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# DETERMINATION OF THE IMPACT OF TOXIC INFLOWS ON THE PERFORMANCE OF ACTIVATED SLUDGE BY WASTEWATER CHARACTERIZATION

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## ABSTRACT

A rational approach for the design of the activated sludge process based on wastewater and biomass characterization techniques as applied to the upgrading of the treatment plant of Volos, a city in the central part of Greece, is presented. The study investigates possible nitrification inhibition and carbon inadequacy, due to high salinity, industrial inflows and pre-precipitation by iron salts. The experimentation was carried out by means of batch Ammonium Uptake Rate (AUR) and Nitrates Uptake Rate (NUR) tests. The results show that within the studied range, 900-4000 mg $l^{-1}$, chlorides did not inhibit nitrification. Contrary to this, the industrial wastewater entering the plant was found to be toxic. With the existing 1:15 ratio of industrial to total wastewater flow a 50 % inhibition to the nitrification process was observed, which is higher than the 25 - 30 % inhibition caused by typical domestic sewage. Industrial contributions exceeding 20 % resulted in complete inhibition of nitrification. With respect to denitrification it was found that the industrial wastewater provided a suitable source of carbon, without any adverse effects on denitrification. Pre-precipitation removed about 25 % of the filtered COD, thus reducing the amount of nitrates which could be rapidly denitrified. Design of the biological reactors on the basis of the findings indicate that a significant under-design may result if typical nitrification and denitrification rates obtained from the literature and practice concerning typical domestic sewage are adopted. 

## KEYWORDS

Activated sludge; nitrification; denitrification; wastewater characterization; toxicity.

## INTRODUCTION

The design of municipal wastewater treatment plants is usually based on the assumption that the origin of the wastewater to be treated is domestic, despite the well recognized fact of a variable and in some cases significant contribution of industrial wastewaters to the total flow. This assumption leads to the employment of design criteria suitable for domestic wastewaters with, in some cases, some small and ill-defined allowance (usually in terms of safety factors) for the potential presence of substances which are inhibitory to sensitive processes, e.g. the nitrification process. The arbitrary adoption of a reasonably moderate safety factor can prevent excessive overdesign while at the same time accommodating for, the typical in many municipalities, limited presence of inhibitory material. It is however evident that a more rational approach is needed in cases of increased non domestic inflows to the sewerage system and/or large treatment plants where the combination of the increased risk of under or over designing and the economy of scale justify a more systematic approach.

This paper presents a case study of the problem and describes a rational approach for the design of the activated sludge process based on wastewater and biomass characterization techniques, as applied to the upgrading of the treatment plant of Volos, a city in the central part of Greece.

The municipality of Volos with a population of 135000 produces a sewage flow of 32000 $m^3 d^{-1}$ This flow is jointly treated with some 2000 $m^3 d^{-1}$ industrial wastewaters originating from the industrial area, located on the outskirts of the city. The existing treatment plant consists of preliminary treatment, chemically assisted sedimentation and sludge treatment. The mixture of sewage and industrial wastewater is subjected to screening, grit and oil removal and air flotation which removes part of the solids and the organic load. Following this, iron salts in the form of $FeClSO_4$ are added and after coagulation the flow passes through rectangular primary sedimentation tanks. The produced sludge from the air flotation unit is pumped to the anaerobic digestors. The primary and chemical sludges are subjected to gravity thickening and the thickened sludge is introduced to the digestors. The digested sludge is dewatered by belt presses and subsequently removed for co-disposal with municipal refuge to a sanitary landfill. A schematic representation of the existing and future treatment works is shown in Figure 1.

The effluent from the treatment plant, with average concentrations of $BOD_5$, COD and SS 80 mg $l^{-1}$, 160 mg $l^{-1}$ and 30 mg $l^{-1}$ respectively, is discharged through an outfall to the nearby gulf of Pagasiticos.

In view of the EU Directive 91/271 concerning the treatment of municipal wastewaters (Council of the European Communities, 1991), it was decided to upgrade the treatment plant in order to achieve a final effluent which complies with the required effluent quality for discharge to sensitive recipients, that is:

| | |
|---|---|
| $BOD_5 < 25$ mg $l^{-1}$ | $NH_4$-N < 2 mg $l^{-1}$ |
| COD < 125 mg $l^{-1}$ | TotalN < 12 mg$l^{-1}$ |
| SS < 30 mg $l^{-1}$ | TP < 2 mg$l^{-1}$ |

The desired effluent characteristics will be achieved through biological treatment based on the activated sludge process with nitrification-denitrification and chemical phosphorus removal.

