FACULTÉ DES SCIENCES ET DE GÉNIE

Département de génie civil

modelEAU Internship report

Design of single-sludge activate systems to remove organic matter, nitrogen and phosphorus

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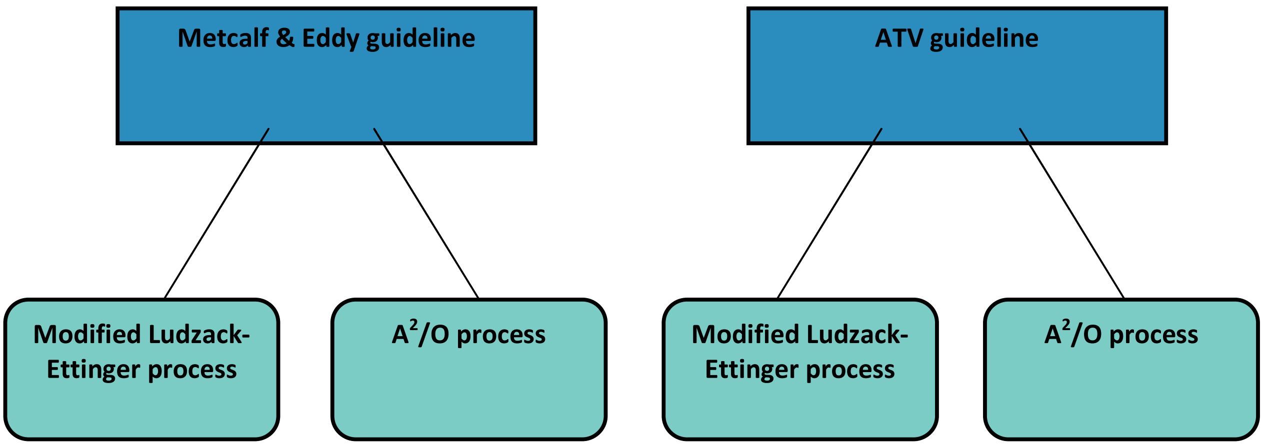
1 INTRODUCTION

The project is under supervision of Lluís Corominas for the group modelEAU. The Excel programs were initialized by Estelle Lagacé in spring 2009 and the design processes programs were developed by Marie-Eve Boucher in summer 2009.

The objective of this report is to have access to information that completes an Excel program that computes a design for a wastewater treatment plant (WWTP) for nitrogen, BOD and phosphorus removal. The computing executes by Excel is based on the approach suggests in Wastewater Engineering: treatment and reuse by Metcalf and Eddy and with the approach of the German ATV-DVWK: rules and standards. Two different design processes are suggested: Modified Ludzack-Ettinger with a combination of chemical precipitation for phosphorus removal (M.L.E) and A^2/O. For each one, an Excel program was named: Process_MLE (Metcalf and ATV) and Process_A2O (Metcalf and ATV).

The first section identifies and briefly describes the two guidelines: Metcalf & Eddy and ATV. It also extensively presented the standards and requirements used in the design. The second section contains a description of the two processes studied: A^2/O and Modified Ludzack-Ettinger. Finally the third section illustrates the results and the different levels of phosphorus removal for the two guidelines and two processes.



Two guidelines have been used for designing the Neptune plant: Metcalf and Eddy and ATV. For each of these guidelines, an Excel sheet is ready to get the appropriate design that takes into account the specific equations for those references. A global comparison of the guidelines and the technical details of the equations used in the program will be presented. Next, the standards common to the two guidelines will be briefly describe. Finally, the requirements for the discharge of urban wastewater treatment plant will be identified.

1.1 ATV

For the dimensioning of the wastewater treatment plant, ATV considers that the biological reactor is the combination of an anoxic zone for denitrification and an aerobic zone for nitrification or just an aerobic zone. The anaerobic mixing tank for phosphorus removal is not considered to be a part of the total biological reactor.

The first step for ATV is the dimensioning of the biological reactor. Different equations can be use for every process: plants with organic matter removal but without nitrification, plants with organic matter removal with nitrification and plants with organic matter removal with nitrification and denitrification. For designing the Neptune plant, the design with nitrification and denitrification was selected. The critical parameters are the dimensioning sludge age and the ratio of the volume of the biological reactor used for denitrification and the volume of the biological reactor used for nitrification. This ratio (Vn/Vat) of the volumes of the biological reactors is determined with the amount of nitrate to be denitrified per amount of influent BOD. Ratio of volumes can vary from 20% to 50%.

To calculate the total volume of the biological reactors, ATV requires the mass of suspended solids in the biological reactor which can be calculate using the BOD5 loading rate and the sludge loading rate. To get those rates, a phosphorus balance and the determination of sludge production must be done.

The second step is the dimensioning of the secondary settling tank. The main parameters are the sludge volume index with the thickening time of the sludge in the secondary settling tank, which determine the suspended solids concentration in the return sludge and the return sludge ratio. The overflow rate, the sludge volume index and the dimensioning peak flow determine the required surface area of the secondary settling tank. Finally, ATV considers, for the depth of the secondary settler, individual partial depths for functional zones. The security factor used in the design is 1.45. ATV suggests using a safety factor of 1.45 for a population of 100 000 p.e. due to the more pronounced influent BOD loading.

To conclude, ATV guideline is based on a small number of equations. Those equations are for most, using mass balance or different constants that came from experiments or applications. This method could involve too much risk considerations and generate oversize tank(s).

1.2 Metcalf and Eddy

Metcalf and Eddy dimensioning of a wastewater treatment plant is based on simplified activated sludge model that considers the kinetics and stoichiometry processes. Many equations consider reaction parameters (nitrification and heterotrophic bacteria kinetics) and some are using operational parameters (overflow rate, chemical product specifications, etc.).

The first step suggests by Metcalf and Eddy is the design of the aerobic reactor, which is based on the solids retention time required for nitrification.

The second step is to determine how much nitrate is produced in the aerobic zone using a balance on nitrogen. Also, it has to calculate the internal recycle ratio to assure that the system meet the effluent nitrate requirement.

In Wastewater, the authors use the specific denitrification rate to design the anoxic tank, which is the nitrate reduction rate in the anoxic tank normalized to the MLSS concentration[1]. In the case studied, the SDNR used was the specific denitrification rate based on biomass concentration at 20°C versus food to biomass ratio for the percentage of readily biodegradable COD relative to the biodegradable COD in the influent wastewater. The value of SDNR obtained is also corrected for the temperature and internal recycle ratio.

The curves of the figure 8-23 in Metcalf and Eddy were put in a data base, and specific constants were given for each curve:

$$SDNR_b = y_0 + a * \left(\frac{F}{M_b}\right)^b$$

Then, to compare the amount of nitrate that can be reduced and the amount of nitrate that is fed to the anoxic tank, an excess capacity ratio must be calculates. The ratio is the capacity of the anoxic tank to reduce the nitrate divided by the amount of nitrate fed in the anoxic zone. The excess nitrate-removal capacity should be around 0% (ratio of 1.00). To get an acceptable ratio, the detention time in the anoxic zone should be change (lower or higher).

