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CARBONACEOUS, NITROGENOUS AND PHOSPHORUS MATTERS REMOVAL FROM DOMESTIC WASTEWATER BY AN ACTIVATED SLUDGE REACTOR OF NITRIFICATION-DENITRIFICATION TYPE

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Abstract

This paper proposes an environmental engineering method based on biotechnology approach as one of the expected solutions that should be considered to implementing the activated sludge for improving the quality of water and living environment, especially to remove the major pollutant elements of domestic wastewater. Elimination of 3 major pollutant elements, i.e., carbon, nitrogen and phosphor containing the domestic wastewater is proposed to carry out biological method of an anoxic-aerobic reactor therein these types of pollutants should be consecutively processed in three steps. Firstly, eliminate the carbonaceous matter in the aerobic reactor. Secondly, to remove the carbonaceous and nitrogenous matters, it is necessary to modify the reactor's nature from the aerobic condition to an anoxic-aerobic reactor. And finally, when the cycle of nitrification-denitrification is stable to achieve the target's efficiency of reactor by adding the ferric iron into the activated sludge, it can be continued to remove the carbonaceous, nitrogenous and phosphorous matters simultaneously. The efficiency of carbonaceous and nitrogenous matters removal was confirmed with the effluent standard, COD is less than 100 mgO_2/L and the value of global nitrogen is less than 10 mgN/L. The effectiveness of suspended matter removal is higher than 90% and the decantation of activated sludge is very good as identifying the Molhman's index is below of 120 mL/L. The total phosphorus matter removal is more effective than the soluble phosphorus matter. By maintaining the reactor's nature at the suitable condition, identifying the range of pH between 6.92 and 7.16 therefore the excellent abatement of phosphor of about 80% is achieving with the molar Fe/P ratio of 1.4.

Keyword: Anoxic-aerobic reactor, Activated sludge, Simultaneous pollutant elements removal.

Nomenclatures

Q_t	Inlet and outlet flows
r_s	Organic pollutants diminution rate
r_x	Microorganisms growth rate
S	Organic pollutants in effluent
S_m	Organic pollutants in influent
t_h	Hydraulic retention time
V	Volume of reactor
X	Number of microorganisms in effluent
X_m	Number of microorganisms in influent

1. Introduction

The major part of Asian countries from the year-to-year facing the environment degradation due to the population growth as well as the economic development whereas the development's actors have yet consider correctly applying the 3 pillars of the UN framework of sustainable development, i.e., the economic, social and environmental aspects. Degradation of living environment mainly in the developing countries is remarkably urged to the high economic development and population growth in the last decades. Of course, it brings to the difficult condition therein the tendency of conflict interest between the economic development demands and sustainability of environmental balance. This paper is proposed to promote the appropriate engineering approach which may be considered to apply the activated sludge based on biotechnology method in management of wastewater to improve the quality of environment.

The original quasi-totality of pollutants coming from domestic wastewater composing three major elements – i.e., carbon, nitrogen and phosphor thereof, the biological process is used to remove these elements and the procedure of controlling the amount of activated sludge in the reactor is conventionally utilized to a unit of domestic wastewater treatment plant. It is clearly to remove carbonaceous and nitrogenous pollutants which are effectively proceed in the biological treatment plant and, this technology has been fixed to the definitive design of environmental engineering. But the biological procedure of phosphorous pollutants removal has yet consider as suitable technology in the formality engineering design. Thereby, the chemical precipitation procedure is technically recommended to reduce the phosphorous matter which contains in domestic wastewater in order to achieve the admissible norm at the expected value of effluent standard.

Managing the amount of activated sludge is promoted to carry out controlling of reactor's loads – hereby expressed as art of biological wastewater treatment process – realizing the maintaining of the content of SS at certain quantity. Defining the age of sludge and maintaining the reactor with suitable condition, it is possible to realize the implementation of this technology. Whereof, it exists three categories of treatment procedure, i.e., low, medium and high loads of reactor that have been technically adopted to remove the organic pollutants accompanying domestic wastewater. Using the mass balance expression it is possible to carry out monitoring of the SS in the influent and the effluent and to regulate the reactor's loads which purge the amount of sludge periodically.

