

**UTILIZATION OF POLYVINYL ALCOHOL (PVA) WITH COAL
ASH TO IMMOBILIZE NITRIFYING BACTERIA FOR
AMMONIA-NITROGEN REMOVAL IN SHRIMP CULTURE
WASTEWATER RECIRCULATION SYSTEM**



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Thesis
entitled

**A NONLINEAR MODEL OF RED BLOOD CELLS WITH
EFFECTIVE DELAYS**



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UTILIZATION OF POLYVINYL ALCOHOL (PVA) WITH COAL ASH TO IMMOBILIZE NITRIFYING BACTERIA FOR AMMONIA-NITROGEN REMOVAL IN SHRIMP CULTURE WASTEWATER RECIRCULATION SYSTEM

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ABSTRACT

Immobilization of nitrifying bacteria using polyvinyl alcohol (PVA) and coal ash may be an effective method to remove ammonia-nitrogen from recirculating aquacultural water. This could help improve water quality for shrimp culture and reduce capital and operating costs. The objective of this research was to investigate the effects of mixture ratio (% PVA : coal ash) of 10.0%, 12.5%, and 15.0% (w/v) of pure PVA in combination with 3%, 5%, and 7% (w/v) of coal ash in gel beads, at hydraulic retention times (HRT) of 1, 2, and 4 hrs. A continuous nitrification bioreactor was fed with synthetic shrimp culture wastewater containing 2 mg/L ammonia-nitrogen for the determination of the removal efficiency under the optimum operating conditions of the mixture ratio and HRT.

The results showed that the average $\text{NH}_3\text{-N}$ removal efficiencies were in the range of 76-96%. The average $\text{NH}_3\text{-N}$ removal efficiencies under different conditions were significantly different ($p < 0.05$). The $\text{NH}_3\text{-N}$ removal efficiencies were affected by the mixture ratios (% PVA : coal ash) and hydraulic retention time (HRT). The average $\text{NH}_3\text{-N}$ removal efficiencies of the mixture ratio (% PVA : coal ash): 10.0:3, 5, 7 were 87%, 94%, and 95% when operated at HRT 1, 2, and 4 hrs, respectively. But there were no significant differences related to the mixture ratio (% PVA : coal ash) and HRT on chemical oxygen demand (COD) removal efficiencies ($p < 0.05$).

The optimum operating conditions of the PVA-coal gel beads in synthetic shrimp culture wastewater was at the mixture ratio (% PVA : coal ash) of 10.0:3, 5, 7 and HRT of 2 hrs., which yielded $\text{NH}_3\text{-N}$ and COD removal efficiencies of 93.64%, and 1.62%, respectively with an ammonia removal rate of 24.26 g/m³-day. The high removal efficiency and removal rate obtained in this research work indicates that coal ash could be mixed with PVA to immobilize nitrifier and the immobilized nitrifier technology has a high potential application for the removal of ammonia-nitrogen from recirculating aquaculture wastewater.

KEY WORDS : THE PVA-COAL IMMOBILIZATION OF NITRIFYING BACTERIA / THE AMMONIA-NITROGEN REMOVAL EFFICIENCY / MIXTURE RATIO (% PVA: COAL) / HYDRAULIC RETENTION TIME (HRT)

173 pp.

การใช้โพลีไวนิล แอลกอฮอล์ ร่วมกับเถ้าถ่านหินในการตรึงแบคทีเรียไนตริไฟอิง เพื่อกำจัดแอมโมเนียในโตรเจนในระบบหมุนเวียนน้ำเสียจากการเพาะเลี้ยงกุ้ง (UTILIZATION OF POLYVINYL ALCOHOL (PVA) WITH COAL ASH TO IMMOBILIZE NITRIFYING BACTERIA FOR AMMONIA-NITROGEN REMOVAL IN SHRIMP CULTURE WASTEWATER RECIRCULATION SYSTEM)

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บทคัดย่อ

การตรึงเชื้อไนตริไฟอิงแบคทีเรียโดยใช้โพลีไวนิล แอลกอฮอล์ (PVA) ร่วมกับเถ้าถ่านหิน (coal ash) เป็นวิธีการหนึ่งที่มีประสิทธิภาพในการกำจัดแอมโมเนียในโตรเจนในระบบหมุนเวียนน้ำเสียจากการเพาะเลี้ยงกุ้ง เพื่อปรับปรุงคุณภาพน้ำให้เหมาะสมสำหรับการเพาะเลี้ยง และเป็นการลดค่าใช้จ่ายในการจัดการอีกด้วย การศึกษานี้จึงมีวัตถุประสงค์เพื่อศึกษาผลกระทบบของอัตราส่วนของส่วนผสมที่ต่างกัน ในเจลบีท (gel beads) คือ 10.0, 12.5, และ 15.0 ของพีวีเอ (PVA) (ร้อยละน้ำหนักโดยปริมาตร) และพีวีเอ (PVA) ในอัตราส่วนดังกล่าวผสมกับเถ้าถ่านหิน (coal ash) 3, 5, และ 7 (ร้อยละน้ำหนักโดยปริมาตร) ในเจลบีท (gel beads) และระยะเวลาที่เก็บน้ำในระบบที่ต่างกันคือ 1, 2, และ 4 ชั่วโมง น้ำเสียสังเคราะห์ที่มีความเข้มข้นของแอมโมเนียในโตรเจน 2 มิลลิกรัมต่อลิตร ถูกนำมาวิเคราะห์และหาประสิทธิภาพในการกำจัดแอมโมเนียในโตรเจน เพื่อใช้เป็นดัชนีชี้วัด สำหรับการหาสภาวะที่เหมาะสมของอัตราส่วนของส่วนผสมในเจลบีท (พีวีเอ : เถ้าถ่านหิน) และระยะเวลาที่เก็บน้ำในระบบ

จากผลการทดลองพบว่า ประสิทธิภาพการกำจัดแอมโมเนียในโตรเจนเฉลี่ยอยู่ระหว่างร้อยละ 75.73-95.68 ประสิทธิภาพการกำจัดแอมโมเนียในโตรเจนของแต่ละอัตราส่วนของส่วนผสมมีความแตกต่างกันอย่างมีนัยสำคัญ (ที่ระดับความเชื่อมั่น 95%) โดยที่อัตราส่วนของส่วนผสมในเจลบีท และระยะเวลาที่เก็บน้ำในระบบมีผลต่อประสิทธิภาพการกำจัดแอมโมเนียในโตรเจน แต่ไม่มีผลต่อประสิทธิภาพการกำจัดซีโอดีอย่างมีนัยสำคัญ (ที่ระดับความเชื่อมั่น 95%) ซึ่งประสิทธิภาพการกำจัดแอมโมเนียในโตรเจนเป็นร้อยละ 86.49, 93.64, และ 95.30 เมื่อใช้เจลบีทที่มีอัตราส่วนของส่วนผสม พีวีเอ:เถ้าถ่านหิน เป็น 10.0 : 3, 5, 7 (ร้อยละน้ำหนักโดยปริมาตร) ทำการทดลองที่ระยะเวลาที่เก็บน้ำเป็น 1, 2 และ 4 ชั่วโมง ตามลำดับ

สภาวะที่เหมาะสมของการกำจัดแอมโมเนียในโตรเจนในน้ำเสียสังเคราะห์ คือ ที่อัตราส่วนของส่วนผสมในเจลบีท (พีวีเอ : เถ้าถ่านหิน) เป็น 10.0 : 3, 5, 7 (ร้อยละน้ำหนักโดยปริมาตร) และระยะเวลาที่เก็บน้ำในระบบเป็น 2 ชั่วโมง ซึ่งมีประสิทธิภาพในการกำจัดแอมโมเนียในโตรเจน และ ซีโอดี เป็นร้อยละ 93.64 และ 1.62 ตามลำดับ และมีอัตราการกำจัดแอมโมเนียในโตรเจน เป็น 24.26 กรัมต่อลูกบาศก์เมตรต่อวัน งานวิจัยครั้งนี้ชี้ให้เห็นว่าเถ้าถ่านหินสามารถใช้เป็นส่วนผสมในพีวีเอในการตรึงเชื้อไนตริไฟอิงแบคทีเรียและเทคโนโลยีการตรึงเชื้อไนตริไฟอิงแบคทีเรียมีศักยภาพสูงในการกำจัดแอมโมเนียในโตรเจนและในน้ำเสียที่ใช้ในระบบหมุนเวียนน้ำเสียจากการเพาะเลี้ยงสัตว์น้ำได้

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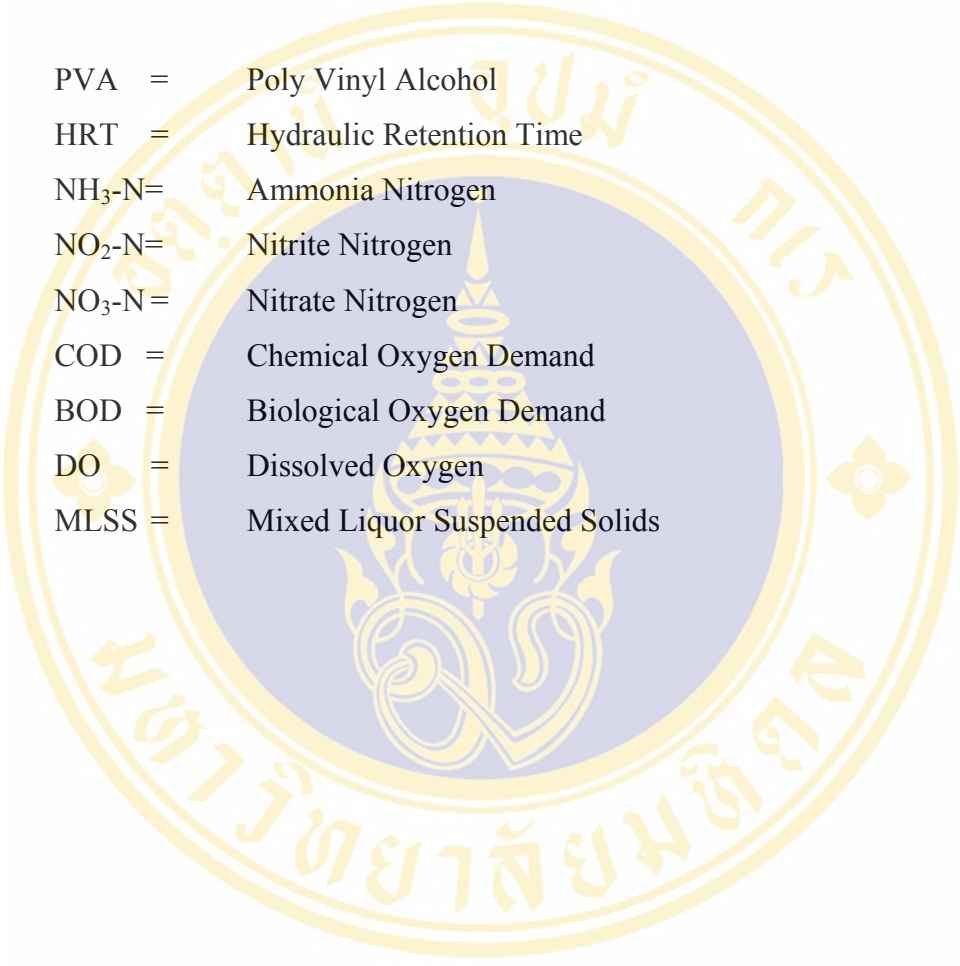
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LIST OF ABBREVIATIONS



PVA	=	Poly Vinyl Alcohol
HRT	=	Hydraulic Retention Time
NH ₃ -N	=	Ammonia Nitrogen
NO ₂ -N	=	Nitrite Nitrogen
NO ₃ -N	=	Nitrate Nitrogen
COD	=	Chemical Oxygen Demand
BOD	=	Biological Oxygen Demand
DO	=	Dissolved Oxygen
MLSS	=	Mixed Liquor Suspended Solids

CHAPTER I

INTRODUCTION

1.1 Rationales and Justifications

Ammonia is the main nitrogenous waste that is produced by aquatic animal via metabolism and is excreted across the gills as ammonia gas. Ammonia can also be produced from the decomposition of organic wastes resulting in the breakdown of decaying organic matter such as animals and uneaten food. Ammonia is present in two forms in water – as a gas NH_3 or as the ammonium ion (NH_4^+). Ammonia can cause gill irritation, respiratory problem, and affects on their food ingestion as well as growth and survival rates of aquatic animal, such as shrimp.

Nitrification is a microbial process by which reduced nitrogen compounds (primarily ammonia) are sequentially oxidized to nitrite and nitrate. Nitrification in marine biological filters has been studied in order to design a closed recirculation marine aquaculture system for marine shrimp culture.[1] The ammonia and nitrite concentrations were reduced in rearing water, and nitrification performance in marine system was studied.

Ammonia, within recirculation systems of the wastewater treatment plant, is broken down by the bacteria within the biofilter via nitrification. Ammonia levels will depend on the temperature of the water and its pH. If ammonia levels become elevated it is important to check the effectiveness of the biofilter within the recirculation system.[66]. Biofilters can be failed due to mechanical failure or biological failure caused by the inhibition of bacterial activity. Bacterial activity can be reduced due to toxicity from chemicals, natural aging, lack of oxygen, pH, etc. It is important to remember that bacteria are living organisms and require just as much care as the culture species [68]. Bacteria survival is extremely important as it ensures the health, growth, and survival of shrimp.

Recently, immobilized-cells processes have been receiving an increasing attention in the field of wastewater. Because the immobilization of nitrifier bacteria cells in support gel is one important step to maintain a high cell density and prevent washout of the slow-growth autotrophic nitrifying under a low water temperature or high water flow condition [2]. Furthermore, the sensitivity to temperature of the nitrification process is less in the case of the immobilized bacteria [3], which is good for many biological nutrients removal (BNR) processes.

There are two types of immobilization technique: attachment and encapsulation. Immobilization by attachment can be obtained by spontaneous biomass adhesion onto porous support media such as polyurethane foam and inorganic matrix. Encapsulation is accomplished using porous polymeric materials such as alginate, agar, polyacrylamide, carrageenan, cellulose acetate and poly-vinyl alcohol (PVA) to confine the migration of microorganisms [4–6]. The most widely used material for encapsulation is PVA because the freezing–thawing method is a simple technique, which does not involve chemical initiation. Many studies have been carried out with PVA encapsulation for nitrification [7–9] to treat wastewater using the encapsulation technique. [50, 51, 53]

PVA as support material needs to satisfy physical stability requirements. For example, solubility, biodegradability, diffusivity and mechanical stability are priority concerns. PVA offers various advantages over the conventional alginate hydrogels including high durability and chemical stability, and non-toxicity to viable cells but high cost to processing. The properties for immobilized biosorption agent include: maximum amount of biomass with minimal quantities of binding agent present, excellent porosity, Chemical resistance, Structure integrity and low cost to process. [10, 56]

As coal is burned in a power plant or industrial boiler, its noncombustible mineral content (ash) is partitioned into coal ash (or slag), which remains in the furnace, and fly ash, which rises with flue gases. Coal ash is easy to collect since it is removed during routine cleaning of the boilers. The properties of coal ash make it a good road base and construction material, and, as such, it can be readily given away or sold.

The feature of coal ash granulated material as a geotechnical material is followed as: Particle density is comparatively small, because it has voids in a particle. Amount of gravel is few and the particles size distribution is similar to sandy soil. This results in water permeability, water absorption, and optimum moisture content are also comparatively high. Since bearing capacity characteristic is comparatively large, it can be used as embankment material and subgrade material. [11]

The possibility of using coal ash mixed with Poly vinyl alcohol (PVA) to form gel beads was studied. Since the feature of coal ash has the properties to be used as an admixture to reinforce and replace the percentage of PVA in gel beads, it reduced the capital and operating investment costs.

The aims of the experimental works are, therefore, to investigate the optimal percentages of PVA and coal ash used for immobilization of nitrifying bacteria to remove ammonia-nitrogen under different hydraulic retention times (HRTs). The efficiency of ammonia-nitrogen removal by the immobilized nitrifying bacteria in the continuous bioreactors is finally evaluated.

1.2 Research Objectives

1.2.1 General Objective

To investigate the ammonia-nitrogen removal efficiency in shrimp culture wastewater recirculation system using the mixture of Polyvinyl alcohol-coal ash (PVA-coal) to immobilize nitrifying bacteria gel beads in the continuous bioreactor under different ratio of PVA : coal ash in gel beads and hydraulic retention times (HRTs).

