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On-Site Sequencing "Anaerobic- Anoxic- Aerobic" Biological Process For Wastewater Reuse

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Abstract

The increasing scarcity of water around the world has become more evident at the beginning of this century. Management of this valuable resource is not only an environmental issue, it is also an important economic issue and its management has significant social implications. Moreover, the predicted decreases in annual rainfall around Australia, threatening the image of providing a sustainable water source for a majority of its population. The solution partly lies through the promotion of water conservation strategies involving wastewater recycling and reuse.
A pilot scale 5-stage wastewater treatment system was investigated in regards to its feasibility for removing Biochemical Oxygen Demand (BOD_5), Total Suspended Solids (TSS), Turbidity, Total Kjeldahl Nitrogen (TKN), Ammonia Nitrogen (NH_3-N), Nitrate Nitrogen (NO_3-N), Organic Nitrogen (Org-N) and Total Phosphorus (TP) for the period of one year from Jan.2004 to Dec. 2004. The system readily reduced the concentration of BOD_5 from average 189 mg/L to 5 mg/L (removal rate of 94%), TSS from average 216 mg/L to 3 mg/L (removal rate of 97%) and Turbidity from average 105 NTU to 2 NTU (removal rate of 96%).
The removal rate for nitrogen and phosphorus was also quite satisfactory and this system was capable of reducing the Total Nitrogen (TN) from average of 41 mg/L to 5 mg/L (removal rate of 86%) and TP from average of 9 mg/L to 2 mg/L (removal rate of 81%).

Keywords: Anaerobic, Anoxic, Aerobic, Sequencing zones, Nutrient, On-site Reusable wastewater

1. Introduction

Inadequate water supply and water quality deterioration represent serious contemporary concern for many municipalities, industries and the environment in various parts of the world. Several factors have contributed to these problems such as continued population growth in urban areas, contamination of surface waters and ground waters, uneven distribution of water resources and frequent droughts caused by the extreme global weather patterns. Water reuse has been considered the great challenge of the 21st century as water supplies remain practically the same and water demand increase because of increasing population and per capita consumption [2]. Water reuse accomplishes two fundamental functions; first the treated effluent is used as a water resource for beneficial purposes, and secondly the effluent is kept out of the streams, lakes and beaches; thus reducing the pollution of surface waters and ground waters. The reliable treatment of wastewater to meet strict water quality requirements and the protection of public health has been the great concern of regulatory authorities. Table 1 describes the wastewater reuse requirement set by Australian government and other authorities around the world and Table 2 describes the allowed categories for wastewater reuse.

Table 1: Worldwide requirements for reusable wastewater

Parameters	Australian Standard[1]	American standards[2]	European standard[3]
TSS (mg/L)	<10	<10	5-10
BOD5 (mg/L)	<10	<10	5-10
Turbidity (NTU)	<5	<2	0.3 -3
TN (mg/L)	<5	<10	5-10
TP (mg/L)	<2	<2	1-3
Fecal Coliform (MPN/100ml)	<5	< 5	5-20

Table 2: Wastewater reuse categories

Agricultural Irrigation	Crop Irrigation	Commercial Nurseries	Gardens
Landscape Irrigation	Residential Landscape	Golf Courses	School Yards
Non- potable Urban Reuse	Fire protection	Air conditioning	Toilet flushing
Industrial Reuse	Cooling water	Boiler feed	Process water
Groundwater recharge	Groundwater replenishment		Saltwater intrusion control

The specific objectives of this study are:

- To investigate a 5 stage wastewater treatment process for producing on site reusable wastewater for residential homes.
- To remove nutrients from residential wastewater using on-site treatment systems.
- To evaluate the level of treatment taking place in each of the chambers in order to determine the quality of effluent being discharged to the environment and ultimately to the receiving waters.
- To identify appropriate design parameters for a 5 chamber wastewater treatment system.

2. Experimental Method

A pilot scale wastewater treatment system was set up at the Engineering Innovation Centre of University of Wollongong. This wastewater treatment system consisted of 5 sequencing zones of "Anaerobic- Anoxic-Aerobic- Anoxic and Aerobic" for the removal of organic compounds as well as nutrient from residential wastewater. The wastewater was collected from Bellambi Sewage Treatment Plant located in residential areas north of Wollongong. This pilot scale tank was made from 6 mm thick perspex with the dimensions of 2000 mm length, 150 mm width and 300 mm depth. This system comprised a nutrient removal system, a final clarifier and a sand filter for final polishing of effluent. A schematic of the system is shown in Figure 1.

