 0.5\ O_2 \rightarrow NO_3^- + (15.4\text{-}20.9)$$

$$\text{Kcal / mol}\ NO_2^- \qquad (2)$$

During these aerobic reactions energy is released which can be used by two bacterial groups; Nitrosomonas and nitrobacter, for metabolic functions, such as the synthesis of carbon dioxide for cell growth. As can be seen in Eq.(1) hydrogen ions are produced in the nitrification reaction. Theoretically 7.14 mg / L alkalinity as Ca $Co_3$ is used per mg N nitrified, and therefore the pH in wastewater with little buffering capacity may drop and cause inhibition of the process. Both Nitrosomonas and Nitrobacter are sensitive to their own substrate and even more to the substrate of the other and since both the ammonia-ammonium and nitrite-nitrous acid equilibria depend on pH, the pH of the reaction is very important [2].

Theoretically, 4.57 mg oxygen is needed per mg of $NH_4$-N to be oxidized. The oxygen concentration in the reactor should be kept above 1.5 mg / L to ensure nitrifier growth and an appropriate reaction rate. The oxygen concentration should not decrease below 0.5 mg / L, since the nitrifiers are obligatory aerobic. Temperature greatly influences the reaction rate, the optimal temperature is between 28 to 36°C [3].

The number of nitrifying organisms influences the observed rate of nitrification. In activated sludge process several operational parameters indirectly affect the nitrifier concentration and thereby the nitrification rate. Among these are sludge age and organic loading. The growth rate of nitrifiers is low compared to that of heterotrophic bacteria and if other parameters are held constant, the rate of nitrification decreases with increased organic loading since heterotrophic bacteria outgrow the nitrifiers. For the same reason a certain sludge has to be reached in order to keep nitrifiers in the system. The necessary sludge age depends on the temperature of the reaction system.

### 2. *Denitrification*

Denitrification is carried out by microorganisms which have the ability to use dissolved oxygen as well as nitrate or nitrite as a terminal acceptor of the electron flow generated by the energy yielding reactions. Stoichiometrically 1 g $NO_3$ - N is equivalent to 2.86 g $O_2$ . The biochemical reaction of denitrification can be simplified to :

$$NO_3^- + 2\ H^+ \rightarrow NO_2^- + H_2O \qquad (3)$$

$$NO_2^- + 3\ H^+ \rightarrow 1/2\ N_2 + H_2O + OH^- \qquad (4)$$

The presence of oxygen prevents the denitrification reaction. The oxygen concentration should not exceed 0.5 mg / L. However, if the oxygen concentration is as high as 0.5 mg / L denitrification can be indirectly inhibited because the carbon source is used for consumption of the oxygen instead. Optimal pH for denitrification is between 7 and 9, and outside this range the denitrification rate drops significantly [1]. Another parameter that greatly influences denitrification rate is the accessibility of the carbon source. For example, it is considerably lower when the endogenic respiration of biomass is used as carbon source compared to methanol.

## REACTOR CONFIGURATIONS FOR NITROGEN REMOVAL

Existing activated sludge reactors can be adapted to nitrogen removal. Special activated sludge configurations have been proposed to reduce the hydraulic retention time while maintaining a high sludge age. In contact stabilization, the return sludge is aerated, and its high concentration leads to lower tankage volumes for the same mass load. This process has lately been adapted to nutrient removal by adding denitrification zone between the aeration tank for nitrification and sludge reaeration.

There are also two basic configurations for the single sludge nitrification-denitrification system depending on the type of energy source:

1) *Internal (influent) energy source*

Ludzack et al. [4] were first to propose a process configuration utilizing the biodegradable material in the influent as the main energy source for denitrification. The influent is discharged to anoxic reactor and the underflow recycle from the settling tanks is discharged to the aerobic reactor. Nitrification takes place in the aerobic reactor. The nitrified mixed liquor is cycled to the anoxic reactor. This configuration is also known as pre-denitrification system.

2) *Self-generated energy source*

In this configuration endogenous death and lysis provides the energy for denitrification. The first reactor, which is aerobic, receives the influent flow and sludge return flow from the settling tank. The contents of the aerobic reactor discharge to the anoxic reactor (also called the post-denitrification reactor) where denitrification takes place. The rate of energy release due to organism death and lysis is low, resulting in a low rate of denitrification.