1.2.2 Specific Objectives

The specific objectives of this study are as followed:

- 1) To maintain a high nitrifying bacteria cell density and to prevent the wash out of bacteria under high water flow condition by immobilizing it with PVA-coal gel beads.

2) To investigate the optimum ratio (percentage) of PVA : coal ash to remove ammonia-nitrogen ($\text{NH}_3\text{-N}$) and nitrite-nitrogen ($\text{NO}_2\text{-N}$) in the continuous nitrification bioreactor.

3) To investigate ammonia-nitrogen ($\text{NH}_3\text{-N}$) and nitrite-nitrogen ($\text{NO}_2\text{-N}$) removal efficiency under the different of hydraulic retention times (HRTs).

1.3 Research Hypotheses

1.3.1 The removal efficiencies of ammonia-nitrogen ($\text{NH}_3\text{-N}$) and nitrite-nitrogen ($\text{NO}_2\text{-N}$) will differ with different ratio of mixture by volume (PVA : coal).

1.3.2 The removal of ammonia-nitrogen ($\text{NH}_3\text{-N}$) and nitrite-nitrogen ($\text{NO}_2\text{-N}$) concentrations in effluents will increase as the hydraulic retention times (HRTs) increase.

1.4 Research Variables

1.4.1 Independent Variables

- The ratio (percentage) of PVA : coal ash in beads.
- Hydraulic retention times (HRTs).

1.4.2 Dependent Variables

- Ammonia-nitrogen ($\text{NH}_3\text{-N}$)
- Nitrite-nitrogen ($\text{NO}_2\text{-N}$)
- Nitrate-nitrogen ($\text{NO}_3\text{-N}$)
- Chemical oxygen demand (COD)

1.4.3 Control Variables

- Volume of immobilized PVA-coal nitrifying bacteria gel beads. (0.3 liter of PVA-coal immobilized nitrifying bacteria gel beads / 3 liter bioreactor)
- Characteristics of the synthetic feeding media

- Salinity of synthetic wastewater (20 g/l.)
- The concentration of dissolved oxygen

1.5 Scope of the Study

This research is an experimental research involving an operation of continuous nitrification bioreactor, made from acrylic plastic. The continuous nitrification bioreactor is continuously operated at all time. The scopes of this research include the followings:

1.5.1 The nitrifying bacteria used in this study was enriched by inoculating activated sludge from Sri-Phraya treatment plant with specific medium prepared for nitrifying bacteria growth.

1.5.2 Polyvinyl alcohol (PVA) 70,000-100,000 avg.MW. used for immobilizing nitrifying bacteria was obtained from Sigma Co.,Ltd., USA.

1.5.3 Coal ash used for mixture with polyvinyl alcohol (PVA) was obtained from the coal slag, which was a by-product in the boiling unit of Charoen Pokphand Foods Co., Ltd., Samuth-Sakorn, Thailand.

1.5.4 The synthetic wastewater contained ammonia-nitrogen ($\text{NH}_3\text{-N}$) concentration of about 2 mg/l, salinity 20 g/l, which sea water from dilution of brine water was obtained from Phaonarong-phaojinda Co., Samuth-Sakorn, Thailand.

1.6 Limitation of the Study

1.6.1 This experimental lab-scale apparatus was installed and operated at the Water Quality laboratory, Charoen Pokphand Foods Co., Ltd., Samuth-Sakorn, without temperature control.

1.6.2 PVA-coal gel beads processing were manually practiced.

1.6.3 Synthetic wastewater in this study was imitated shrimp culture wastewater.

1.7 Definition of Keywords

1.7.1 Nitrifying bacteria: Microorganisms were classified as Autotrophic, have the ability to transform ammonia into less harmful chemicals.

1.7.2 Nitrification: Nitrification comprises the oxidation of ammonia to nitrite and the subsequent oxidation of nitrite to nitrate by nitrifying bacteria within aerobic condition.

1.7.3 Pure Culture: A microorganism growing on or on a medium and it is only one kind of microorganism.

1.7.4 Polyvinyl alcohol (PVA): A polymer prepared from polyvinyl acetates by replacement of the acetate group with hydroxyl group used to immobilize nitrifying bacteria.

1.7.5 Immobilization: Immobilized nitrifying bacteria with polyvinyl alcohol (PVA) to maintain a high cell density and prevent the washout of the slow-growth autotrophic nitrifying under a low water temperature or high water flow condition.

1.7.6 Coal ash: The finely divided residue that results from the combustion of coal.

1.7.7 Recirculation aquaculture system: Comprises rearing aquatic animal pond and treatment pond which water effluent from rearing aquatic animal pond was treated in treatment pond and reused in rearing aquatic animal pond again.

1.7.8 Nitrogen removal: Inorganic nitrogen was removed from system by nitrifying bacteria.

1.7.9 Hydraulic retention time (HRT): Period of influent water pass bioreactor.

1.7.10 Ammonia removal efficiency: Efficiency of remove ammonia out of system expressed in percentage.

1.7.11 Removal rate: Rate of remove expressed in g/m^3 per day.

1.7.12 Sludge: All those solids, which settle to the bottom of the sediment tank of wastewater treatment plant.

1.7.13 Total Ammonia-nitrogen (TAN): The combined total concentration of unionized and ionized ammonia.

1.7.14 Chemical oxygen demand (COD): The oxygen demand of the organic and inorganic matters that can be oxidized by using a strong chemical oxidizing agent.

1.7.15 mixed liquor suspended solids (MLSS): The concentration of suspended solids (both organic and inorganic) in the mixed liquor of an aeration tank. MLSS is used as a measure of the concentration of microorganisms present



1.8 Conceptual framework

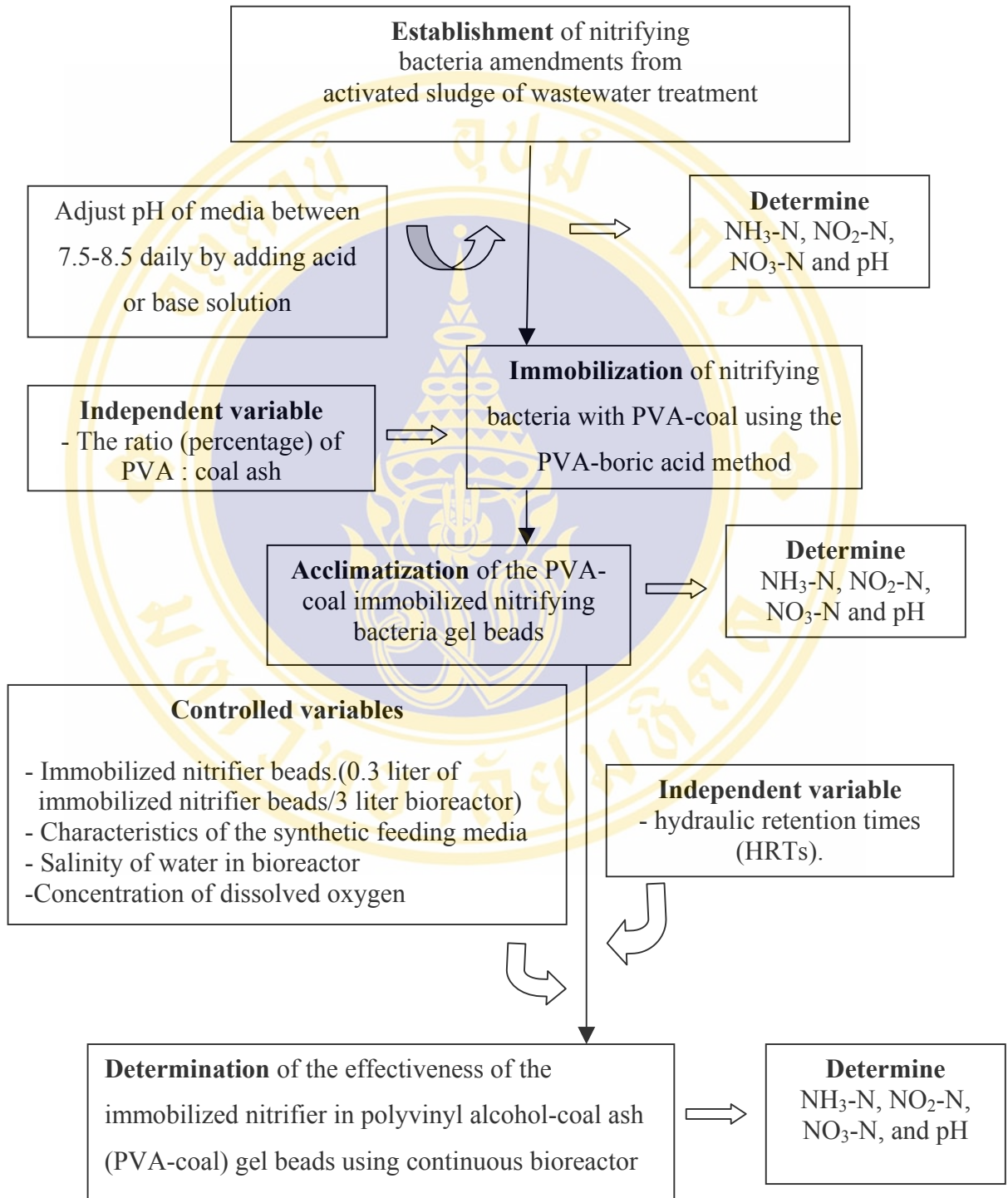


Figure 1.1 Conceptual framework

CHAPTER II

LITERATURE REVIEW

2.1 Shrimp Culture System

Marine shrimp farming was a century-old practice in many Asian countries. Until a decade ago, this commodity was generally considered as a secondary crop in traditional fish farming practices. Shrimp trapped in salt beds, coastal paddy fields or brackishwater fishponds were allowed to grow according to marketable size and harvested. However, in recent years when higher income were derived from the harvest of shrimp than the principal crop, many farmers have converted their rice fields, salt beds, and fishponds into shrimp farms.

The success in the mass production of hatchery shrimp has accelerated shrimp farming development in the region. With improved pond culture techniques, yield from traditional shrimp ponds has been raised to 80–128 kg/rai/year without supplementary feeding. Pond yield can be further increased to 5,000–10,000 kg through supplementary feeding and intensive pond management.

The long gestation period in the development of shrimp farming practice may be due to inadequate technical and financial inputs to effectively demonstrate its commercial viability. Shrimp farming has now developed into an important export-oriented food industry, especially in South Asian countries. The perception of an unlimited market demand, high export price, generation of employment, and increase in foreign exchange earnings may have encouraged many countries in the region rich in aquatic resources to place high emphasis on the development of the shrimp culture industry.

2.1.1 Pond Culture System

Although shrimp farming has been developed for more than a century in Southeast Asia, the main farming operations are still traditional. Such operational

practice is characterized by low yield and also relatively low technical and financial inputs. Due to high market demand of products and low cost of land, these traditional farms are still commercially profitable.

Shrimp yield in ponds can be increased by applying modern farming techniques such as intensification of culture operation through regularization of pond size, increase stocking density, employment of aeration, application of formulated feed, etc. This will mean a considerable increase in financial and high technology inputs which most small farmers in the developing countries may not be able to afford.

- Extensive method of culture operation

Extensive culture operation is considered as the simplest culture approach. Seedstock normally come from the wild and supply is season dependent. Shrimp found in these farms either gained entrance during water exchange or are intentionally stocked by the farmer with fry collected from the wild. Extensive farming employs very low stocking densities, usually in the range of about 480–800 shrimps per rai. In this grow-out scheme, supplementary feed is not given and water management is by tidal exchange.

- Semi-intensive method culture operation

In this farming method, the improvement over the traditional approach is in the introduction of a systematic pond configuration. Each pond has separate inlet and outlet gates to facilitate water exchange, pond preparation and harvesting. The typical rate of stocking shrimps for semi-intensive culture operation varies from 3,200 to 8,000 shrimps per rai. Supplementary feed, either formulated or fresh, is given daily in addition to the existing natural food produced through the application of fertilizers. This operation also requires the use of a water pump to facilitate water exchange.

- Intensive method of culture operation

This culture operation is more sophisticated requiring very high financial and technical inputs. The rearing facilities are either earthen ponds or concrete tanks. The distinct features of this culture operation is the complete

dependence on hatchery-bred shrimp, high stocking density, use of formulated feeds, application of aeration to increase dissolved oxygen level in pond water and intensive water management.

The shrimps are fed daily with high protein formulated diet. Stocking density ranges from 200–250 per m² and average production ranges from 1,500 to 3,000 kg per crop in 1,000 ton tank.

2.1.2 Water Quality Management

In any shrimp farming, management of water quality is of primary consideration particularly in ponds with higher stocking rates. Degradation of water quality is detrimental to shrimp growth and survival. Good quality water is usually defined as the fitness or suitability of the water for survival and growth of shrimp.

- Salinity

Juvenile shrimps appear to tolerate a wider fluctuation of salinity than the adults. The post-larvae of many Penaeid species can tolerate wide salinity fluctuation which has little effect on their survival or growth. In pond condition, *P. monodon* can tolerate wide range of salinity from as low as 5 g/l. to a high of 40 g/l. Many *Metapenaeus* also tolerate high salinity. *P. merguensis* and *P. indicus* prefer brackish water while *P. semisulcatus* and *P. japonicus* require more saline condition for growth (27–32 g/l).

Due to high evaporation rate in some provinces, salt concentration in ponds gradually increases during the summer months. Salinity may increase to beyond 40 g/l and thus retard growth. This should be taken into consideration when brackishwater species are used since salinity may increase above their limit of tolerance. In such cases, the species cultured should be changed during the summer months to conform with increasing salinity or the water should be changed frequently either by pumps or through tidal exchange.

- pH

The pH of the pond water is indicative of its fertility or potential productivity. Water with pH ranging from 7.5 to 9.0 is generally regarded as suitable

for shrimp production. The growth of shrimps is retarded if pH falls below 5.0. Water with low pH can be corrected by adding lime to neutralize the acidity.

Water of excessive alkalinity (pH values > 9.5) may also be harmful to shrimp growth and survival. In ponds which are excessively rich in phytoplankton, the pH of pond water usually exceeds 9.5 during late afternoon. However, at daybreak, the pH is usually lower. Excessive plankton growth can be corrected by water exchange.

-Dissolved oxygen (DO)

Maintenance of adequate level of dissolved oxygen in pond water is very important for shrimp growth and survival. Prolong exposure to the stress of low concentration of oxygen lowers their resistance to disease and inhibits their growth. In most cases, oxygen depletion often resulted in mass mortality of shrimp stock. This is particularly common in intensive culture operation.

Dissolved oxygen in the pond water comes from two sources. Most of it comes as a by-product of photosynthesis. The other source is from the diffusion of atmospheric air. The amount of dissolved oxygen in the pond water is affected by many factors particularly water temperature, respiration and the level of organic matter. In tropical shrimp pond, the oxygen level in the pond water is normally low because of the higher temperature. However, tropical species are able to adapt to lower oxygen concentration than their temperature counterparts.

During daytime, more oxygen is produced through photosynthesis than is removed from the water by the respiration of shrimps. At night, both plants and shrimps continue to respire while oxygen is being added to the water only from the atmosphere.

- Nitrogen compound

Nitrogen in pond exists in different forms such as ammonia, nitrite, nitrate and various forms of organic nitrogen. Organic nitrogen ranges from relatively simple dissolved compounds such as amino acids to complex particulate organic matter. Nitrogen occurs in the mud in the same form that exist in water. In pond culture activities, ammonia nitrogen (in the form of un-ionized ammonia) is

considered important since this compound is toxic to aquatic animals at certain concentrations. Ammonium ions which is another form of ammonia nitrogen is harmless except at extremely high concentrations.

Ammonia nitrogen is a product of shrimps metabolism and decomposition of organic matter by bacteria. The pH and temperature of the water regulate the proportion of total ammonia which occurs in un-ionized form. The highest concentration of total ammonia nitrogen usually occur after the peak of phytoplankton bloom when most of them died. The pH of the water is low because of high concentration of carbon dioxide.

- Temperature

Water temperature plays a very important role in regulating the activities of shrimps. The rate of chemical and biological reactions is said to double every 10°C increase in temperature. This means that aquatic organisms will use twice as much dissolved oxygen and chemical reactions will progress twice as fast at 30°C than 20°C. It follows therefore that dissolved oxygen requirement of aquatic species is higher in warmer than in cooler water.

