U.P.B. Sci. Bull., Series B, Vol. 79, Iss. 4, 2017 ISSN 1454-2331

SIMULATION OF BARDENPHO WASTEWATER TREATMENT PROCESS FOR NITROGEN REMOVAL USING SUPERPRO DESIGNER SIMULATOR

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The simulation of remediation the increasing of ammonia or nitrite/nitrate concentration in municipal wastewater effluents on the base of Bardenpho process was done using the SuperPro Designer v8.5 simulator. The reducing of ammonia or nitrite/nitrate concentrations in effluent was realized by modifications of several operating process parameters: residence time of the anoxic reaction and/or the aerobic bio-oxidation zones, flowrates of diffused air for the aerobic bio-oxidation zones, the recirculation rate of effluent back into process. Direct control of these operating parameters does not raise any problems. By these means the ammonia or nitrite/nitrate concentrations in effluent were decreased below the maximum legal admitted concentration.

Keywords: wastewater treatment, Bardenpho process, computer simulation

1. Introduction

Municipal wastewater treatment (Fig.1) is the process of ejecting the harmful pollutants from wastewater. The main source of pollutants is the domestic use. The pollutants are treated by various methods like physical, chemical, and biological process [1].

Nitrogen content in treated effluents is important in wastewater treatment because of the effects that nitrogenous materials can have on the environment. The need for removal of nitrogenous materials in treated wastewater effluents typically focuses on ammonia nitrogen and nitrate. The reasons for needing to limit the amount of these forms of nitrogen in treated effluents vary with the water quality requirements in effect for the receiving stream. Reasons for removal of ammonia nitrogen from treated effluents can be summarized as follows [2]:

1. Ammonia exerts an oxygen demand on the receiving stream. Thus, if an excessive amount of ammonia is present in an effluent, the oxygen content in the receiving stream can be depleted below that required by water quality standards.

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2. Excessive amounts of ammonia can be toxic to biological life in the receiving stream.
3. Ammonia reacts with chlorine to form chloramines which can interfere with disinfection.

Fig. 1. A municipal wastewater treatment plant [1]

Of these three reasons, the first comprises the major need for removal of ammonia nitrogen in treated effluents.

The need for removal of nitrate nitrogen from treated effluents is largely confined to locations where nutrient content is critical for the receiving stream. Nitrate is a nutrient which serves as a fertilizer and the growth of aquatic plants can thrive in its presence. In certain bodies of water, it is necessary to limit the amounts of fertilizing nutrients such as nitrates and phosphates which may be discharged in treated effluents to prevent excessive growths of algae and aquatic plants. Through a process known as eutrophication, such excessive growths result in large masses of algae and nuisance plants that can cause serious harm or even destroy the aesthetic value of a body of water.

2. The Bardenpho Wastewater Treatment Process

The Bardenpho Process of Wastewater Treatment was developed by James Barnard of South Africa in the 1970’s [3]. The Bardenpho process is a single-sludge system comprised of four alternating anoxic and aerobic zones in series

(Fig. 2). The first and third zones are anoxic while the second and fourth zones are aerobic. Mixed liquor is recycled from the first aerobic zone to the first anoxic zone at a rate of four to six times the influent flow rate. Return activated sludge is also recycled from the clarifier back to the first anoxic zone. This process is designed to achieve more total nitrogen removal than is possible with two-sludge or three-sludge systems. Effluent concentrations of 2 to 4 mg/l of total nitrogen is possible with this system.

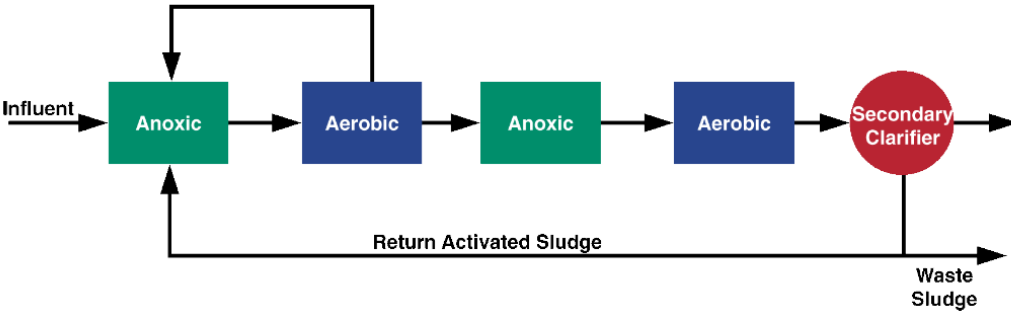

Fig. 2. The Bardenpho process [3]

