ANAEROBIC COUPLED-INTEGRATED SEQUENTIAL ANOXIC AEROBIC (AN-ISA) REACTOR FOR ORGANIC MATTER AND NUTRIENT REMOVAL FROM WASTEWATER

by

LEONG HUA QIAN

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Dissertation submitted in partial
fulfilment of the requirements for the

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Approved by,

(_____________________________)

A.P. DR. MOHAMED HASNAIN ISA

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(__________________________)

LEONG HUA QIAN

Abstract

The aim of the project is to develop an anaerobic coupled-integrated sequential anoxic aerobic reactor to remove organic matter and nutrient from wastewaters. Wastewater is rich in carbon source which through an anaerobic reaction can produce methane (CH_4), a biogas that can be effectively used as a renewable energy source. Nitrogen source that is present in the wastewater is the main contributor to eutrophication. With denitrification process that occurred in the anoxic-anaerobic region of the reactor, nitrate and nitrite can be reduced to nitrogen gas. In a conventional wastewater treatment plant, the setting demands a vast areas of land. This novel reactor will integrates anoxic, anaerobic, aerobic treatment into a single vertical unit which reduces the land requirement as well as the operating cost. Reactor's performance was evaluated in terms of energy recovery, organic matter and nitrogen removal. OECD synthetic wastewater was used in testing the reactor's performance. The proposed COD concentration of the influent is 300mg/L to 2500mg/L with a steady flow of 5 L/day. The effluent treated meets the discharge limit of Standard A by removing up to 97% of COD, biogas is being collected at the rate of 2.5L.day.

Acknowledgement

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1 Introduction

1.1 Background

Wastewater treatment involves removal of contaminants from both domestic and commercial wastewater. A treatment plant can include physical, chemical and biological processes. In Malaysia, as requested by the Department of Environment the treated water has to meet Standard A if the effluent is released upstream of a water intake and Standard B if it is at the downstream. Biological wastewater processes can be aerobic or anaerobic. Figure 1.1 shows the diagram of a conventional wastewater treatment facility.

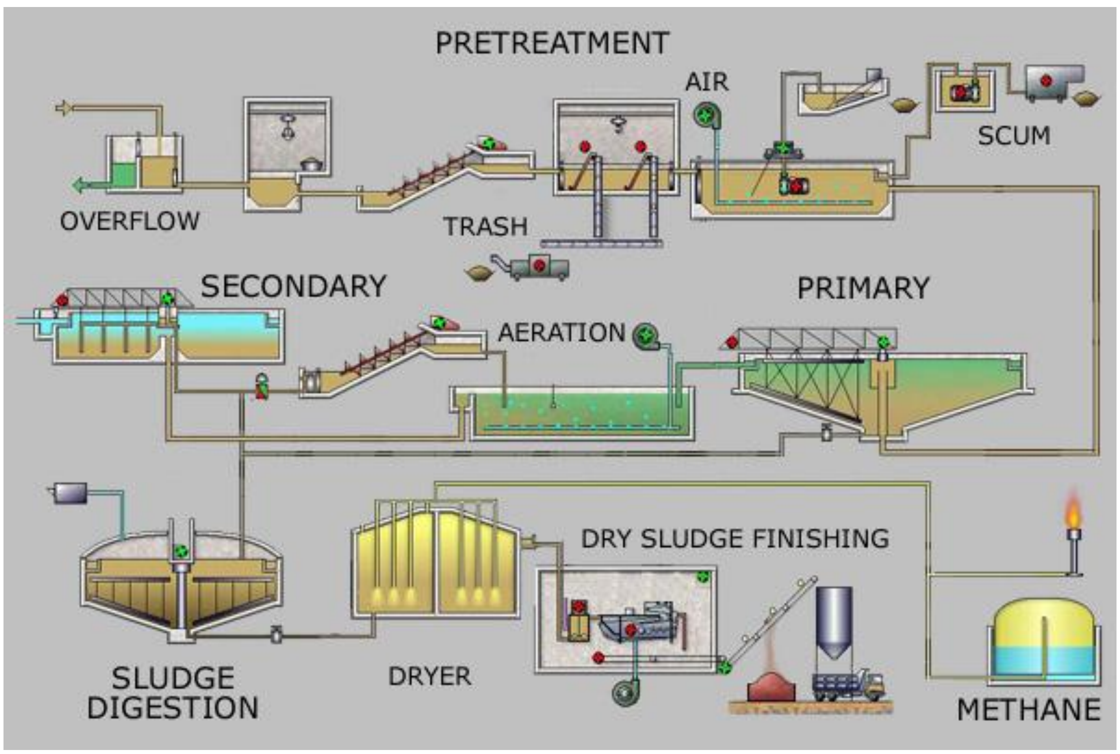

Figure 1.1 Diagram of a Conventional Waste Water Treatment Plant

Sustainable development is also one of the trend headed by the wastewater treatment industry. In order to achieve that, wastewater treatment plant has to be able to power on its own and have a small footprint as land is getting scarce in urban areas.

Discharging of nitrogen in its various forms (ammonia-nitrogen, nitrate ion) will stimulate harmful algae blooms and eutrophication in rivers. The decomposition of the large number of dead algae will consume lots of dissolved oxygen. Thus, it will lead to the depletion of oxygen and that threatens the aquatic life of the area. Moreover, some species of algae may even produce neurotoxins which can cause a severe health problem to humans in high concentration (Goldstein & Peterson, 2006).

It had also been found that excess nitrite causes blue baby syndrome during their first 6 months of life. In addition, prolonged exposure to nitrate-contaminated drinks may lead to diabetes, thyroid disease and cancer. (Knobeloch, Saina, Hogan, Postle, & Anderson, 2000)

Furthermore, a conventional biological nitrogen removal plant operates in separated spaces due to the different environmental requirements of microorganism responsible for nitrification and denitrification; which requires a relatively longer retention time or large volume in completing the nitrogen removal process (Lee, Bae, & Cho, 2001). Besides, the requirement of anoxic tank increases the usage of space, number of equipment, power consumption as well as the operating cost.