Another configuration to concentrate biomass and to avoid recirculation of mixed liquor is the step feed alternate zone process. This process was demonstrated on full scale in England [5], Germany [6], and France [7]. The flexible step feed and the possibility of solids storage in the first part of the tanks make this process particularly adapted to plant with high stormwater inflow.

## MATERIALS AND METHODS

### *Pilot Plant*

For the purpose of this research, the experimental work was conducted on a pilot plant unit, using settled wastewater from the Eastern Alexandria Treatment Plant (EATP).

The pilot plant was fabricated and located at the Sanitary Engineering Laboratory in the Faculty of Engineering, Alexandria University. The pilot plant consisted of a feed tank with a 3.0 $m^3$ volume, the feed tank was constructed out of galvanized mild steel, gentle mixing was needed to keep the solids in suspension. The feed tank followed by an activated sludge unit consisted of three Plexiglas 125 liter (each) completely mixed reactors in series with the capability of directing the feed flow to any reactor according to the experimental plan. The reactors followed by a final settler, 2 different settlers with different size were available. The first was 0.16 $m^2$ surface area and 0.5 m depth, while the second was 0.36 $m^2$ surface area and 0.6 m depth. According to the experimental plan the selected settler was connected to the system. 2 peristaltic pumps (Masterflex - computer controlled with flowrate digital displaying) were used, the first as a feed pump, and the second for recycling the sludge from the settler underflow to the first reactor. In order to keep reactors operating in aerobic mode, compressed air was used for mixing and aeration. In case anoxic condition is required in any reactor, its air valve was closed, and a mixer was employed to keep the solids in suspension. A schematic showing the pilot plant is depicted in Figure (1).

### *Wastewater Composition*

The incoming wastewater is a primary settled wastewater from the EATP. The average values, range and standard deviation of the wastewater during the course of this research are given in Table (1).