Anaerobic sludge is obtained from the anaerobic treatment tank of the plant and mixed with food waste, grass, or wastepaper. This organic waste material is subjected to anaerobic fermentation for a period of 2 to 4 days at a temperature of 30 to 40 ºC. Anaerobic sludge is used to obtain broth for fermentation. The fermentation broth is then sent through alternating anaerobic-aerobic-anoxic cycles in batch reactors.

When under anaerobic conditions, phosphorous is secreted from the microbes that accumulate phosphorous. When the fermentation broth is then subjected to aerobic conditions, the phosphorous is taken up by the accumulating microbes. Nitrifying bacteria oxidize the ammonia nitrogen in this stage. When the final anoxic tank is filled with this broth, the oxidized nitrogen is converted to nitrogen gas by the bacteria.

Nitrogen in the original wastewater is mainly in the form of ammonia and this ammonia passes through the first two zones without any change. It is only in the third aerobic zone that the sludge has aged sufficiently for complete nitrification to take place and that the ammonia nitrogen gets converted to nitrates and nitrites. When this reaches the anoxic zone, because of the absence of dissolved oxygen, the nitrates are converted by the bacteria to nitrogen gas by using the organic carbon compounds as donors for hydrogen. This nitrogen escapes to the atmosphere. The effluent is then subjected to aeration in the final zone which raises the dissolved oxygen levels and prevents further denitrification.

Advantages of the Bardenpho Process[3]

As no chemicals are used, operating costs are lower and there is also no problem with disposing of the sludge. Bardenpho Process plants are simple to operate and do not require any retraining of personnel. The sludge that is obtained in the final stages does not require any further treatment and can be easily disposed of.

Disadvantages of the Bardenpho Process[3]

One of the main disadvantages of the Bardenpho process is the number of tanks required, which greatly increases capital cost. Another disadvantage is the detention times that need to be very strictly monitored and evaluated.

3. Bardenpho Wastewater Treatment Process Simulation using SuperPro Designer

An existing wastewater treatment plant (Fig. 3) is designed to handle an average flow of 46,000 m^3/day. The equipments and dimensions are [4]:

- Aeration Basin - 4 tanks each having a volume of 2,500 m^3 with a depth of 2 m; the four tanks form two pairs operating in sequence (AB-101 and AB-102).
- Secondary Clarifier (CL-101) - 4 tanks each having a surface area of 490 m^2 with a depth of 4 m.
- Aerobic Digester (AB-103) - 1 tank of 2,500 m^3 with a depth of 2 m.
- Sludge Thickener (TH-101) - 2 tanks each having a surface area of 250 m^2 with a depth of 4 m.
- Belt Filter Press (BF-101) - 1 unit with a belt width of 1.5 m.

The Pro-Designer flowsheet for Bardenpho process shows the two anoxic and two aerobic stages as separate process units. In reality, all four stages are accommodated by the four initial tanks. A single icon on the flowsheet may represent multiple identical units operating in parallel.

For a reference case, the input flowrate is 1901.225 m^3/h, and the influent and effluent concentrations are indicated in Table 1

Table 1

Component	Reference influent concentration (mg/L)	Reference effluent concentration (mg/L)	Explanation
DomWaste	105.1953	0.6045	substrate - organic, soluble, biodegradable material
X-vss-h	52.5977	34.8422	active volatile solids in suspension (heterotrophic biomass)

