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Statistical analysis of pollution parameters in activated sludge process

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ABSTRACT

In order to minimize the energy consumption in activated sludge treatment process, chosen in our study, an analysis of the pollution parameters of removal yields involved in the process was affected. Indeed, statistical analysis of the decisive parameters in appreciation of the biological process performance includes, among other things, the removal efficiency related to physicochemical parameters in upstream and downstream of the pilot plant such as: suspended solids (SS), organic matter (COD, BOD), nutrients (NH_4^+–N, NO_3^-–N, NO_2^-–N, and TKN) and phosphorus (PO_3^-–P), as well as energy consumption. A comparison of target removal yields, corresponding to elimination required by the standard, and those observed show an excessive removal of organic matter and NH_4^+. The repercussion on energy consumption was studied.

Keywords: Activated sludge; Wastewater; Optimization; Energy consumption

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1. Introduction

In recent years, the increase in environment restrictions has led to an increase in efforts aimed at attaining higher effluent quality from wastewater treatment plants (WWTPs) [1]. In order to meet standards required, control of wastewater treatment plants (WWTPs) is needed. The principle of a biological process is to use the organisms to eliminate pollution in wastewater. These systems are composed primarily of heterotrophic microorganisms that degrade organic matter [2].

The activated sludge process is the most used in Algeria (127 plants) for wastewater treatment. Although the purification performance and reliability of this method are approved, several malfunctions may occur due to qualitative and quantitative changes of water to be treated, the aeration time, the amount of oxygen injected into the inside the reactors, the amount of recirculated sludge. For that, a proper balance must be maintained between the amount of food (organic matter), organisms (activated sludge), and aeration duration.

The activated sludge process should be controlled in such a way that plant operating costs are minimized, while effluent standards are maintained. Thus, the modeling of these processes is facing to the following challenges: a) The complexity of the reactions involved; b) the low number of available measures; c) They can have functioning different from an experience to another for the same experimental conditions d) microorganisms are heterogeneous and the conditions of growth can change constantly in time because of permanent competitions between the various sorts of bacteria for the digestion of multiple substrates.

Computer simulations are today increasingly used ASM1, ASM2, and ASM3 [3–5], in order to optimize the control and predict the behavior of full-scale plants under varying operating conditions, these proposed

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models are complex due to the large numbers of parameters used and which are unable to simultaneously process variations on more than one or two key variables of the process.

The constraints of increasingly stringent quality releases tend to increase the energy costs of treatment. It is known that the largest share of energy consumption is due to the aeration basin. To a large station, the energy consumption of aeration represents 60% of consumption [6–8]. The daily duration of the exhaust is usually determined by either a simple clock or subject to a dissolved oxygen concentration. In both cases, it is ultimately not really to consider the real needs of the purifying biomass. Therefore, and with a commendable sense of efficiency, it is common that the aeration is too high. This is a lesser evil because if too long aeration will only result in an unnecessary expense.

Therefore, the purpose of this study is to compare the removal yields with target ones, corresponding to the standards required of downstream in order to rationalize the energy consummation. The process control of the activated sludge treatment is to determine the optimal values of decision parameters to eliminate the pollution load contained in wastewater (organic pollutant and mineral pollutant) while meeting the discharge standards required by the environment. In order to improve the performance of these processes, a multiple regression model was used to determine the energy to deploy into the aeration basin. This model determines the aeration profile of the reactor that minimizes energy consumption while respecting the specific constraints (regulatory discharge standards).

2. Description of the activated sludge plant

Many different processes happen simultaneously in wastewater treatment plants (WWTP), which were originally designed to reduce the biological oxygen demand, total suspended solids (SS) and nitrogen and phosphorus pollution [9].

The treatment plant is located in Boumerdes coastal area 50 km east of Algiers. It is intended for purifying domestic sewage of the city of Boumerdes and neighboring municipalities.

First, the arrival of sewage into the storm basin, a portion of the effluent is pumped directly into the pretreatment of the channel to extract maximum suspended solids.

The pretreated water is directed to 3 aeration basins that are mixed with an aerated biomass and kept in suspension, each basin comprises 3 aerators. We get mixed liquor composed of flocculated sludge and treated water directed to the clarifiers. In output thereof, the biomass is separated by decantation; a part of the biomass is recirculated in the basins. The excess biomass is removed from the system and constitutes the secondary sludge. At the end of the process, the clarified water passes into a concrete structure ensure prolonged contact between the water to be disinfected and chlorinated water. At the exit of the plant, Water is discharged into the natural environment.