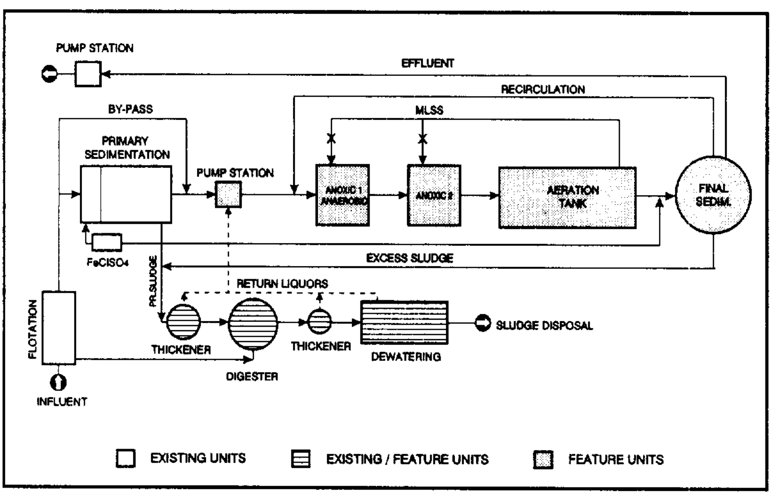


Fig. 1. Schematic representation of the Volos treatment plant.

## CONVENTIONAL DESIGN PROCEDURE

### Nitrification

The design of single stage nitrification systems is usually based on the determination of the appropriate for the desired degree of nitrification Sludge Retention Time (SRT) and the subsequent estimation of the necessary volume of the oxic reactor.

The following set of equations can be used (WPCF, 1983):

$$\min(SRT) = \frac{1}{\mu_v} \quad (1)$$

$$SRT=\min (SRT)^* S_f \quad (2)$$

$$\mu_N=\mu_{Nmax} \frac{NH_4\text{-}N}{NH_4\text{-}N+ K_N} \quad (3)$$

$$\mu_{Nmax(T)}=0.18 \exp (0{,}116 (T-15)) \quad (4)$$

$$K_{N(T)}=0.405 \exp (0.118 (T-15)) \quad (5)$$

where:

$\mu_N$ = nitrifiers growth rate ($d^{-1}$)
$S_f$ = safety factor
$NH_4$-N = ammoniacal nitrogen effluent concentration ($mgl^{-1}$)
$K_{N(T)}$= half saturation constant ($mg\ l^{-1}$) at temperature T
T= Temperature ($^0C$)
$\mu_{Nmax(T)}$= maximum nitrifiers growth rate at temperature T ($d^{-1}$)

Employing these equations for the case of Volos the results of Table 1 were obtained. The adoption of a safety factor of 1.30 is based on the assumption usually made in Greece, that a municipal wastewater maintains its essentially domestic nature if the inhibition of the nitrification process (in terms of $\mu_N$ reduction) does not exceed 25%.

### Denitrification

The volume of the anoxic reactor can be estimated on the basis of an average denitrification rate, $q_{DN}$, from the equations (WPCF, 1983):

$$q_{DN}= 6.40+10^{10} \exp (-15880/RT_K) \quad (6)$$

$$V_{an}= \frac{NO_3\text{-}N \text{ denitrified}}{q_{DN} \,.\, MLVSS} \quad (7)$$

where:

R = constant =1.987
$T_k$ = temperature

TABLE 1. CONVENTIONAL DESIGN OF BIOLOGICAL STAGE

| | Nitrification | | Denitrification |
|---|---|---|---|
| Critical Temperature | 13 °C | Critical Temperature | 13 °C |
| $\mu_v$ | 0.1425 $d^{-1}$ | N denitrified | 740 kg $d^{-1}$ |
| SRT | 8 d | $q_{DN}$ | 0.047 $d^{-1}$ |
| MLSS | 5000 mg $l^{-1}$ | MLSS | 5000 mg $l^{-1}$ |
| MLVSS | 2600 mg $l^{-1}$ | MLVSS | 2600 mg $l^{-1}$ |
| Voxic | 7200 $m^3$ | Vanoxic | 6050 $m^3$ |