Many Penaeid species are tropical or subtropical species. The optimum temperature is about 25–30°C and hence many of the species such as *P. indicus*, *P. monodon* and *P. merguensis* can be cultured throughout the year while *P. japonicus* and *P. orientalis* are limited to the summer growing seasons only.

- Hydrogen sulfide, H₂S

Hydrogen sulfide can severely affect shrimp growth in pond. H₂S is produced by chemical reduction of organic matter that accumulates and forms a thick layer of organic deposits at the bottom. The bottom soil turns black and a rotten smell is discharged if disturbed. High levels of hydrogen sulfide would affect directly to burrowing shrimps such as *P. monodon*. At levels of 0.1–0.2 mg/l in the water, the shrimps appear to loss their equilibrium and die instantly at a concentration of 4 mg/l.

Using iron oxide (70% ferrous oxide) to treat the bottom soil containing high levels of H₂S would not be economical. The cheaper means is by frequent exchange of water to prevent building up of H₂S in the pond.

2.2 Nitrogen

Nitrogen (N) is an essential nutrient for all organisms, being present in the form of proteins, nucleic acids, adenosine phosphates, pyridine nucleotides, and pigments. Fish and shrimp expel various nitrogenous waste products through gill diffusion, gill cation exchange, urine, and feces. In aquaculture, uneaten feed also contributes to nitrogenous waste loading. [13]

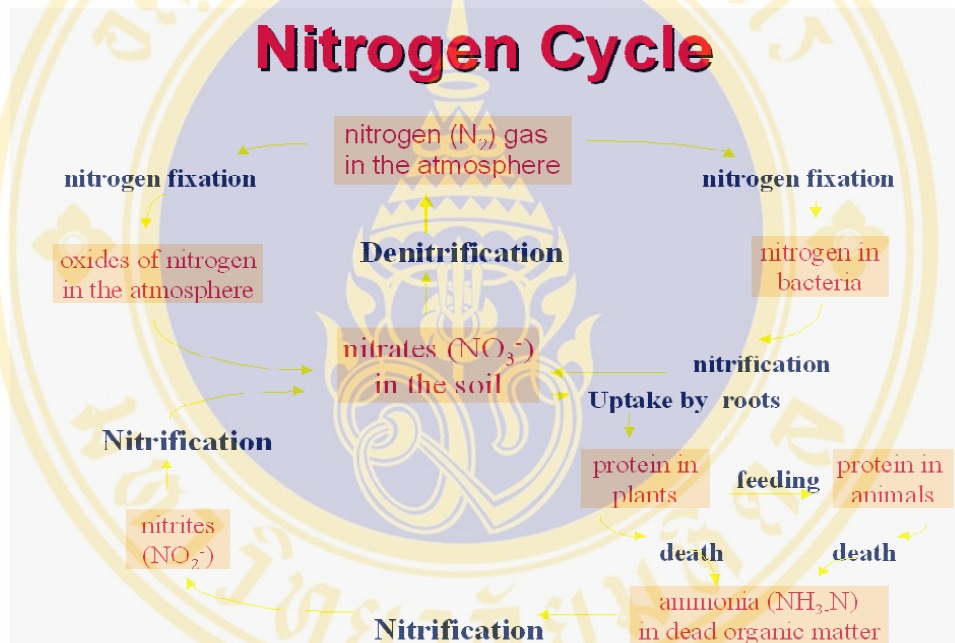


Figure 2.1 The nitrogen cycle

The nitrogen cycle involves ammonia fixing and nitrifying reactions in organising and denitrification, which is the same process in reverse. The nitrification process involves oxidation of ammonia to nitrite and nitrite to nitrate which is an energy yielding process utilized by nitrifying bacteria.

All of the steps in the familiar nitrogen cycle (Fig. 2.1) occur even in small ponds. Most transformations in the cycle are biochemical, and nitrogen usually undergoes a valence change at each step. Valence states of nitrogen range from -3 for

ammonia to +5 for nitrate. In contrast to the largely a biotic phosphorus cycle, the nitrogen cycle in ponds is regulated primarily by biological activity.

2.2.1 Transformations of Nitrogen

Fixation of molecular nitrogen (N_2) from the atmosphere by biological, meteorological, or industrial processes is the primary source of inorganic nitrogen for ecological systems. Table 2.1 lists the oxidation states that elemental nitrogen may assume and the corresponding inorganic species. Proteinaceous nitrogen is present in the most reduced form (i.e. -3). The same is true for the nitrogen atom in ammonia and ammonium. For nitrite, the oxidation state is -3. For nitrate, the most oxidized form of nitrogen, it is +5. Since these are the inorganic species of importance to water quality.

Table 2.1 Simple forms of inorganic N and oxidation state of the N atom

Species	Common name	N
NH_3	Anhydrous or free or un-ionized ammonia, ammonia gas	-3
NH_4	Ammonium, ammonium ion, ionized ammonia	-3
NH_4OH	Ammonium hydroxide	-3
N_2H_4	Hydrazine	-2
N_2H_5	Hydrazinium ion	-2
N_2H_5OH	Hydrazine hydrate	-2
NH_2OH	Hydroxylamine	-1
HN_3	Hydrogen azide, hydrazoic acid	-1/3
N_3	Azide ion	-1/3
N_2	Nitrogen, nitrogen gas, dinitrogen gas	0
N_2O	Nitrous oxide, nitrous oxide gas, 'laughing gas'	-1
$H_2N_2O_2$	Hyponitrous acid	-1
NO	Nitric oxide, nitric oxide gas	-2
NO_2	Nitrite ion	-3
HNO_2	Nitrous acid	-3

Species	Common name	N
N ₂ O ₃	Dinitrogen trioxide, anhydrous nitrous acid	-3
NO ₂	Nitrogen dioxide	-4
N ₂ O ₄	Dinitrogen tetroxide, nitrogen peroxide	-4
NO ₃	Nitrate ion	-5
HNO ₃	Nitric acid	-5
N ₂ O ₅	Dinitrogen pentoxide, anhydrous nitric acid	-5

However, our discussion will begin with the decomposition of organic matter. Most of the nitrogen in organic matter exists as amino groups in protein. Through microbial activity, proteins are delaminated and ammonia nitrogen is called ammonification and ammonia is produced. This process is called ammonification and ammonia is released to the environment (mineralization) or assimilated into microbial tissue. Any ammonia released to the environment establishes the following equilibrium with the ammonium ion:



In most habitats, ammonium ion will be the predominant species for reasons, which will be explained later. Ammonification is a heterotropic process, which occurs under either aerobic or anaerobic conditions.

Ammonia is a major metabolic waste product from aquatic animal. It is excreted across the gill membranes and in the urine. The primary source of ammonia in aquaculture systems is animal feed. When feed is eaten by aquatic animal it is metabolized into the energy, nutrients, and proteins used for survival and growth. As with all animals, there is waste produced by these normal metabolic processes. Ammonia is the principal waste product excreted by aquatic animals. In trace amounts, ammonia is odorless and colorless, so the only way for an aquaculturist to know if it is there is to test the water.

2.2.2 Ammonia and Nitrite Toxicity

1). Ammonia

Scientific study has clearly proven that wastes excreted by aquatic animals are in the form of ammonia and urea. At a pH range of 6-8 approximately 90% of the total nitrogenous waste is excreted across the gills, with ammonia accounting for approximately 85% of this total. Excretion of urea usually makes up the remaining 10-20%. The amount of ammonia excreted by aquatic animals varies with the amount of feed put into the aquarium, accelerating as stocking and feeding rates increase. In well-planted tanks most of the ammonia is taken up directly by the plants (including algae), as most plants prefer ammonia if given a choice. When nitrate is used, the nitrate must first be reduced to ammonia (the reverse of nitrification). However, in the average aquarium most of the ammonia will be converted by nitrifying bacteria to nitrite, and then nitrate.

Ammonia is toxic to fish and must be removed or converted into benign substances before it builds up to lethal levels. It exists as a mixture of two forms, unionised ammonia (NH_3) and ionised ammonia (NH_4^+) in equilibrium. The combined total concentration of unionized and ionized ammonia is termed the “Total Ammonia Nitrogen” concentration, or TAN for short. This does not mean that they are present in equal proportions, but that they are converted from one to the other at an equal rate depending upon the pH, temperature and salinity of the water. Ammonia increase is often concomitant with decrease in DO and increase in CO_2 . The level of ammonia will also depend on the activity of the nitrifying and denitrifying bacteria, referred to earlier. At a pH of 7.0 most of the ammonia is in the ionised form while at a pH of 8.0 the majority is in the unionised form. As the pH falls, the ammonia equilibrium shifts in the direction of ionised ammonia (ammonium) - the total ammonia does not change.

The unionized form of ammonia is highly toxic to shrimp, while ionized ammonia is relatively non-toxic. The unionized ammonia 48-hr LC50 for juvenile shrimp (the concentration that will kill 50 % of the shrimp in 48 hr) was 1.26 mg $\text{NH}_3 - \text{N}$ / liter. Concentrations below 0.1 mg/l of unionized ammonia are considered “safety level” in the sense that these concentrations are non-lethal.

However, chronic exposure to concentrations above 0.03 mg NH₃ – N / liter will produce a number of non lethal effects on the shrimp, including reduced growth rates, increased feed conversion, swollen gills, reduced tolerance to low dissolved oxygen conditions, and decreased resistance to disease.

If high levels ammonia is present within the pond's water, a number of measures can be taken. These include:

- Reduce or stop feeding
- Flush the tanks with fresh water
- Reduce the stocking density
- Increase aeration
- In emergencies – reduce the pH level

The amount of ammonia present in the water can be calculated by recording the total ammonia nitrogen (TAN), pH and temperature (Table 2.2).

For example to obtain the concentration of NH₃: Water at pH 8.4, 28^oC and 2mg/l of TAN (sampled measurement) contains 15% NH₃ (from table). Therefore $2 \text{ mg/l} \times 15\% / 100 = 0.3 \text{ mg/l}$ of NH₃.

Table 2.2: Percentage of TAN in the toxic unionised form NH₃ at different temperature and pH levels.[14]

pH	Temperature (^o C)						
	8	12	16	20	24	28	32
7.0	0.2	0.2	0.3	0.4	0.5	0.7	1.0
8.0	1.6	2.1	2.9	3.8	5.0	6.6	8.8
8.2	2.5	3.3	4.5	5.9	7.7	10.0	13.2
8.4	3.9	5.2	6.9	9.1	11.6	15.0	19.5
8.6	6.0	7.9	10.6	13.7	17.3	21.8	27.7
8.8	9.2	12.0	15.8	20.1	24.9	30.7	37.8
9.0	13.8	17.8	22.9	28.5	34.4	41.2	49.0
9.2	20.4	25.8	32.0	38.7	45.4	52.6	60.4

pH	Temperature (°C)						
	8	12	16	20	24	28	32
9.4	30.0	35.5	42.7	50.0	56.9	63.8	70.7
9.6	39.2	46.5	54.1	61.3	67.6	73.6	79.3
9.8	50.5	58.1	65.2	71.5	76.8	81.6	85.8
10	61.7	68.5	74.8	79.9	84.0	87.5	90.6
10.2	71.9	77.5	82.4	86.3	89.3	91.8	93.8

Total ammonia (NH_3 plus NH_4^+) in mg/l or mg/l is most commonly measured with a test kit. Most test kits measure the sum of both forms of ammonia. The only way to know how much ammonia is in the toxic form is by determining the pH and temperature and then calculating the percentage in toxic form. Unionised ammonia based on water temperature, pH, and total ammonia levels. High temperatures and high pH levels can cause lethal concentrations of unionised ammonia, which is probably responsible for more unexplained aquatic animals losses in aquariums than anything else.

The toxicity of ammonia is mainly caused by the unionised ammonia (UIA) (NH_3). The unionised ammonia NH_3 (UIA) is 300 – 400 times more toxic than NH_4 . The effect of ammonia toxicity is high, at higher pH, the proportion of unionised ammonia being higher at higher pH. This aspect has been indeed well studied recently, especially owing to its importance in intensive culture systems.

The amount of %UIA at different levels of pH can be calculated from the constant (pka) values for ammonia, shown below:

Temp. (°C)	5	10	15	20	25	30
pka	9.90	9.73	9.56	9.40	9.24	9.09

Using the formula:

$$\% \text{UIA} = \frac{100}{1 + \text{antilog}(pK_a - \text{pH})}$$

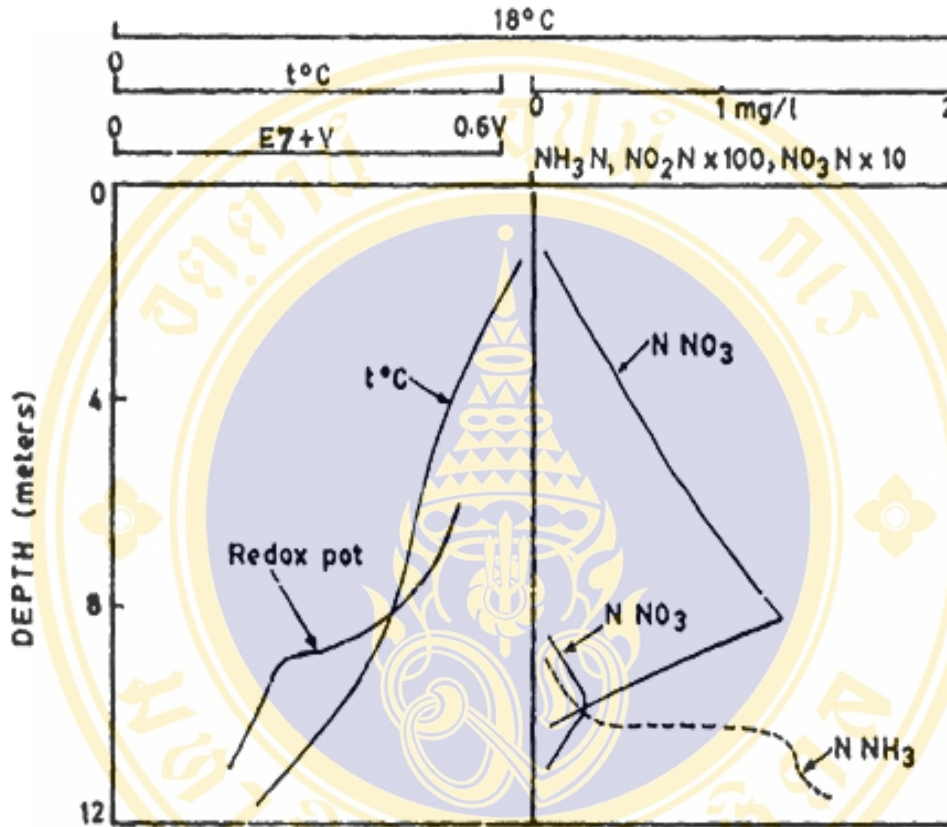


Figure. 2.2: Distribution of ammonia, nitrite, nitrate and redox potential and temperature in a temperate lake. [15]

The levels of UIA can be estimated: e.g. UIA at 30°C and pH 7.5

$$\begin{aligned}
 &= \frac{100}{1 + (9.09 - 7.50)} \\
 &= \frac{100}{1 + \text{antilog } 1.59} \\
 &= \frac{100}{1 + 38.90} = 2.5 \%
 \end{aligned}$$

The % UIA in aqueous solution at different pH and temperature has been tabulated by several workers recommends total unionized ammonia contents in fresh water provided dissolved solid content is negligible. These values are reproduced in Table 2.3, where % UIA values for 0 – 30°C, at pH 6 – 10 are given. % UIA values for salt waters (18 – 22% and 23 – 27%) are given in Tables 2.4 and 2.5 respectively. % UIA values for S = 32 – 40%, are given in Table 2.6. [16]