3. Results and discussions

3.1. Statistical study

In order to describe quantitatively the operation of the treatment plant, chosen in our study, a statistical analysis of the curves of pollution parameters yield involved in the biological wastewater treatment was given. Indeed, the statistical analysis of critical parameters in assessing the performance of the biological process includes the removal efficiencies related to the physicochemical parameters observed upstream and downstream of the pilot plant.

Database collection of the downstream and stream from the station was conducted. The series of data was collected daily from January 2009 until 2015. In addition, 237 daily data yields describing the pollution control were collected during a weekly measurement.

The graphs of removal yield of treated water of nitrate and nitrite were not submitted because they present in excess relative to the raw water.

In the following the elimination yields curves of parameters (COD, BOD, SS, TKN, PO_4^{3-}–P and NH_4^+–N) that exceed the discharge norms illustrated by Figs. 1–3 compared with target elimination yields curves calculated from the required standards. We defined a target elimination threshold for each of the pollution parameters corresponding to the standards required.

The activated sludge process is feasible for the removal of organic matters COD, BOD, SS and NH_4^+–N. A part of organic matter is transformed into carbonic gas, water, and energy. Decomposition is achieved by a heterogeneous culture of microorganisms which in part utilize the waste organic substrates in the synthesis of their own biological cell material [10].

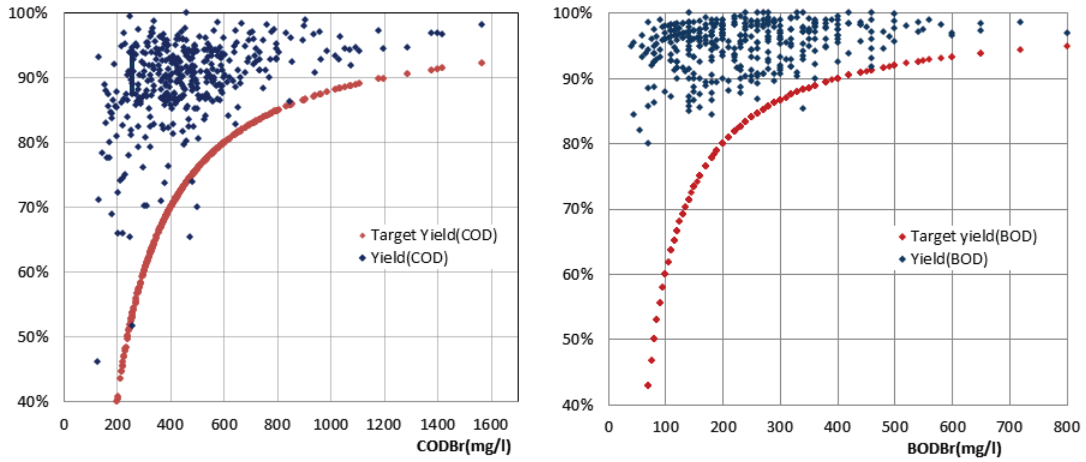
The reduction of ammonium ion (NH_4^+–N) due to the assimilation of a part for the bacterial synthesis and the other part is removal by the conversion of ammonia to nitrates [11–13], in presence of oxygen, by the action of autotrophic microorganisms, which obtain their energy from these reactions [14]. During the nitrification process, ammonia-oxidizing bacteria oxidase ammonium (NH_4^+) to nitrite (NO_2^-–N), and subsequently, nitrite-oxidizing bacteria oxidase nitrite to nitrate (NO_3^-–) [12,14,15].

Fig 1(a) shows the removal of COD in percentage depending on the COD raw values of the water compared to the target yields curves (COD_{sd} = 120 (mg/l).

We note that:

- The scatter plot is above the target yield curve.
- The center of gravity of scatter plot is between 200 and 800 (mg/l) COD_{raw}.
- The number of observations that yield spread (deviation) relatively high is more important.
- The spread between the target yield curve and observed yield is lower when the concentration of COD_{raw} is important, in other words, the process of elimination of the organic matter is better when concentrations are high.

The removal rate of BOD in percentage according to the observed values of the raw water (BOD raw) in



(a) (b)

Fig. 1. Elimination yield of (a) COD, (b) BOD.