- If the excess capacity ratio is under 1.00, increase the detention time in the anoxic tank.
- If the excess capacity ratio is above 1.00, decrease the detention time in the anoxic tank.

The next step suggests by Metcalf and Eddy is to compute the settler dimensions. First, define the return sludge recycle ratio. Then, to determine the area and the volume of the secondary settler, the approach use is to base the design on two parameters: the surface overflow rate and the solids loading rate. A typical value is use for the overflow rate to get the design of the secondary settler, and the result is confirmed with the computation of the solids loading rate within acceptable range.

Finally, the phosphorus removal can be done by chemical precipitation or with a biological reactor. Metcalf and Eddy give a methodology to evaluate the performance of an anaerobic tank (biological phosphorus removal – BPR). A simple rule is used to design the anaerobic reactor.

Metcalf and Eddy suggest a complete computation approach for the dimensioning of a wastewater treatment plant with BOD, nitrogen and phosphorus removal. Results of the guidelines will be compared in the section III.

2 PROCESSES

One of the main goals of dimensioning the Neptune benchmark plant is to compare nitrogen and phosphorus removal using two types of process configurations: a) predenitrification plant with chemical phosphorus precipitation and b) biological nitrogen and phosphorus removal. The processes are: a) Modified Ludzack-Ettinger (MLE) process is combined with a chemical

[1] Metcalf and Eddy, page 754

precipitation and b) A^2/O process has the same configuration than the MLE adding an anaerobic tank for biological phosphorus removal.

2.1 Modified Ludzack-Ettinger

The Modified Ludzack-Ettinger configuration is composed of an anoxic and aerobic tanks and a secondary settler. The influent wastewater is first fed to the anoxic tank for denitrification and next to the aerobic zone for nitrification. An internal recycle flow from the aerobic tank to the head of the anoxic tank provides an extra nitrate for denitrification. After these two processes (anoxic and aerobic), the wastewater goes to the secondary settler for a clarification. A part of the sludge, the return activated-sludge, goes back at the head of the anoxic zone to help increase the amount of nitrate available for denitrification.

The chemical addition is done at the head of the anoxic head. It provides the precipitation of phosphorus with iron. The program allows two product options: ferric chloride and alum. The results present in this study have been obtained using ferric chloride. The use of chemical precipitates adds an extra sludge and extra cost.

2.2 A^2/O

The configuration of A^2/O is a modification of the Modified Ludzack-Ettinger. The process is composed of an anaerobic zone followed by the same configuration of MLE. The return activated-sludge goes at the head of the anaerobic tank. The use of the anoxic tank helps decrease the amount of nitrate in the anaerobic tank that returns from the activated-sludge.

In the last section of this report, the performance of this process using an anaerobic tank for biological phosphorus removal will be evaluated.

3 CASE STUDIES

3.1 Effluent requirements

Values entered as effluent requirements were selected using the CEE European directive. These values respect the requirements for the discharges from urban waste water treatment plant of the CEE European directive (Council of the European Communities). These parameters are applied for a local situation of 100 000 p.e. (person equivalent).

Effluent requirements			
Parameters	**Chosen -- Values**	**CEE -- Values[2]**	**Units**
Given characteristics			
Effluent total 5-d biochemical organic demand	25	25	g/m^3
Effluent total suspended solids	35	35	g/m^3
Effluent nitrate expressed in nitrogen	6		g/m^3
Effluent ammonia expressed in nitrogen	1		g/m^3
Total nitrogen concentration in the effluent	7	10	g/m^3
Effluent phosphorus	1	1	g/m^3

Table 1: Effluent requirements

3.2 Methodology

This point presents the methodology used from the guidelines. The standards used in the computation for both guidelines are presented.

3.2.1 Metcalf and Eddy standards

- Reaction parameters

The kinetics coefficients are specific to removal of carbonaceous material and to nitrification with activated sludge. The theoretical parameters for the chemical precipitation for phosphorus removal, for the aeration tank, for the alkalinity and for the settler were taken from Metcalf and Eddy or from Material Safety data[3].

- Reaction parameters (values of the table 8.10 and 8.11 of Metcalf and Eddy)
  - Nitrification kinetics
  - Heterotrophic bacteria kinetics
- Theoretical parameters
  - General (mixing energy, ratios to convert hours in day(s), grams in kilograms, decimal in percentage, etc.)
  - Chemical precipitation for phosphorus removal (chemical product specifications)
  - Aeration tank (theoretical ratios)
  - Alkalinity (alkalinity required for the nitrification, equivalent weights, residual alkalinity)
  - Settler (overflow rate based on Metcalf and Eddy table 8.7)

- Dissolved oxygen

[2] Council directive (91/271/EEC)
[3] Material Safety data, http://www.msds.com

The dissolved oxygen concentration value used is 1.5 g/m^3. Metcalf and Eddy suggest a value greater than or equal to 2 g/m^3. However, most of the modelling software uses a dissolved oxygen value around 1.1 to 1.7 g/m^3.

The dissolved oxygen value is directly used to calculate nitrification kinetic. The amount of nitrogen oxidized to nitrate in the aerobic tank is directly dependent on the DO value. If you increase the DO value, you will decrease the amount of nitrogen that can be oxidized to nitrate (NOx) and directly the volume of the aerobic tank will decrease.

The amount of nitrogen oxidized to nitrate is dependent on the dissolved oxygen as said before and on the ammonia concentration in the effluent. NOx is obtained by calculating a nitrogen mass balance for the system. An estimation of the amount of nitrogen oxidized to nitrate (NOx) can be assumed that NOx is 80% of TKN. This ratio is proposes by Metcalf and Eddy (p.714).

- Surface overflow rate

The design of the secondary settler is normally based on the surface overflow rate parameter. The selection of this value is influenced by the type of wastewater treatment and the effluent requirements. The surface overflow rate given by Metcalf and Eddy for a settling for phosphorus removal and a phosphorus effluent concentration around of 1.00 g/m^3 ranges from 16.00 to 24.00 $m^3/m^2 \cdot d$. The chosen value is 22.00 $m^3/m^2 \cdot d$.

3.2.2 ATV and Metcalf and Eddy standards

- MLSS concentration

The MLSS concentration is the suspended solids concentration in the aerobic reactor. The value must be high enough to ensure sufficient enrichment of the biomass. Remember that the MLSS concentration have influence on two major parameters: the aerobic reactor and the secondary settler. If you increase the MLSS concentration: the volume of the aerobic reactor reduces and the surface of the of the secondary settler increases. The selection of a design MLSS concentration has influence in the determination of the volume of the aerobic tank and the hydraulic residence time in the aerobic tank. Metcalf and Eddy suggest a value between 1200 to 4000 g/m^3. For both ATV and Metcalf and Eddy designs, the chosen value is 3500 g/m^3.

- Return sludge concentration

The return sludge concentration from the secondary settler helps keeping a sufficient concentration of activated sludge in the reactor. Typical values range from 4000 to 12 000 g/m^3. For both ATV and Metcalf and Eddy designs, the selected value is 8000 g/m^3.