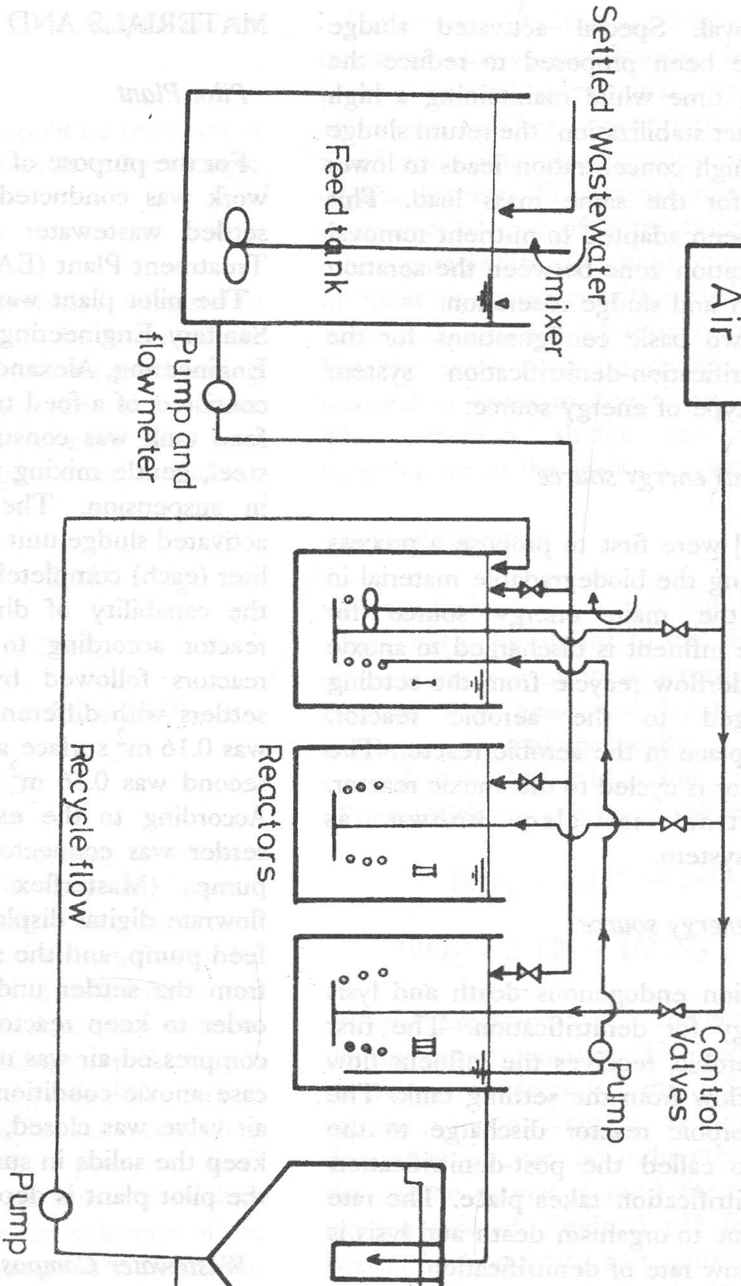

Figure 1 Experimental Facility

**Table 1.** Wastewater Composition.

| Parameter | | Ave. | Range | S.D | No. of Samples |
|---|---|---|---|---|---|
| pH | - | 7.53 | 7.23-7.78 | 0.15 | 30 |
| COD | mg/L | 273 | 210-360 | 52.80 | 30 |
| BOD | mg/L | 142 | 104-180 | 25.60 | 10 |
| S.S | mg/L | 364 | 190-640 | 192.40 | 30 |
| $NH_4$-N | mg/L | 17 | 11-24 | 6.18 | 30 |
| $NO_3$-N | mg/L | 0.3 | 0.1-0.8 | 0.25 | 30 |
| $PO_4$-P | mg/L | 13 | 10-18 | 4.88 | 10 |
| Temp. | °C | 26 | 20-33 | 7.32 | 30 |

### *Analytical Procedures*

Twenty four hour composite samples were collected from the sampling points, and stored in a refrigerator at 5°C until analyses were made during day. The samples were analyzed for pH, COD, BOD, and suspended solids according to the Standard Methods [8]. Analyses of $NH_4$, $NO_3$ and $PO_4$ were performed using reagent kit for photometric analysis (CHEMets, USA).

## EXPERIMENTAL PLAN

In order to evaluate the performance of the four different processes, pilot plant experiments were carried out. The experimental program for the pilot plant comprised of 2 phases:

### *Phase 1: Start-up*

The aim of this phase was to achieve the steady state condition before carrying out the planned experiments. Activated sludge seed was taken from the aeration tank of Kafr El- Dawar wastewater treatment plant. After screening through square openings wire mesh sieve, the sludge seed was completely mixed and evenly distributed among the three reactors. The reactors were operated at the projected hydraulic retention time (HRT) of 9 h and the target solids retention time (SRT) was 10 days. During the start- up period, all reactors were operated under aerobic condition, the dissolved oxygen concentration (DO) never fall below 2.5 mg/ L. Steady state condition is considered to be achieved by the constance of the measured parameters during a period of equal to 1-2 times of the solids retention time, it was achieved in our case after 13 days from the starting date.

### *Phase 2: Experiments*

The experiments phase consists of 4 different runs (Figure 2).

### Run1: Conventional Activated Sludge System (Normal Operation)

During this run, the feed point was directed to the first reactor resulting in 9 hours detention time. All reactors were kept aerobic with DO never less than 2.5 mg/ L.

### Run 2: Contact Stabilization

This modification was achieved by directing the feed point to reactor No.3 (contact tank) while reactors No.1 and 2 can be considered as stabilization tank. All reactors were kept aerobic. At the end of this run the feed point was returned back to the first reactor (normal operation). It is important to return to the normal operation after every run for at least 18 hours before carrying out new runs to avoid any disturbance from the previous experiment (run).

### Run 3: Pre-Denitrification

The process configuration that was simulated in this run consisted of one anoxic reactor, 2 aerobic reactors, and a final settler (small), with sludge recycle from the final settler to the anoxic reactor and mixed liquor recirculation from the 2nd aerobic reactor to the anoxic reactor.