X-vss-i	51.0197	15.7968	inert volatile solids in suspension
X-vss-n	3.1559	0.9698	vss for nitrifiers (autotrophic biomass)
FSS	60.4873	14.5330	fixed suspended solids (non-biodegradable)
TDS	305.0665	304.9001	total dissolved solids (non-biodegradable)
NO_3	2.6299	0.6690	nitrite/nitrate
Ammonia	13.1494	1.8671	dissolved NH_3/NH_4 (not NH_3-N)
Carbon Dioxide	51.0197	0.1396	dissolved CO_2 (in the form of HCO_3^- or H_2CO_3)

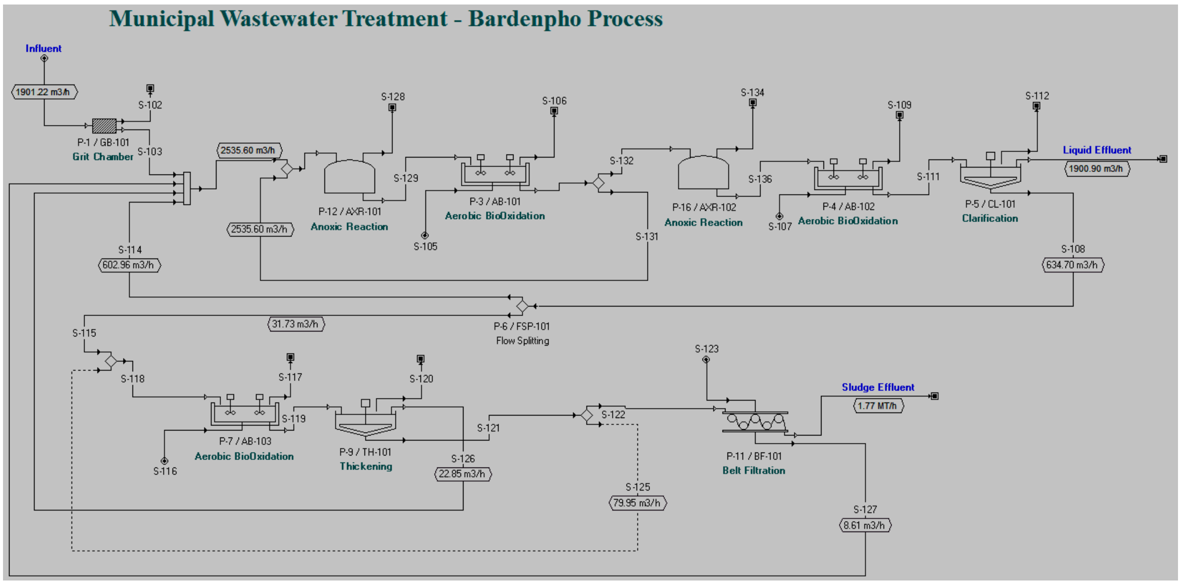

Fig. 3. The flowsheet of a wastewater treatment plant [4]

The following stoichiometry and kinetic constants in the aeration basin and aerobic digester are:

a) Substrate (DomWaste) degradation (the stoichiometry is on a mass basis)

$$\begin{array}{ccccccccccccc} \text{DomWaste} & + & NH_3 & + & O_2 & ===> & \text{X-vss-h} & + & H_2O & + & CO_2 \\ 1\text{ g} & & 0.1\text{ g} & & 1.4\text{ g} & & 0.8\text{ g} & & 0.8\text{ g} & & 0.9\text{ g} \end{array}$$

For those who are used to thinking in terms of yield coefficients, the above stoichiometry is equivalent to the following yield coefficient:
$Y = 0.8$ mg vss / mg DomWaste.
Moreover, since 1 mg DomWaste is equivalent to $2 \times 0.68 = 1.36$ mg BOD5 (biochemical oxygen demand for 5 days) the yield coefficient is also equal to:

$Y = 0.8/1.36 = 0.588$ mg vss / mg BOD5.

The following values of kinetic constants were obtained:

k = 2.61 mg BOD5 / (mg vss - d) = 0.109 mg BOD5 / (mg vss - h) or

k = 0.08 mg DomWaste / (mg vss - h) (since 1 mg DomWaste = 1.36 mg BOD5); K_s = 6.8 mg BOD5 / L = 5 mg DomWaste / L.

The above rate constant is assumed to apply for T = 20 ^oC.