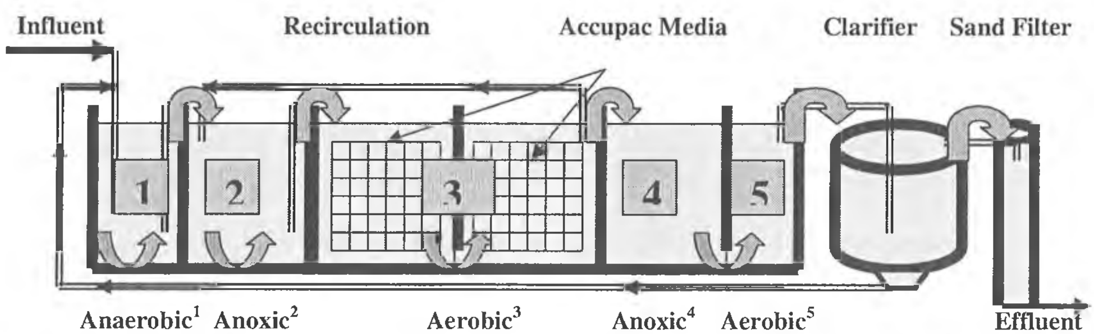

Figure 1: Schematic of the 5 stage biological reactor with Final Clarifier and sand filter polishing

This system was also designed to remove nitrogen by aerobic biological nitrification and subsequent denitrification in anoxic zones. The nitrified effluent from the end of the first aerobic zone was pumped back to the head of the first anoxic zone, where it was introduced into the incoming wastewater and mixed under anoxic conditions for the reduction of nitrate to nitrogen gas. The second anoxic zone was provided for additional denitrification. Biological phosphorus removal was initiated in the anaerobic zone (first chamber) and it was removed as the result of sludge wasting in the subsequent anoxic and aerobic zones (2^{nd} and 3^{rd} Chambers). The last aerobic zone reoxygenated the process flow stream and stripped it of any remaining dissolved nitrogen gas and minimised the release of phosphorus in the final clarifier.

3. Design Parameters

Table 3 indicates all important parameters for designing an on-site wastewater treatment system for the purpose of on-site wastewater recycling and reuse with the specific attention on nitrogen and phosphorus removal. The most important parameter in designing such a system was the Hydraulic Retention Time (HRT) of each chambers. Long HRT may lead to septicity, excess nitrification or either undesirable secondary release of phosphorus and short HRTs may not give enough time for sedimentation of suspended solids, proper denitrification and sufficient release of phosphorus in anaerobic chamber. The ratio of activated sludge return from clarifier to the first chamber and effluent recycle ratio from the aerobic chamber to the first anoxic chamber are another important factors. Specific surface area of biomedia plays an important role in organic loading rate.

Table 3: Design parameters for designing a 5 chamber On-site wastewater treatment system

Parameters	Present study
Flow rate (mL/min)	65
Internal recycle (mL/min)	200
Activated sludge return (mL/min)	65
Specific surface area of Biomedia (m^2/m^3)	226
Total surface area (m^2)	18.3
Anaerobic Contact time (h)	2
First anoxic contact time (h)	4
First aerobic contact time (h)	10
Second anoxic contact time (h)	4
Second aerobic contact time (h)	1.5
Final Clarifier contact time (h)	4
Hydraulic retention time (h)	25.5
Hydraulic Loading Rate (Volumetric) ($m^3/m^3.d$)	0.89
Hydraulic Loading Rate (Surface) $m^3/m^2.d$	5.1×10^{-3}
Organic Loading Rate (Volumetric) $kgBOD/m^3.d$	0.15
Organic Loading Rate (Surface) kg $BOD/m^2.d$	0.9×10^{-3}
BOD Removal Rate (Volumetric) $kgBOD/m^3.d$	0.14
BOD Removal Rate (Surface) (kg $BOD/m^2.d$)	0.86×10^{-3}
Sand Filter Surface Loading Rate ($m^3/m^2.d$)	11.8
Sand Filter Organic Loading Rate (kg $BOD/m^2.d$)	0.097
Sand Filter BOD Removal Rate (kg $BOD/m^2.d$)	0.051