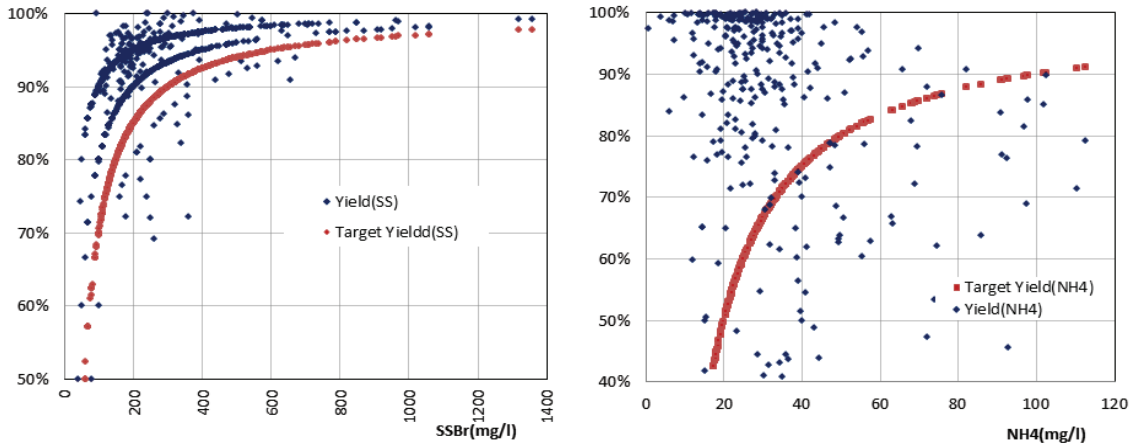
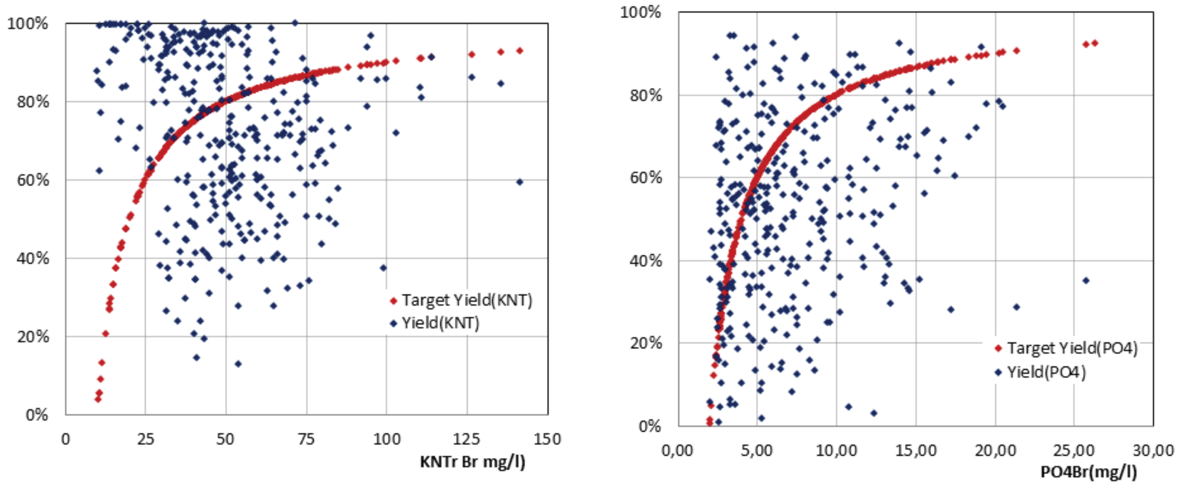


Fig. 2. Elimination yield of (c) SS and (d) NH_4^+–N.



(e) (f)

Fig. 3. Elimination yield of (e) KNT and (f) PO_4^{3-}–P.

(mg/l) is shown in Fig 1b. This graph represents the scatter plot compared to the target yield curve corresponding to removal yield of required standard (BOD_{sd} = 40 (mg/l)).

We note that the spread between the observed yield and the target yield is inversely proportional to the BOD_{raw}. Indeed, for superior values of BOD_{raw} than 500 (mg/l), the values of observed yield are above the target removal with a difference less than 10%. By contrast, the differences are between 10% and 20% containing the center of gravity of the scatter plot for values that varied between 100 and 400 (mg/l).

Fig. 2c shows the removal rate in percentage of SS dependence to the observed values of the raw water (SS_{raw}) in (mg/l) compared to the target elimination yields curves corresponding to elimination required standard.

The scatter plot is between 100 and 400 (mg/l) of SS raw compared with the variation of optimum removal rate corresponding to the requirements of the standard (SS_{st}= 30 (mg/l)) related to the value of the SS raw.