Table 2.3: Percent NH₃ in aqueous ammonia solutions for 0–30°C and pH 6–10

Temp (°C)	pH								
	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
0	.00827	.0261	.0826	.261	.820	2.55	7.64	20.7	45.3
1	.00899	.0284	.0898	.284	.891	2.77	8.25	22.1	45.3
2	.00977	.0309	.0977	.308	.968	3.00	8.90	23.6	49.4
3	.0106	.0336	.106	.335	1.05	3.25	9.60	25.1	51.5
4	.0115	.0364	.115	.363	1.14	3.52	10.3	26.7	53.5
5	.0125	.0395	.125	.394	1.23	3.80	11.1	28.3	55.6
6	.0136	.0429	.135	.427	1.34	4.11	11.9	30.0	57.6
7	.0147	.0464	.147	.462	1.45	4.44	12.8	31.7	59.6
8	.0159	.0503	.159	.501	1.57	4.79	13.7	33.5	61.4
9	.0172	.0544	.172	.542	1.69	5.16	14.7	35.3	63.3
10	.0186	.0589	.186	.586	1.83	5.56	15.7	37.1	65.1
11	.0201	.0637	.201	.633	1.97	5.99	16.8	38.9	66.8
12	.218	.0688	.217	.684	2.13	6.44	17.9	40.8	68.5
13	.0235	.0743	.235	.738	2.30	6.92	19.0	42.6	70.2
14	.0254	.0802	.253	.796	2.48	7.43	20.2	44.4	71.7
15	.0274	.0865	.273	.859	2.67	7.97	21.5	46.4	73.3
16	.0295	.0933	.294	.925	2.87	8.54	22.8	48.3	74.7
17	.0318	.101	.317	.996	3.08	9.14	24.1	50.2	76.1
18	.0343	.108	.342	1.07	3.31	9.78	25.5	52.0	77.4
19	.0364	.117	.368	1.15	3.56	10.5	27.0	53.9	78.7

Temp (°C)	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
20	.0397	.125	.396	1.24	3.82	11.2	28.4	55.7	79.9
21	.0427	.135	.425	1.33	4.10	11.9	29.9	57.5	81.0
22	.0459	.145	.457	1.43	4.39	12.7	31.5	59.2	82.1
23	.0493	.156	.491	1.54	4.70	13.5	33.0	60.9	83.2
24	.0530	.167	.527	1.65	5.03	14.4	34.6	62.6	84.1
25	.0569	.180	.566	1.77	5.38	15.3	36.3	64.3	85.1
26	.0610	.193	.607	1.89	5.75	16.2	37.9	65.9	85.9
27	.0654	.207	.651	2.03	6.15	17.2	39.6	67.4	86.8
28	.0701	.221	.697	2.17	6.56	18.2	41.2	68.9	87.5
29	.0752	.237	.747	2.32	7.00	19.2	42.9	70.4	88.3
30	.805	.254	.799	2.48	7.46	20.3	44.6	71.8	89.0
32*	-	-	.950	-	8.77	-	49.0	-	90.6

Table 2.4: Percent un-ionized ammonia in seawater (S=18–22‰) at different temperatures and pH's

Temp (°C)	pH										
	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5
10	0.527	0.662	0.832	1.05	1.31	1.65	2.07	2.59	3.23	4.04	5.03
15	0.763	0.959	1.20	1.51	1.90	2.37	2.97	3.71	4.63	5.76	7.14
20	1.11	1.39	1.74	2.18	2.73	4.41	4.26	5.30	6.58	8.15	10.0
25	1.60	2.00	2.51	3.14	3.91	4.88	6.07	7.62	9.28	11.40	14.00
30	2.24	2.81	3.51	4.38	5.45	6.77	8.38	10.32	12.65	15.43	18.67

Table 2.5: Percent un-ionized ammonia in seawater (S=23–27‰) at different temperatures and pH's.

Temp (°C)	pH										
	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5
10	0.49	0.61	0.77	0.97	1.23	1.54	1.93	2.42	3.03	3.78	4.71
15	0.71	0.89	1.13	1.41	1.77	2.22	2.78	3.47	4.33	5.39	6.70
20	1.03	1.30	1.63	2.04	2.55	3.19	3.98	4.97	6.17	7.65	9.44
25	1.49	1.87	2.34	2.93	3.66	4.57	5.68	7.05	8.72	10.7	13.1
30	2.16	2.71	3.30	4.23	5.26	6.54	8.09	9.98	12.2	14.9	18.1

Table 2.6: Percent un-ionized ammonia in seawater (S=32–40‰) at different temperatures and pH's

Temp (°C)	pH										
	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5
10	0.459	0.577	0.726	0.912	1.15	1.44	1.80	2.26	2.83	3.54	4.41
15	0.665	0.836	1.05	1.32	1.66	2.07	2.60	3.25	4.06	5.05	6.28
20	0.963	1.21	1.52	1.90	2.39	2.98	3.73	4.65	5.78	7.17	8.87
25	1.39	1.75	2.19	2.74	3.43	4.28	5.32	6.61	8.18	10.1	12.40
30	2.02	2.52	3.16	3.94	4.91	6.11	7.57	9.35	11.49	14.05	17.06

2). Nitrite

Nitrite is present in natural waters only in smaller quantities. It has been found to be toxic to aquatic animals, as NO_2 combines with hemoglobin, and forms methemoglobin, causing the brown coloration of blood. The presence of chloride ions and calcium inhibit nitrite toxicity. In contrast to ammonia, nitrite toxicity increases at lower pH levels. Therefore recommends that levels of pH, calcium content (bicarbonate hardness) and chloride content (salinity) should be indicated when reporting NO_2 concentrations.

Nitrite is also toxic to shrimp. The 96-hr LC50 of nitrite for shrimp is about 13.6 mg NO₂⁻ / l [17]. These authors recommend 1.36 mg/l as the safe level of nitrite for shrimp. The mechanism for nitrite toxicity in shrimp is not as well understood as it is in fish. In fish, high nitrite levels interfere with the uptake of oxygen by hemoglobin in the blood of fish and can cause the fish to die from asphyxiation. Shrimp have a different blood pigment, hemocyanin, which transports oxygen to the tissues. It is likely that the mechanism for nitrite toxicity is similar to the mechanism in fish.

2.3 Nitrification

In aquaculture, a mechanism called The Nitrogen Cycle eliminates ammonia from the water. As ammonia is excreted, it is converted to another compound called nitrite (NO₂⁻). Nitrite is also toxic to aquatic animals. This change from ammonia to nitrite is accomplished by bacteria called *Nitrosomonas*. Another group of bacteria, called *Nitrobacter*, convert nitrite to nitrate (NO₃⁻). Nitrate is not toxic to aquatic animals except at extremely high levels, and can be considered harmless. This constant change from ammonia to nitrite to nitrate is called the nitrogen cycle (Figure 2.3).

One important point to mention about the nitrogen cycle, is that both groups of nitrifying bacteria need oxygen to function. If oxygen levels are not sufficient, the process can break down, and you will start seeing levels of ammonia and nitrite rise in the system.

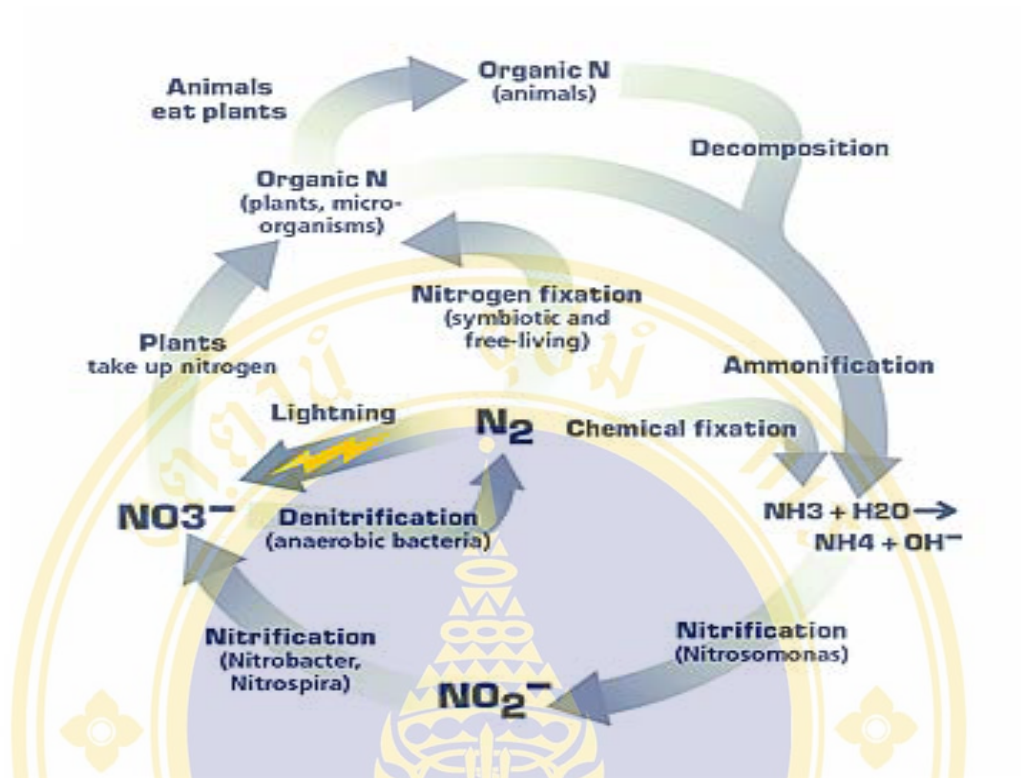
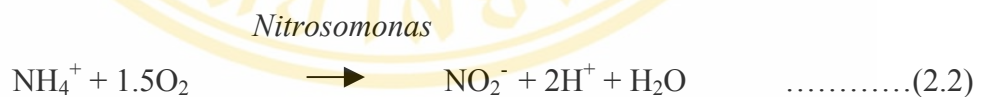


Figure 2.3: The Microbial Nitrogen Cycle

<http://www.learner.org/channel/courses/biology/archive/images/1869.html>

The nitrification process is carried out by two different types of bacteria. *Nitrosomonas* carry out the first step of the process, producing nitrite:



The resulting nitrite is then converted to nitrate by *Nitrobacters*:



2.3.1 Nitrifying Bacteria [18, 67]

Nitrifying bacteria, classified as autotrophic, have the ability to transform ammonia into less harmful chemicals. Autotrophic bacteria consume inorganic substances, and heterotrophic bacteria consume organic substances.

The oxidation of ammonia into nitrite, and the subsequent oxidation to nitrate are performed by two different bacteria (nitrifying bacteria). The first step is done by bacteria of the genus *Nitrosomonas* and *Nitrosococcus*. The second step (oxidation of nitrite into nitrate) is mainly done by bacteria of the genus *Nitrobacter*. All organisms are autotrophs, which mean that they take carbon dioxide as their carbon source for growth.

Bacteria of the genera *Nitrosomonas*, *Nitrosococcus*, *Nitrospira*, *Nitrosolobus*, and *Nitrosovibrio*, participate in the first stage of nitrification. The second stage involves the genera *Nitrobacter*, *Nitrococcus*, *Nitrospira*, and *Nitrospina* [19]. All members of the *Nitrobacteraceae* family are gram-negative chemoautotrophs, also known as lithotrophs. Chemoautotrophic bacteria are characterized by the ability to utilize an inorganic chemical substrate (e.g. NH_3 , H_2 , Fe^{2+}) as a source of electrons for the immobilization of inorganic carbon (i.e. CO_2 (aq) or HCO_3^-) into biomass. This sole energy source drives carbon fixation, the assimilation of monomers into precursor metabolite, and the subsequent polymerization of building blocks and macromolecules. Chemoautotrophs are aerobic, usually employing dioxygen gas (O_2) as the final or terminal electron acceptor. In contrast to photoautotrophic cyanobacteria and algae, there is no net production of oxygen. In contrast to chemoorganotrophs (or heterotrophs), there is no net production of carbon dioxide. Some heterotrophic organisms are capable of oxidizing organically bound N (rather than simply liberating it as ammonia), but this is a co-metabolism and not coupled to energy generation [20]. Also, a larger variety of end products are formed during heterotrophic nitrification. [21]

Nitrosomonas is the most abundantly cited and extensively studied nitrifier. The bacteria are short rods (0.8 x 1–2 μm), typically non-motile, and ubiquitous in soils [22]. Other *Nitrosomonas* species have one or two subpolar flagella and inhabit freshwater and marine sediments [23].

There are a few specific factors which limit nitrification. These factors include carbon dioxide and oxygen along with pH, concentrations of ammonia, and temperature [52]. To know the level of nitrification taking place, the levels of these factors need to be known, along with the density of the bacteria, or nitrifiers' population.

2.3.2 Rates of Nitrification

The rates of nitrification reaction are highly dependent on a number of environmental factors. These include the substrate and oxygen concentration [59], temperature, pH, and the presence of toxic or inhibiting substances. The kinetics can be described with the Monod expression, and in most cases the rate is limited by the first step, the oxidation of the ammonia. At steady state, the amount of NO_2^- present is usually small and can be ignored in initial design.

Nitrifying bacteria (like *Nitrosomonas* and *Nitrobacter*) are sensitive organisms and extremely susceptible to a wide variety of inhibitors [65]. The factors affect the nitrification process:

(1) **Concentration of ammonia and nitrite**; A variety of organic and inorganic agents can inhibit the growth and action of these organisms. High concentrations of ammonia and nitrous acid can be inhibitory.

(2) **BOD₅/TKN ratio**; If there remains certain concentration of BOD₅ in the water of the treatment plant, nitrifying bacteria cannot be dominant in competition with BOD-removal bacteria. Figure 2.4 shows the effect of remaining BOD to $\text{NH}_4\text{-N}$ removal efficiency. If BOD is reduced to less than 20 mg/l, nitrification is enhanced. On the other hand, if BOD is more than 40 mg/l, nitrification can be barely expected.

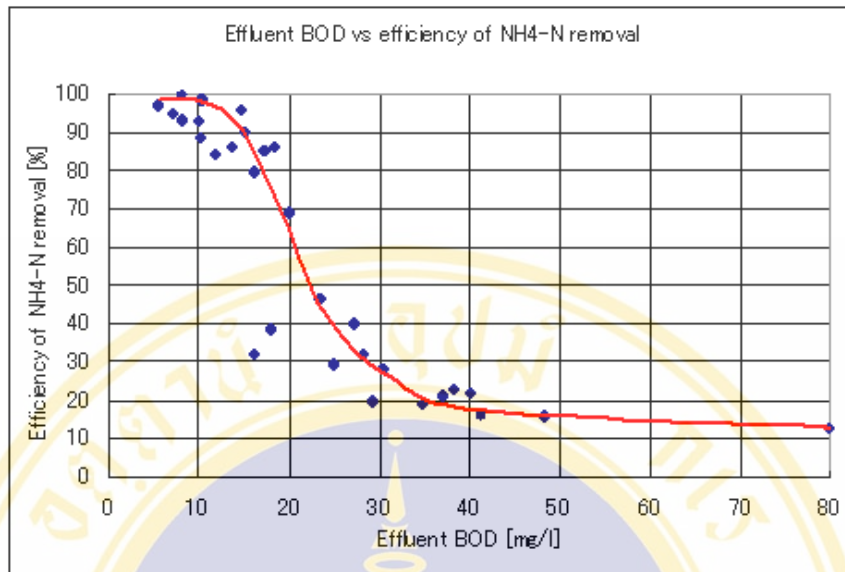


Figure 2.4: Effect of remaining BOD on nitrification efficiency

(3) **Dissolved oxygen concentration;** Nitrifying bacteria are especially sensitive to low oxygen concentrations, and providing enough oxygen in wastewater treatment plants is often the most important design consideration. Figure 2.5 shows the effect of dissolved oxygen (DO) on nitrification efficiency. DO concentrations above 1 mg/l are essential for nitrification to occur. If DO levels drop below this value, oxygen becomes the limiting nutrient and nitrification slows or ceases.