4 RESULTS

This section will cover the design results obtained from the two guidelines proposed, the ATV and Metcalf and Eddy. One of the objectives of the project was to define the Neptune benchmark plant. The equations of the two guidelines were conducted in Excel. The summary of the results will be followed by the presentation of the removal efficiency between the two processes which are Modified Ludzack-Ettinger and A^2/O.

4.1 Design with Metcalf and Eddy

Different values for dissolved oxygen concentration and the requirements effluent nitrate concentration and effluent ammonia concentration, and effluent ammonia concentration were tested in the excel application. Different design volumes were obtained for the aerobic and the anoxic reactors. Figure 1 presents the results of these designs.

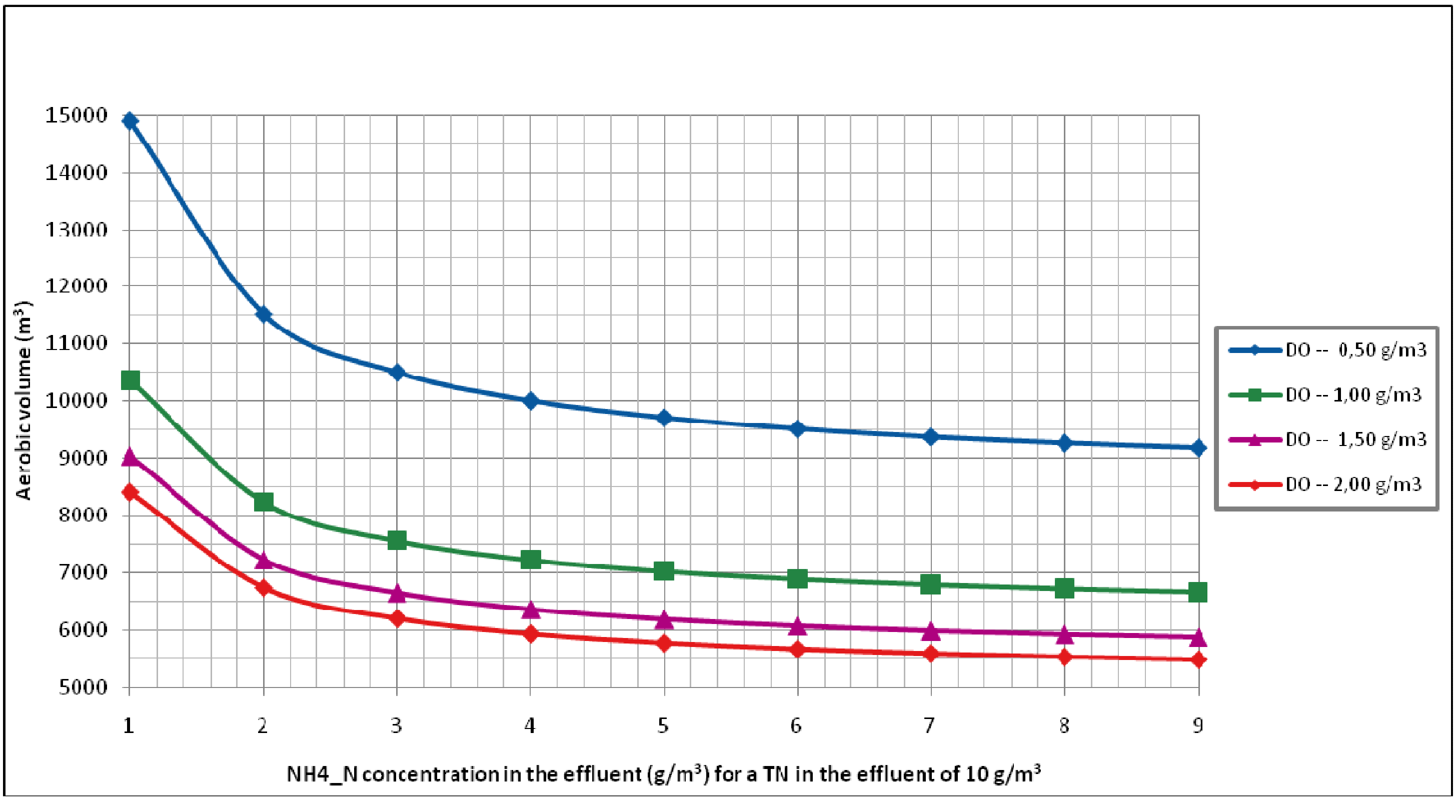


Figure 1: Plot of the aerobic volume versus the ammonia concentration in the effluent for various concentration of dissolved oxygen

The figure 2 shows the influence of dissolved oxygen concentration on the anoxic volume. The anoxic volume depends on the amount of dissolved oxygen in the aerobic tank, because this parameter has a direct influence on the solids retention time (SRT) and the concentration of active biomass in the internal recycle flow is inversely proportional to the SRT. If you increase the DO, the SRT will decrease and the concentration of active biomass will increase. The dissolved oxygen is consequently a critical parameter because if its concentration is increased, the capacity of nitrate that can be reduced decrease. Its presence suppresses the enzyme system needed for denitrification[4].