The spread between the target curve and observed yield is lower when raw SS is important that results in an elimination rise to high values of raw SS.

The removal rate of NH_4^+–N in percentage according to the observed values of the raw water (NH_4^+–N_{raw}) in (mg/l) is shown in Fig. 2d.

A minimum number points of NH_4^+–N is obtained due to their values which are inferior to the norms.

We note that the spread between the observed yield and target yield is inversely proportional to the NH_4^+–N_{raw}. Indeed, for superior values of NH_4^+–N_{raw} than 90mg/l the values of observed rate is above the target removal with a difference of less than 30%. By contrast, the differences are between 20 and 60% containing the center of gravity of the scatter plot for values that varied between 40 and 80 mg/l.

There is a draw down of the parameters SS, BOD, COD, and nitrogen NH_4^+–N according to the vocation of the WWTP. However, the excess of elimination describes energy consumption.

- The scatter plot is above the target yield curve.
- The center of gravity of scatter plot is between 40 and 70 mg/l NH_4^+–N_{raw}.
- The number of observation that yields spread relatively high is more important.

Activated sludge process shows an important removal yield of BOD, COD, SS, and NH_4^+–N, on the other hand, the exceed energy consumption is generated.

The elimination yield curves of parameters PO_4^{3-}–P and TKN corresponding to the observed curves of the raw water (PO_4^{3-}–P and TKN) in mg/l are illustrated in the following Fig. 3 (e, f) respectively compared to the target yields curves.

The results show that major points of elimination yield are below the target yield curve. The elimination yield of PO_4^{3-}–P and TKN are insufficient which means that elimination is not satisfactory for these parameters.

Means shall be provided to rationalize energy consumption. Indeed, the aeration phases are generally fixed in a daily way, which requires operator intervention to minimize energy consumption, and in order to improve the removal efficiency of NO_3^-–N, NO_2^-–N, TKN and PO_4^{3-}–P.

A setting of activated sludge process, to optimize the aeration system, is important in better control the process.

3.2 Water pollution index

Water-quality index can be formulated in two ways: one in which the index numbers increase with the degree of pollution (increasing scale indices) and the other in which the index Water Quality Indices numbers decrease with the degree of pollution (decreasing scale indices). One may classify the former as 'water pollution indices' and the latter as 'water-quality indices' [16]. In our case, we interesting to the water pollution index.

According to Fig. 1a,b and Fig. 2c,d, an excessive removal of BOD, COD, SS and NH_4^+ is noticed. Instead of reasoning with respect to any of these parameters a new two variables, Global Yield and Pollution Indices, were introduced:

1. Global yield (GY) that encompasses the yield parameters BOD, COD, SS, NH_4^+ and normalized global yield (NGY) calculated from the required standards given in Eqns. (1) and (2) respectively:

$$GY = \left(\frac{Y_{BOD}^2 + Y_{COD}^2 + Y_{SS}^2 + Y_{NH_4}^2}{4}\right)^{1/2} \tag{1}$$

$$NGY = \left(\frac{NY_{BOD}^2 + NY_{COD}^2 + NY_{SS}^2 + NY_{NH_4}^2}{4}\right)^{1/2} \tag{2}$$

2. The geometric point that includes these settings named pollution indices (PI), calculated from the raw pollution of the input plant [Eq. (3)].

$$GP = \left(\frac{BOD_{raw}^2 + COD_{raw}^2 + SS_{raw}^2 + NH_{4raw}^2}{4}\right)^{1/2} \tag{3}$$

To have a standardized index named pollution indices (PI), we divided GP by the maximum global pollution (GP max) given in Eq. (4).

$$PI_j = \frac{G_j P}{GP_{\max}} \tag{4}$$

The curve of the GY compared to the curve of NGY according to the PI is given in Fig. 4.

The curves confirm an excess of removal of organic matter expressed in terms of BOD, COD, and SS. Excess elimination is due to the aeration of which generates energy consumption.

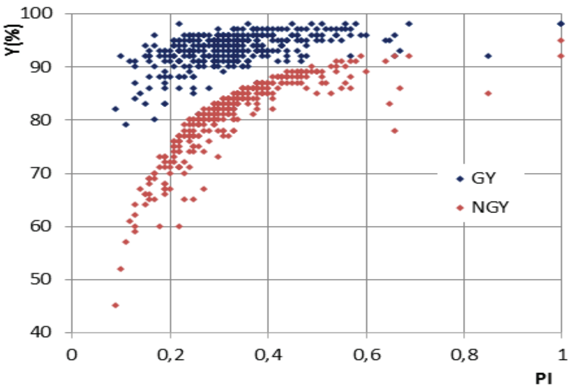


Fig. 4. Comparison between GY and NGY curves.