1.2 Problem Statement

i) Energy Requirement

The extensive use of aerobic digestion of organic matter in conventional wastewater treatment consumes significant amount of energy to maintain sufficient amount of oxygen and its product is mainly carbon dioxide. Currently our major source of energy comes from the combustion of fossil fuels which will one day be depleted. Wastewater is rich in organic matter which is a carrier of carbon energy (Frijns, et al., 2013). The use of anaerobic digestion of organic matter eliminates the need for energy consuming elements like aerators while producing significant amounts of biogas, mainly methane. Methane is a biogas which is highly combustible. Its usage is in generators for electricity production and heating purposes.

ii) Land Requirement and Operating Cost

Current secondary wastewater treatment involves two separate tanks for microbial reactions, in addition to a couple of sedimentation tanks for biomass separation. This demands vast areas of land, often a scarce resource in an urban setting. Furthermore, conventional treatment plants demand special tools to function at an optimum level. For example, submersible mixers or floating aerators are the keys to increase the efficiency of aerobic processes to a viable level. Demand for land and use of specialized tools increase the capital and running costs of these systems, often borne by government or the general public.

1.3 Project Definition

The An-ISA design will integrate the secondary and tertiary wastewater treatment stages into a vertical unit, reducing space requirement and operating cost of the system. Moreover its function is to generate biogas from sewage to move the reactor towards self-sustaining.

Worldwide, people have successfully applied anaerobic technology for the treatment of wastewater for decades. It is getting more and more common because it has the potential to reduce global warming. Currently, over 300 sewage treatment plants in Japan producing enough methane to heat digester or to generate biofuel or electricity. (Kobayashi, 2010). Table 1.1 shows the theoretical methane gas that can be recovered from the treatment process. Our aim is to recover a high percentage of methane gas.

Table 1.1. *Stoichiometry of Methane Fermentation*

Feedstock	Stoichiometry of methane fermentation	Biogas yield ($m^3 \cdot kg^{-1}$-VS)	Methane (%)
Carbohydrate	$(C_6H_{10}O_5)_n + nH_2O \rightarrow 3nCH_4 + 3nCO_2$	0.830	50.0
Protein	$C_{16}H_{24}O_5N_4 + 14.5H_2O \rightarrow 8.25CH_4 + 3.75CO_2 + 4NH_4^+ + 4HCO_3^-$	0.764	68.8
Lipid	$C_{50}H_{90}O_6 + 24.5H_2O \rightarrow 34.75CH_4 + 15.25CO_2$	1.425	69.5
Cattle manure	$C_{22}H_{31}O_{11}N + 10.5H_2O \rightarrow 11.75CH_4 + 9.25CO_2 + NH_4^+ + HCO_3^-$	0.970	56.0
Municipal solid waste	$C_{46}H_{73}O_{31}N + 14H_2O \rightarrow 24CH_4 + 21CO_2 + NH_4^+ + HCO_3^-$	0.888	53.3
Sewage sludge	$C_{10}H_{19}O_3N + 5.5H_2O \rightarrow 6.25CH_4 + 2.75CO_2 + NH_4^+ + HCO_3^-$	1.003	69.4

1.4 Proposed Solution

Through an integrated design of the reactor, the following are the proposed solutions attainable:

i. Organic matter digestion primarily through anaerobic reaction, producing and capturing biogas (methane) effectively as renewable energy source.
ii. Nutrient (nitrogen) removal to prevent issues such as eutrophication.
iii. Space reduction by integrating secondary & tertiary treatment and sedimentation tanks into a vertical unit.
iv. Oxygen only required for nitrification, lower volume of air needs to be pumped, reducing energy consumption of system.

1.5 Project Objectives and Scope

i. To develop a novel biological reactor for organic matter and nutrient removal from wastewater.
ii. To evaluate the performance of the reactor in terms of energy recovery and organic matter and nitrogen removal

1.6 Feasibility of Study

The study is feasible as there is no foreseeable risk or external party interference. The reactor will be fabricated locally in UTP. It will be used to treat synthetic wastewater that will be prepared in the laboratory. All instruments for analysis and reactor monitoring are available in the laboratory.

2 Literature Review

2.1 Theory

Human population is increasing rapidly. It is vital that existing systems will need to be reworked to be able to support the growing load. In order to achieve international development target of halving the proportion of people without access to improved sanitation or water by 2015, wastewater treatment takes precedence for a major improvement.

2.1.1 Characteristics of Wastewater

The purpose of wastewater treatment is to take the waste and water that makes up "waste stream" and treat it to a level that is harmless to the receiving body (Drinan, 2001). Wastewater quality is described in terms of physical, chemical and biological characteristics. The major components of municipal wastewater are suspended solids, organic matter and pathogens (Riffat, 2013). Table 2.1 shows the typical characteristics of untreated municipal wastewater

Table 2.1 Typical Characteristic of Untreated Municipal Wastewater

Component	Concentration Range
Biochemical oxygen demand, BOD at 20°C	100-360 mg/L
Chemical oxygen demand, COD	250-1000 mg/L
Total Kjeldahl nitrogen (TKN)	20-85 mg/L
Total phosphorus	5-15 mg/L

2.1.2 Wastewater Treatment and Discharge Limits

Wastewater treatment is a sequential process consisting of 3 major treatment stages; primary, secondary and tertiary treatments. Primary treatment involves physical removal of suspended solids, usually by sedimentation, conventional secondary treatment primarily degrades organic matter and reduces solids by biological means, typically aerobic oxidation and tertiary treatment includes nutrient removal (Riffat, 2013).

The discharge limit of treated wastewater in Malaysia is regulated by the Environmental Quality Act 1974. This act is enforced by two standards; Standard A and Standard B. Standard A applies to discharge of treated wastewater to any inland waters within catchment areas as specified in the Third Schedule of the Environmental Quality (Sewage) Regulations 2009 whereas Standard B applies to discharge to any other inland waters and Malaysian waters. Table 2.2 shows the limits for both standards.