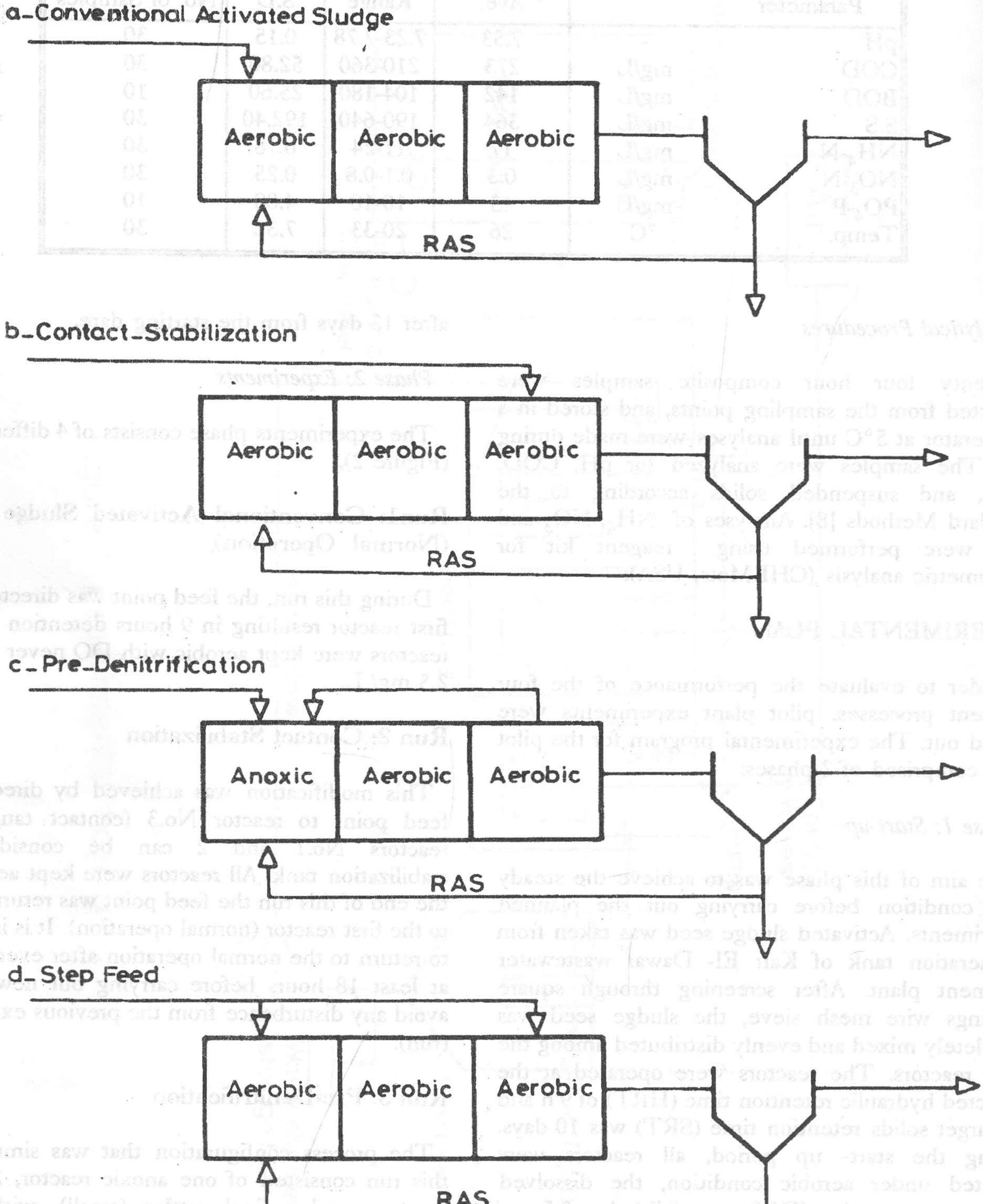

Figure 2. Process configurations for Nitrogen removal.

### Run 4: Step Feed

In order to simulate the step feed on the pilot plant, the 3 reactors were operated under aerobic condition. During this run 80% of the influent wastewater was directed to the first reactor, while 20% of the flowrate was directed to the last reactor, with the sludge recycle from the final settler (S.A. = 0.36 $m^2$) to the first reactor. No mixed liquor recirculation was needed.

## RESULTS AND DISCUSSION

For the purpose of this research, the pilot plant system was operated for about 100 days. Daily operating conditions were kept and laboratory analysis of the system was conducted and recorded during this period. These data provided the basis for evaluating the capabilities of each examined process. The measured parameters were averaged during their best steady state condition. A summary of these averages is presented in Table 2 and Figures (3), (4), (5), and (6).