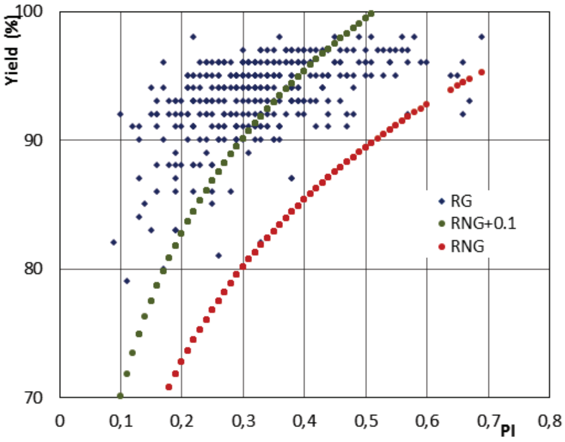


Fig. 5. Representation of the interval of the first selection.

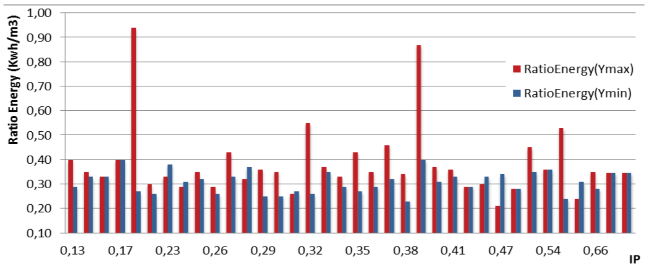


Fig. 6. Representation of the interval of the second selection.

3.3 Energy optimization

To optimize the energy consumption of the WWTP of Boumerdes, we focus on optimizing the aeration time of the biological basin. A selection of the best experiments was made based on two criteria:

1. At first, we detect the best experiences among all data yields, describing the pollution control, where the efficient removal of the station is close to the target yield, admitting an error margin of 10% and selecting all experiences being on within this interval shown in Fig 5.
2. The second criteria are based on the choice of the best experiences of energy consumption by the aerators.

The ratio energy (En (kWh/m^3) represents the report between the energy consumed and the flow entering the station.

$$En = \frac{E}{Q}$$

where: E: Energy (KW)
Q: Flow (m^3/h)
En: KWh/m^3

For the same pollution index, we find different values of energy consumption, minimal values are selected. Note that statistically, for the same index of pollution, the energy ratio is minimum when the global yield is minimum and conversely (Fig. 6).

Once the selection has been made, we developed the multiple regression model using data where experiences are considered best. The equation derived from the selected data is given in following:

The parameters considered determining for the simulation of the energy ratio (E) can be listed in three classes most probably independent:

- The parameters describing the effluent in the entrance of the STEP: in quantity (Flow (Q)) and in quality (pollution index (PI)).
- The parameters describing the biological process: such as the global elimination Yield of the pollution expressed by (GY), as well as the amount of Q_r.
- In the end, the parameters describing the ambient environment: the temperature (T).

A multiple regression model developed to determine the energy gain was affected. The equation is given in following equation (5):

$$\text{En} = \left[0,4 + 3Q_r + -0,2Q_r^2 + 18T - T^2 - 12Q + Q^2 - GY - 0,1GY^2 - 15(PI - PI^2)\right] \Big/ 100 \quad (5)$$

The graph below represents the energy observed according to the simulated energy by application of the quadratic regression model.

We notice that the scatter plot is a proximal to the bisector with a correlation coefficient of $R^2 = 84\%$.

The simulation energy (Esim) of non-selected data, calculated using the regression model (Eq. (5)), is shown in Fig. 8. A significant difference between the observed energy (Eobs) and the optimized energy (EOpt) was detected confirms the energy overconsumption.

The difference between observed energy consumption and optimized one represents the gain of electrical energy. The results of the annual daily average of electrical energy gain are represented in the following histogram (Fig. 9).