Table 2.2 Discharge limits of Standard A and B

Component	Unit	Standard A	Standard B
COD	mg/L	50	100
Ammoniacal Nitrogen	mg/L	10.0	20.0
Nitrate (river)	mg/L	10.0	20.0
Phosphorus	mg/L	5.0	10.0

2.1.3 Removal of Primary Pollutants

Activated sludge is used for organic matter removal for biological treatment of municipal and industrial wastewaters (Riffat, 2013). Let CHONS represent organic matter and $C_5H_7O_2N$ represent new cells. The breakdown of organic matter is given by equation 2.1

$$CHONS + O_2 + nutrients \xrightarrow{Bacteria} C_5H_7O_2N + CO_2 + NH_3 + other\ products \quad (2.1)$$

The endogenous respiration is given by equation 2.2

$$C_5H_7O_2N + 5O_2 \xrightarrow{Bacteria} 5CO_2 + NH_3 + 2H_2O + energy \quad (2.2)$$

Hence, according to air or oxygen is supplied to the activated sludge process to provide oxygen required by the aerobic microorganisms for degradation of organic matter. Extensive use of aerobic digestion of organic matter in conventional wastewater treatment consumes significant amount of energy to pump and to maintain a sufficient amount of oxygen. In fact, aeration devices used for activated sludge system are the most significant energy consumers within a wastewater treatment system.

Furthermore, as equation 2.2 describes, the major byproduct of aerobic removal of organic matter is carbon dioxide, a gas with limited use and a major contributor to the greenhouse effect. However, wastewater being rich in organic matter is an effective carrier of carbon energy which can be recovered (Frijns, Hofman, & Nederlof, 2013). The use of anaerobic digestion of organic elements reduces the dependency on energy consuming elements like aerators while producing significant amounts of biogas, mainly methane. In fact biogas produced by the digestion of “biosolids” contains up to 60%

methane which can be used to power process boilers, engine-powered generators, engine-powered pumps or blowers.

Advantages of anaerobic processes compared to aerobic processes

- Less energy required
- Less biological sludge production
- Fewer nutrients required
- Methane production, an energy source
- Smaller reactor volume required
- With acclimation most organic compounds can be transformed
- Rapid response to substrate addition after long periods without feeding.

Disadvantages

- Longer start-up time to develop necessary biomass inventory
- May require alkalinity and specific ion addition
- May require further treatment with an aerobic treatment process to meet discharge requirements.
- Biological nitrogen and phosphorus removal is not possible
- Much more sensitive to the adverse effect of lower temperatures on reaction rates
- May be more susceptible to upsets due to toxic substances
- Potential for production of odors and corrosive gases.

(Tchobanoglous, Burton, Stensel, Metcalf, & Eddy, 2003)

Excess nutrients like nitrogen and phosphorus can cause eutrophication problems when discharged to natural water bodies. Biodegradation of proteins and urea discharged from body waste contribute to the nitrogen compounds in domestic wastewater. Typical wastewater treatment plants use biological processes for nutrient removal. Commonly use method to remove nitrogen from influent wastewater is biological nitrification-denitrification (Hung, 2009).

The process is given as below

$$NH_4^+ \leftrightarrow NH_3 + H^+ \tag{2.3}$$

$$2NH_4^+ + 3O_2 \xrightarrow{Nitrosomonas} 2NO_2^- + 4H^+ + 2H_2O + energy \tag{2.4}$$

$$2NO_2^- + O_2 \xrightarrow{Nitrobacter} 2NO_3^- + energy \tag{2.5}$$

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \tag{2.6}$$

Equation 2.3 shows that aqueous ammonium ion (NH_4^+) and gaseous free ammonia (NH_3) species remain in equilibrium in solution. Equation 2.4 and 2.5 describe the nitrification process. Nitrification happens in aerobic condition conditions. Based on equation 2.5, 4.57 g O_2/g N is needed for total oxidation of ammonia. Equation 2.6 shows the reduction of nitrate to nitric oxide (NO), nitrous oxide (N_2O) and nitrogen gas. This process is called denitrification and it takes place in presence of nitrates and absence of oxygen. Dissolved oxygen level must be at or near zero and a carbon supply must be available for the facultative bacteria. When bacteria break apart nitrate (NO_3^-) to gain the oxygen (O_2), the nitrate is reduced to nitrous oxide (N_2O) and, in turn produce nitrogen gas (N_2). Since nitrogen gas has low water solubility, it escapes into the atmosphere as gas bubbles. Free nitrogen is the major component of air, thus its release does not cause any environmental concern. (Tchobanoglous et al., 2003)

2.1.4 Potential of the Integrated Biological Reactor

Figure 2.1 shows conventional secondary wastewater treatment involves 2 stages of process demanding two separate tanks; aeration tank for bacteria reaction and clarification tank for biomass separation and a separate facility for nutrient removal.

This demands vast areas of land, which is hard to come by in major cities. In fact, land and site development costs are a major part of direct capital costs.

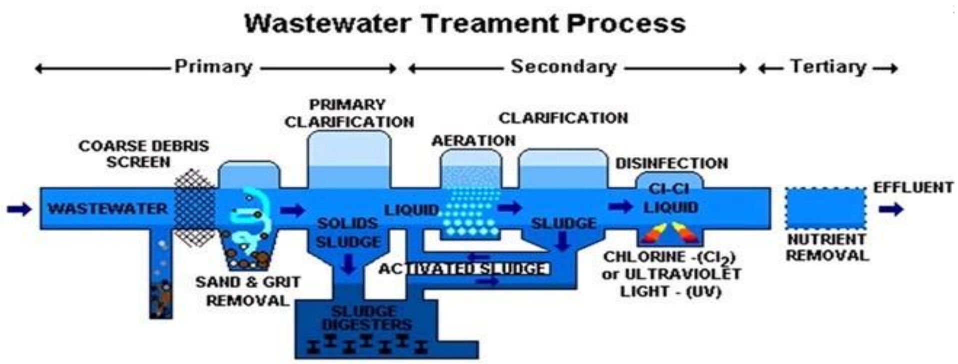

Figure 2.1 Wastewater Treatment Process

Yao et al. (2013) used submerged membrane bioreactor with the air of a heterotrophic nitrifying –aerobic denitrifying bacterial strain, *Bacillus methylotrophicus L7*. They found an optimum condition for COD removal of 96%, NH4, 77.5% and TN, 53% without nitrite accumulation. The factors that affected the removal efficiency of COD and Nitrogen are,

- Dissolved Oxygen = 4.5mg/L
- Influent pH = 7.5
- C/N ratio in influent = 3.5
- Influent ammonia concentration = <100mg/L

This is an interesting example that shows wastewater can be treated more effective and more economically by manipulating the characteristic of the influent and choosing the right type of reactor. However, membrane reactor uses requires high pressure to work, therefore it has a relative high energy cost. (Yao, Zhang, Liu, & Liu, 2013)