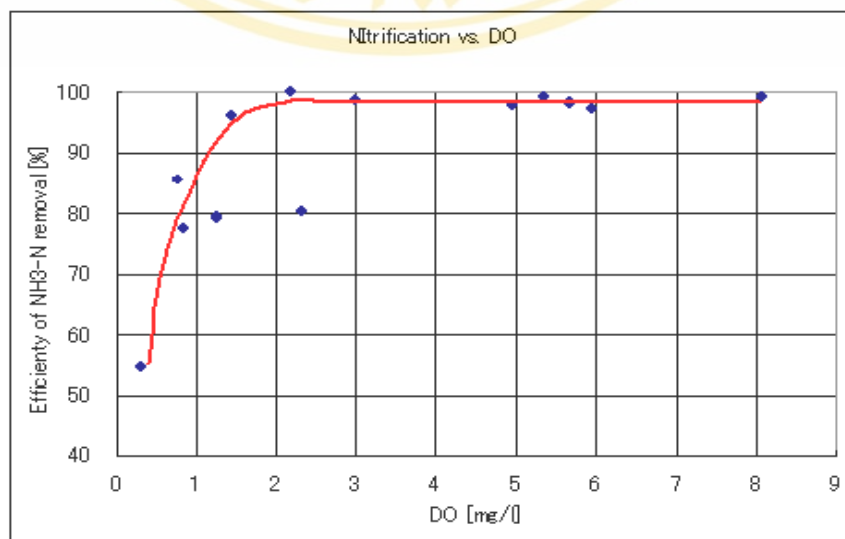


Figure 2.5: Effect of DO on nitrification efficiency

(4) **Temperature Dependency:** Like all microbes, nitrifying bacteria are temperature sensitive. Rapid changes in temperature do not produce rapid changes in growth rates. A slow adaptation period, with a lower than expected rate follows such changes. At higher temperatures the growth rate increase as the model would suggest,

Temperature has a significant effect on nitrification rate. The overall nitrification rate $\mu_n(t)$ at certain temperature decreases with decreasing temperature and is accounted for with the following relationship;

$$\mu_n(t) = \mu_n(15)\Theta^{t-15}$$

where $\mu_n(15)$, Θ , and t are the growth rate of nitrifying bacteria at 15 degrees Celsius, nitrification rate constant, and temperature, respectively. Figure 2.6 shows the effect of temperature on the growth rate of nitrifying bacteria. Ordinate is the value of $\mu_n(t) / \mu_n(15)$. The optimum temperature is approximately 35 degrees. To maintain high efficiency of nitrification, the temperature is usually kept above 15 degrees.

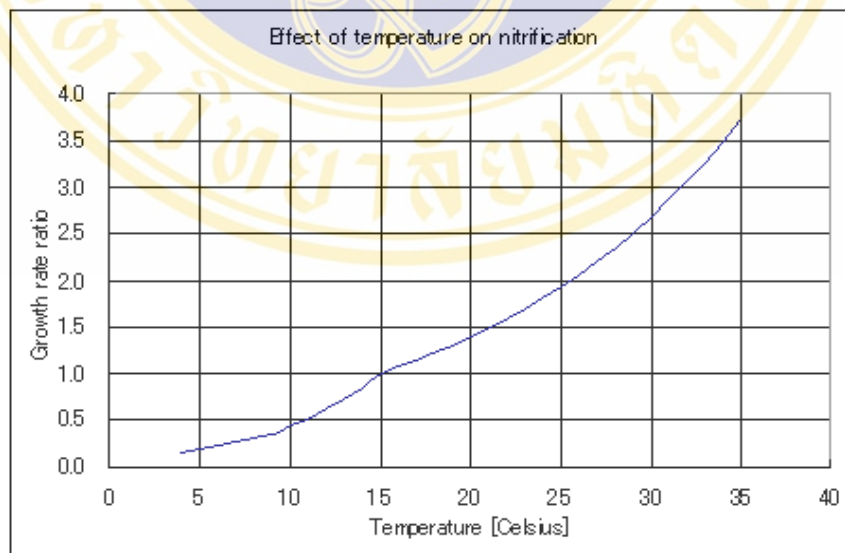


Figure 2.6: Effect of temperature on nitrification

(5) **pH.** ; pH has strong effect on nitrification rates. The reactions occur fastest when pH is from 8 - 9, although if the bacteria exist in flocs or films the pH at the cell surface will be lower than the bulk pH due to the production of H^+

ions. The exact mechanisms by which pH effects the reaction rates are not fully understood, although it is believed that inhibitions, particularly from the neutral NH_3 and HNO_2 species, become important. It has been observed that the maximum rate of nitrification occurs between pH values of about 7.2 and 9.0. Figure 2.7 shows the effect of pH on nitrification.

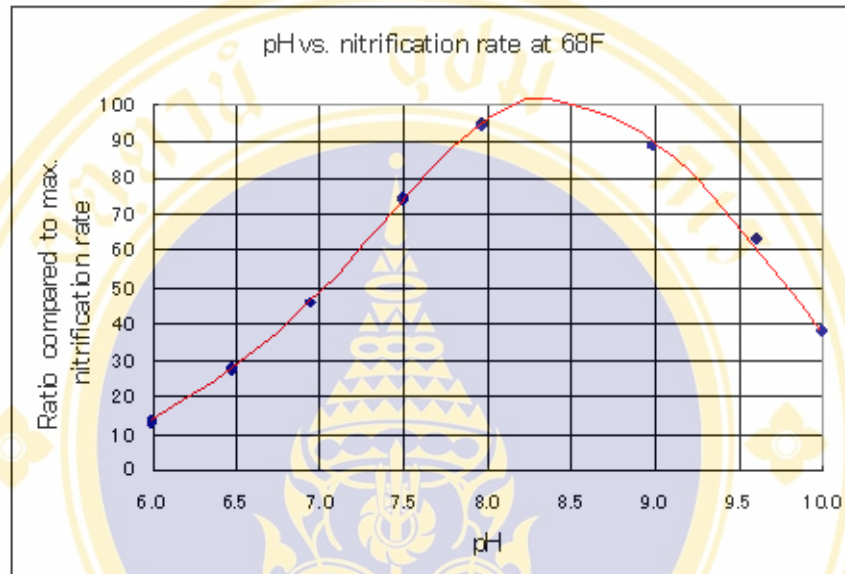


Figure 2.7: Effect of pH on nitrification

2.4 Immobilization techniques

Although free biomass has been shown the superior adsorption capacity than immobilized biomass [24-26], for use in industrial or technical operations, natural microbial biomass has several disadvantages in that it may cause problems in the operation of reactors by blocking flow lines and flogging filters, while separation of biomass and effluent can be difficult and expensive [27,28]. In addition the free cells of microorganisms are not reusable because of their mechanical instability and their susceptibility to microbial degradation [29]. Nakajima et al. reported that during 5 cycles adsorption-desorption, the dry weight of free *Streptomyces* cells decreased from 438 to 225 mg. According, free cell can not be used for long period.

Immobilization of biomass in a polymeric matrix can yield beads or granules with optimum size, mechanical strength, rigidity and porosity characteristics [28, 30, 31]. It serves to improve the physical characteristics of the biomass for use in reactors, permits reusability of the substance, and tends to make the microorganism biomass more inert to microbial degradation.

For the application of immobilization technique in biosorption process, cell supporting materials should be chosen with consideration of high carrier activity, availability of the carrier in commercial quantities, low cost immobilization, ease of separation scale-up, excellent mechanic strength to support long-time operation, and physiological and environment safety. [31-36]

Emily JT, et al.[56] suggested that the immobilization technology must have a number of characteristics with result in the stable and active biosorbent at reasonable cost. The desirable properties for immobilized biosorption agent include:

- 1) Maximum amount of biomass with minimal quantities of binding agent present (binding materials can increase production cost of biosorbent).
- 2) Excellent porosity (binding material should not diminish porosity of adversely affect biomass metal binding sites that reside within the granule. Porosity must be retained to allow diffusion of soluble metals into granular particles).
- 3) Chemical resistance (the immobilization technology should produce a granule which remains stable in the wastewater that oscillates from the acidic to alkaline pH extremes).
- 4) Structure integrity (the granule must have the physical stability for prolonged use in fluid bed contactors and passage through pumps. Granule pumping may be necessary for biosorbent regeneration and metal recovery).[64]
- 5) Cost (The binding technology must be accomplished at low cost to keep the process competitive with other available wastewater treatment system).

The various immobilization techniques may be arranged into three major groups. The carrier-binding method can be based on physical, ionic, or covalent binding. Immobilization by entrapment represents another method. Such entrapment may be achieved by retaining the microorganisms within the small gratings of a highly polymerized gel (grating type) or by covering them with a semipermeable membrane

(microcapsule type). A third procedure involve crosslinking. These methods are visualized in Figure 2.8



Figure 2.8 : Schematic diagrams of immobilization [31]

2.4.1 Adsorption

Immobilization by adsorption (see Fig. 2.8) is the simplest method and involves reversible surface interactions between cells and support material [37, 38]. The force is involved mostly electrostatic, such as van der Waals forces, ionic and hydrogen bonding interactions, although hydrophobic bonding can be significant. These forces are very weak, but sufficiently large in number to enable reasonable binding. For example, it is known that yeast cells have a surface chemistry that is substantially negatively charged so that use of a positively charged support will enable immobilization. Existing surface chemistry between the cells and support is utilized so

no chemical activation/modification is required and little damage is normally done to enzymes or cells in this method of immobilization. The procedure consists of mixture together the biological component(s) and a support with adsorption properties, under suitable conditions of pH, ionic strength, and so on, for a period of incubation, followed by collection of the immobilized material and extensive washing to remove nonbound biological components.

Among the advantages are:

- Little or no damage to cells.
- Simple, cheap and quick to obtain immobilization
- No chemical changes to support or cells.
- Reversible to allow regeneration with fresh cells.

Disadvantages include:

- Leakage of cells from the support/contamination of product.
- Nonspecific binding.
- Overloading on the support.
- Steric hindrance by the support.

The most significant disadvantage is leakage of biocatalyst from the support. Desorption can occur under many circumstances, and environmental changes in pH, temperature, and ionic strength will promote desorption. Some times a cell, firmly adsorbed, is readily desorbed during reaction as a result of substrate binding, binding of contaminants present in the substrate, product production, or other conditions leading to change in protein conformation. Physical factors, such as flow rate, bubble agitation, particle-particle abrasion, and scouring effect of particulate materials on vessel walls, can lead to desorption. Desorption can be turned to advantage if regeneration of support is built into the operational regimen to allow rapid expulsion of exhausted biocatalyst and replacement with fresh biocatalyst.

2.4.2 Carrier-Binding Method

The carrier binding method is based on direct binding of cells to water-insoluble carrier by physical adsorption, ionic bonds, or covalent bonds. As carriers water-insoluble polysaccharides (cellulose, dextrane, and agarose derivatives), proteins (gelatin and albumin), synthetic polymers (ion-exchange resins and

polyvinylchloride), and inorganic materials (brick, sand, and porous glass) are used [31,33]. Major problems with physical and inorganic binding methods are autolysis cell leakage and toxicity of the coupling agents for cell immobilization process. In addition, binding of the reactor may occur. Because of these disadvantages, the carrier-binding method is not widely used [31, 33, 39].

2.4.3 Encapsulation

Encapsulation of cells can be achieved by enveloping the biological components within various forms of semipermeable membranes [40,41] It is similar to entrapment in that the cells are free in solution, but restricted in space. Large protein cannot pass out of or into the capsule, but small substrates and products can pass freely across the semipermeable membrane. Many materials have been used to construct microcapsules varying from 10-100 μm in diameter; for example, nylon and cellulose nitrate have proven popular. The problem is that the immobilized cell may have a density fairly similar to that of the bulk solution with consequent problems in reactor configuration, flow dynamics, and so on. It is also possible to use biological cells as capsules, and a notable example of this is the use of erythrocytes (red blood cells). The membrane of the erythrocyte is normally only permeable to small molecules. However, when erythrocytes are placed in a hypotonic solution, they swell, stretching the cell membrane and substantially increasing the permeability. In this condition, erythrocyte proteins diffuse out of the cell and can diffuse into the cell. Returning the swollen erythrocytes to an isotonic solution enables the cell membrane to return to its normal state, and the enzymes trapped inside the cell do not leak out. A distinct advantage of this method is coimmobilization. Cells may be immobilized in any desired combination to suit particular applications.[54,55]

2.4.4 Crosslinking

In the immobilization method known as crosslinking microorganisms are joined together by reagents having two or more functional groups. Various chemical reactions can be involved, such as formation of a Schiff's base (Glutaraldehyde), peptide binding (isocyanate derivatives) or diazo coupling (N,N'-ethylenebismaleimide, bisdiazobenzidine). Functional groups of microorganisms

taking part in these crosslinking reactions include α - or ϵ - amino groups (lysine,etc.) phenol groups (tyrosine), sulfhydryls(cysteine), and imidazol groups (histidine) [31,33,39,58]

2.4.5 Entrapment

This method involved incorporating cells or enzymes into the lattice of semi-permeable polymer membrane, which has improved to be very satisfactory for cell immobilization. The material to be immobilized is suspended or dissolved in a solution, which is caused to form a gel, either by polymerization or by cross-linking, thus entrapping the cells very well but are too large to retain soluble enzyme [39]. Many materials have been employed for the entrapment of cells but the most widely used are polyacrylamide, kappa-carrageenan and calcium alginate.

1) Calcium alginate

Alginate is extracted from seaweed, which structure is a linear copolymer of D-mannuronic and L-guluronic acid [25, 39] It can be gelled by multivalent ions such as calcium and albumin. For immobilization of cells, the cross-linking of alginate with Ca^{2+} is preferred method to enhance bead stability.[33]

2) Polyacrylamide

Cell entrapment in polyacrylamide gels, which has been used extensively for immobilization of microbial, plant, and animal cells. The procedure involves the polymerization of an aqueous solution of acrylamide monomers in which the microorganisms are suspended. The technique is straightforward and generally results in an effective entrapment of the cell. A major disadvantage of the polyacrylamide is the toxicity of the acrylamide monomer, the cross-linking agent, the initiator, and the accelerator. [31]

Table 2.7: Summarizes the advantages and disadvantages of each entrapment material.

Material	Advantages	Disadvantages
Polyacrylamide	Wide range of pore size possible. Excellent gel strength.	Toxic monomers. Free radical produced on polymerization may damage cells.
Kappa Carrageenan	Food grade material. Good gel strength. Retains cell activity.	Heat treatment may cause cell damage.
Calcium alginate	Food grade material. Excellent gel strength. No heat required forming gel. Retains cell activity.	Unstable to chelating agent.

Source : Regional workshop on immobilized microbial enzymes and cells [31].

2.5 Coal bottom ash and boiler slag

Coal bottom ash and boiler slag are the coarse, granular, incombustible by-products that are collected from the bottom of furnaces that burn coal for the generation of steam, the production of electric power, or both. The majority of these coal by-products are produced at coal-fired electric utility generating stations, although considerable bottom ash and/or boiler slag are also produced from many smaller industrial or institutional coal-fired boilers and from coal-burning independent power production facilities. The type of by-product (i.e., bottom ash or boiler slag) produced depends on the type of furnace used to burn the coal.

1) Coal Bottom Ash

The most common type of coal-burning furnace in the electric utility industry is the dry, bottom pulverized coal boiler. When pulverized coal is burned in a dry, bottom boiler, about 80 percent of the unburned material or ash is entrained in the flue gas and is captured and recovered as fly ash. The remaining 20 percent of the ash is dry coal bottom ash, a dark gray, granular, porous, predominantly sand size minus 12.7 mm. material that is collected in a water-filled hopper at the bottom of the furnace.[42] When a sufficient amount of coal bottom ash drops into the hopper, it is removed by means of high-pressure water jets and conveyed by sluiceways either to a disposal pond or to a decant basin for dewatering, crushing, and stockpiling for disposal or use.[43,63]

2) Boiler Slag [62]

There are two types of wet-bottom boilers: the slag-tap boiler and the cyclone boiler. The slag-tap boiler burns pulverized coal and the cyclone boiler burns crushed coal. In each type, the bottom ash is kept in a molten state and tapped off as a liquid. Both boiler types have a solid base with an orifice that can be opened to permit the molten ash that has collected at the base to flow into the ash hopper below. The ash hopper in wet-bottom furnaces contains quenching water. When the molten slag comes in contact with the quenching water, it fractures instantly, crystallizes, and forms pellets. The resulting boiler slag, often referred to as “black beauty,” is a coarse, hard, black, angular, glassy material.

When pulverized coal is burned in a slag-tap furnace, as much as 50 percent of the ash is retained in the furnace as boiler slag. In a cyclone furnace, which burns crushed coal, some 70 to 80 percent of the ash is retained as boiler slag, with only 20 to 30 percent leaving the furnace in the form of fly ash.[42]

A general diagram depicting the production and processing operations associated with bottom ash and boiler slag management is presented in Figure 2.9.