2. Configuration of Pilot Plant

The main objective of the configuration of pilot plant is clearly to have a design that can be applied by using activated sludge to reduce the major pollutant elements of domestic effluent. Thereafter, the treated wastewater may be directly ejected to the river or other destined natural ecosystem. Regarding the application of this technology in the developing countries it is considerable to design a simple hydraulic engineering infrastructure which is able to match with the local conditions.

This configuration is tendency selected the total oxidation process system or the category of low loads reactor that characterizes with the hydraulic time of 12 hours and the age of sludge of 15 days as well as the recycle discharge of activated sludge is over than 100% [1]. The schematic chart of domestic wastewater pilot plant is shown in Fig. 1 and the principle dimensions are described in Table 1.

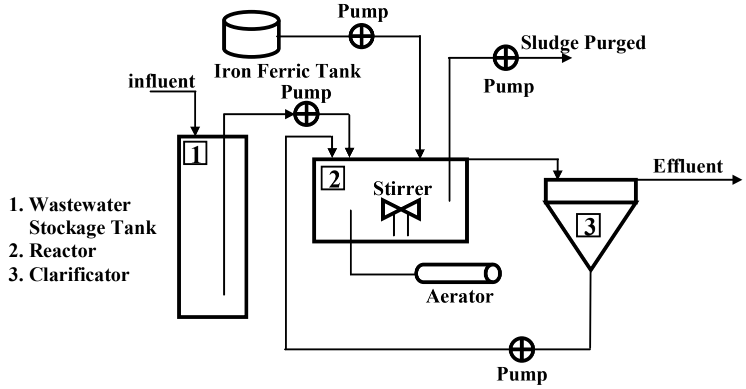

Fig. 1. Schematic Chart of Reactor Configuration [2].

Table 1. Principle Dimension of the Pilot Scale Treatment Plant [3].

No	Pilot element	Unit	Dimension
1	Equalization tank	liter	200
2	Reactor's volume	liter	10
	Hydraulic retention time	hour	12
	Sludge's age	day	15
	Influent and effluent discharges	liter/hour	0.83
	Recycle flows of activated sludge	liter/hour	1.66
3	Ferric iron tank	liter	4
	Ferric iron alimentation flow	liter/day	1.24
4	Decanter	liter	3

Standard operational procedure is used to run the biological treatment process that can be successively proposed to do through several steps as follows:

1. Raw domestic wastewater is collected in the equalization tank and maintained temperature at $4^{o}C$ and also it is necessary to stir wastewater that being sure mixed completely;

2. Pumping the influent with a regulated discharge into the reactor and controlling the amount of activated sludge by monitoring the concentration of SS in the influent and in the effluent;
3. Efficiency of reactor is initially verified by monitoring the concentrations of COD, NH_4^+ and PO_4^{3-} at certain time; and
4. Efficiency of reactor related to remove carbon, nitrogen and phosphorus elements is verified by monitoring the concentrations of COD, NH_4^+, NO_3^- and PO_4^{3-} in conformity with the biological process step of nitrification-denitrification and the biological-chemical process step of phosphorous precipitation.

Eliminating three major pollutant elements, i.e., carbon, nitrogen and phosphor by using an anoxic-aerobic reactor is essential to follow three successively steps. Firstly, elimination of the carbonaceous matter is accomplished by setting the reactor into an aerobic condition. Secondly, elimination of the carbonaceous and nitrogenous matters simultaneously is practiced by modifying the complex media of reactor from the aerobic condition to anoxic-aerobic condition which is capable to bring this culture media of activated sludge from aerobic to facultative reactor of nitrification-denitrification type. And finally, the elimination of the carbonaceous, nitrogenous and phosphorous matters simultaneously is carried out after the cycle of nitrification-denitrification is stable. Whereby, in this step the reduction of these matters is regularly affected by adding the ferric iron ($FeCl_3.6H_2O$) into the reactor.