An Anaerobic-Aerobic Sequencing Batch Reactor (SBR) is being monitored during the treatment of piggery wastewater. It was obeserved that in the anaerobic tank both anaerobic digestion and denitrification contributes to the COD removal and gas was produced. With the collection of 70% Nitrogen gas, denitrification is the major process that occurred in the Anaerobic reactor. But, our aim is to collect a high percentage of Methane gas. It is suggested that composition of the wastewater will affect the composition of the gas collection. In the presence of high nitrite or nitrate concentration, the reactor will go through denitrification. With the low nitrogen content in the OECD synthetic wastewater, we can expect a higher percentage of methane collection. (Moletta, 1999)

In Turkey, a combined upflow anaerobic fixed-bed and suspended aerobic reactor equipped with a membrane unit has tested to exhibit a high performance on the removal of organic matter with efficiency up to 98%. It recorded phosphorus and nitrogenous material removal efficiency of 95% and above. The use of membrane requires a higher amount of maintenance. To add to that, this reactor uses two different tanks for aerobic and anaerobic which does not contribute to the space saving. It is suggested that the aerobic reactor can combined with the anaerobic reactor with a biofilm separating the two zones. This creates a macro- and micro environments within the system, so that different bacteria involved in different reactions can concentrate in zones within the reactor to their metabolic activities. (Kocadagistan, Kocadagistan, Topcu, & Demircioğlu, 2005)

3 Methodology / Procedure

3.1 Gantt Chart and Milestones

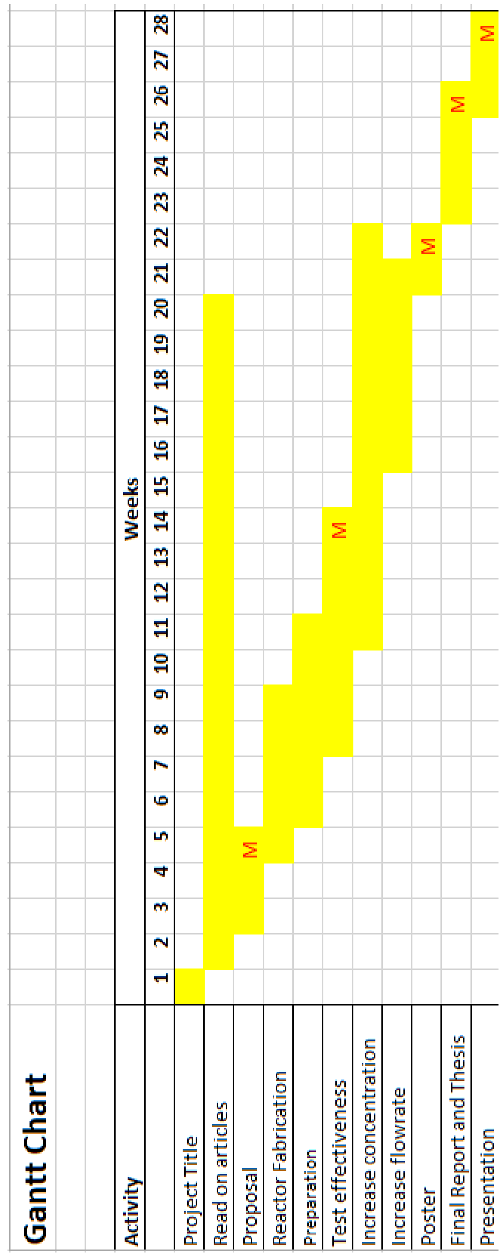

Figure 3.1 Gantt Chart

M: Milestone of the project includes proposal submission, testing effectiveness of the reactor, poster preparation, thesis, presentation.

3.2 Design & Operating Principl

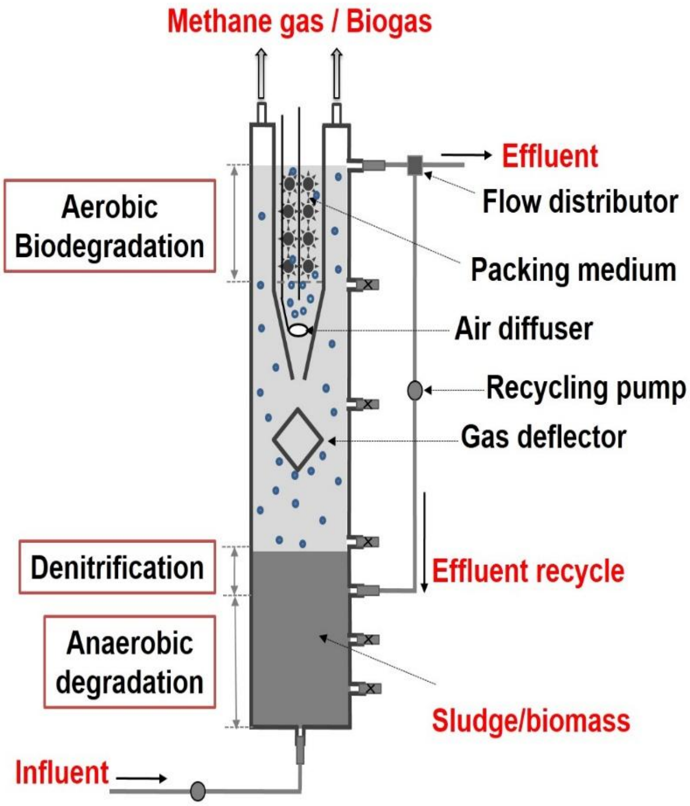

Figure 3.2 Schematic Diagram of An-ISA Reactor

Figure 3.3 An-ISA running in the laboratory

Figure 3.2 shows the schematics of the integrated biological reactor. Influent enters the reactor from the bottom, passing through the anaerobic region where sludge is present. Then it makes its way up to the aerobic region to stimulate nitrification process. The influent is then recycled and it reenters the chamber at the anaerobic section where denitrification occurs. Figure 3.3 shows the actual experimental setup of the reactor.

Organic matters are degraded by anaerobic means which produces methane in place of carbon dioxide. Furthermore, the influent moves upwards against the pull of gravity at a steady rate, this enhances the removal of nitrogen and carbon from the influent.