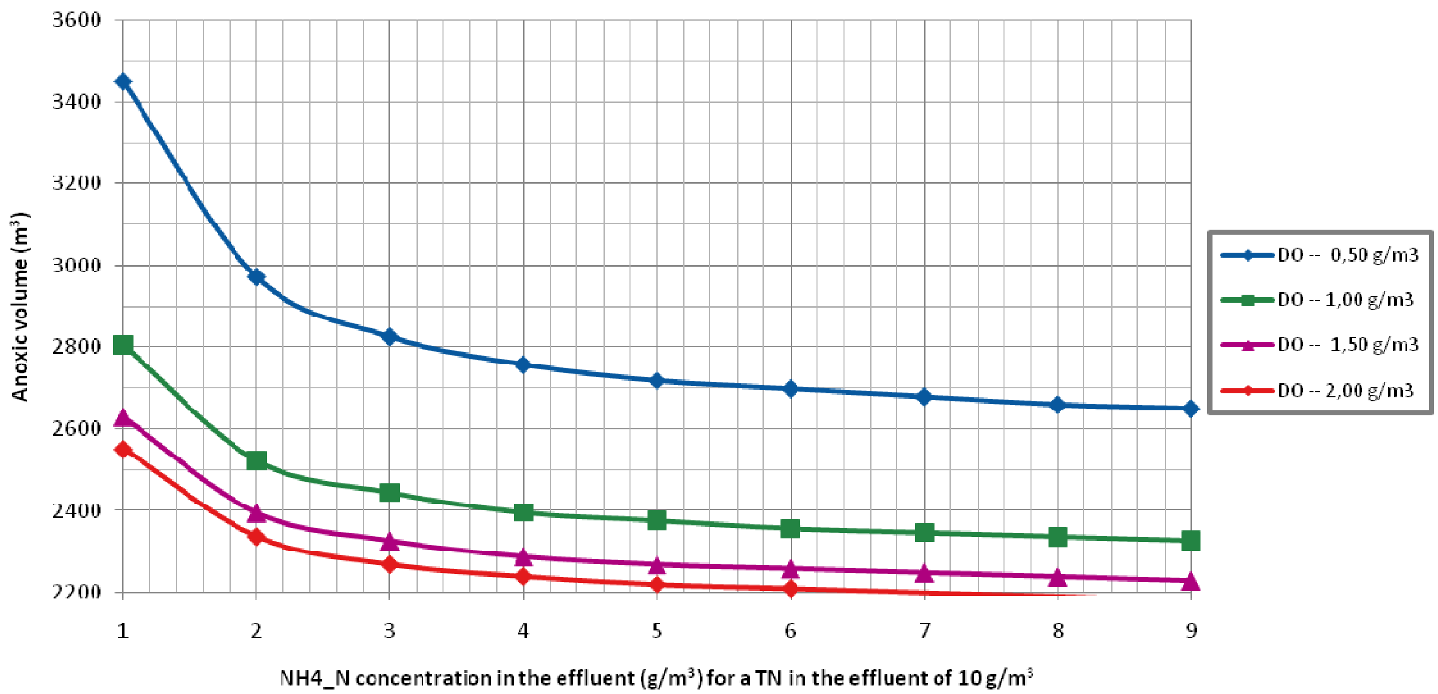


Figure 2: Plot of the anoxic volume versus the ammonia concentration in the effluent for various concentrations of dissolved oxygen

Figure 3 presents a summary of the two first plots. Considering the information written before, we decided to keep for the final design a dissolved oxygen concentration of 1.5 g/m^3 and requirements concentrations for the nitrate of 6 g/m^3 and the ammonia of 1 g/m^3. These concentrations allow having acceptable values for the anoxic and aerobic volumes. To confirm our final choice, the next graph (figure 4) shows the volume variation of the reactors by changing the nitrate concentration and by keeping the dissolved oxygen concentration at 1.5 g/m^3 and the ammonia concentration in the effluent at 1 g/m^3. And the figure 5 also shows the volume variation

[4] United Nations, Waste-water treatment technologies: a general review, Economic and social condition for Western Asia, New York 2003, page 20.

when changing the ammonia concentration and by keeping the dissolved oxygen concentration at 1.5 g/m^3 and the nitrate concentration in the effluent at 6 g/m^3.

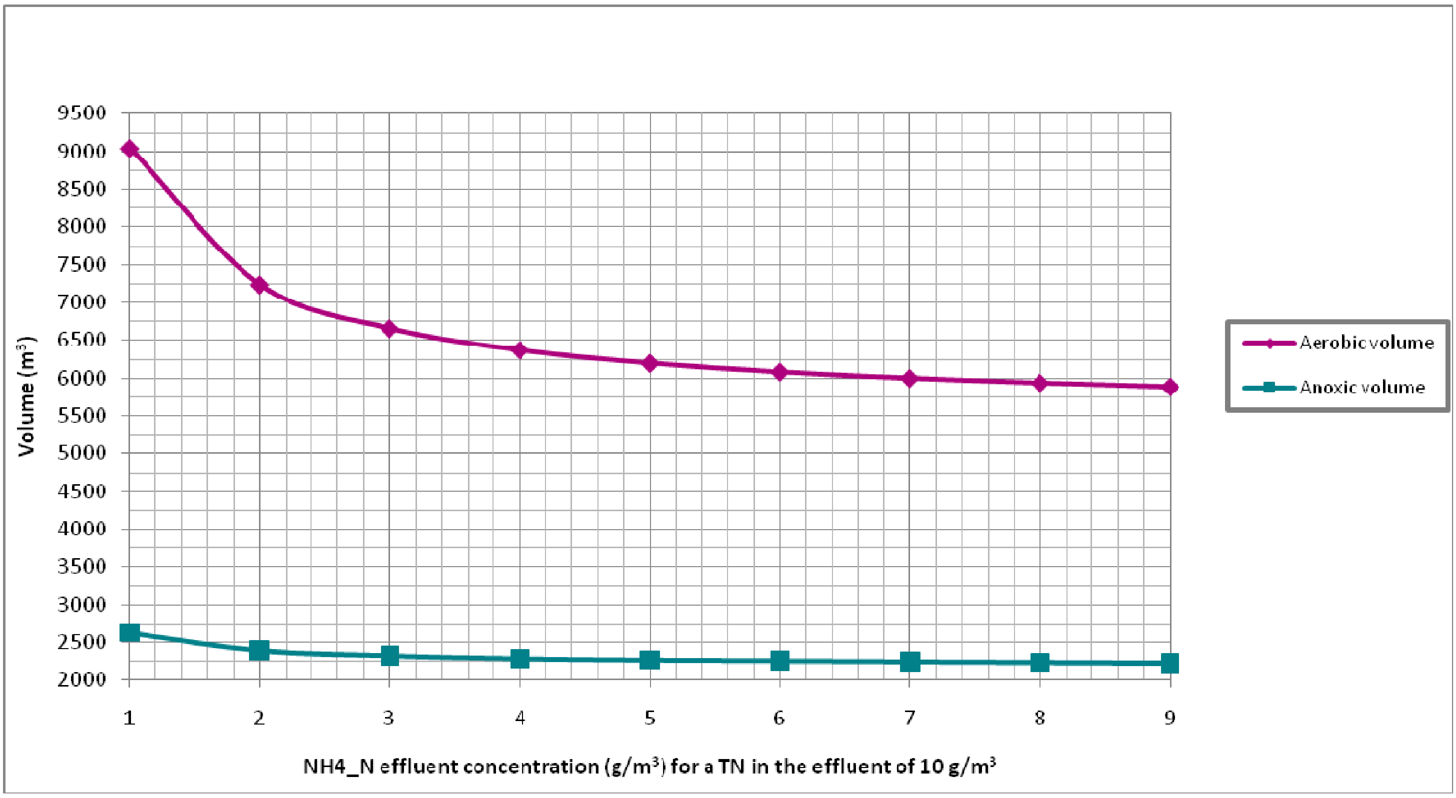


Figure 3: Plot of the aerobic and anoxic volumes versus the ammonia concentration in the effluent for a dissolved oxygen concentration of 1.5 g/m3