From Table (2), it is clear that the conventional activated sludge system (Run 1) was able to remove about 91% of the COD and 73% of $NH_4$-N. This run was used as a base for the comparison.

For both COD and $NH_4$-N lower removal efficiency was obtained during the contact stabilization phase (Run 2). This is due the short hydraulic retention time in the contact reactor (3 hours).

In the pre-denitrification system (Run 3), the anoxic or denitrification zone was ahead of the nitrification (aerated) reactors and a large quantities of nitrified wastewater was internally recycled from the nitrification reactor (reactor 3) to the anoxic reactor (reactor 1). According to this modification biological denitrification took place in the anoxic reactor where no dissolved oxygen was present but oxygen was available as a part of the nitrate ion in the mixed liquor recycled from the nitrification reactor. Under these conditions a wide range of facultative heterotrophic bacteria can modify their mechanism utilize nitrate as an oxygen source. Bacteria need a biodegradable source of carbon, which is available in the influent wastewater, the biodegradable material in the municipal sewage expressed as COD is divided into two fractions, (a) easily biodegradable (about 24% of the total biodegradable COD), and (b) particulate slowly biodegradable (76%). The growth of heterotrophic bacteria is assumed to take place in both aerobic and anoxic reactors, while the growth of nitrifiers can take place only in aerobic reactors. According to the results obtained, the pre-denitrification process can remove about 95% of COD and 86% of $NH_4$-N, a good denitrification level could also be recognized.

The pilot plant was also used to evaluate the step feed modification. All reactors were kept aerobically (nitrification). As stated before 80% of the influent flowrate was directed to the first reactor, while 20% of the influent was directed to the reactor. This 20% of the flowrate is important to provide the carbon source required for denitrification which occurred in the final settler.

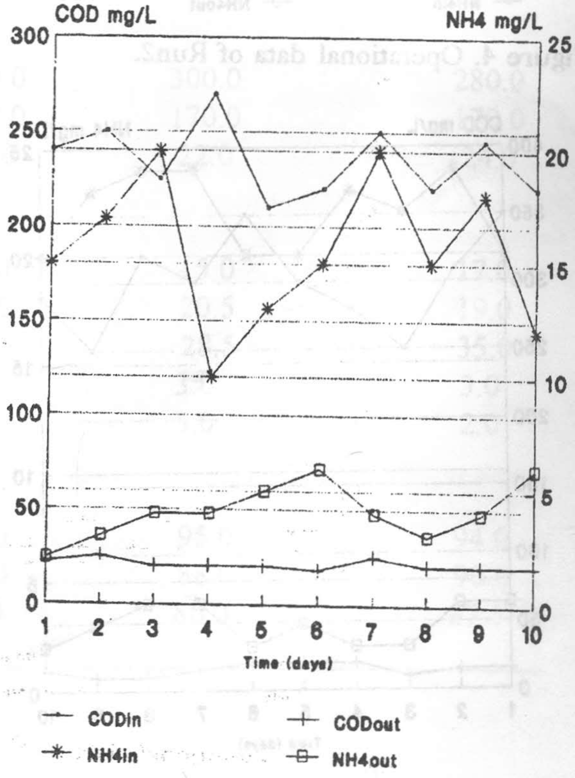

Figure 2. Operational data of Run1.

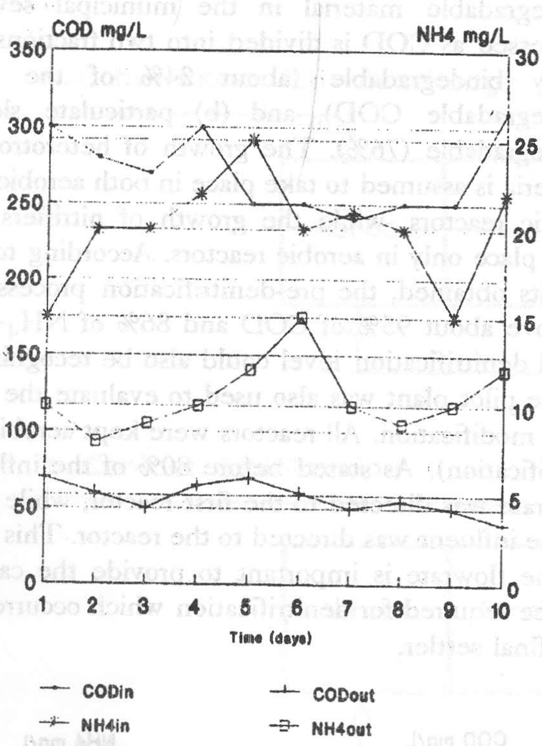

Figure 4. Operational data of Run2.