The methane and nitrogen produced is trapped effectively by diverting the gas bubbles away from the aerobic region towards the collecting chamber for collection. The diamond-shaped diverter does not block the flow of influent to the aerobic region but channels the gas bubbles to the collection chambers effectively.

3.3 Justification in Choosing Design

The design is chosen because:-

- Combines anaerobic, anoxic and aerobic units into a single reactor.
- Facilitates production and capture of methane, a natural gas which can be used for energy generation.
- Maintains a more steady flow of influent through the chamber for effective removal of organic and inorganic matters.

3.4 Experimental Procedure

For this project, the goal is to see whether the reactor can reduce how much COD, and other primary pollutants such as phosphorus, TKN. On the other hand, generating methane gas, CH3.

The parameters tested for both influent and effluent are COD, phosphorus, nitrate, TKN, pH and alkalinity. Synthetic wastewater with the characteristic of a domestic waste will be used on this reactor. Starting from wastewater with COD 500mg/L, Phosphorus 4mg/L, TKN of 20mg/L. Effluents were taken every day. When the COD removal achieves 90%, the COD concentration has to be increase by 100mg/L. The target is to achieve Standard B.

i) Anaerobic

The anaerobic zone of the reactor has a volume of 3.8L. Assuming an average organic loading of 10kg COD/m^3•day. The flow rate can support up to 30L/day. However, to test the efficiency of the reactor, it is suggested that the steady flow rate will be at 5L/day.

ii) Aerobic

Aerobic zone has a volume of 3.25L. The Aerobic Microorganisms are being cultivate in an external bucket filled with bio balls before being transferred into the reactor. The recycle rate of the effluent will start from 30% of the total flow rate. It will be adjust accordingly up to 60% depending on the final effluent standard.

3.5 Synthetic Sewage Preparation:

OECD synthetic sewage was used as the feed for the model plants

The synthetic sewage will contain the following composition:

1. 16g of Peptone (OXOID LP29)
2. 11g of meat extract (OXOID LP37)
3. 3g of urea
4. 0.7g of Sodium Chloride (NaCl)
5. 0.4g of Calcium Chloride dihydrate ($CaCl_2$•$2H_2O$)
6. 0.2g of Magnesium Sulphate Heptahydrate ($MgSO_4$•$7H_2O$)
7. 2.8g of dipotassium Hydrogen Orthophosphate (K_2HPO_4, anhydrous)
8. 1000ml of distilled water

The solution gives a 22,000 COD value. It was sterilized prior at 4 up to 1 week. The pH of the feed solution was 7.5. In this experiment, the solution will be diluted and we will be testing COD from 500 COD up to 3000 COD.

3.6 Hardware

1. Anaerobic Coupled-Integrated Sequential Anoxic Aerobic Reactor
   - Reactor where the bacteria treats the synthetic sewage by both aerobic and anaerobic reaction and produces methane gas
2. Air Diffuser:
   - Produces air bubbles for the aerobic part of the reactor
3. Mechanical Stirrer
   - Stir the synthetic sewage to avoid settlement in the feed tank
4. Water Pumps
   - Pumps water from the feed and for the recycled water
5. Gas Trap
   - Used for the collection of methane gas produced from the reactor
6. COD Test Equipment
   - COD vial, COD reactor, electronic stirrer, micropipette and spectrophotometer
7. Lab Equipment
   - Weighing balance, volumetric flask, measuring cylinder and etc.

3.7 Data Gathering and Analysis

For this project, there are 2 main things that wanted to be found out: the COD and nitrogen removal rate. These data were used to find out whether it is sufficient compared to a standard secondary and tertiary wastewater treatment plant.

I) COD Removal

To find out whether the COD of the wastewater is reduced after it goes out of the reactor, the COD test has to be conducted. First, finding the COD of the initial synthetic wastewater and the COD of synthetic wastewater after it has been treated inside the reactor.

By measuring both of the samples by COD test on a daily basis; there would be ability to find out the rate of the COD removal of the reactor

II) Methane Gas Collection Nitrogen Removal

Methane gas collection was conducted by using a gas trap which uses the concept of water displacement. The gas trap is first filled with water. It contains and inlet for the gas from the reactor and another inlet of the removal of displaced water. The displaced water is collected in a beaker whereby this displaced water represents the amount of methane gas produced and the amount of methane produced is measured using a measuring cylinder. This is also done on a daily basis.

Once all of these data were gathered, they had been analyzed, the COD removal rate and methane production rate of the reactor. Based on the methane gas production data, Later calculation of the energy production rate of the reactor can be applied, also comparison of the COD removal rate and the energy production rate of the reactor to the standard of the secondary and tertiary treatment of the normal wastewater treatment plant.

4 Results and Discussion

4.1 Reactor Startup

The reactor was fabricated and checked for leakage. Peristaltic pumps were being calibrated. Sludge from a palm oil mill was introduced to the reactor and acclimatized to the feed. Initial that the sludge is dilute. Hence, more sludge was taken from the STP and introduced into the reactor. To test whether the microbes was active, COD of the influent and effluent is taken every day. No oxygen was supplied to provide an anoxic-anaerobic reaction in the reactor.

After a successful start-up period, the reactor was operated at 5 L/day with a recycle volume of 2.5L/day. Which gave a recycle ratio of 0.5. The total volume of the reactor is 8L which amounted to a HRT of 38.4 hours which is a lot shorter compared to the combined anaerobic-aerobic SBR (N.Bernet, 1999) which is 30 days. Influent COD started from 100mg/L and gradually increased to 1300mg/L. It was then kept constant at 1300mg/L for the performance of the reactor to be stabilized. The efficiency of the reactor will be evaluated in terms effluent COD, CH_4 production, effluent NO_3^-, effluent NH_3.

Initially, during the start-up period, the effluent COD was much higher than the influent COD. This is attributed to the residual COD from the palm oil mill sample used for seeding the reactor. Table 4.1 indicates the influent COD and effluent COD during the start-up period. On the 5th and 7th day, the sludge is being acclimatized and started to remove the COD from the synthetic wastewater.