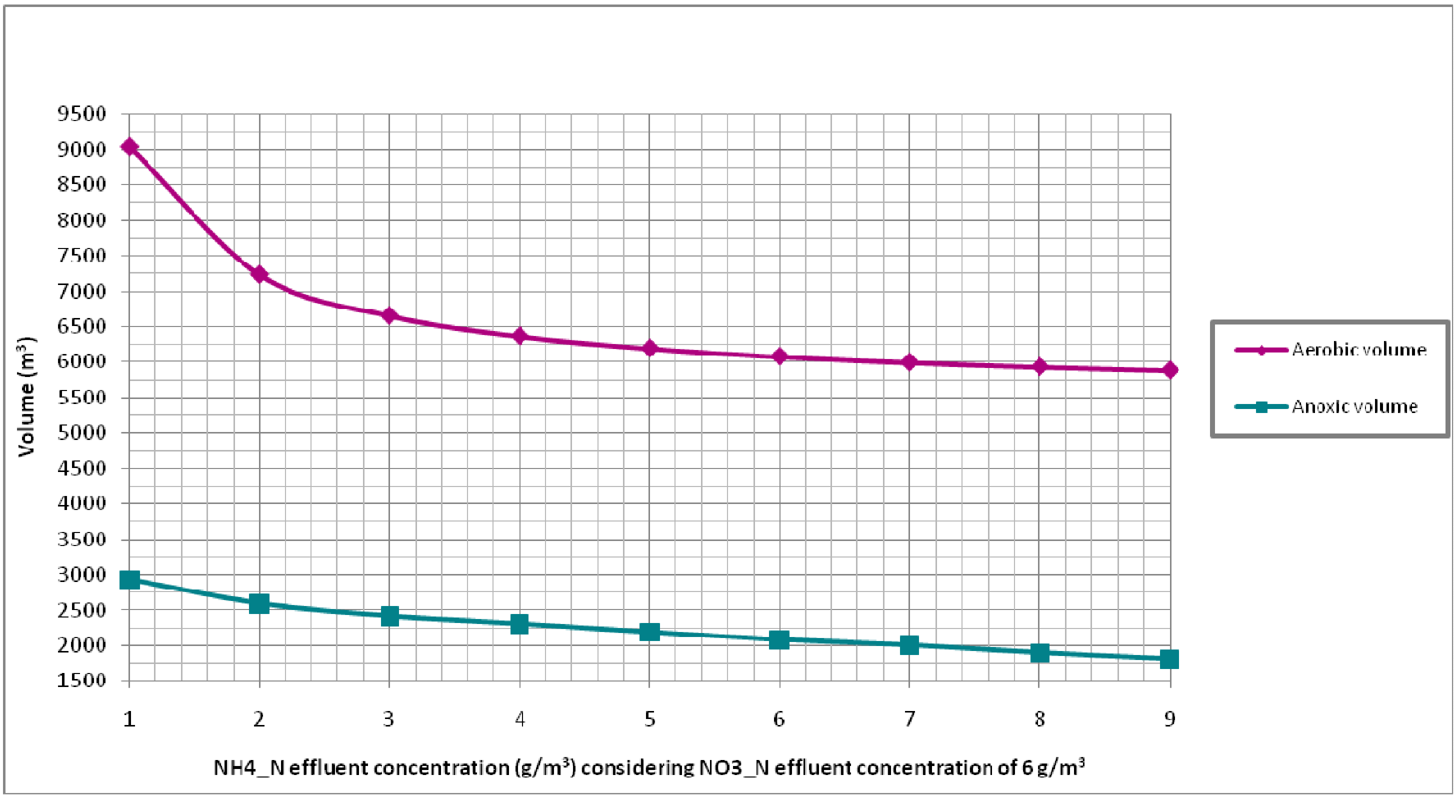


Figure 4: Plot of the aerobic and anoxic volumes versus the nitrate concentration in the effluent for a dissolved oxygen concentration of 1.5 g/m3 and an ammonia concentration of 1 g/m3

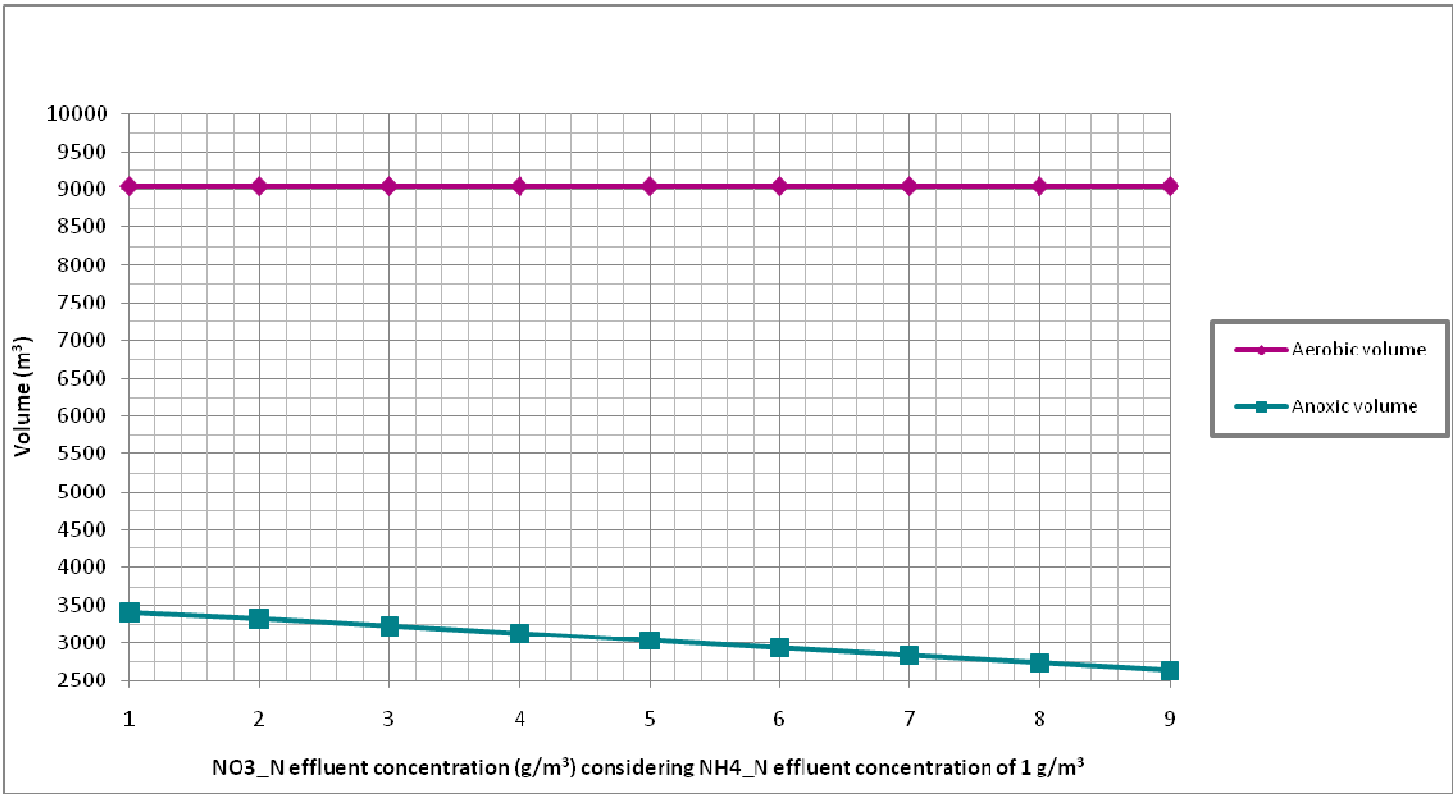


Figure 5: Plot of the aerobic and anoxic volumes versus the ammonia concentration in the effluent for a dissolved oxygen concentration of 1.5 g/m3 and a nitrate concentration of 6 g/m3

Finally, we have check that the values of the other main parameters respect the typical design parameters given by Metcalf and Eddy for each processes. If a value was not respecting the ranges, the Excel cell was coloured in red. There is only one cell coloured in red when using the guideline of Metcalf and Eddy and this is the internal recycle ratio. The limit is a ratio of 4.00 and the value we have is 4.37. We decided to keep the values as they were even if the internal recycle ratio is a little bit above the maximum range.