3. Characteristics of Domestic Wastewater

The impurities present in domestic wastewater consisting the organic and inorganic matters entrained by the liquid flow in the form of suspended solids – settleable floating and colloidal – or, to a varying extent, matter dissolved in the water. To such matter it contains microorganisms liable to decompose organic matter and cause putrid fermentation [4]. One of the main characteristics of domestic wastewater is biodegradable, and depending of a food balance supplied to bacteria. The characteristics of domestic wastewater applying in this study which are remarked the ratio of the soluble to total matters in the raw wastewater is about 50% such as the average value of soluble COD is 279 mgO_2/L and this of total COD is 504 mgO_2/L as well as the average value of soluble phosphorus is 5.5 mgP/L and this of total phosphorus is 10.5 mgP/L, as shows in Table 2.

Regarding the carbonaceous and nitrogenous matters as well as the solid particles are characterized by the moderate concentration of untreated domestic wastewater [5] while the phosphorous matters accompanying domestic wastewater theoretically present different compounds of phosphor with the total concentration range varies from 10 to 25 mgP/L which corresponds to the domestic pollutant loads of 3.9 to 4.2 grams of phosphor per equivalent inhabitant per day [6]. One part of 50 to 70% is in the form of orthophosphate and the rest is in form of polyphosphate and organic phosphorus [2]. During the transportation of domestic wastewater in the sewerage network system of a city, the polyphosphate and organic phosphorus containing the sewage transferred by hydrolysis process into the form of orthophosphate and, finally after passing the wastewater treatment plant the phosphorous compound in the clarify effluent remains about 90% in the form of orthophosphate [6].

Table 2. General Characteristics of Domestic Wastewater [1].

No.	Parameter	Unity	Concentration		
			Minimum	Average	Maximum
1	Soluble COD	mgO_2/L	138	279	381
	Total COD	mgO_2/L	432	504	615
2	Suspended solids	mg/L	280	339	595
3	Ammonium	mgN/L	27.5	44.2	54.8
4	Soluble phosphorous	mgP/L	3.4	5.0	6.2
	Total phosphorous	mgP/L	5.5	10.5	12.5
5	Soluble iron	mgFe/L	0.1	0.12	0.2
	Total iron	mgFe/L	1.4	2.6	4.5
6	Ph	-	7.5	7.7	8.0
7	TAC	$mgCaCO_3/L$	296	342	380

The characteristics of domestic wastewater from Labege's municipality present in Table 2 which is indicated by the concentration of total phosphorus of 5.5 to 12.5 mgP/L, it is possible to consider that the loss of phosphorous matter during the transportation in the sewerage network system is caused by transferring the biodegradation organic matter into the biomass and by settling the phosphor through chemical precipitation onto the partition of ditch along the sewerage system.

4. Methodology to Control the Reactor

The capacity of reactor is designed to accommodate the discharge of influent which maintaining the hydraulic retention time of 12 hours and the reactor's loads of 3 g/L of SS. Wherewith, the age of activated sludge is regulated to 15 days [1,7]. Sludge is also called as complex media which is necessary with stirring continuously to maintain in homogeneity.

Setting up the reactor into aerobic condition at the beginning should be affected by aeration in order to conserve the dissolved oxygen (DO) is about 2 mgO_2/L and it is necessary to maintain this condition in order that the biological process is stable identifying the effectiveness of wastewater treatment more than 85% of carbonaceous pollutant with, the concentration of COD is below of 100 mgO_2/L and the Molhman's index is below 120 mL/L [1].

Nitrification phenomenon is naturally taking place in the reactor by using dissolved oxygen due to the presence of aerobic and autotrophic bacteria while starting the nitrosomonas bacteria catalyzes oxidation process in order to change nitrogenous matters from ammonium to nitrite form and pursuit the nitrobacter acts to complete total oxidation of nitrogen matter which changes nitrite to nitrate.