Application of equation 6 for a temperature of 13 °C ($T_k$=286) results in a $q_{DN}$ value of 0.047 $d^{-1}$. The quantity of $NO_3$-N to be denitrified can be estimated on the assumption of full nitrification which gives a daily quantity of 1248 kg $NO_3$-N. The amount in the final effluent is 384 kg $d^{-1}$ (at 12 mg $l^{-1}$) and the amount used for synthesis (assuming 8 % N content in the excess biomass) is 124 kg $d^{-1}$. Therefore the amount to be denitrified equals 740 kg $d^{-1}$. Applying equation 7 for $NO_3$-N=740 kg $d^{-1}$, $q_{DN}$=0.047 $d^{-1}$ and MLVSS=2600 mg $l^{-1}$, the calculated volume of the anoxic reactor is 6050 $m^3$ (Table 1).

## NITRIFICATION-DENITRIFICATION EXPERIMENTS

### Inhibition of nitrification

The degree of inhibition of the nitrification process was determined by parallel experiments in which the nitrification rates (measured as nitrates production rates) of a reference nitrifying sludge fed with ammonium solution (blank) and wastewater respectively were compared. The reference sludge was obtained from a laboratory scale activated sludge pilot unit fed with a mixture of domestic and synthetic sewage. Figures 2, 3 and 4 show three indicative experiments with municipal wastewater, a typical mixture of municipal and industrial wastewater (industrial wastewater 7 % of total) and an enriched mixture of municipal and industrial wastewater (20 % industrial wastewater) from Volos. Figure 5 shows the measured ratios of the nitrification rates (wastewater over blank) for various percentages of industrial wastewater.

The results show that for the municipal wastewater the degree of inhibition was to the order of 30 %, which is in agreement with results reported for other municipal treatment plants in Greece (NTUA, 1996 a, b). The introduction of industrial wastewaters from the industrial area in the case of Volos at the typical contribution of 7 % results in an increased inhibition of about 50 %. The toxicity of the industrial wastewater is evidenced by the fact that at a 20 % or higher contribution the inhibition to the nitrification process was complete.

Similar experiments were performed with wastewater samples at different salinity levels. The concentration of chlorides in the samples from Volos varied between 900-1500 mg $l^{-1}$, but additional experiments with chloride enriched samples (up to 4000 mg $l^{-1}$) were also conducted. Within this range no inhibition effects were observed.

### Denitrification rates

The results of the denitrification experiments are shown in Table 2. The experiments were conducted using the reference sludge and by measuring the comparative denitrification rates using acetate (blank) and wastewater as carbon sources. Figures 6 and 7 show two indicative experiments with the influent to and the effluent (after pre-precipitation) from the treatment plant respectively. Figure 8 showing a similar experiment with industrial wastewater indicates that despite the toxicity of the wastewater the denitrification rate is not reduced. In fact it can be seen that the organic carbon of the industrial wastewater is in a form which favours denitrification (comparable rates to the rate obtained with acetate), while the organic carbon of the influent or effluent is inferior to acetate (denitrification rates 25-30 % lower).

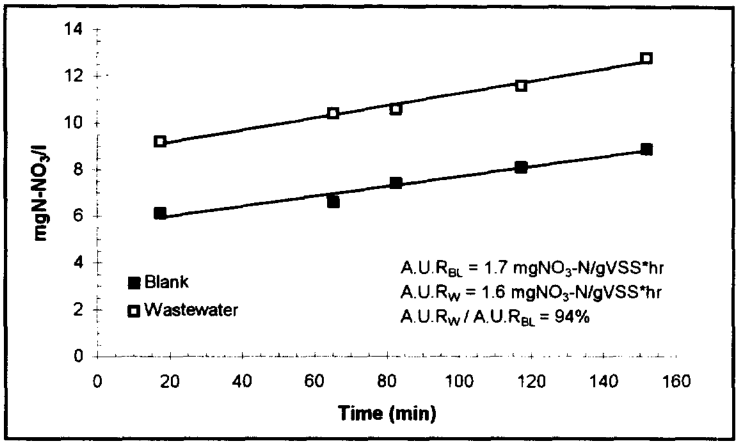


Fig. 2. Example of AUR test with domestic wastewater.