4.2 Design with ATV

The implementation of ATV equations in an Excel sheet was a way to compare the guideline of Metcalf and Eddy with another structure of equations. We decide to do the same exercise than we did with Metcalf and Eddy. Some differences between the guidelines must be exposed:

- ATV does not consider the dissolved oxygen concentration in the equations. It is indicate that the dissolved oxygen content must be kept at less than 2 g/m^3.
- ATV considers a ratio which is the volume of the reactor for denitrification (anoxic) divided by the total volume of the biological reactor (aerobic and anoxic volumes).
- ATV gives strange volume values when the ratio is 0.50. It gives the same volume values for the anoxic and aerobic reactors.
- To calculate this proportion of the volume of the biological reactor (total), ATV calculates the daily average nitrate concentration to be denitrified, which result of a nitrogen mass balance
- Finally, ATV is dimensioning the anoxic reactor by considering the amount of nitrate to be denitrified per amount of BOD in the influent.

So if we decide that the total nitrogen in the effluent is 10 g/m^3, even if we change the value of the nitrate of the ammonia, the volume of anoxic tank and the aerobic tanks will be the same. To understand the variation for the anoxic and aerobic volumes, we decided to play with two parameters: the influent BOD by adding BOD as readily suspended solids and the influent TN.

The figure 6 shows the variation of the volumes of the anoxic and aerobic tanks. The yellow curve is when the aerobic and anoxic reactors have the same volume (when the ratio is 0.50). So if we were adding BOD in the influent, around 20 g/m^3, we would have anaerobic and anoxic volumes with interesting values and a ratio of BOD/TKN around 4.00; value recommended by Metcalf and Eddy[5].

The same situation is observed on the figure 7. If we decrease the total nitrogen concentration in the influent, we obtained a recommend BOD/TKN ratio around 4.00 and acceptable values for the reactors volume.

[5] Metcalf and Eddy page ???

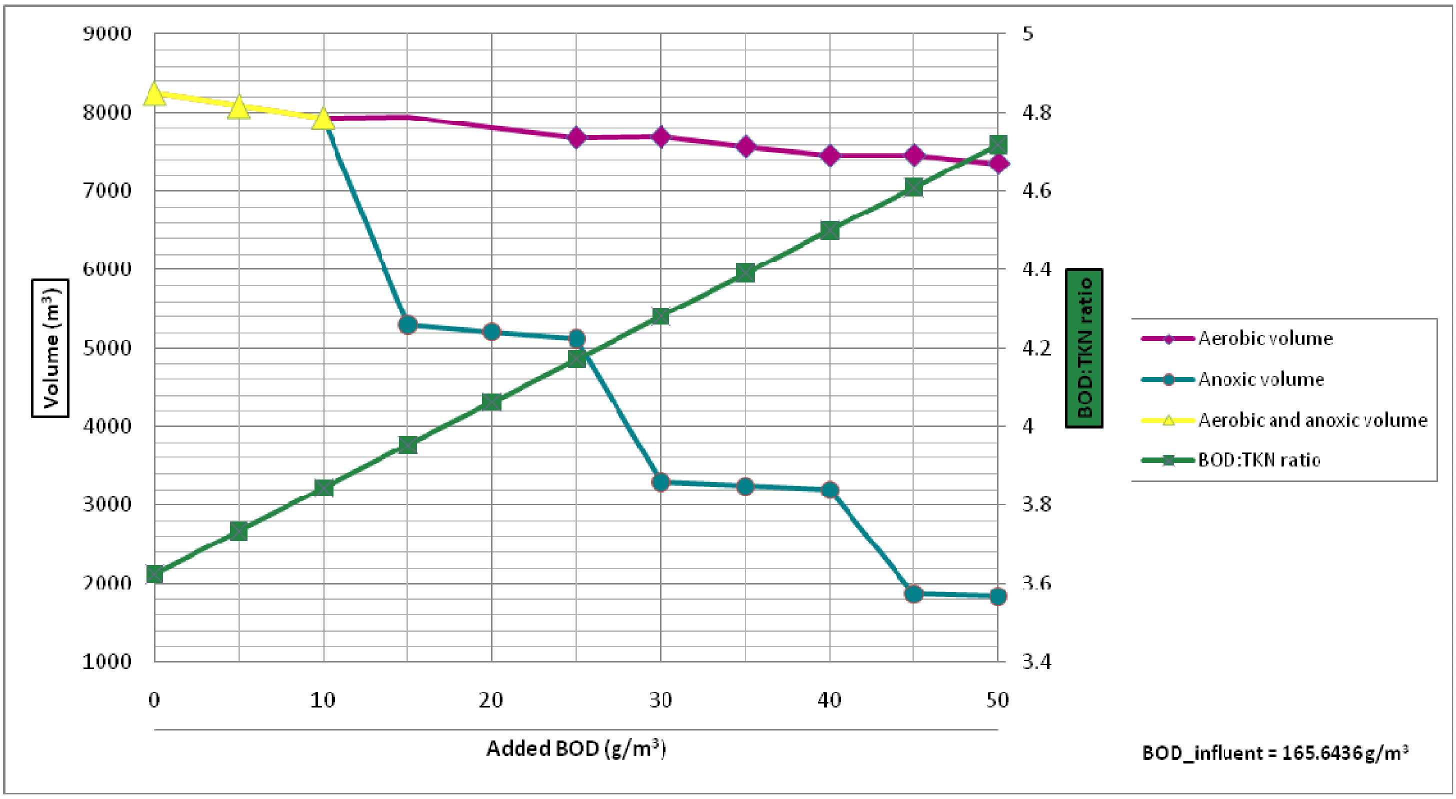


Figure 6: Plot of the aerobic and anoxic volumes versus the readily suspended solids concentration in addition to the BOD in the influent