Table 4.1 Results of COD removal before Aerobic Treatment

Date	Influent	Effluent	Removal Efficiency
10-Apr	116	499	-330%
14-Apr	149	451	-202%
15-Apr	345	212	39%
18-Apr	391	203	48g%
21-Apr	443	106	77%

When the COD removal efficiency was up to 80%, the aerobic sludge from the STP was introduced into the top (filter section) of the reactor. Its main function is to further reduce the COD so that it will meet Standard A.

4.2 COD Removal

Table 4.2 indicates the COD removal after the addition of the aerobic treatment.

Table 4.2 Influent and Effluent COD with Aerobic Treatment

Day	Influent	Midpoint	Effluent	Removal Efficiency
14	497	166	75	85%
18	482	182	77	84%
22	493	86	73	85%
26	428	80	73	83%
30	448	77	76	83%
34	496	128	25	95%
38	512	62	36	93%
42	550	93	66	88%
46	874	295	206	76%
50	888	66	53	94%
54	856	52	50	94%

58	987	44	40	96%
62	987	85	69	93%
66	1293	132	77	94%
70	1286	112	42	97%
74	1345	125	67	95%
78	2185	168	106	95%
82	2196	145	87	96%
86	2258	125	67	97%
90	2679	159	118	96%
94	2758	123	98	96%
98	2777	98	74	97%

If the effluent standard achieves standard A, the concentration of the COD will be increased. As an overall, the removal efficiency improves after the addition of aerobic degradation. It can go up to 97% removal. It is unachievable by other reactor such as the SAR and MBR. By comparing to the UAF-B Membrane Reactor (B. Kocadagistan et al, 2005), removal rate of 98%, it utilizes less energy. In addition to that, maintenance of the UAF-B reactor is more complicated when it comes to backwashing or replacing the filter membrane. As for the An-ISA reactor, the excessive sludge can remove from the reactor just by gravity flow.

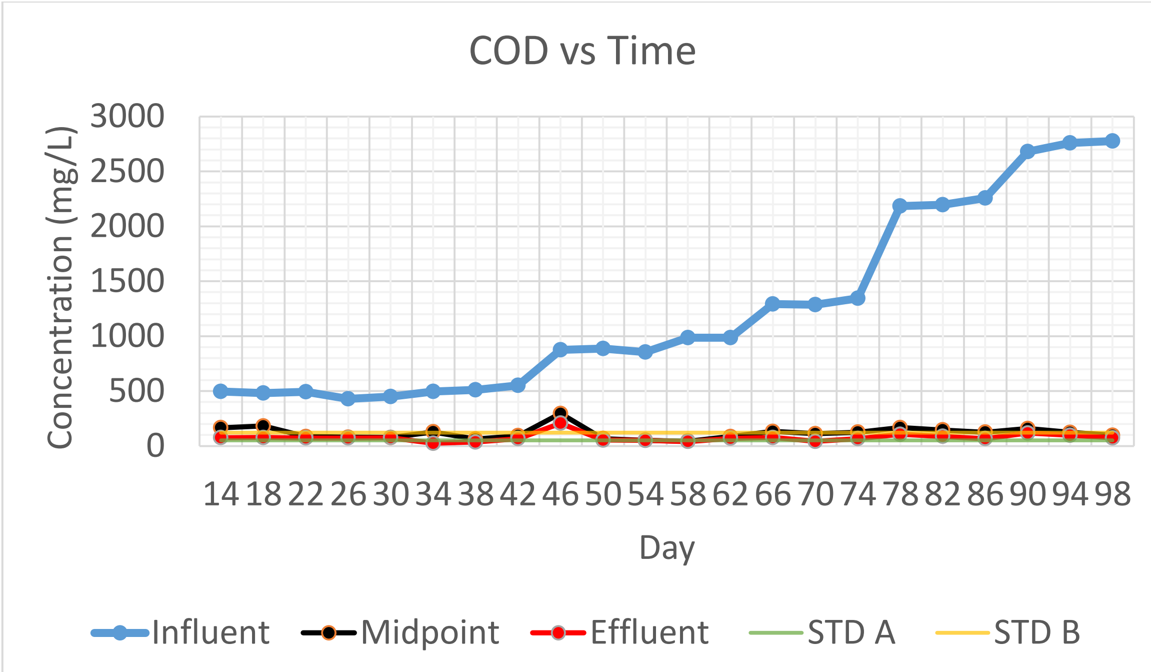

Figure 4.1 COD Concentration Vs Time

From figure 4.1, we can observe that the Effluent COD is always well below Standard B except for the time where the increment of Influent COD is being made. The reactor works effectively even at the influent concentration of 2700mg/L. This is similar to the wastewater concentration from the food production industry such as the dairy products, and the canned food.

According to visual observations, there is no significant amount of microorganism growth in the bio balls. This is mainly because the anaerobic process has removed up to 85% of COD, only a small amount is left for the aerobic process.

4.3 Ammonia Removal

Table 4.3 Influent and Effluent Ammonia Concentration

Day	Influent	Effluent
9	41.75	12
18	51	12
27	70.5	12.5
36	75	13
45	119	27
54	101	7
63	120	15
72	137	11
81	168	12
90	172	10
99	188	12