4. Results and Discussion

The influent and effluent of the pilot tank were analysed for various wastewater quality parameters such as Temperature, Dissolved oxygen (DO), pH, Turbidity, Total suspended solids (TSS), Biochemical oxygen demand (BOD_5), Total Kjeldahl nitrogen (TKN), Ammonia-nitrogen (NH_3-N), Organic-nitrogen (Org-N), Nitrate-nitrogen (NO_3^--N) and Total phosphorus (TP) over one year period. Table 4 shows the variation in influent and effluent wastewater parameters with their minimum, maximum and average values during the sampling period. The results were compared with the data obtained for conventional systems [4] and the primary difference was the higher removal efficiency of nitrogen and phosphorus for the present system.

Table 4: Influent and Effluent wastewater quality parameters

Parameters	Present study							Conventional Systems[4]
	Influent (Raw Sewage)			Effluent (SandFilter)			Removal (%)	Removal (%)
	Min	Max	Ave	Min	Max	Ave		
BOD (mg/L)	109	257	189	3	17	5	94	<95
TSS (mg/L)	120	348	216	1	18	3	97	<95
Turbidity (NTU)	63	143	105	1	5	2	96	<90
TN (mg/L)	15	54	41	4	15	5	86	<50
TP (mg/L)	5	17	9	1	5	2	81	<40

4.1 Biochemical Oxygen Demand (BOD5)

The influent BOD_5 varied between 109 mg/L and 257 mg/L, with the average concentration of 189 mg/L while the effluent BOD_5 concentration had the minimum of 3 mg/L and maximum of 17 mg/L with the average of 5 mg/L. The average effluent BOD_5 of 5 mg/L was an indication of a significant removal efficiency of this 5 stage treatment system. Figure 2 shows the contribution of each chamber for total BOD_5 removal. The anaerobic chamber removed only about 6% of total BOD_5 in the process and did not contribute to the BOD_5 removal significantly, however as expected the 3rd chamber (aeration chamber) contributed towards significant BOD_5 removal of 38% and the 5^{th} chamber provided the second highest contribution towards BOD_5 removal of about 15%. The 2^{nd} chamber and the 4^{th} chamber (anoxic chambers) had the average removal efficiencies of about 10%. The sand filter had the lowest contribution in the whole process and removed only 3% of the total BOD_5. Although the present system showed slightly lower overall BOD_5 removal of 94% compare to conventional systems of 95% but higher removal efficiency are expected from this advanced treatment system. This can be improved by using more sophisticated air diffusers with higher oxygen transfer capability.