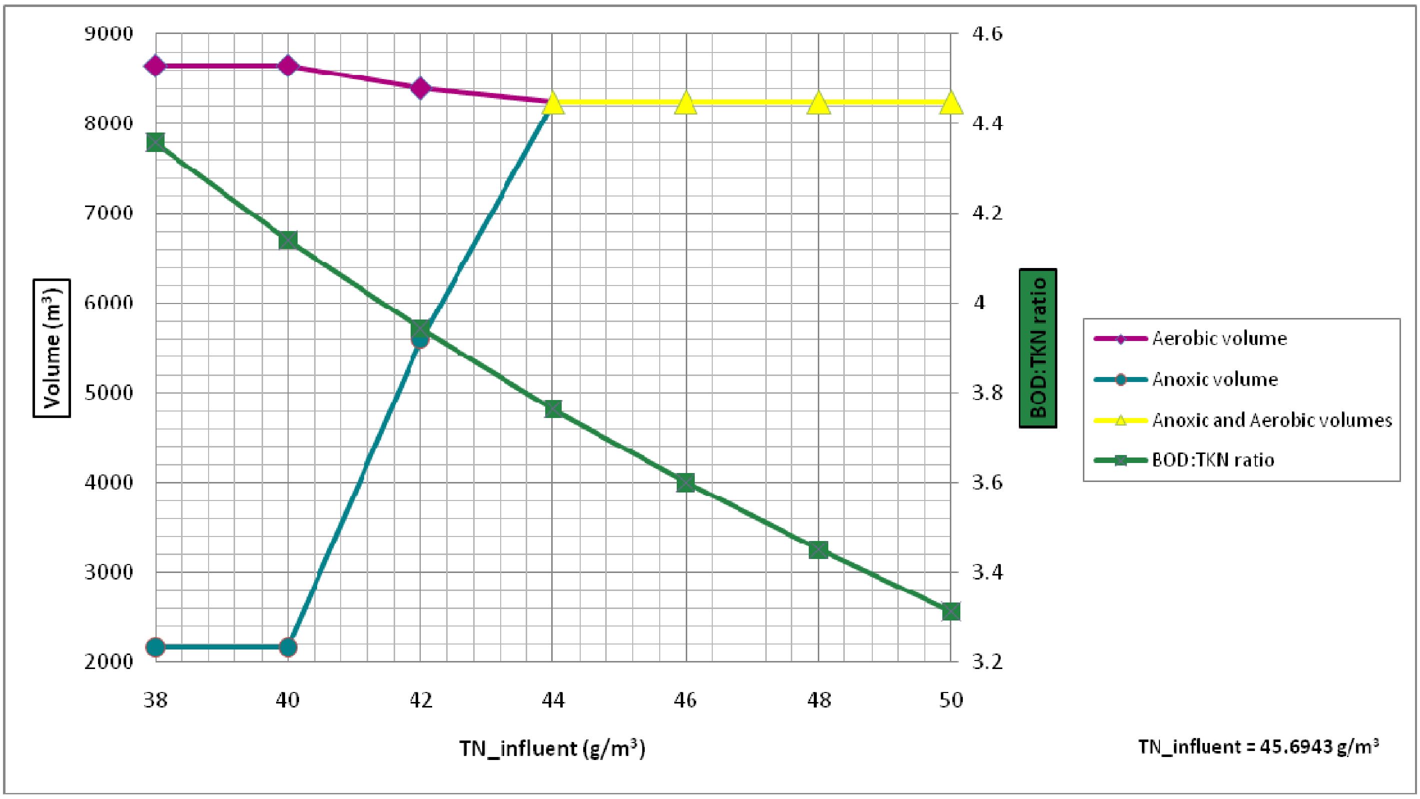


Figure 7: Plot of the aerobic and anoxic volumes versus the total nitrogen concentration in the influent

Except the volume of the anoxic reactor, which is really oversized, the other main parameters obtained when we use the ATV guideline respect the typical values given by Metcalf and Eddy for the two processes.

Finally, it is important to mention, that if we are adding BOD or decreasing TKN, it makes a big difference on the obtained volumes. The volumes are very sensitive to these parameters.

To conclude, the tables 2-3 present a summary of the results obtained from Metcalf and Eddy and from ATV guidelines. Cell coloured in red, as explain earlier, does not respect the typical value given by Metcalf and Eddy for A^2/O process.

Scenario A^2/O process with Metcalf and Eddy design		
Design parameters		
NH4_N concentration in the effluent	1.00	g/m^3
NO3_N concentration in the effluent	6.00	g/m^3
Dissolved oxygen	1.50	g/m^3
Total volume of the biological reactors	12222.84	m^3
Anaerobic reactor		
Anaerobic volume	977.64	m^3
Anaerobic detention time	1.00	h
Aerobic reactor		
Solids retention time	7.97	d
Total volume of the aerobic tank(s)	9045.50	m^3
Volume of the aerobic tank(s)	3015.17	m^3
Detention time in the aerobic reactor	9.25	h
Internal recycle ratio	4.37	-
Internal recycle flow	102479.29	m^3/d
BOD_5 volume loading rate	429.67	$kg\ BOD_5/(m^3 \cdot d)$
Anoxic reactor		
Total volume of the anoxic tank(s)	2199.70	m^3
Volume of the anoxic tank(s)	1099.85	m^3
Detention time in the anoxic reactor	2.25	h
Secondary settler		
External recycle ratio	0.74	-
External recycle flow	17366.84	m^3/d
SS concentration in RAS	8000.00	g/m^3
Waste sludge flowrate from the return sludge line (approx)	496.41	m^3/d
Diameter of the secondary settler	21.27545597	m
Depth of the secondary settler	3.5	m
Area of the secondary settler	355.5065727	m^2
Volume of the settler	1244.273005	m^3

Table 2: Summary of the A^2/O process using the Metcalf and Eddy approach

Scenario A^2/O process with ATV design		
Design parameters		
NH4_N concentration in the effluent	1.00	g/m^3
NO3_N concentration in the effluent	6.00	g/m^3
Dissolved oxygen	1.50	g/m^3
Addition of suspended solids to increase the BOD5	0.00	g/m^3
Total volume of the biological reactors	16494.01	m^3
Anaerobic reactor		
Anaerobic volume	1034.89	m^3
Anaerobic detention time	0.75	h
Aerobic reactor		
Solids retention time	10.33	d
Total volume of the aerobic tank(s)	8247.00	m^3
Volume of the aerobic tank(s)	2749.00	m^3
Detention time in the aerobic reactor	8.44	h
Internal recycle ratio	2.59	-
Internal recycle flow	60747.57	m^3/d
BOD_5 volume loading rate	485.02	g $BOD_5/(m^3 \cdot d)$
Anoxic reactor		
Total volume of the anoxic tank(s)	8247.00	m^3
Volume of the anoxic tank(s)	4123.50	m^3
Detention time in the anoxic reactor	8.44	h
Secondary settler		
External recycle ratio	0.78	-
External recycle flow	18249.34	m^3/d
SS concentration in RAS	8000.00	g/m^3
Waste sludge flowrate from return sludge line (approx)	349.27	m^3/d
Diameter of the secondary settler	42.98	m
Depth of the secondary settler	3.87	m
Area of the secondary settler	1450.91	m^2
Volume of the settler	5612.15	m^3

Table 3: Summary of the A2/O process using the ATV guideline

4.3 Phosphorus removal efficiency

This section presents a comparison of the two processes: Modified Ludzack-Ettinger and A^2/O with chemical addition. The two processes precipitated phosphorus. The first use a chemical precipitates addition (in this example, ferric chloride[6]) and the second use the presence of microorganisms to incorporated phosphorus into biological solids. The removal of phosphorus is in fact, the removal of the chemical precipitates or microorganisms that contains phosphorus after the process.

Metcalf and Eddy and ATV will be presented. The two guidelines are not using the same equation to calculate the level of phosphorus removal using an anaerobic tank. Consider that the effluent requirement for phosphorus concentration is 1 g/m^3.