Assuming the chemical composition of nitrifiant bacteria is considerable in form of $C_5H_7O_2N$. Therefore, utilizing one gram of ammonium needs 4.2 grams of oxygen to synthesize a new biomass which yields 0.13 grams of bacteria's cells [2]. During the period of nitrification, it seems that the oxidation of ammonium reduces the amount of alkalinity in the water wherein one gram of ammonium consumes 8.6 grams of alkalinity [2]. Indeed, in the case of inadequate bicarbonate in a domestic wastewater, pH decreases. The biological process meanwhile produces the effluent with riches of nitrate identifying the passing of the effluent standards.

After the nitrification process is considerable stable identifying that the concentration of nitrate in the effluent is constant. The elimination of nitrogenous pollutants may be continued to change the reactor from aerobic to anaerobic condition so that, the nitrification process starts due to the presence of certain chemi-organotrope bacteria in the activated sludge which able to replace DO as sources of oxygen with the oxygen of nitrate and yielding free nitrogen as the final step of denitrification process. It is energetically remarked that the denitrification process is more effective than nitrification and, as a consequence, during the denitrification phase the growth rate of bacteria is more important so that this period is short.

The cycle of nitrification-denitrification is achieved by using the regulated timer which arranges at the switch-on to aerate and the switch-off to stop the aeration and vice versa and, when this cycle is correctly stable identifying that the global nitrogen is below 10 mgN/L which confirms to the effluent standards, we can continue to implement the chemical-biological phosphorus precipitation process.

The principle problem affects to the surface water caused by the presence of high concentration of phosphor is able to degrade the living environment which appears the rupture of ecological equilibrium in an aquatic ecosystem as the receiving media [8]. Based on this factual it is necessary to remove the excess of phosphor that presents in wastewater.

It is classically approached that in a normal biological assimilation the phosphor matter entry to the biomass through synthesis reaction of polyphosphates to be needed the ratio of C: N: P is about 100: 5: 1 with, the minimal concentration of DO is 0.5 mgO_2/L [6]. By excluding the chemical phosphorous precipitation, the efficiency of biological phosphorus matter removal depends on COD/P's ratio of a domestic wastewater. The phosphorus matters contain in the solid phase may be increased from 0.7 to 2.5% of VSS if the COD/P's ratio decreases from 200/1 to 60/1 and, for certain condition, the phosphorous accompanying an activated sludge vary from 2.2 to 3.6 % of VSS or from 2.6 to 4.2 % of SS [1]. It is surely incapable by a pure conventional biological process to remove the phosphorus matter due to high concentration of phosphor presents in a raw wastewater and so that needs to be improved technology with combining the chemical precipitation in order to confirm with the strictly effluent standard.

A number of configurations of reactors have been developed to realize the chemical phosphorous removal of a domestic wastewater, i.e., direct precipitation, pre-precipitation, simultaneous precipitation, post-precipitation and contact filtration. The basic principles of chemical precipitation mechanism are able to transfer by coagulation the soluble phosphorus matter from liquid to solid phase and pursuit the separation of solid phase by sedimentation, floatation and/or filtration. In the case of phosphorus simultaneous precipitation by using the ferric iron as writing in this paper, with this method the phosphorus matter removal is engaged to settle into activated sludge that realizing after the cycle of nitrification-denitrification is stable. It can be described by precipitation, adsorption and ion exchange phenomena and that the precipitated phosphorus matter of solid phase considers as metallic phosphates, i.e., metal-hydroxy-phosphates [1,9].

Considering the mass transfer phenomenon is to change organic matter into biomass form, the expression of microorganisms' mass balance can be described as follows:

$$0 = Q_t X_m - Q_t X + V r_x \quad (1)$$

$$r_x = t_h X - t_h X_m \quad (2)$$

And then the expression of organic pollutants mass balance is described as follows:

$$0 = Q_t S_m - Q_t S + V r_s \quad (3)$$

The reactor's load is controlled to maintain concentration of SS at the certain quantity of activated sludge and it can be realized by purging the sludge periodically. By monitoring the quantity of SS in the influent and in the effluent the balancing of biomass in the reactor is calculated pursuant to the model of mass balance expression.