The kinetic constants are expresed in terms of DomWaste concentration and not BOD5 because BOD5 is not a component in SuperPro-Designer, but a stream property. BOD5 is treated as a stream property and not as a component, because many different components (e.g., DomWaste, NH_3, biomass, etc.) may contribute to BOD5.

b) *Nitrification (the stoichiometry is on a mass basis)*

NH_3	+	O_2	+	CO_2	===>	X-vss-n	+	H_2O	+	NO_3
7.5 g		24.6 g		1.8 g		1 .0 g		7.7 g		25.2 g

In reality a large amount of alkalinity is consumed: 8.64 g HCO_3^- is converted to H_2CO_3 per g of ammonia-nitrogen oxidized. Since here is not considered ionic speciation, the above equation simply shows the net carbon (in the form of CO_2) utilized for biomass synthesis. The detailed stoichiometry of nitrification equations can be found in [5].

k = 0.790 mg NH_3-N / (mg X-vss-n - d) = 0.033 mg NH_3-N / (mg X-vvv-n - h) or k = 0.040 mg NH_3 / (mg X-vss-n - h) K_s = 1.4 mg NH_3 / L
The above rate constant is assumed to apply for T = 20 ^oC.

c) *Biomass decay (the stoichiometry is on a mass basis)*

X-vss-a,n	+	O_2	===>	X-vss-i	+	FSS	+	H_2O	+	NH_3	+	CO_2
1.05 g		1.15 g		0.2 g		0.1 g		0.35 g		0.1 g		1.45 g

k_d = 0.06 1/d = 0.002 1/h.
The above rate constant is assumed to apply for T = 20 ^oC.

In SuperPro-Designer biomass decay is handled through separate reactions. In other words, a decay coefficient is never specified but instead it is specified a decay reaction with its own kinetic constants. This is a richer representation compared to the traditional way because it enables the user to distinguish between active and inert biomass.

d) *De-nitrification*

The following stoichiometry and kinetic constants were assumed for the de-nitrification reaction [5,6]:

NO_3	+	DomWaste	===>	X-vss-a	+	H_2O	+	N_2	+	CO_2
62.0 g		34.6 g		7.4 g		42.6 g		13.2 g		33.4 g

k = 0.02 mg NO_3 / (mg vss - h), Ks = 0.44 mg NO_3 / L

The above rate constant is assumed to apply for T = 20 ^{o}C.

Applications

Two important application are studied: first is the simulation and remediation of an increasing of ammonia concentration and the second one is the **s**imulation and remediation of an increasing of nitrite/nitrate concentration.

4. Results and discussion

Case 1. It is assumed an increasing of ammonia influent concentration resulting in an over the legal limit ammonia effluent concentration (8.9518 in Table 2). The maximum admited value of ammonia effluent concentration is 2 mg/L [7]. In order to remediate this situation the following modifications of the operating process parameters were made:

- the residence time of the first anoxic reaction zone was decreased from 0.421 h to 0.025 h (a decreasing with 94%);
- the residence time of the second anoxic reaction zone was decreased from 0.631 h to 0.037 h (a decreasing with 94%);
- the residence time of the first aerobic bio-oxidation zone was increased from 0.842 h to 0.887 h (an increasing with 5%);
- the residence time of the second aerobic bio-oxidation zone was increased from 0.210 h to 0.222 h (an increasing with 5%);
- the flowrates of diffused air for the first aerobic bio-oxidation zone was 5 times increased from 0.6 m^3/h to 3 m^3/h;
- the flowrates of diffused air for the first aerobic bio-oxidation zone was 20 times increased from 0.6 m^3/h to 12 m^3/h.

The residence times were modified in agreement with the restrictions over the working volumes limits. The reasons of the above modifications of the operating process parameters were to reduce the denitrification in the anoxic reaction zones, and to increase the nitrification in the aerobic bio-oxidation zones.