4.3.1 Metcalf and Eddy

Metcalf and Eddy attribute a percentage of 1.5% of the biomass production for the amount of phosphorus used for heterotrophic biomass synthesis. This phosphorus utilized for biomass growth can be combining with the phosphorus removed by biological phosphorus removal mechanism. The biological phosphorus removal efficiency is mostly base on the amount of readily biodegradable COD. The rbCOD is the primary source of volatile fatty acids for phosphorus-storing bacteria. This conversion is done in the anaerobic zone.

But the total amount of rbCOD cannot be considered only for BPR. To obtain the rbCOD available for phosphorus removal, the amount of rbCOD used for nitrate consumption must be calculated. By considering that the influent does not contain nitrate and the only source of nitrate in the anaerobic tank is the return of activated-sludge, the nitrate concentration in the RAS must be calculated and the rbCOD/NO3_N ratio must be applied. It is now possible to determine the rbCOD available for phosphorus removal.

If the A^2/O process is used, the level of phosphorus that can be removed is 78.52% only with the anaerobic reactor. To reach the phosphorus requirement of 1 g/m^3, chemical addition must be used. The flow of product solution required per day is around 0.41 m^3/d.

A short summary is presented in the table 4.

[6] The specific information on ferric chloride are presented in Annex II

Scenario A^2/O process with Metcalf and Eddy design		
Anaerobic reactor		
Total phosphorus removed in the anaerobic reactor	8.54	g/m³
Phosphorus concentration from the effluent of the anaerobic reactor	2.34	g/m³
Level of phosphorus removal in the anaerobic reactor	78.52	%
Chemical precipitation for phosphorus removal with ferric chloride		
Amount of product solution required per day	0.41	m³/d
Precipitant required for precipitation with the product	602.49	kg/d
Phosphorus soluble in the effluent	1.00	g/m³
Total phosphorus removed	9.88	g/m³
Level of phosphorus removal	90.81	%

Table 4: Phosphorus removal for A2/O process using Metcalf and Eddy guideline

If the Modified Ludzack-Ettinger process is used with a chemical addition for phosphorus removal, to reach the phosphorus requirement of 1 g/m^3 the amount of product solution required per day is 3.03 m^3/d. This flow of ferric chloride solution considers the amount of phosphorus used for heterotrophic biomass synthesis.

A short summary is presented in the table 5.

Scenario MLE process with Metcalf and Eddy design		
Chemical precipitation for phosphorus removal with ferric chloride		
Amount of product solution required per day	3.03	m³/d
Precipitant required for precipitation with the product	4450.87	kg/d
Phosphorus soluble in the effluent	1.00	g/m³
Total phosphorus removed	9.88	g/m³
Level of phosphorus removal	90.81	%

Table 5: Phosphorus removal for MLE using Metcalf and Eddy guideline

4.3.2 ATV

To determine the amount of phosphorus to be precipitated, ATV uses a phosphorus balance. In this mass balance, ATV considers the total phosphorus concentration in the influent, the effluent requirement concentration, the amount of phosphorus necessary for the build-up heterotrophic biomass and the concentration of phosphorus removed with biological phosphorus removal process.

ATV attributes for the amount of phosphorus utilized for biomass growth a percentage of 1.00% of the BOD_5 in the influent. The value obtained for ATV is 1.66 g/m^3. So, for A^2/O configuration, I have considered the total equation. The level of phosphorus removal with the anaerobic tank is around 38.06%. This major difference between the two guidelines can be explained with the non-applied method of ATV. In fact, ATV considers that the biological phosphorus removal can be calculated with a constant (0.01 to 0.015) applied on the BOD in the influent. The amount of phosphorus that can be removed with the BPR mechanism is 2.48 g/m^3 for ATV instead of 7.64 g/m^3 for the Metcalf and Eddy guideline. To reach the phosphorus requirement of 1 g/m^3, chemical solution must be added. The flow of product solution required per day is around 2.60 m^3/d.

Scenario A^2/O process with ATV design		
Anaerobic reactor		
Total phosphorus removed in the anaerobic reactor	4.14	g/m^3
Phosphorus concentration from the effluent of the anaerobic reactor	6.74	g/m^3
Level of phosphorus removal in the anaerobic reactor	38.06	%
Chemical precipitation for phosphorus removal with ferric chloride		
Amount of product solution required per day	2.60	m^3/d
Precipitant (iron) required for precipitation with the product	3820.88	kg/d
Phosphorus soluble in the effluent	1.00	g/m^3
Total phosphorus removed	9.88	g/m^3
Level of phosphorus removal	90.81	%

Table 6: Phosphorus removal for A2/O process using ATV guideline

If the Modified Ludzack-Ettinger configuration is used. The chemical addition should be around 8.18 m^3/d to reach the effluent requirement for phosphorus removal.

Scenario MLE process with ATV design		
Chemical precipitation for phosphorus removal with ferric chloride		
Amount of product solution required per day	8.18	m^3/d
Precipitant required for precipitation with the product	12017.36	kg/d
Phosphorus soluble in the effluent	1.00	g/m^3
Total phosphorus removed	9.88	g/m^3
Level of phosphorus removal	90.81	%

Table 7: Phosphorus removal for MLE using ATV guideline

5 LITERATURE

- Commission directive of 27 February 1998. Council directive of 21 May 1991 concerning urban waste water treatment (91/271/EEC).

- German association for water, wastewater and waste. Standard ATV-DVWK-A 131E: Dimensioning of single-stage activated sludge plants, May 2000, 45 pages.

- Environmental Health & Safety, Material safety data sheet for Ferric Chloride, CAS No 10025-77-1 Hexahydrate.

- Metcalf and Eddy, Inc. Wastewater Engineering: Treatment, Disposal and Reuse, fourth edition (New York), McGraw-Hill, 1991, 1819 pages.

- United Nations. Waste-water treatment technologies: a general review, Economic and social condition for Western Asia, New York 2003, 122 pages.

6 APPENDIX I

Ferric chloride information

Chemical precipitation for phosphorus removal		
Product strength (Alum or Ferric chloride)	0.507	-
Density of the product (Alum or Ferric chloride)[7]	2.898	kg/L
Molecular weight of alum (Alum or Ferric chloride) [8]	270.30	g/mol
Chemical element molecular weight (Aluminium or Iron)[9]	55.85	g/mol
Number of atoms in the molecule (Aluminium or Iron)[10]	1.00	-
Phosphorus molecular weight[11]	30.97	g/mol
Theoretical dosage of aluminium per phosphate or of iron per phosphate[12]	1.00	mol/mol
Ratio to determine how mole(s) of the chemical element will be required per mole of P[13]	2.20	mol/mol

[7] Material safety data sheet, Ferric Chloride Hexahydrate
[8] Material safety data sheet, Ferric Chloride Hexahydrate
[9] Metcalf & Eddy, page 496
[10] Metcalf & Eddy, page 496
[11] Metcalf & Eddy, page 503
[12] Metcalf & Eddy, page 502
[13] Metcalf & Eddy, figure 6-14, page 506