4.1 Suspended matters removal

The effectiveness of suspended matters removal as represented by SS parameter is more than 90% (Fig. 2) indicating that the biological wastewater treatment process is acceptable to remove suspended matter with this proposed biotechnology. And by controlling the reactor' regime of low charge type it is suitable to manage this approached technology confirming with the sustainable development programme. Considering the ratio of volatile suspended solids (VSS) to SS is about 83% it is clearly indicating that the fermentable sludge is major part of SS in the reactor and also confirming the decantation of activated sludge is very good as showing the Molhman's index in Fig. 3 which is below of 120 mL/L [5].

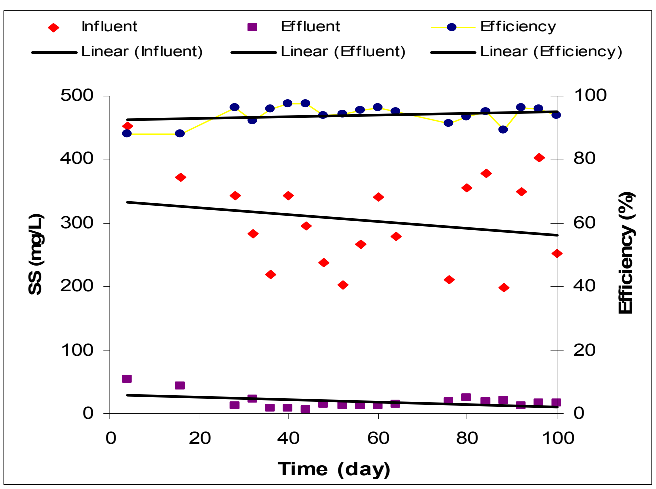

Fig. 2. Evolution of SS.

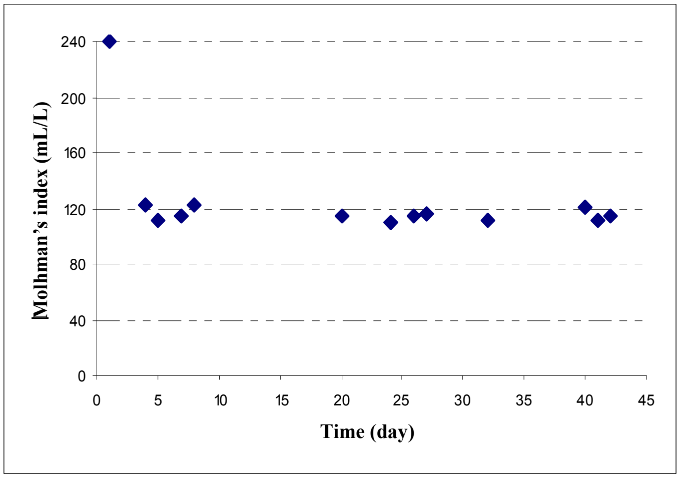

Fig. 3. Evolution of Molhman's Index.

By adding the ferric iron into the activated sludge it is changeable to the nature of media and it is necessary to maintain the reactor' load with the value of SS is bout 3 grams per liter. The VSS/SS's ratio decreases from 83% to 60 – 70% due to increase the solid particles in the activated sludge in form of the complex metallic phosphates salts [1,8].

4.2 Carbonaceous and nitrogenous pollutants removal

With this pilot scale of domestic wastewater treatment plant it is remarked that the proposed biotechnology is acceptable to remove carbonaceous and nitrogenous matters of a domestic wastewater with which confirms to the effluent standards i.e., the value of COD is less than 100 mgO_2/L and the value of global nitrogen (N-gbl) is less than 10 mgN/L.