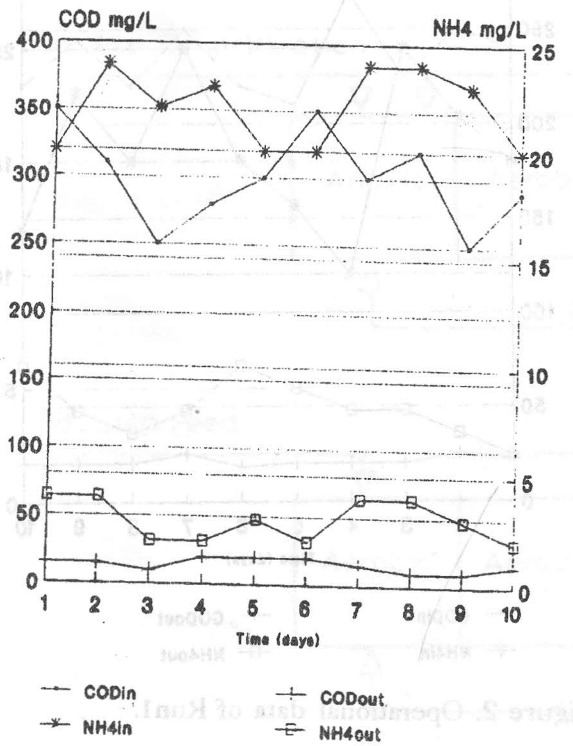

Figure 5. Operational data of Run3.

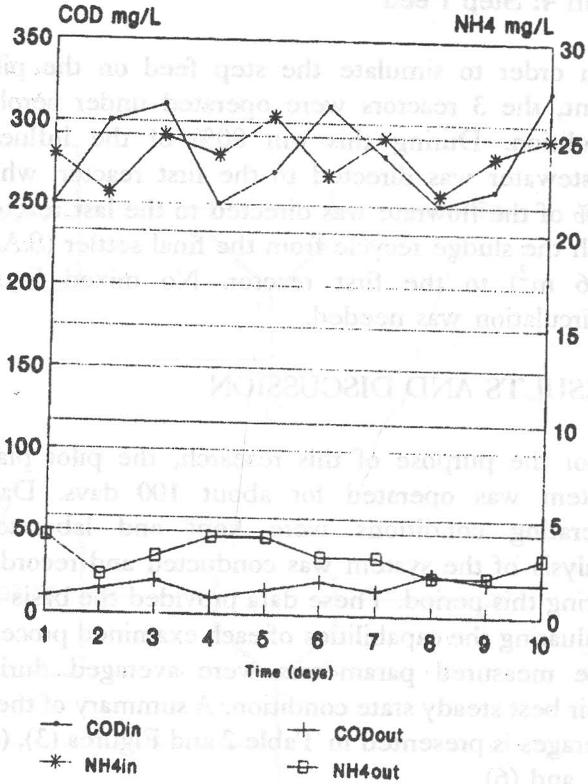

Figure 6. Operational data of Run4.

Generally, the purpose of the final settler is to separate particulate solids from the mixed liquor and thicken the solids sufficiently so that a balance is maintained between incoming suspended solids in the settler feed and outgoing suspended solids in the settler underflow. In the step feed system the final settler was also considered as a bioreactor where denitrification can take place. Denitrification in the final settlers can substantially increase overall denitrification of activated sludge systems if settler volume is big as compared to denitrification volume and if the sludge blanket is maintained in the thickening zone of the settler [9]. This is why the large settler was used in Run 4. The step feed modification gave the best results for $NH_4$-N removal, and 94% removal efficiency of COD was also observed.