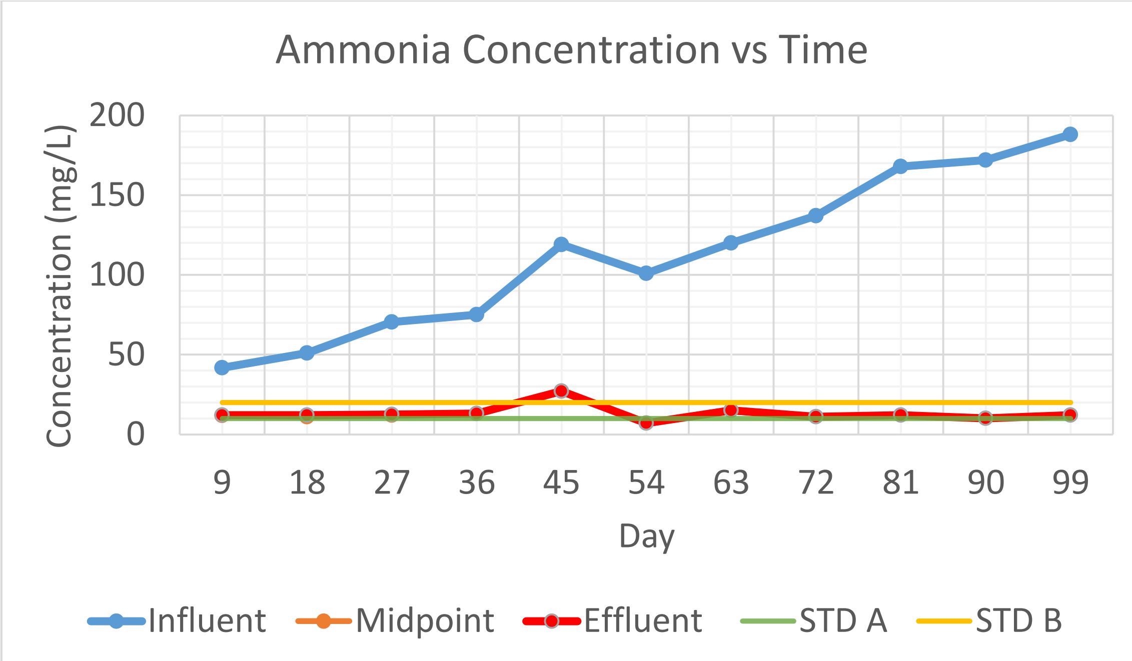

Figure 4.2 Ammonia Concentration vs Time

Table 4.3 and Figure 4.2 indicate the influent and effluent ammonia concentrations. The concentration of influent ammonia increases with the influent COD. The effluent ammonia is slightly exceeded the discharge limit of standard A. It is suggested that alkalinity of 2000 mg/L as $CaCO_3$ is being maintained in the effluent to facilitate the nitrification process. Hence, Sodium Bicarbonate, $NaHCO_3$ is used as a buffer solution to maintain the pH value around 8.3.

$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$

$CaCO_3 = 100g/mol$

$(HCO_3)^- = 61g/mol$

$$1\ mg/L\ of\ CaCO_3 = 1.22mg/L\ of\ NaHCO_3 \quad (4.1)$$

From equation 4.1, we have calculated that 3.5g of $NaHCO_3$ is needed to be added to every liter of the influent. We can see that after the addition of alkalinity the effluent ammonia concentration finally achieves the discharge level of Standard A.

Ammonia removal achieves 93% which is far effective than the submerged membrane reactor by Yao et al. of 77.5%. In addition, An-ISA reactor works well with the DO concentration of 0.16mg/L and pH value of 8.3. Thus eliminating the need of aerators to maintain the DO concentration and a higher tolerance to varying pH condition.

4.4 Nitrate Removal

Table 4.4 Influent Nitrate and Effluent Nitrate Concentration

Day	Influent	Effluent
9	1.8	16.1
18	1.5	9.5
27	1.68	2.4
36	2.2	9.3
45	4.8	2.7
54	3.3	2.6
63	2.4	1.3
72	3.2	4.3
81	2.7	5.8
90	2.4	4.2
99	2.2	3.1

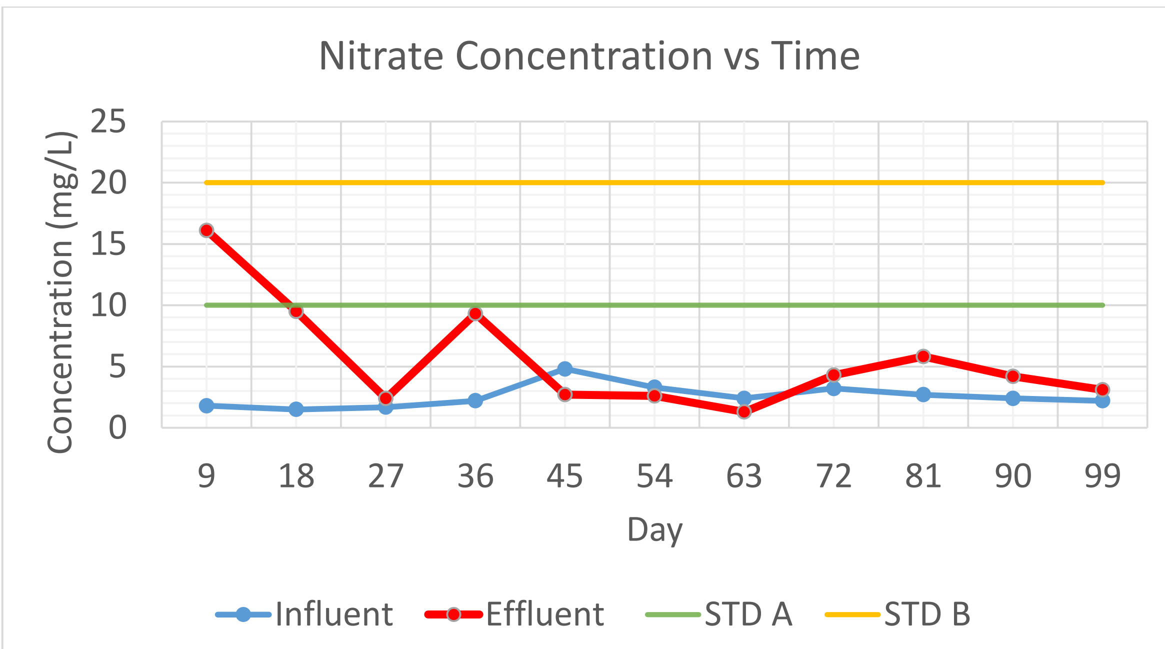

Figure 4.3 Nitrate Concentration vs Time

Table 4.4 and Figure 4.3 show the influent and effluent nitrate concentrations. The effluent nitrate concentration is higher compared to the influent nitrate concentration. This is because nitrification occurs and oxidizes ammonia to nitrate. It is then recycled in the anoxic region to be reduced into nitrogen gas. At the starting the nitrate concentration is relatively high, this is due to the denitrifying bacteria takes a longer time to grow. The effluent nitrate is always well within the discharge limit of Standard A.

4.5 Biogas Collection

Gas is being produced at the rate of 2.5L/day. The biogas content was analyzed using gas chromatography. Figure 4.4 indicates the result obtained from the chromatography.