As result of these modifications of the operating process parameters, the effluent ammonia concentration was reduced at 0.6704 mg/L (Table 2), therefore, under the maximum admitted value of 2 mg/L. Also, it can be observed that nitrite/nitrate effluent concentration remained in the accepted limit, approx. 14 mg/L, the maximum admitted value of nitrite/nitrate effluent concentration being 25 mg/L [7]. Therefore, the modifications of the operating process parameters for decreasing of ammonia effluent concentration, did not increase nitrite/nitrate effluent concentration too much, over the legal limit.

Table 2

Component	Influent concentration for the case of ammonia increasing (mg/L)	Wrong regime effluent concentration (mg/L)	Remediated regime effluent concentration (mg/L)
DomWaste	105.6669	0.4078	0.7606
X-vss-h	52.8335	36.6556	38.1164
X-vss-i	51.2485	15.8673	15.9064
X-vss-n	3.1700	1.0222	0.9621
FSS	60.7585	14.5979	14.5974
TDS	306.4341	306.2797	306.2582
NO_3	2.6417	1.0755	14.0313
Ammonia	21.1334	8.9518	0.6704
Carbon Dioxide	51.2485	0.1123	0.2436

Case 2 It is assumed an increasing of nitrite/nitrate influent concentration resulting in an over the legal limit nitrite/nitrate effluent concentration (Table 3).

Table 3

Component	Influent concentration for the case of nitrite/nitrate increasing (mg/L)	Wrong regime effluent concentration (mg/L)	Remediated regime effluent concentration (mg/L)
DomWaste	105.1881	0.0001	0.0001
X-vss-h	52.5941	35.3484	47.5250
X-vss-i	51.0163	15.7868	21.8642
X-vss-n	3.1556	0.9875	1.1991
FSS	60.432	14.5311	20.0289
TDS	305.0456	304.8944	304.8923
NO_3^-	78.8911	45.8371	21.2723
Ammonia	5.2594	1.9586	0.0511
Carbon Dioxide	51.0163	0.0621	0.0729

In order to remediate this situation the following modifications of the operating process parameters were made:

- the recirculation rate at flow spliting FPS 101 was increased from 95% to 97%.

- the residence times of the anoxic reaction zones was reduced with 3%, respectively from 0.421 h to 0.410 h for the first zone, and from 0.632 h to 0.615 h for the second zone.

The residence times were modified in agreement with the restrictions over the working volumes limits. Due to the increasing in the recirculated flow rate these residence times can not be decreased so much as in the previous case. The reasons of decreasing of these residence times were to reduce the denitrification in the anoxic reaction zones.

The modifications of the parameters of the aerobic bio-oxidation zones have no effect on the decreasing of nitrite/nitrate concentration.

Increasing of the recirculated flow rate gives a decreasing of nitrite/nitrate concentration in the entire process, but will increase the total operating cost, due to increasing of pumping energy.

As result of these modifications of the operating process parameters the effluent nitrite/nitrate concentration was reduced at 21.2723 mg/L (Table 3), therefore under the maximum admitted value of 25 mg/L. Also, it can be observed that ammonia effluent concentration is 0.0511 being in the accepted limit.

5. Conclusions

The need for removal of nitrate nitrogen from treated municipal wastewater effluents is a very important task. Nitrate is a nutrient and the growth of aquatic plants can thrive in its presence. It is necessary to limit the amounts of fertilizing nutrients such as nitrates which may be discharged in treated effluents to prevent excessive growths of algae and aquatic plants, that can cause serious harm or even destroy the aesthetic value of water. Other adverse effect is the consumption of dissolved oxygen in the emissaries. This effect could lead to a toxic aquatic environment, affect the efficiency of chlorine disinfection, endanger public health and affect the possibility of reuse of treated wastewater.

The simulation of remediation the increasing of ammonia or nitrite/nitrate concentration in municipal wastewater effluents on the base of Bardenpho process was done using the SuperPro Designer v8.5 simulator. The reducing of ammonia or nitrite/nitrate concentrations in effluent was realized by modifications of several operating process parameters: residence time of the anoxic reaction zones and of the aerobic bio-oxidation zones, flowrates of diffused air for the aerobic bio-oxidation zones, the recirculation rate of effluent back into process. By these means the ammonia or nitrite/nitrate concentrations in effluent were decreased below the maximum admitted concentration.

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