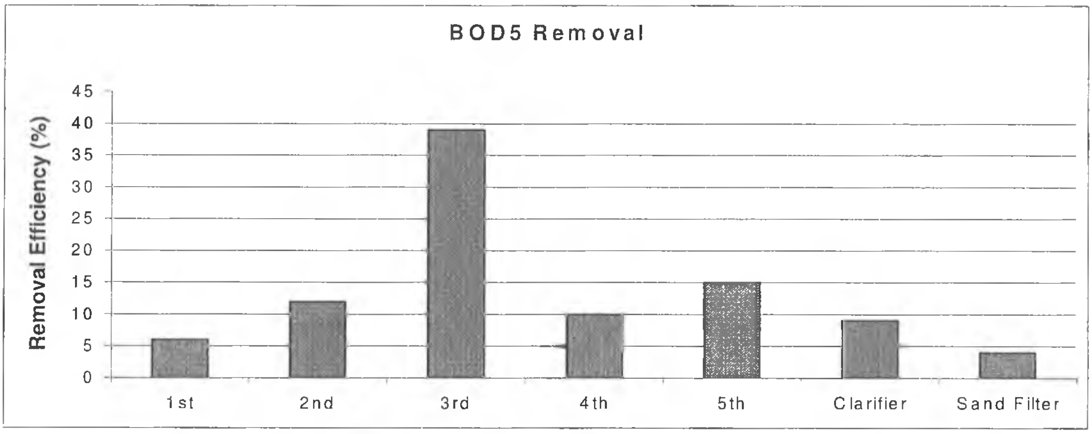

Figure 2: BOD_5 Removal efficiencies in each chamber

4.2 Total Suspended Solids (TSS)

The comparison of the influent and effluent TSS values indicates the occurrence of a high TSS removal efficiency in AWTS. This 5 stage system reduced the influent average TSS concentration from 216 mg/L to 3 mg/L which was well below the required limit of 10 mg/L by NSW Department of Health [1]. The contribution of each chamber to the whole removal process are illustrated in Figure 3. The highest removal rate was in the 3^{rd} chamber that can be partly contributed to attached growth of biofilms over the surface of biomedia and sludge wasting. The 5^{th} chamber had the removal of about 15% and the 2^{nd} and 4^{th} chamber also contributed to the TSS removal process with removal rate of 14% and 10% respectively. The overall removal rate of the pilot plant (97%) was slightly higher than the conventional systems of 95%.

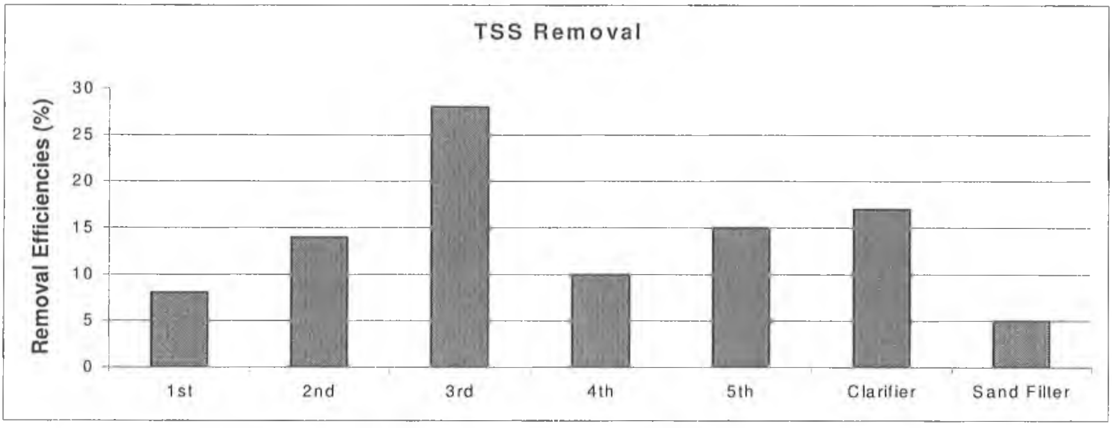

Figure 3: TSS removal efficiencies in each chamber

4.3 Turbidity

The turbidity variations of influent wastewater varied between 63 NTU to 143 NTU with the average of 105 NTU. Comparing the influent average turbidity with the effluent average turbidity of 2 NTU indicates that the colloidal matters were reduced significantly due to the treatment of wastewater by Accupac trickling filters in each chambers. Figure 4 indicates the contribution of each chamber to the whole turbidity removal process. The average turbidity removal of 25% and 16% in the 3rd chamber and the 5th chamber respectively is an indication of a better performance by aerobic chambers. The clarifier contributed about 17% to the whole removal process and the first chamber and sand filter did not contribute to the removal process significantly. The overall removal efficiency of 96% by the pilot tank was higher than of conventional AWTS of about 90%.