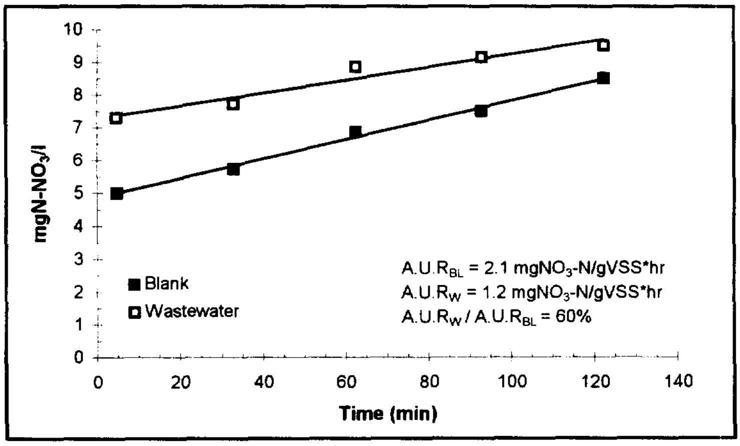


Fig. 3. Example of AUR test with typical domestic and industrial mixture.

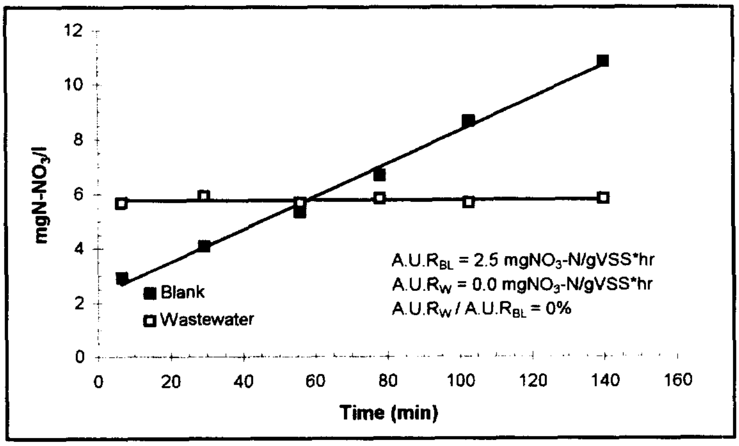


Fig. 4. Example of AUR test with industrial wastewater.

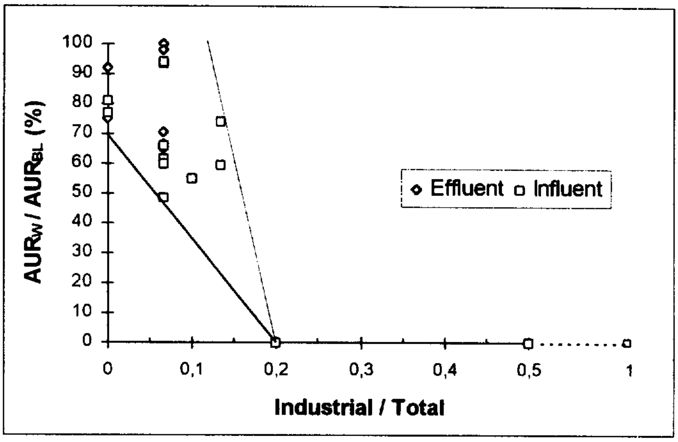


Fig. 5. Influence of industrial wastewater contribution to inhibition of nitrification

The experiments with the wastewater indicate two different denitrification rates. The higher rate corresponds to the utilization of the soluble COD. After exhaustion of the degradable soluble COD the denitrification rate proceeds at a much lower rate corresponding to the slowly degradable particulate COD and/or endogenous carbon sources. The high denitrification rate is approximately 3 mg $NO_3$-N g $MLVSS^{-1}$ $hr^{-1}$ and the low rate about 1 mg $NO_3$-N g $MLVSS^{-1}$ $hr^{-1}$ (Table 2).