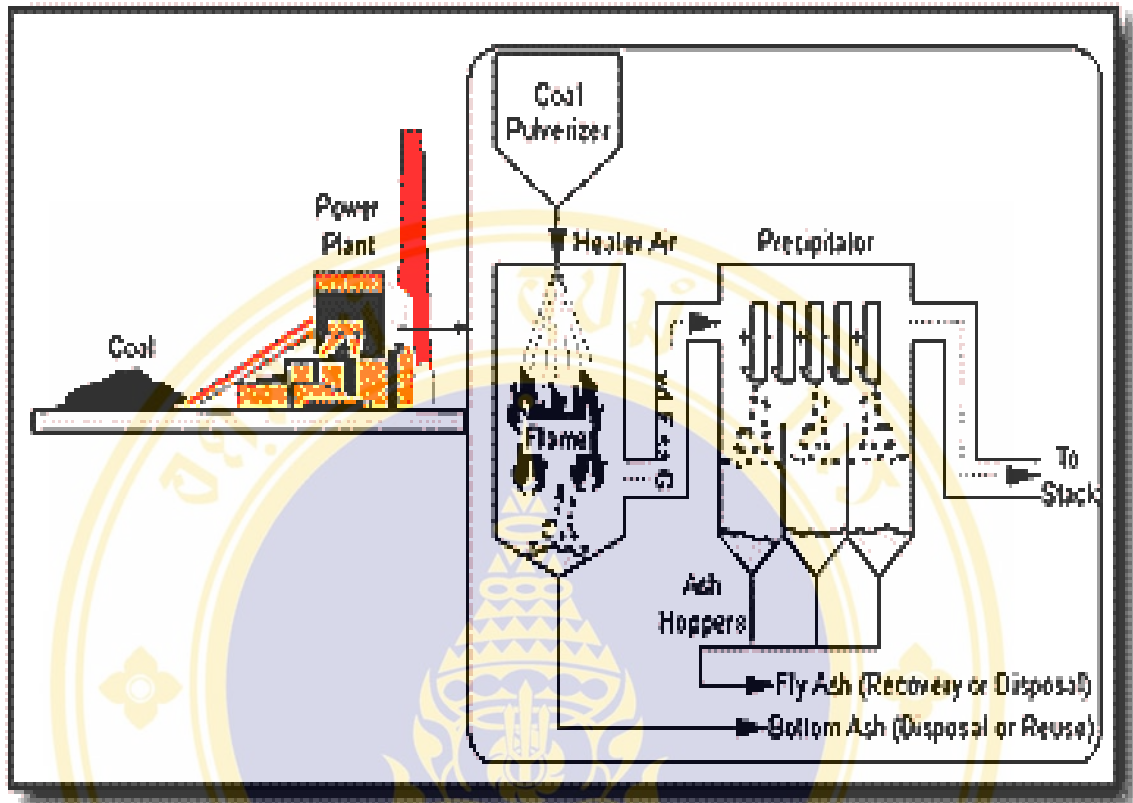


Figure 2.9: Production and processing of bottom ash or boiler slag.

<http://www.tfrc.gov/hnr20/recycle/waste/cfa51.htm>

2.5.1 Current management options

1) Recycling

According to recent statistics on coal combustion by-product utilization, 30.3 percent of all bottom ash and 93.3 percent of all boiler slag produced in 1996 were utilized. Leading bottom ash applications are snow and ice control, as aggregate in lightweight concrete masonry units, and raw feed material for production of Portland cement. Bottom ash has also been used as a road base and subbase aggregate, structural fill material.[46], and as fine aggregate in asphalt paving and flowable fill. Leading boiler slag applications are blasting grit, roofing shingle granules, and snow and ice control. Boiler slag has also been used as an aggregate in asphalt paving, as a structural fill,[46] and in road base and subbase applications.[43]

The U.S. EPA is presently undertaking a study of power plant wastes prior to disposal by the utility. It is possible that EPA's study on mixed power plant wastes could have a regulatory impact on beneficial use or reuse of any mixed materials. It is anticipated that this investigation will be completed in 1998.

2) Disposal

Discarded bottom ash and boiler slag are either landfilled or sluiced to storage lagoons. When sluiced to storage lagoons, the bottom ash or boiler slag is usually combined with fly ash. This blended fly ash and bottom ash or boiler slag are referred to as ponded ash. Approximately 30 percent of all coal ash is handled wet and disposed of as ponded ash.[44]

Ponded ash is potentially useable, but variable in its characteristics because of its manner of disposal. Because of differences in the unit weight of fly ash and bottom ash or boiler slag, the coarser bottom ash or boiler slag particles settle first and the finer fly ash remains in suspension longer. Ponded ash can be reclaimed and stockpiled, during which time it can be dewatered. Under favorable drying conditions, ponded ash may be dewatered into a range of moisture that will be within the vicinity of its optimum moisture content. The higher the percentage of bottom ash or boiler slag there is in ponded ash, the easier it is to dewater and the greater its potential for reuse. Reclaimed ponded ash has been used in stabilized base or subbase mixes and in embankment construction, and can also be used as fine aggregate or filler material in flowable fill.

2.5.2 Material properties

1) Physical Properties

Bottom ashes have angular particles with a very porous surface texture.[59] Bottom ash particles range in size from a fine gravel to a fine sand with very low percentages of silt-clay sized particles. The ash is usually a well-graded material, although variations in particle size distribution may be encountered in ash samples taken from the same power plant at different times. Bottom ash is predominantly sand-sized, usually with 50 to 90 percent passing a 4.75 mm (No. 4)

sieve, 10 to 60 percent passing a 0.42 mm (No. 40) sieve, 0 to 10 percent passing a 0.075 mm (No. 200) sieve, and a top size usually ranging from 19 mm (3/4 in) to 38.1 mm (1-1/2 in).

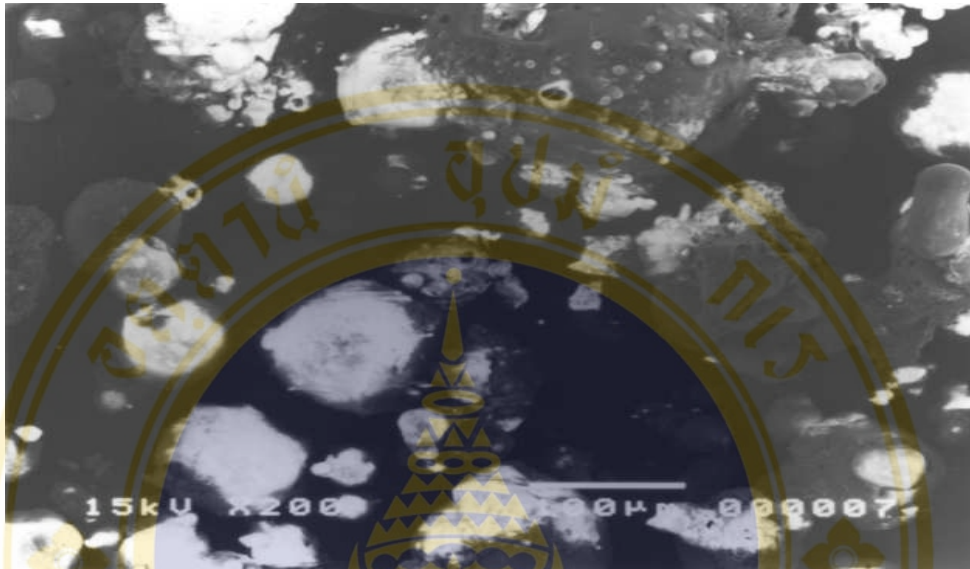


Figure 2.10: Scanning electron micrographs of coal ashes (bottom ash). [74]

Boiler slags are predominantly single-sized and within a range of 5.0 to 0.5 mm (No. 4 to No. 40 sieve). Ordinarily, boiler slags have a smooth surface texture, but if gases are trapped in the slag as it is tapped from the furnace, the quenched slag will become somewhat vesicular or porous. Boiler slag from the burning of lignite or subbituminous coal tends to be more porous than that of the eastern bituminous coals. Boiler slag is essentially a coarse to medium sand with 90 to 100 percent passing a 4.75 mm (No. 4) sieve, 40 to 60 percent passing a 2.0 mm (No. 10) sieve, 10 percent or less passing a 0.42 mm (No. 40) sieve, and 5 percent or less passing a 0.075 mm (No. 200) sieve.

2) Chemical Properties

Bottom ash and boiler slag are composed principally of silica, alumina, and iron, with smaller percentages of calcium, magnesium, sulfates, and other compounds. The composition of the bottom ash or boiler slag particles is controlled primarily by the source of the coal and not by the type of furnace.

Due to the salt content and, in some cases, the low pH of bottom ash and boiler slag, these materials could exhibit corrosive properties. When using bottom ash or boiler slag in an embankment, backfill, subbase, or even possibly in a base course, the potential for corrosion of metal structures that may come in contact with the material is of concern and should be investigated prior to use.

Corrosivity indicator tests normally used to evaluate bottom ash or boiler slag are pH, electrical resistivity, soluble chloride content, and soluble sulfate content. Materials are judged to be noncorrosive if the pH exceeds 5.5, the electrical resistivity is greater than 1,500 ohm-centimeters, the soluble chloride content is less than 200 parts per million (mg/l), or the soluble sulfate content is less than 1,000 parts per million (mg/l).[47]

Table 2.8 The chemical characteristic of Coal ash (bottom ash). [74]

Compositions	Average value in percent weight (%wt)	
	Bottom ash	
SiO ₂	43.30	
Al ₂ O ₅	23.00	
Fe ₂ O ₅	13.68	
CaO	13.60	
MgO	2.09	
Na ₂ O	1.10	
K ₂ O	3.13	

2.6 Related researches

Tansakul P., 2004. [50] studied that the optimum hydraulic retention time for operating with the PVA- immobilized nitrifying bacteria gel beads in the continuous nitrification bioreactor was 2 hr., which yielded the ammonia-nitrogen removal efficiency of 91.25% and provided the effluent ammonia-nitrogen (NH₃-N) and nitrite- nitrogen (NO₂-N) which were 0.19 and 0.16 mg/l., respectively. With 2 hr. of HRT, it gave the ammonia-nitrogen removal rate of 122.22 g/m³/day and the effluent ammonia-nitrogen (NH₃-N) and nitrite- nitrogen (NO₂-N), which were not harmful to aquatic animals.

Travieso L, F, Sanchez E, Dupeyron R, and Dominguez AR [51] carried out the experiments on immobilization of microalgae for nutrient removal in wastewater treatment. They found that higher efficiencies were obtained with the utilization by *Chlorella vulgaris* in an expanded-bead as the columns were operated under natural light. Internal immobilization and the use of an upflow pattern with pretreated cattle manure due to the dark colour of this substrate, but good efficiencies were obtained at hydraulic loadings in the range of 0.5-2.5 l/1-day using downflow columns.

Zhu S. and Chen S. [52] studied the impact of temperature on nitrification rate in fixed film biofilter. They found that temperature increment at 20 °C resulted in nitrification rate increase of 1.018 % / °C and 4.275 % per °C under DO and TAN limited condition.

Hashimoto S and Furukawa K.[53] studied immobilization of activated sludge by PVA-boric Acid Method. They found that total organic and total nitrogen were removed at efficiencies of 93 and 30-40 %, respectively.

Chen K, Lee S, Chin S, and Hough J.,[54] studied simultaneous carbon-nitrogen removal in wastewater using phosphorylated PVA-immobilized microorganisms. They found that more than 90 % of COD removal efficiency was obtained at a COD loading rate lower than 2.0 g COD l⁻¹ d⁻¹ accompanied by total nitrogen removal efficiency at around 45 %

Chen K and Lin Y.,[55].studied immobilization of microorganisms with phosphorylated PVA gel. They found that a steady denitrification efficiency of more than 99 % was achieved in the continuous reactor.

Emily JT, Leenen M, Vitor AP, Santos D, Katja CF, Tramper J, et al.,[56] studied characteristics of and selection criteria for support materials cell immobilization in wastewater treatment. They found that treatment of wastewater with immobilized cells, support material need to meet the following criteria: insoluble, not biodegradable, high mechanical stability, high diffusivity, simple immobilization procedure, high biomass retention, minimal attachment of other organisms and preferable a low cost price.

Chen K, Chen S, And Houng J., [57] studied improvement of gas permeability of denitrifying PVA gel beads. They found that the modification process with alginate would not cause a significant decrease in the nitrate reduction rate of immobilized beads. The gas permeability of beads increased as high as 62 %

Amanda K, Wu D and Keith D Wisecarver., [58] investigated cell immobilization using PVA crosslinked with Boric Acid. They found that the PVA-alginate beads proved to be very strong and durable, with no noticeable degradation of the beads after 2 weeks of continuous operation of the fluidized bead.

A. Rushdi, R. Gupta., [59] investigated the deposit structure in terms of the bulk porosity for bituminous coals, using two indirect techniques: a density measurement technique and by scanning electron microscopy (SEM) and thermomechanical analysis technique (TMA). The results showed a significant difference between the two techniques. The density measurement underestimated the bulk porosity of the deposit due to the closed pores within the deposit structure.

Z. Sarbak, A. Stan'czyk, M. Kramer-Wachowiak.,[60] studied the fly ashes obtained as a result of black and brown coal combustion by the following methods: chemical analysis, X-ray diffraction (XRD), infrared (IR) spectroscopy, differential thermal analysis, (DTA), low-temperature nitrogen and methylene blue adsorption and scanning electron microscopy (SEM). The samples of fly ashes under different types were characterised by different chemical compositions, structures, surface areas and porosities.

A.M. Raichur, S.P. Vijayalakshmi.,[61].studied the surface properties of coal and solution pH play a major role in determining the adhesion of microorganisms. In this study, the adhesion of the bacterium *Bacillus polymyxa* to these coals has been

investigated. It was found that due to the high ash content of coal, adhesion was found to be dependent on the ash content and the surface free energy of the coals.

Qian, G. et al. *Journal of Hazardous Materials*, [62] Studied the behaviour of heavy metals mercury and zinc immobilized in an alkali-activated slag (AAS) matrix has been evaluated using physical property tests, pore structure analysis and XRD, TG-DTG, FTIR and TCLP analysis. Low concentrations (0.5%) of mercury and zinc ions had only a slight affect on compressive strength, pore structure and hydration of AAS matrixes. The addition of 2% Hg ions to the AAS matrix resulted in a reduction in early compressive strength but no negative effects were noticed after 28 days of hydration. Meanwhile, 2% Hg ions can be effectively immobilized in the AAS matrix with the leachate meeting the USEPA TCLP mercury limit. For a 2% Zn-doped MS matrix, the hydration of the AAS paste was greatly retarded and the zinc concentration in the leachate from this matrix was higher than 5 mg/l even at 28 days. Based on these results, it was concluded that the physical encapsulation and chemical fixation mechanisms were likely to be responsible for the immobilization of Hg ions in the AAS matrix while only chemical fixation mechanisms were responsible for the immobilization of Zn ions in the AAS matrix.

Shaobin Wang, Mehdi Soudi , Li Lib, Z.H. Zhub., [63] studied that Fly ash was modified by hydrothermal treatment using NaOH solutions under various conditions for zeolite synthesis. The XRD patterns are presented. The results indicated that the samples obtained after treatment were much different. The XRD profiles revealed a number of new reflexes, suggesting a phase transformation probably occurred. Both heat treatment and chemical treatment increased the surface area and pore volume. It was shown that fly ash and the modified forms could effectively absorb heavy metals.

CHAPTER III

MATERIALS AND METHODS

3.1 Research design

This experiment was planned to be 36 operating conditions by varying ratios weight of mixture in beads (% PVA:coal) and hydraulic retention times (HRTs). $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ were analyzed to determine the removal efficiencies as indicators for the optimum operating condition of PVA:coal (%) and HRT. The experimental research using a laboratory scale batch reactor installed and experimented at the Shrimp Culture Research Center laboratory located at Samuth-Sakorn province.

The experiments aim to study the efficiency of immobilized nitrifying bacteria with PVA-coal (polyvinyl alcohol-coal ash) to remove ammonia and nitrite in order to develop a nitrifying unit for a recirculation aquaculture system. The experiments consisted of 4 parts as followed:

- 1) Enrichment for nitrifying bacteria was achieved by incubating activated sludge of wastewater treatment in Nitrite-formation medium, Nitrate-formation medium and mixed culture medium.

- 2) Immobilization of nitrifying bacteria; the immobilized nitrifying bacteria in polyvinyl alcohol-coal ash (PVA-coal) beads were prepared by using the PVA-boric acid method.

- 3) Acclimation of PVA-coal immobilized nitrifying bacteria gel beads, the PVA-coal immobilizing nitrifying bacteria gel beads were added to the tank contained with the synthetic recirculation aquaculture wastewater to recovery nitrifying bacteria activities after cell being immobilized.