The efficiency of carbonaceous matter removal endures during the first 20 days of running, the pilot is able to fluctuate as shows in Fig. 4. This variation the functioning of the reactor is probably due to present the new phenomenon in the reactor's media with which decreases the content of biomass replacing by precipitating the phosphorus matter and increases the denitrifiant bacteria during the period of dinitrification. The efficiency of treatment tends to increase slowly during 100 days of monitoring as shows in Fig. 4 and the abatement of COD value is more 85%. With this condition, the correlation between the specific substrate removal rate (SSRR) and applied mass loading (AML) as in Fig. 5 gives a straight line [1].

According to the results monitored during the longtime of aeration period, i.e., the first 15 days of running the pilot that ammonium transfers to nitrites and pursuit to transfers into the form of nitrates as terminal form of inorganic nitrogen due to oxidation of nitrogen matters. Nevertheless, under aerobic condition the efficiency of nitrogenous matters removal is remarked less than 40% due to present the rest of nitrates in the effluent discharge.

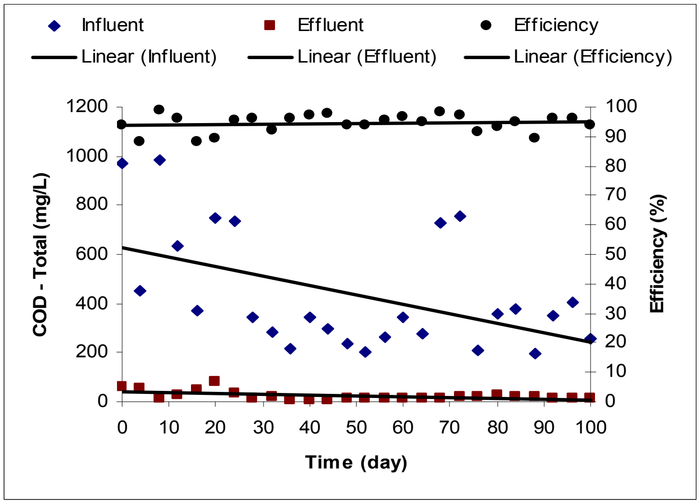

Fig. 4. Evolution of Total COD.

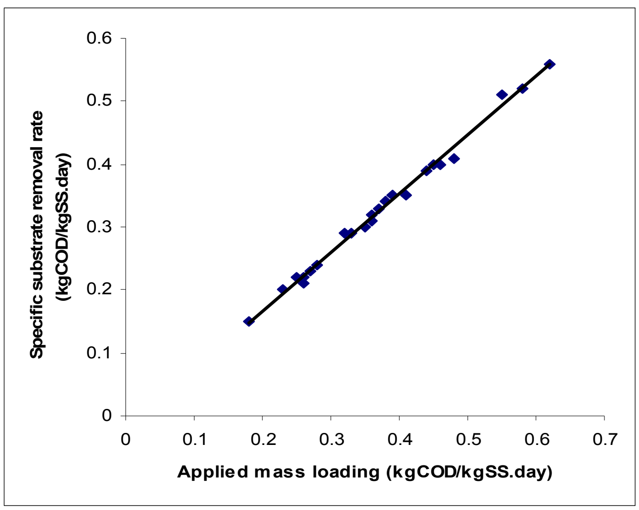

Fig. 5. Correlation between Specific Substrate Removal Rate and Applied Mass Loading.

By changing the reactor from aerobic to anoxic-aerobic condition the process of nitrification and denitrification endures vice versa (Fig. 6) and the abatement of global nitrogen reaches at the value of greater than 50%. The excellent result of nitrogenous matters removal achieves with which the C/P's ratio is suitable to match with microorganism growth and remarking the efficiency of nitrogenous matters removal is greater than 80%. And, it is remarked that the ferric iron is added into the reactor to remove the phosphorus pollutant through precipitation of complex metallic phosphorus salts in which realizing after the cycle of nitrification-denitrification is stable.