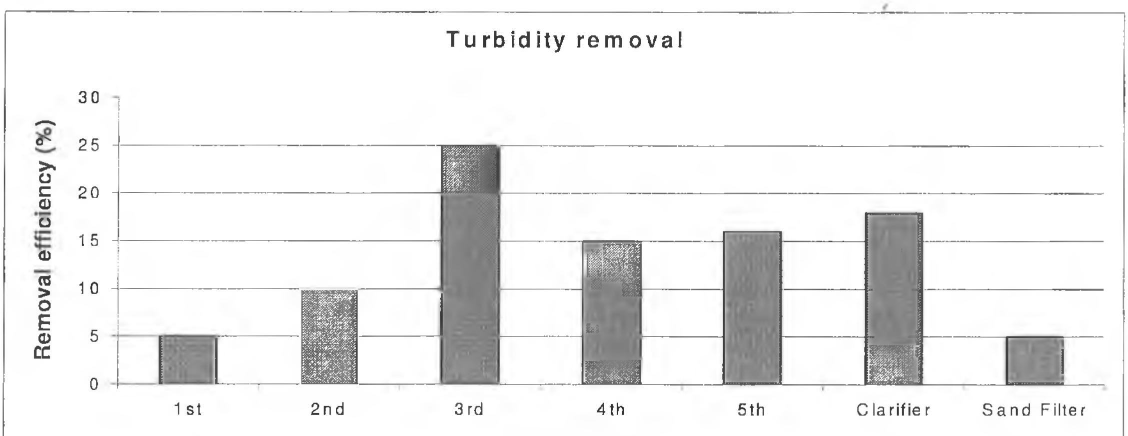

Figure 4: Turbidity removal efficiencies in each chamber

4.4 Total Nitrogen (TN)

Total nitrogen (TN) is the sum of the concentrations of nitrogen in the form of ammonia, organic nitrogen, nitrite and nitrate in the wastewater. In this study the influent ranging from 15 mg/L to 54 mg/L with an average of 41 mg/L was observed. Metcalfe and Eddy Inc. et.al (2003) indicates a range of 20 mg/L to 70 mg/L of total nitrogen for domestic wastewater and suggests that this range corresponds to medium strength wastewater. The average effluent concentration of 5 mg/L was an indication that this treatment system provides conditions for significant nitrogen removal with the overall removal efficiency of 86% compare to conventional AWTS of about 50% nitrogen removal. Figure 5 demonstrates the removal efficiency of each chambers and contribution of each chamber to the whole process. The highest nitrogen removal occurred in the 2nd and 4th chambers (anoxic zones) due to denitrification. The removal rate of 8% and 6% was observed in the 5th chamber and clarifier respectively. The other chambers did not contribute to nitrogen removal process significantly.