**Table 2. Comparison of pilot plant operational results.**

| Process | Conventional A. S. | Contact Stabilization | Pre-Denitrification | Step Feed |
|---|---|---|---|---|
| Reactor | | | | |
| Aerobic % | 100 | 100 | 66.66 | 100 |
| Anoxic % | 0.0 | 0.0 | 33.33 | 0.0 |
| SRT (d) | 10 | 10 | 10 | 10 |
| Recycle % | 50 | 50 | 50 | 50 |
| Recirculation (%) | 0.0 | 0.0 | 100 | 0.0 |
| MLSS(1) mg/L | 3250 | 3500 | 3000 | 3100 |
| MLSS(2) mg/L | 3100 | 3300 | 2090 | 3000 |
| MLSS(3) mg/L | 3050 | 1200 | 2090 | 3300 |
| Settler | small | small | small | large |
| Influent | | | | |
| COD mg/L | 235.0 | 270.0 | 300.0 | 280.0 |
| BOD mg/L | 120.0 | 150.0 | 170.0 | 170.0 |
| $NH_4$-N mg/L | 15.0 | 20.0 | 22.0 | 24.0 |
| Effluent | | | | |
| COD mg/L | 21.0 | 57.0 | 15.0 | 17.0 |
| BOD mg/L | 8.0 | 24.0 | 20.5 | 19.0 |
| SS mg/L | 25.0 | 15.0 | 28.5 | 35.0 |
| NH4-N mg/L | 4.0 | 10.5 | 3.0 | 3.0 |
| NO3-N mg/L | 12.0 | 8.0 | 5.0 | 2.0 |
| Efficiency % | | | | |
| COD | 91.0 | 79.0 | 95.0 | 94.0 |
| BOD | 93.0 | 84.0 | 88.0 | 90.0 |
| NH4-N | 73.0 | 48.0 | 86.0 | 87.5 |

## CONCLUSIONS

1. Nitrogen removal can be achieved by biological nitrification-denitrification processes. The reactor configuration plays a crucial rule in biological nitrogen removal. Accurate selection of the reactor configuration is an important factor to achieve high levels of nitrogen removal.
2. The conventional activated sludge process is able to achieve reasonable removal efficiency of

NH4-N. However, the denitrification level is low.

3. Contact stabilization process is not suitable for nitrogen removal unless some modifications are made. For example, operating the first reactor under anoxic condition.
4. The results showed that the pre-denitrification system is efficient for both nitrification and denitrification. The major disadvantage of this system is the need to third pump to recycle the mixed liquor from the aerobic reactor to the anoxic zone.
5. Good results of nitrification-denitrification was obtained using the step feed system with large volume final settler. This system is claimed to be the most effective since it makes maximum use of organic carbon present in the wastewater.
6. Denitrification in the final settler can increase the overall denitrification of the activated sludge system if settler volume is big and organic carbon source is available.

## REFERENCES

[1] EPA, "Process Design Manual for Nitrogen Control", *U.S EPA Technology Transfer*, 1975.

[2] A.C. Anthonisen, R.C. Loehr, T.B. Prakasam, and E.G. Srinath, " Inhibition of Nitrification by Ammonia and Nitrous Acid" *J.Wat. Poll. Cont. Fed.*, vol. 48(5), pp. 835-852, 1976.

[3] B. Sharma, and R.C. Ahlert, "Nitrification and Nitrogen Removal" *Water Research*, vol. 11, pp. 897-925, 1977.

[4] F.J. Ludzack, and M.B. Ettinger, " Controlling Operation to Minimize Activated Sludge Effluent Nitrogen" *Wat. Pollut. Control Fed.*, vol 34, pp. 920-931, 1962.

[5] P.F. Cooper, B. Collinson, and M.K. Green, "Recent Advances in Sewage Effluent Denitrification" *Wat. Pollut. Control*, vol. 76, pp. 389-401, 1977.

[6] S. Schlegel, "Results of Nitrification Plants with Cascade Denitrification" *GWF WAS. ABW.*, vol. 128, pp. 422-431, 1987.

[7] H.Moreaud, and P Gills, "Elimination of Nitrogen in Wastewater" *TSM. L'Eau*, vol. 74, pp. 241-250, 1979.

[8] *APHA Standard Methods for the Examination of Water and Wastewater*, 17th edition. American Public Health Association, Washington, D.C., 1989.

[9] H. Siegrist, P. Krebs, R. Buhler, I. Purtschert, and R. Rufer, "Denitrification in Secondary Clarifiers" *Modeling and Control of Activated Sludge Processes*, IAWQ, Copenhagen, 1994.