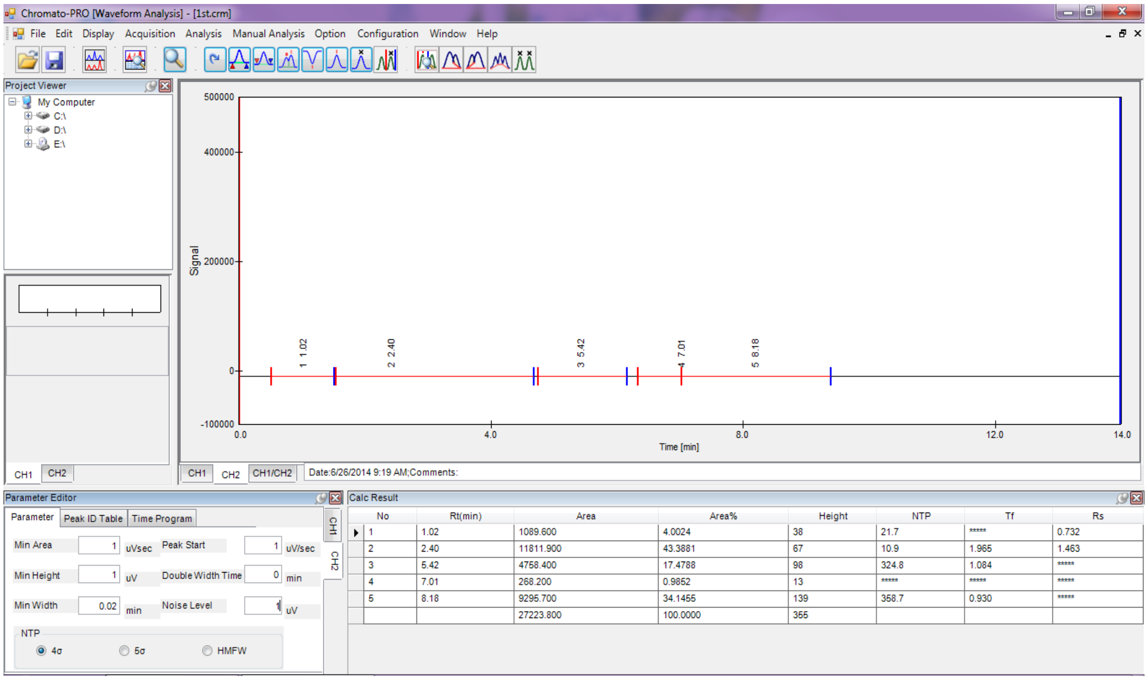

Figure 4.4 Biogas Chromatography

With the aid of the chromatography, it is certain that the biogas includes hydrogen, oxygen, nitrogen, methane and carbon dioxide.

However, further investigation has to be carried out on the exact content of the gas.

Theoretically, by removing 2000mg/L of COD at influent of 5L/day, we can collect 3.9L of methane gas which translates to energy of 128kJ/day. It is able to power a 100 watt pump for 20 minutes.

5 Conclusions and Recommendations

Organic matter and nutrient removal in wastewater was investigated in an integrated aerobic, anoxic anaerobic sequential reactor. The following conclusions were drawn from this study.

The reactor had removed up to 97 % of the COD from the OECD synthetic wastewater. The parameters like the effluent COD, nitrate and ammonia concentration had achieved the discharge limit of Standard A. Gas is being produced at the rate of 2.5 L/day. There is presence of Nitrogen and Methane gas in the gas sample.

The design of this integrated sequential anaerobic-anoxic aerobic reactor applies a simple yet effective solution to wastewater treatment. With the absence of sophistication equipment such as the decanter or aerators, the maintenance of the plant becomes easy.

The sample should be further analyze to determine the exact composition of the collected gas. To further improve the reactor, the height should be extended, to create a “supernatant zone” which acts like a sedimentation tank on top of the reactor. The suspended solid or sloughed microorganisms has a retention zone to let them settle in the reactor itself. Hence, reducing the suspended solid in the effluent.

The study should be prolonged to test the efficiency of reactor on higher range of influent COD. Upon completion of that, actual wastewater should be used instead of synthetic wastewater. It can test the reactors efficiency on real life situation and resistance to different type of chemicals.

6 References

Drinan, Joanne E. (2001). *Water & Wastewater Treatment : A Guide for the Nonengineering Professional*. Florida: Lewis Publishers.

Frijns, Jos, Hofman, Jan, & Nederlof, Maarten. (2013). The potential of (waste)water as energy carrier. *Energy Conversion and Management 65*, 357–363.

Goldstein, enne, & Peterson, Rebecca (Producer). (2006, July). Understanding Algae. *Natural Environmental Systems, LLC*. Retrieved from http://www.naturalenviro.com/Article.php?ArticleSKU=Understanding-Algae

Hung, Lawrence K.Wang;Nazih K.Shammas;Yung-Tse. (2009). *Advanced Biological Treatment Process* (Vol. 9): Humana Press.

Knobeloch, Lynda, Saina, Barbara, Hogan, Adam, Postle, Jeffrey, & Anderson, Henry. (2000). Blur Babies and Nitrate-Contaminated Well Water. *Environmental Health Perspective*, 675-678.

Kobayashi, Yu-You Li; Takuro (Ed.). (2010). *Applications and New Developments of Biogas Technology in Japan*: Imperial College Press.

Kocadagistan, B., Kocadagistan, E., Topcu, N., & Demircioğlu, N. (2005). Wastewater treatment with combined upflow anaerobic fixed-bed and suspended aerobic reactor equipped with a membrane unit. *Process Biochemistry, 40*(1), 177-182. doi: 10.1016/j.procbio.2003.11.055

Lee, Hee-Jae, Bae, Jae-Ho, & Cho, Kwang-Myeung. (2001). Simultaneous Nitrification and Denitrification in a Mixed Methanotrophic Culture. *Biotechnology Letters,* 935-941.

Moletta, N. Bernet; N. Delgenes; J. C. Akunna;J. P. Delgene;R. (1999). COMBINED ANAEROBIC±AEROBIC SBR FOR THE TREATMENT OF PIGGERY WASTEWATER.

Riffat, Rumana. (2013). *Fundementals of Wastewater Treatment and Engineering*. London: IWA Publishing.

Tchobanoglous, G., Burton, F.L., Stensel, H.D., Metcalf, & Eddy, Inc. (2003). *Wastewater Engineering: Treatment and Reuse*: McGraw-Hill Education.