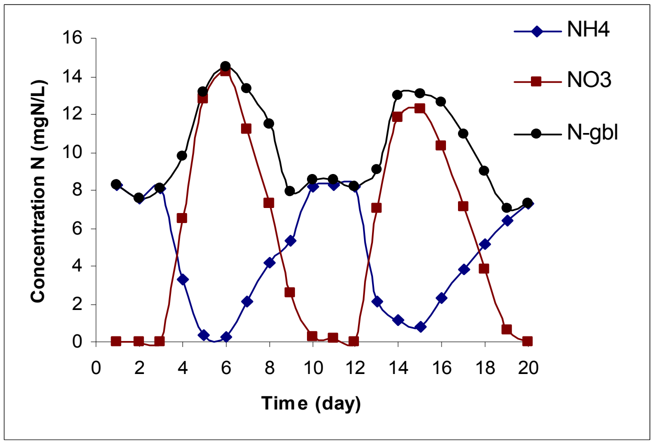

Fig. 6. Cycle of Nitrification-Denitrification.

4.5 Phosphorous pollutants removal

During the first 5 days of running of the reactor with the Fe/P's molar ratio is 1.4, the quantity of phosphor accumulates into activated sludge which is constant with the concentration of total phosphor is about 63 mgP/L [1]. And after passing the hydraulic retention time of sludge – called as sludge's age – i.e., 15 days of running the system, the ferric iron is added into activated sludge and remarking that on the 7th day the content of phosphorous matter increases from 1.5 to 4% of SS due to accumulation of phosphor into activated sludge [1].

Maintaining the reactor's loads with the quantity of 4 grams of SS per liter shows the content of biomass decreases continuously due to replacing the biomass with the chemical compounds of iron phosphates. As justify during the period of monitoring 35 days that is remarked with the VSS/SS's ratio decreases form 83% to 64% [3].

Under biological and chemical process the reduction of total phosphorus matter is more effective than soluble phosphorous matter. The efficiency of elimination of both total and soluble phosphorus matter increases with decreasing of the molar ratio of Fe/P. The contribution of orthophosphates becomes a major part of phosphorus in the treated wastewater. At the molar ratio Fe/P = 1.5, the efficiency of phosphorous removal is about 75% of total phosphorus and is about 55% of soluble phosphorus [1]. The Fe/P's ratio molar of effluent is more important than that of the reactor. It is probably due to the presence of non-stoechiometric precipitation of ferric iron through adsorption of the ferric iron onto the activated sludge.

5. Conclusions

The effectiveness of carbonaceous and nitrogenous pollutants removal by applying the simple configuration of domestic wastewater treatment plant of nitrification-denitrification type as described in this paper is confirmed with the effluent standard. While the phosphorus removal for achieving the standard needs to add ferric iron by simultaneous precipitation, with the consequence of more costly. To date, the major of Asian countries policy has yet consider eliminating the nitrogenous and phosphorous elements in wastewater. For future development of domestic and industrial wastewater treatment, the technology proposed in this paper is worth considered for Malaysia in particular as well as other developing countries in general.

The proposed technology gives the high efficiency of solid particles and carbonaceous matters removal as showing by the abatement of SS value is greater than 90% and the abatement of COD value is about 85%. Although, it is watching with the expected condition of reactor's nature for achieving the stabilized cycle of nitrification-denitrification and the required C/N's molar ratio that the effectiveness of nitrogenous matters removal reach at the confirmed value of the effluent standard as showing the abatement of nitrogenous matters is greater than 80% with the quantity of global nitrogen founded in the effluent discharge is bellow than 10 mgN/L.

Finally, this system shows that the effectiveness of phosphorous matters removal proportionate to the Fe/P's molar ratio and the total phosphorus removal is more effective than the soluble phosphorus removal, and by maintaining the correct characters of reactor's nature and the range of pH between 6.92 and 7.16 therefore the excellent abatement of phosphorus is about 80% achieving for the Fe/P's molar ratio equal 1.4.

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