The average carbon to nitrates uptake rates ratio (CUR/NUR) for the wastewater was found to be between 6.5 and 8.8. Assuming a ratio of 7.5 and an easily degradable COD concentration from the existing plant of approximately 60 mg $l^{-1}$, the results indicate that the amount of $NO_3$-N expected to be denitrified at a high rate is about 260 kg $d^{-1}$ ( 8 mg $l^{-1}$).

TABLE 2. DENITRIFICATION EXPERIMENTS

| | **CODt** (mg/l) | **CODs** (mg/l) | **NUR ($mgNO_3$-N /gVSS*hr)** Blank | 1st Rate | 2nd Rate | **CUR/NUR ($mgCOD/mgNO_3$-N)** Blank | Wastewater |
|---|---|---|---|---|---|---|---|
| | | | **Influent to the existing plant** | | | | |
| | 233 | 119 | 1.9 | 1.0 | | | |
| | 620 | 183 | 2.5 | 2.2 | | 12.9 | 12.7 |
| | 298 | 90 | 2.7 | 3.5 | 1.4 | 14.0 | 7.7 |
| | 550 | 208 | 4.6 | 3.0 | 1.1 | 10.8 | 10.9 |
| | 313 | 60 | 5.3 | 3.6 | 0.8 | 8.9 | 5.5 |
| | 308 | 135 | 3.2 | 2.5 | 1.2 | 11.1 | 7.4 |
| **Average** | **387** | **133** | **3.4** | **2.6** | **1.1** | **11.5** | **8.8** |
| | | | **Effluent from the existing plant** | | | | |
| | 300 | 157 | 4.7 | 4.6 | 1.1 | 16.9 | 12.6 |
| | 208 | 78 | 3.5 | 3.7 | 2.0 | 12.1 | 7.5 |
| | 233 | 192 | 4.6 | 3.2 | 1.0 | 10.8 | 6.5 |
| | 212 | 66 | 5.3 | 4.3 | 1.7 | 8.9 | 3.2 |
| | 122 | 54 | 5.0 | 3.0 | 1.0 | 9.5 | 3.2 |
| | 103 | 90 | 3.8 | 2.6 | 1.1 | 9.9 | 6.9 |
| | 201 | 44 | 3.2 | 2.2 | | 11.1 | 6.7 |
| | 140 | 72 | 2.9 | 2.2 | | 10.5 | 5.4 |
| **Average** | **190** | **94** | **4.1** | **3.2** | **1.3** | **11.2** | **6.5** |

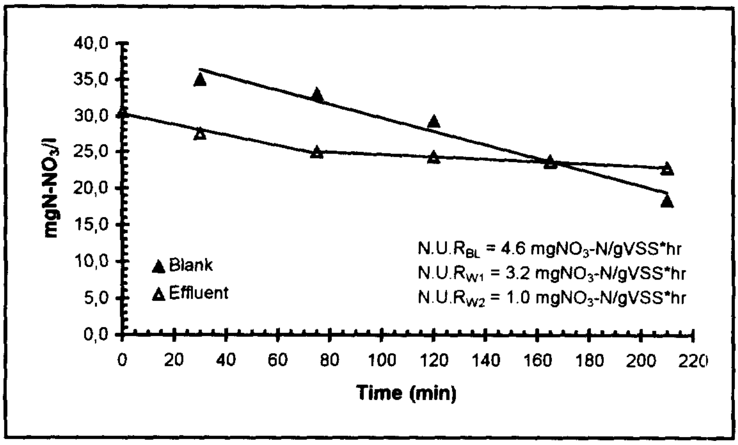


Fig. 6. Example of NUR test with effluent of the existing plant.

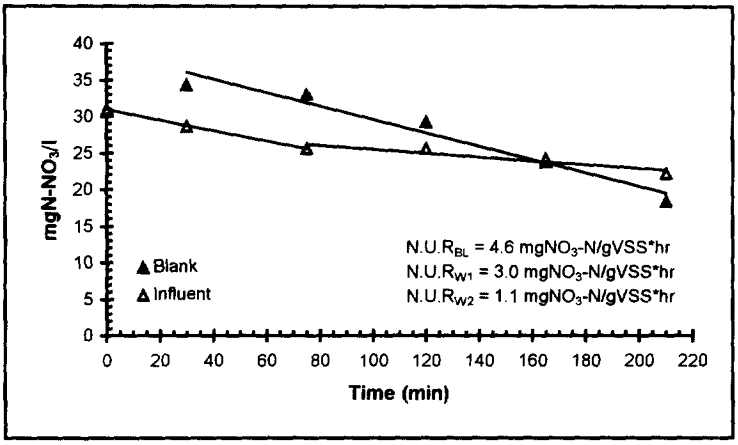


Fig. 7. Example of NUR test with influent of the existing plant.