- 4) Determination of the effectiveness of the immobilized nitrifying bacteria in polyvinyl alcohol-coal ash (PVA-coal) gel beads; the immobilized nitrifying

bacteria in polyvinyl alcohol-coal ash (PVA-coal) gel beads were evaluated for the removal efficiencies of ammonia-N and nitrite-N when operated in the bioreactor.

3.2 Research model

The experimental setup consists of bioreactor, feeding pump, storage tank, influent wastewater containers, and air pump. Figure 3.1 showed the experiment model at the laboratory level.

3.2.1 Bioreactor

The bioreactor was made from acrylic cylinder having a diameter of 11 cm. and a height of 50 cm. The top of cylinder is opened. The bioreactor had a liquid volume of 3 litre after the fill period. This actual volume of 3 litre bioreactor was a three-phase completely mixed and fluidized bead bioreactor type.

3.2.2 Air diffuser

The bioreactor was installed with diffusers at the bottom, which generated porous plumes of tiny air bubbles. Valves were used to control the quantity of air to the bioreactor.

3.2.3 Feeding pump

The pumps were used for feeding the synthetic recirculation aquaculture wastewater to the bioreactor.

3.2.4 Synthetic wastewater (SWW) storage tank

Storage tank was made from fiber glass. The volume of tank was 0.5 m³. Storage tank was used to store the influence synthetic wastewater over times operation.

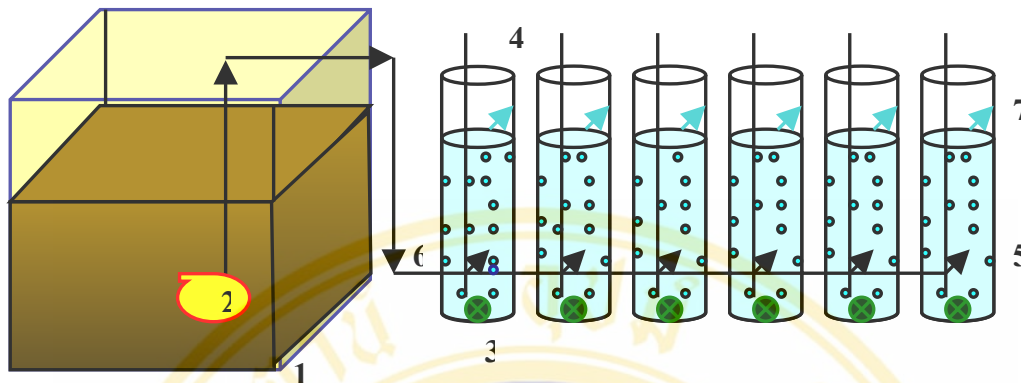


Figure 3.1 Schematic drawing of the experimental model

1	SWW storage tank	2	Feeding pump
3	Air diffusers	4	Nitrifying bioreactors
5	Beads	6	Influents
7	Effluents		

The synthetic wastewater was prepared and stored in SWW storage tank. Pump was continuously used to feed wastewater to the down-site and let the effluent out of the reactor at up-site, in which beads were filled 0.3 litre at 3 litre synthetic wastewater. The DO concentrations in bioreactors were controlled in the range 5-6 mg/l. The experiment was operated according to the designed independent variables (HRT 1, 2 and 4 hrs).

3.3 Experimental procedures and operating conditions

3.3.1 Establishment of nitrifying bacteria amendments from the activated sludge of wastewater treatment

Enrichment for nitrifying bacteria was achieved by incubating activated sludge, which was taken from Sri-phraya wastewater treatment plant in the Nitrite-formation medium and Nitrate-formation medium.

Procedure for establishment of nitrifying bacterial amendments

The medium 50 litre of each nitrifying bacteria media was prepared in fiber tank 120 litre, mixed activated sludge 1 litre per tank, saturate aerated and adjusted pH about 7.5-8.0 by H_2SO_4 or NaOH solution everyday. The Nitrite-formation medium and Nitrate-formation medium was measured the concentration of ammonia-nitrogen ($\text{NH}_3\text{-N}$) and nitrite-nitrogen ($\text{NO}_2\text{-N}$). Di-ammonium sulfate ($(\text{NH}_4)_2\text{SO}_4$) was added if the concentration of ammonia-nitrogen ($\text{NH}_3\text{-N}$) in Nitrite-formation medium tank was decreased lower than 20 mg/l. And Sodium nitrite (NaNO_2) was added if the concentration of nitrite-nitrogen ($\text{NO}_2\text{-N}$) in Nitrate-formation medium tank was decreased lower than 20 mg/l. as show in Figure 3.2

Nitrate-formation medium: 1.0 g NaNO_2 , 1.0 g K_2HPO_4 , 0.3 g MgSO_4 , 0.4 g FeSO_4 were all dissolved in 1,000 ml seawater (salinity 20 g/l.) This medium does not need to be sterilized.

Nitrite-formation medium: 2.0 g $(\text{NH}_4)_2\text{SO}_4$, 1.0 g K_2HPO_4 , 0.3 g MgSO_4 , 0.4 g FeSO_4 were all dissolved in 1,000 ml seawater (salinity 20 g/l.) This medium does not need to be sterilized.



Figure 3.2: The establishment of nitrifying bacteria with medium in the 120 litre tank.

3.3.2 Immobilization of nitrifying bacteria

The immobilized nitrifying bacteria in polyvinyl alcohol-coal ash (PVA-coal) gel beads were prepared by using the PVA-boric acid method.

Procedure for Immobilization of nitrifying bacteria

Dissolving Poly vinyl alcohol (PVA), as control variable, and 2 % Sodium alginate in distilled water was later heated to 60 °C. Cooling the PVA-alginate solution to the room temperature and then poured the concentrated nitrifying bacteria, the ratio 1:1 of Nitrite-formation medium and Nitrate-formation medium were centrifuged with 4,400 rpm for 20 min, mixed in ratio PVA solution : the concentrated nitrifying bacteria as 70:30 (v/v) then gently added coal ash (as designed) as shown in Figure 3.3



Figure 3.3: The mixture of PVA, the concentrated nitrifying bacteria, and coal ash

The final concentrations of the mixture were at 10.0%, 12.5% and 15.0% (w/v) PVA, and 1.5% (w/v) sodium alginate, 30% (v/v) suspended cell and 3%, 5% and 7% (w/v) coal ash.

Immobilization of nitrifying bacteria to form the spherical shape by dropping the PVA-coal nitrifying solution with syringe into 2 % (w/v) Calcium chloride (CaCl_2) and saturated Boric acid solution which cooled then gel beads and refrigerated them at 4 °C for 24 hrs. as shown in Figure 3.4



Figure 3.4: Immobilization of nitrifying bacteria in spherical beads using PVA-boric acid method.

The PVA-immobilized nitrifying bacteria was finally removed and washed with sea water [50], 20 g/l. As show as Figure 3.5

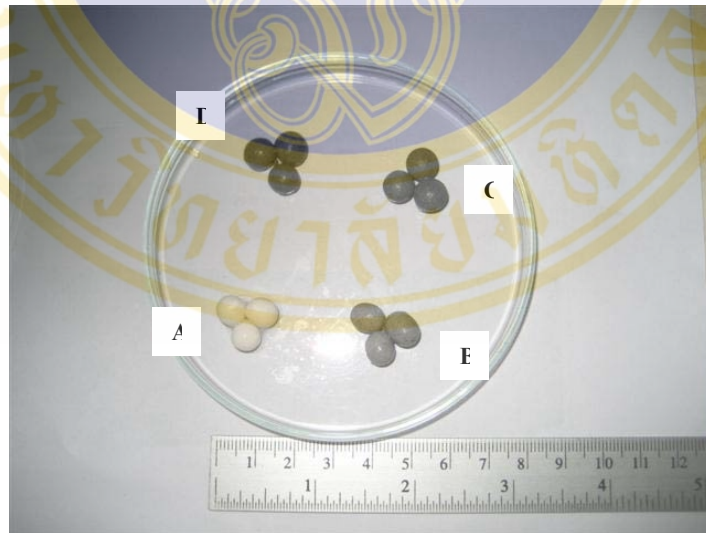


Figure 3.5: The characteristics of PVA-coal nitrifying beads in each ratio of coal ash, A : 0%, B : 3%, C : 5% and D : 7% (w/v) in 12.5 % (w/v) of PVA solution.

3.3.3 Acclimatization of PVA-coal immobilized nitrifying bacteria gel beads

The PVA-coal immobilized nitrifying bacteria gel beads were acclimatized to recovery nitrifying bacteria activities after cell being immobilized. The DO concentration in aeration tank were controlled in the range 5-6 mg/l. Determining the steady state condition of system was made by checking the stability of $\text{NH}_3\text{-N}$ and $\text{NO}_2\text{-N}$ removal efficiencies.

Procedure for Acclimatization of PVA-coal immobilized nitrifying Bacteria gel beads

The PVA-coal immobilized nitrifying bacteria gel beads were filled in 2 litre glass bottle, which contained the synthetic recirculation aquaculture wastewater, with the concentration of ammonia-nitrogen ($\text{NH}_3\text{-N}$) about 2 mg/l, and aerated to recovery nitrifying bacteria activities after cells were immobilized. The synthetic recirculation aquaculture wastewater was exchanged of about 100% daily and determined for the concentration of ammonia-nitrogen ($\text{NH}_3\text{-H}$), nitrite- nitrogen ($\text{NO}_2\text{-N}$) and nitrate-nitrogen ($\text{NO}_3\text{-N}$) as show in Figure 3.6

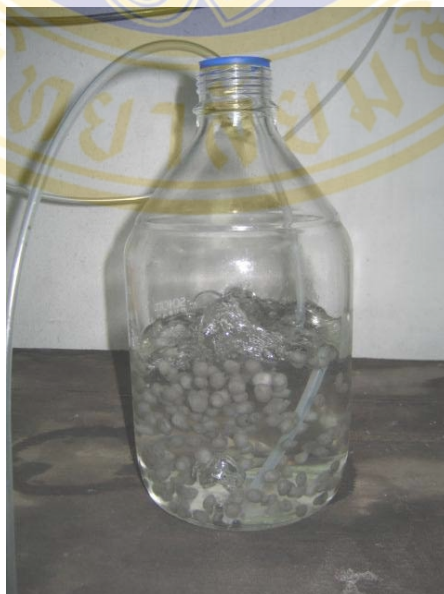


Figure 3.6: Acclimation of PVA-coal immobilized nitrifying bacteria gel beads with synthetic wastewater in glass bottle.

3.3.4 Determination of ammonia removal efficiency using the PVA-coal immobilized nitrifying bacteria gel beads

The PVA-coal immobilized nitrifying bacteria gel beads were evaluated for the removal of ammonia-nitrogen and nitrite-nitrogen by operating under the continuous nitrification bioreactor.



Figure 3.7 Nitrification bioreactor.

Procedure for determining the effectiveness of the immobilized nitrifying bacteria in polyvinyl alcohol- coal ash (PVA-coal) gel beads

1. A 3 litre bioreactor with an air diffuser was used to remove ammonia with 0.3 of the PVA-coal immobilized nitrifying bacteria gel beads.
2. Pump synthetic wastewater feeding into the bioreactor and start the nitrification processes continuously under hydraulic retention time (HRT) of about 1, 2 and 4 hr. and bioreactor operated at 15 days.
- 3 Determine the concentration of ammonia-nitrogen ($\text{NH}_3\text{-N}$), nitrite-nitrogen ($\text{NO}_2\text{-N}$), nitrate-nitrogen ($\text{NO}_3\text{-N}$) daily, and chemical oxygen demand (COD) three times a week.

3.3.5 Synthetic recirculation wastewater

The synthetic recirculation aquaculture wastewater contained glucose serving as a carbon source, ammonium sulfate, manganese sulfate, potassium hydrogen phosphate as phosphorus sources, and sodium bicarbonate as alkaline sources to stabilize pH. The composition of synthetic recirculation aquaculture wastewater were glucose of about 30 mg/l, Na_2HPO_4 40 mg/l, MnSO_4 2 mg/l, and $\text{NH}_3\text{-N}$ 2 mg/l [5] mixed in sea water 20 g/l, which brine water was diluted with fresh water.

3.3.6 Experiment operation conditions

Table 3.1 Operating conditions of this study

Groups	Conditions	Ratio of mixture weight by volume (%, PVA:coal)	HRT (hrs)
1	1	10.0 : 0	1
	2	10.0 : 3	1
	3	10.0 : 5	1
	4	10.0 : 7	1
	5	12.5 : 0	1
	6	12.5 : 3	1
	7	12.5 : 5	1
	8	12.5 : 7	1
	9	15.0 : 0	1
	10	15.0 : 3	1
	11	15.0 : 5	1
	12	15.0 : 7	1
2	13	10.0 : 0	2
	14	10.0 : 3	2
	15	10.0 : 5	2
	16	10.0 : 7	2
	17	12.5 : 0	2
	18	12.5 : 3	2
	19	12.5 : 5	2
	20	12.5 : 7	2
	21	15.0 : 0	2
	22	15.0 : 3	2
	23	15.0 : 5	2
	24	15.0 : 7	2
3	25	10.0 : 0	4
	26	10.0 : 3	4
	27	10.0 : 5	4
	28	10.0 : 7	4
	29	12.5 : 0	4
	30	12.5 : 3	4
	31	12.5 : 5	4
	32	12.5 : 7	4
	33	15.0 : 0	4
	34	15.0 : 3	4
	35	15.0 : 5	4
	36	15.0 : 7	4

Table 3.2 Control variables in this study

Control variables	Conditions
-Volume of immobilized PVA-coal nitrifying bacteria gel beads	-0.3 liter of PVA-coal immobilized nitrifying bacteria gel beads / 3 liter bioreactor.
-Characteristics of the synthetic feeding media	- 2 mg/l NH ₃ -N
-Salinity	- 20 g/l.
-DO	- >5 mg/l

3.3.7 Experiment procedures

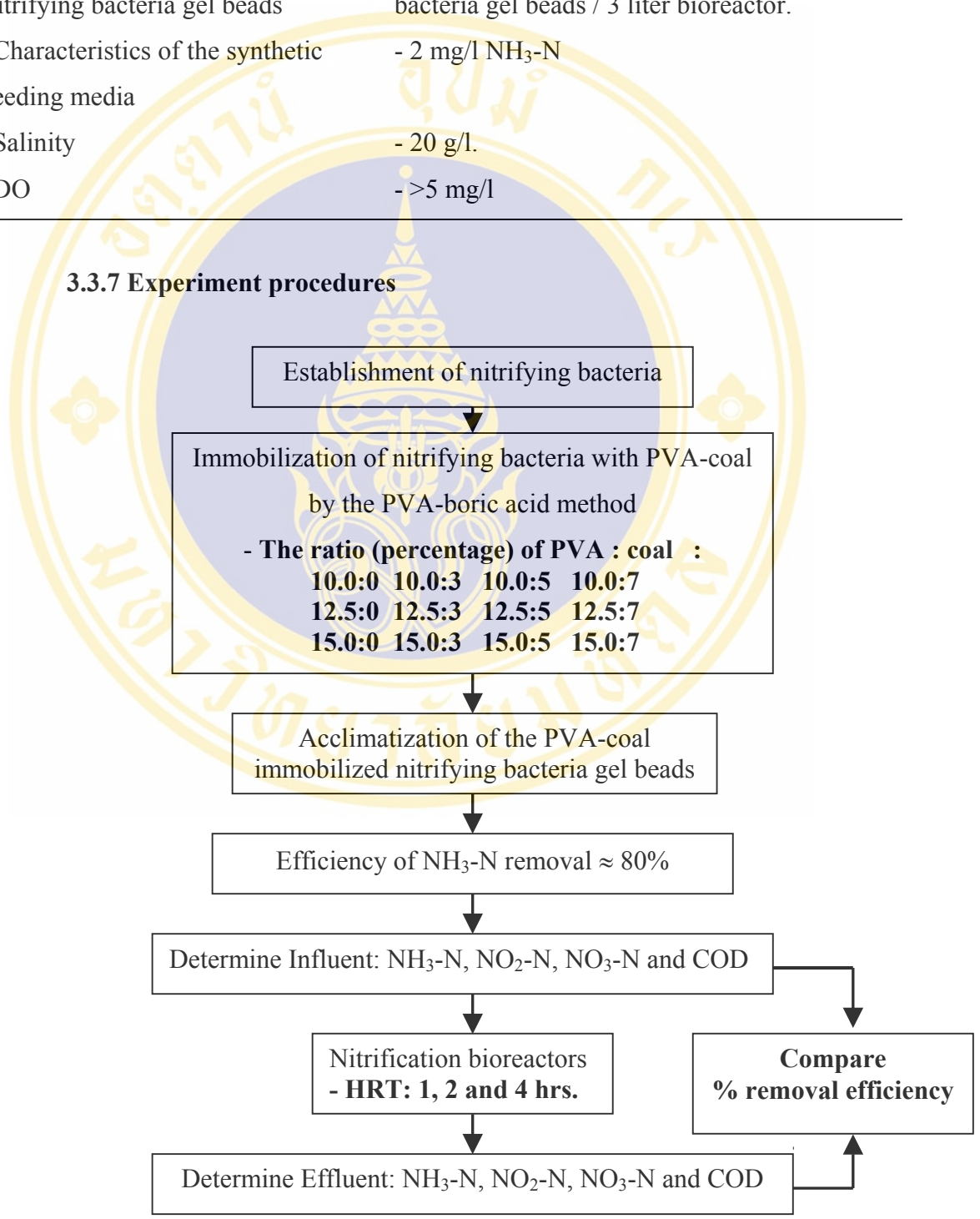


Figure 3.8 Experimental procedures

3.4 Sampling and analytical methods

3.4.1 Sampling method

During the acclimatization of PVA-coal gel beads step and determination of the removal efficiency of PVA-coal gel beads in bioreactors step, samples were collected from the synthetic wastewater tank as influent, and at the up-site of the bioreactors as effluents. The influent and effluent samples were collected continuously for a period of 15 days.