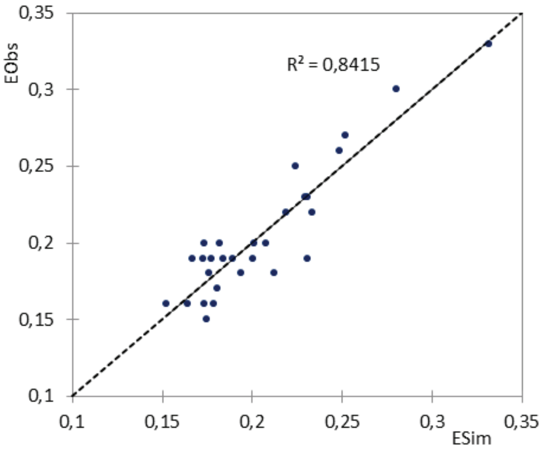


Fig. 7. Representation of the correlation curve (EObs–ESim).

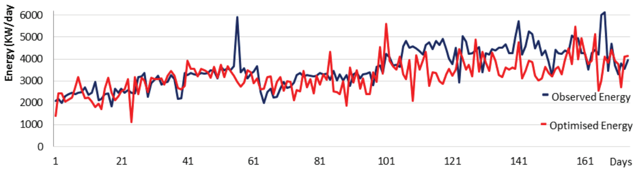


Fig. 8. the curves of the real energy and the optimized energy.

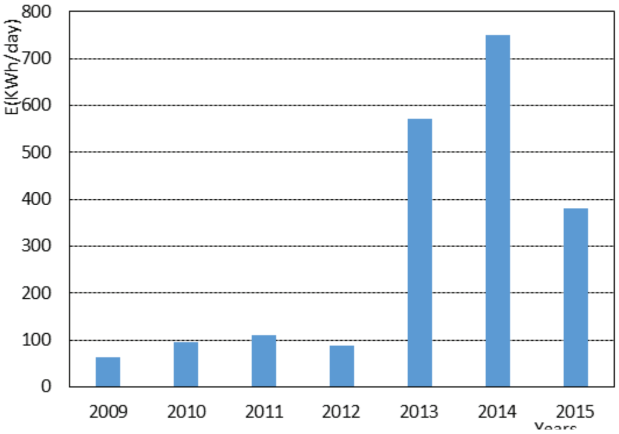


Fig. 9. Annual energy gain (%).

Note from this histogram that the highest percentage in term of gain in energy is between the years 2013 and 2015.

4. Conclusion

This work is part of an environmental theme that is relevant today and even more necessary. The aim of the treatment process is to protect and to safeguard the environment.

Statistical analysis of the data allowed us to conclude that the organic pollution parameters (BOD, COD, and SS) of treated water remain satisfactory and meet the objectives of the station in terms of discharge standards. In contrast to organic matter, removal of parameters KNT and PO_4^{3-}–P appears not sufficient compared to the standards required, which is the major problem of all the processes activated sludge, NH_4^+–N shows satisfactory results or even excessive compared to the required standard, this can be explained by the fact that the process is aerobic which favor the removal of NH_4^+–N.

Energy consumption was detected by an excess of the removal efficiencies of organic pollution parameters, on the one hand, and of a considerable excess concentration of nitrate, on the other hand.

It is noted that the level of operation of the station is very significant in relation to compliance with the standards relating to organic matter and nitrogen pollution parameters. Nevertheless, there is a lack of mastery of the energy consumption of the hand, the high yields of organic matters.

It is noted that the level of the functioning of the station is very significant compared to the respect for the required standards relative to the parameters of pollution of the organic matter.

Nevertheless, we notice a lack of control of the energy consumption of part the high yields of organic matter and the production of nitrate exceeding the required standard. It is, consequently, recommended to envisage the anoxia or downtime zones to favor the denitrification to improve the removal yield of NO_3^-–N, NO_2^-–N, NTK, and PO_4^{3-}–P on one hand, and reduce the energy on the other hand.

If the economy is only a few percent, it is very significant in terms of kWh/year for a decade.

Symbols

BOD — Biological Oxygen Demand,
COD — Chemical Oxygen Demand,
PO_4^{3-}–P — Phosphorus,
NH_4^+–N — Ammoniac,
TKN — Total Kjeldahl Nitrogen,
NO_2^-–N — Nitrite,
NO_3^-–N — Nitrate ,
SS — Suspended solids,
Q_r — Recirculated flow
BOD_{raw} — raw Biological Oxygen Demand
COD_{raw} — raw Chemical Oxygen Demand
$PO_4^{3-}–P_{raw}$ — raw phosphorus
$NH_4^+–N_{raw}$ — raw Ammoniac
TKN_{raw} — raw Total Kjeldahl Nitrogen
PI — Pollution indices
T — Temperature
SS_{raw} — raw Suspended solids
Q — Flow

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