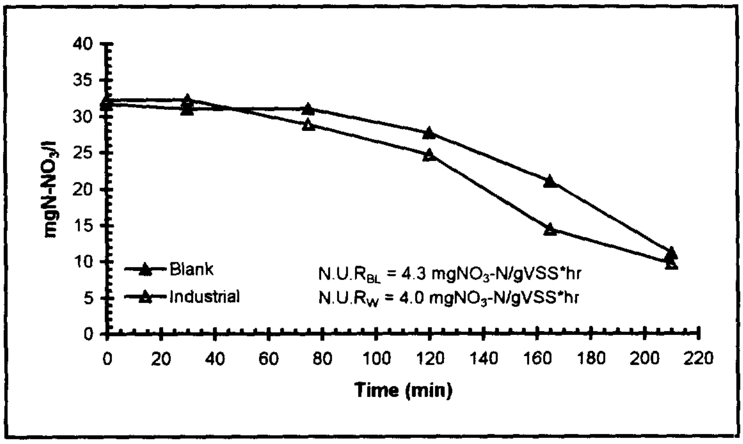


Fig.8. Example of NUR test with industrial wastewater.

## IMPLICATIONS TO THE DESIGN

The observed 50% inhibition of the nitrification indicates that a safety factor of two should be adopted for full nitrification, For a temperature of 13°C the required SRT is 16 days and the oxic volume 11000 $m^3$. However, this is a rather conservative approach in view of the effluent requirements (Council of the European Communities, 1991) as it implies full and stable nitrification even under the extreme conditions of 13°C. A more relaxed approach ensuring compliance with the statistical nature of the EU Directive could lead to the adoption of a volume of approximately 8500 $m^3$ (18 % increased in comparison to the volume of 7200 $m^3$).

From the experimental results it was shown that 260 kg $d^{-1}$ of nitrogen can be removed at the high rate of 3 mg $NO_3$-N g $MLVSS^{-1}$ $hr^{-1}$ in approximately 3 hours. The remaining 480 kg $d^{-1}$ will be denitrified at the low rate of 1 mg $NO_3$-N g $MLVSS^{-1}$ $hr^{-1}$and the required anoxic volume is approximately 7400 $m^3$ (22% increased in comparison to the volume of 6050 $m^3$).

## CONCLUSIONS

The results can be summarised as follows:

- Salinity did not inhibit the nitrification process. Typical chloride concentrations were in the range 1000-2000 mg $l^{-1}$. Tests with concentrations as high as 4000 mg $l^{-1}$ did not show a measurable inhibition of the nitrification process.

- The industrial wastewaters had a marked effect on the nitrification process. Under the existing conditions, with the industrial flows representing on average 7% of the total flow, a 50% inhibition was observed as opposed to a 30% inhibition found with the municipal wastewater alone. It was found that this 30% inhibition is in good agreement with values measured for other typical municipal wastewaters in Greece, and it was estimated that it can be accommodated by typically employed design criteria. However, in the case of Volos a more conservative approach should be adopted. It was also interesting to notice that an increased industrial flow contribution had a drastic effect on nitrification, with complete inhibition at contributions of 20% or higher.

- With respect to denitrification it was found that the industrial wastewaters were able to provide the carbon necessary for denitrification, without inhibition of the denitrification process.

- The pretreatment performed by means of chemically assisted sedimentation removed approximately 30% of the filtered COD. The remaining easily degradable soluble COD was sufficient for the rapid removal of only 25% of the nitrogen to be denitrified. The remaining 75% could be removed at a low (comparable to the endogenous) denitrification rate.

Adoption of the typically used design criteria led to an underdesign of the biological stage by about 20% when compared to the design based on the results of the study.

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