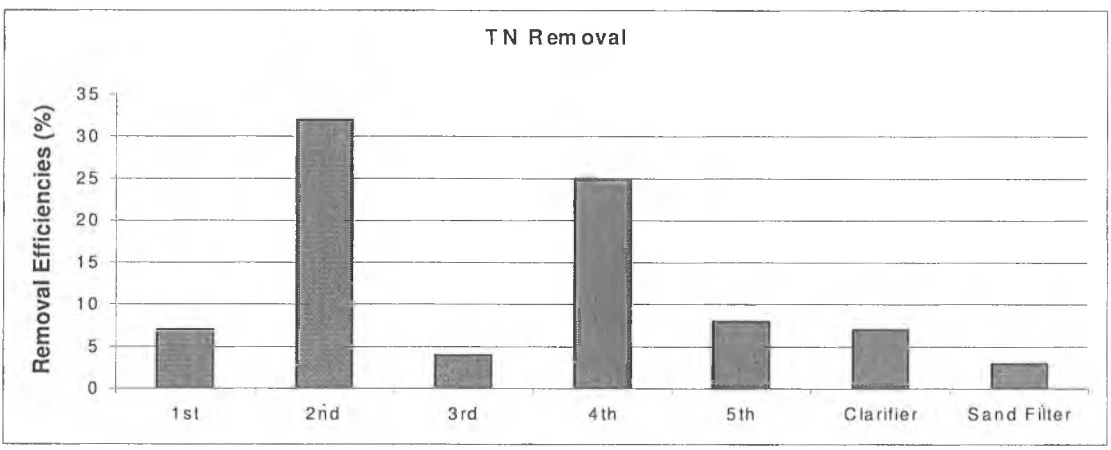

Figure 5: TN removal efficiencies in each chamber

4.5 Total Phosphorus (TP)

The influent wastewater had the maximum Phosphorus concentration of 15 mg/L and minimum of 5mg/L. The average total phosphorus concentration of 9 mg/L was observed for the influent wastewater which is similar to TP concentration reported for the medium strength untreated residential wastewater [2]. The pilot plant produced effluent with TP concentration of 2.6 mg/L which was above the required limit of 2 mg/L set by NSW Department of Health [1]. Figure 6 indicates that the release of phosphorus took place in the 1st chamber. Under anaerobic condition the phosphorus accumulating organisms will assimilate fermentation products such as volatile fatty acids into storage products with the simultaneous release of phosphorus from stored polyphosphates. Subsequently under anoxic-aerobic conditions, the energy which is produced by the oxidation of storage products will help to increase the amount of polyphosphate storage within the cells [2].
The 3rd chamber contributed the most to the removal of phosphorus with 31% removal efficiency. The 2nd chamber (anoxic zones) also contributed significantly to the removal of phosphorus from influent wastewater with the removal rate of 18%. The other chambers did not contribute to the Phosphorus removal significantly. The sand filter contributed the lowest to the whole removal process.
A comparison of the present design removal efficiency of 81% with conventional systems of 40% revealed that this system is capable of removing a greater amount of phosphorus from the influent wastewater. Modifications are needed to improve the removal efficiency of the pilot tank for phosphorus removal even further.

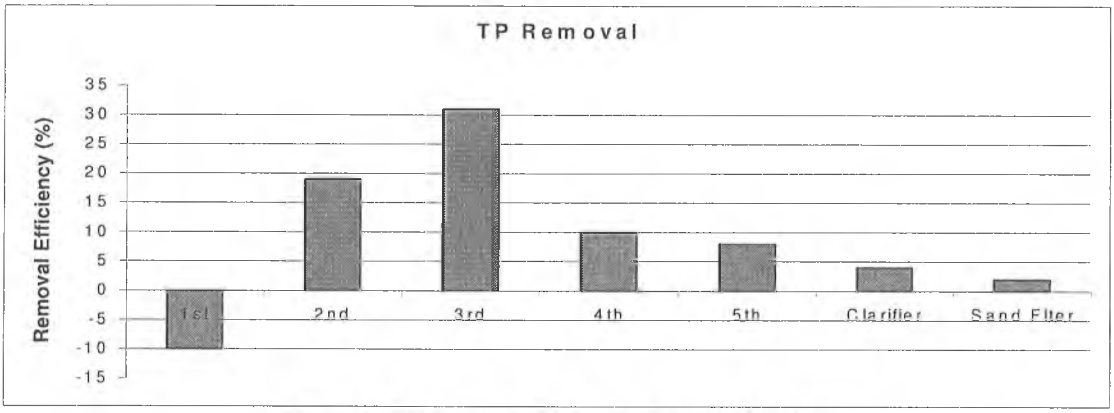

Figure 6: TP removal efficiencies in each chamber

5. Conclusion

This research was conducted to investigate the viability of a 5 stage wastewater treatment system for nutrient removal as well as to evaluate an alternative design that has the potential of producing reusable wastewater for residential homes, particularly in the rural and remote areas of Australia.
A detailed investigation in both theoretical and experimental revealed that this on-site system can easily provide high quality reusable wastewater for residential houses and can be used as a new alternative technology for the promotion of water conservation strategies.
The BOD_5, TSS and Turbidity removal efficiencies of this innovative design were as high as 94%, 97% and 96% respectively with the effluent average concentrations of 5 mg/L of BOD_5, 3 mg/L of TSS and 2 NTU of turbidity. The nitrogen removal efficiency of 86% was also quite satisfactory and the system produced the effluent quality with total nitrogen concentration of 5 mg/L. TP load removal showed a weaker result with the removal efficiency of 81% and effluent TP concentration of 2.6 mg/L which was the above required level of less than 2 mg/L set by the NSW Department of health and other regulatory authorities in Australia and around the world [1,2,3]. Although the bio filter and sand filter contributed to the reduction of organic compounds significantly (removal of BOD_5 and TSS) but did not demonstrate a high potential for nitrogen and phosphorus removal. Modifications are needed to improve the nitrogen and phosphorus removal efficiencies of this 5 stage system .
During the experimental period of one year (from Jan.2004 to Dec 2004) the system was quite stable, requiring the minimum amount of maintenance and relatively low cost compared to other aerated wastewater treatment systems. The effluent from the polishing sand filter is currently being tested to determine its microbiological quality for safe reuse without disinfection. Further studies are required to improve the removal efficiency of this 5 stage wastewater treatment system.

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