Water samples were refrigerated at temperatures of about 4 °C until prior to being analysed for pH, ammonia-nitrogen (NH₃-N), nitrite-nitrogen (NO₂-N), nitrate-nitrogen (NO₃-N), and chemical oxygen demand (COD), according to the methods described in the Standard Methods for Examination of Water and Wastewater 20th edition. The analytical methods, apparatus, and required chemical reagents were presented in Table 3.3.

Table 3.3 The measured parameters and sampling frequency

Parameters	Influent	Effluent
NH ₃ -N (mg/l)	Daily	Daily
NO ₂ -N (mg/l)	Daily	Daily
NO ₃ -N (mg/l)	Daily	Daily
COD (mg/l)	Three times a week	Three times a week
pH	Twice a week	Twice a week
Salinity (g/l)	Daily	Daily

Table 3.4 Analytical methods, apparatus, and chemical reagents for samples analysis

Parameters	Methods	Apparatus	Chemical Reagents
NH ₃ -N	Phenate Method	-Spectrophotometer	- Phenol - Ethyl alcohol - Sodium nitroprusside - Sodium citrate - Sodium hydroxide - Sodium hypochlorite
NO ₂ -N	Colorimetric Method	-Spectrophotometer	- NED dihydrochloride - Sulfanilamide - Hydrochloric acid
NO ₃ -N	Brucine Method	-Spectrophotometer	- Anhydrous Potassium Nitrate - Brucine Sulfate - Sulfuric Acid - Sodium Chloride - Hydrochloric Acid
COD	Dichromate Close Reflux Method	- Digestion vessels with lined screw caps - Heating block - Hot air oven	- Sulfuric Acid (conc.) - 1,10-Phenanthroline Monohydrate - Ferrous Ammonium Sulfate - Ferrous Sulfate Heptahydrate - Potassium Dichromate - Silver Sulfate - Mercuric Sulfate
pH	Glass Electrode Method	- pH meter	
Salinity	Refraction	-Salinometer (Hand Refractometer)	
DO	Membrane Electrode Method	- DO meter	

3.5 Statistical analysis

3.5.1 Descriptive analysis: The concentration and percentage of $\text{NH}_3\text{-N}$, $\text{NH}_2\text{-N}$, $\text{NO}_3\text{-N}$ and COD removal efficiencies were described as mean values, minimum values, maximum values and standard deviation.

3.5.2 The one way ANOVA and nonparametric test at significant level of 0.05 were used to test for statistically significant differences among the levels of dependent variables.

3.6 Experimental research design

The experimental research design of this study was shown in Figure 3.3.

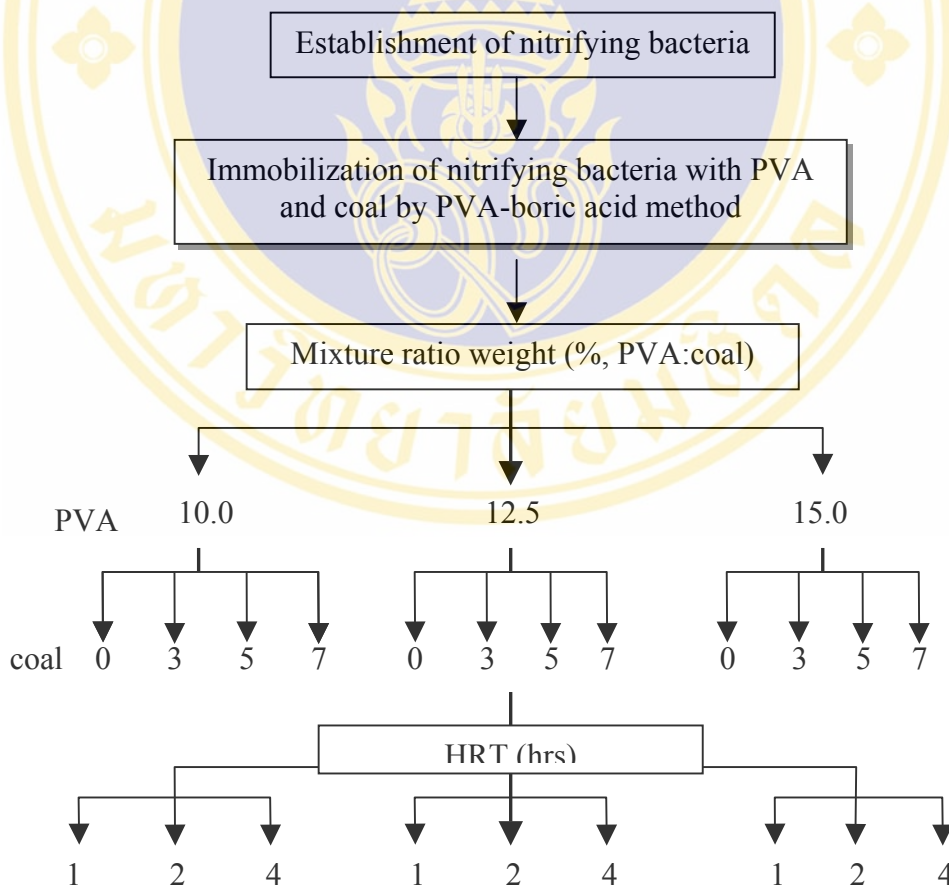


Figure 3.9 Experiment research design

CHAPTER IV

RESULTS

4.1 Shrimp culture wastewater characteristics

The average characteristics of synthetic wastewater, which used as shrimp culture wastewater in this study were NH₃-N 2 mg/l, COD 32 mg/l, salinity 20 g/l. NO₂-N and NO₃-N assumed as zero as presented in Table 4.1.

Table 4.1 Characteristics of the shrimp culture wastewater

Parameters	shrimp culture wastewater				synthetic wastewater			
	Min.	Max.	Mean.	SD	Min.	Max.	Mean.	SD
NH ₃ -N (mg/l)	0.00	2.00	0.71	0.74	1.95	2.47	2.13	0.14
NO ₂ -N (mg/l)	0.00	0.30	0.19	0.13	0.03	0.09	0.05	0.02
NO ₃ -N (mg/l)	0.00	2.50	1.03	0.12	0.00	0.05	0.02	0.02
COD (mg/l)	0.00	65.00	34.50	0.54	34.00	36.80	35.40	0.02

4.2 Performance of nitrifying bacteria during start up period

The experiment was started with an incubation of activated sludge, which was taken from Sri-phraya wastewater treatment plant, in the Nitrite-formation medium and Nitrate-formation medium. During start up period, it was taken at approximately a month. The Nitrite-formation medium and Nitrate-formation medium were measured for the concentration of ammonia-nitrogen (NH₃-N) and nitrite-nitrogen (NO₂-N). Di-ammonium sulfate ((NH₄)₂SO₄) was added if the concentration of ammonia-nitrogen (NH₃-N) in Nitrite-formation medium tank decreased lower than 20 mg/l. Sodium nitrite (NaNO₂) was added if the concentration of nitrite-nitrogen (NO₂-N) in Nitrate-

formation medium tank decreased lower than 20 mg/l. Both of the mediums were 50% exchange with new medium when concentrations of nitrate-nitrogen ($\text{NO}_3\text{-N}$) were higher than 300 mg/l and were adjusted pH for range 7.5-8.5 by acid and base solution. The profiles of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ concentrations of Nitrite-formation medium and Nitrate-formation medium were presented in Figure 4.1

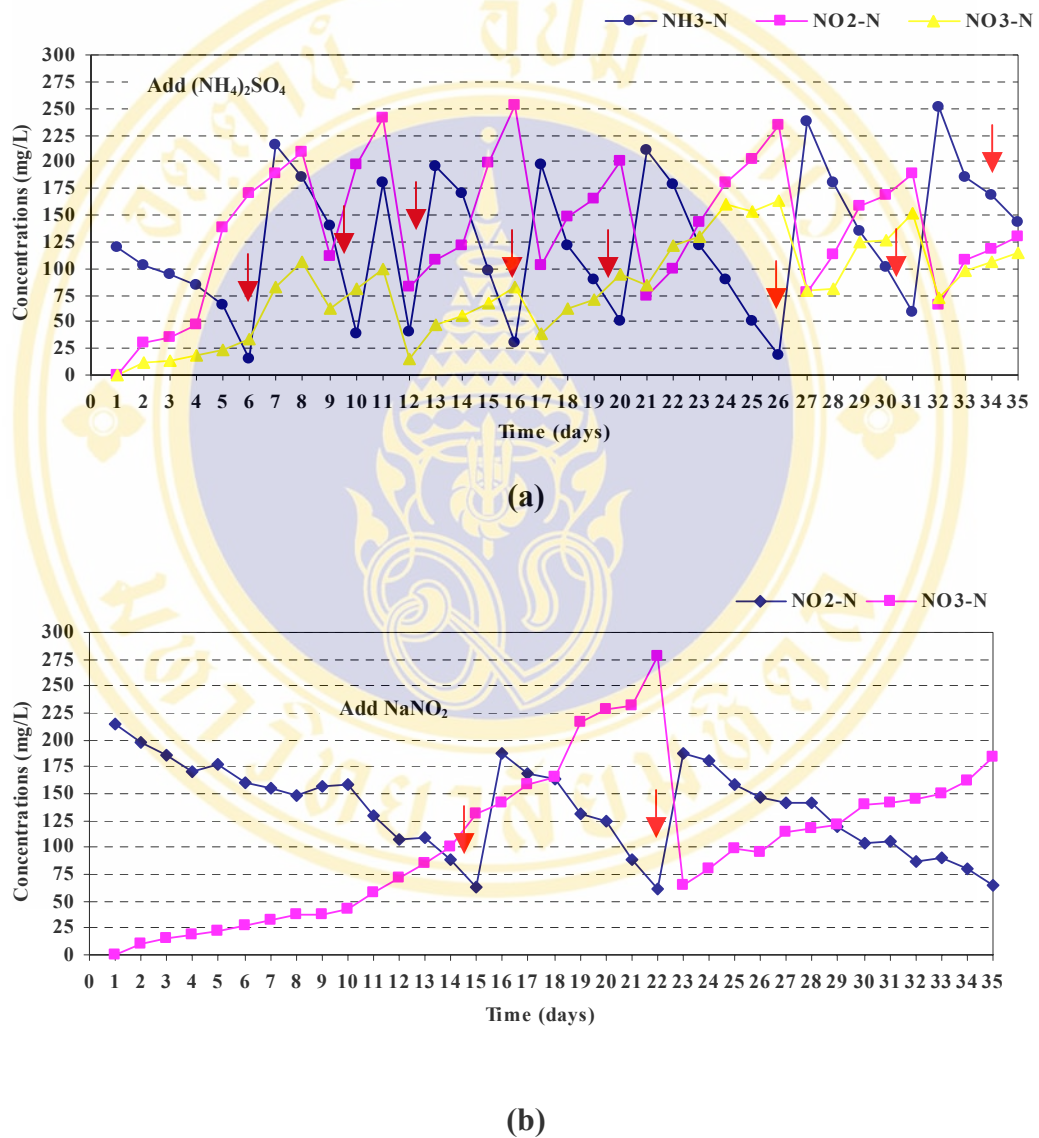


Figure 4.1 The concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ concentrations in the effluent of (a) Nitrite-formation medium and (b) Nitrate-formation medium during establishment period.

4.3 The performance of PVA-coal nitrifying bacteria gel beads during acclimatization period

The PVA-coal gel beads were acclimatized in the synthetic wastewater. The synthetic wastewater was sampled and changed everyday. The PVA-coal gel beads were performed after NH₃-N removal efficiency was greater than 80% and reached the steady state condition

The profiles of effluent NH₃-N concentrations during acclimatization period were illustrated in Figure 4.2.

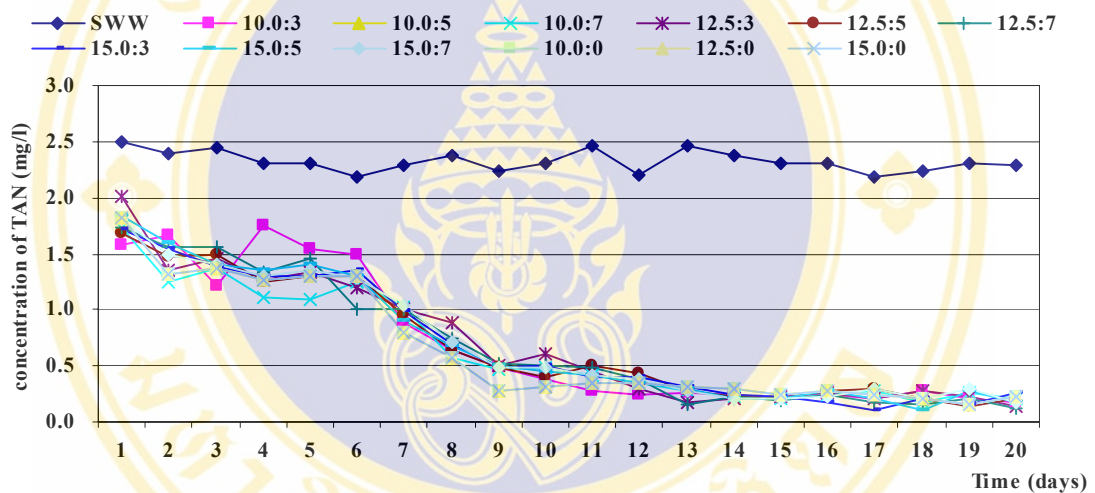


Figure 4.2 The concentrations of NH₃-N in the effluent during acclimatization period.

4.4 The Performance of PVA-coal nitrifying bacteria gel beads under difference operating conditions

The performance evaluations of PVA-coal nitrifying bacteria gel beads were divided into 3 groups under difference mixture weight by volume (% PVA:coal) and variation of HRT); each group consisted of 12 difference conditions. Table 4.2 presented the characteristics of the influent during the pseudo steady state of all experiments (conditions 1-12). The characteristics of the effluent and removal

efficiency percentages during pseudo steady state were separated into 3 groups as followed:

4.4.1 Group 1: Mixture weight by volume (% , PVA:coal) of 10.0:0, 10.0:3, 10.0:5, 10.0:7, 12.5:0, 12.5:3, 12.5:5, 12.5:7, 15.0:0, 15.0:3, 15.0:5 and 15.0:7 at HRT of 1 hrs (Conditions 1-12)

The concentrations of $\text{NH}_3\text{-N}$ in the influent, $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent and $\text{NH}_3\text{-N}$ removal efficiency percentages were summarized in Table 4.2 and illustrated in Figure 4.3.

1) Condition 1: Mixture weight by volume (% , PVA:coal) of 10.0:0 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.32 mg/l, 0.09 mg/l and 1.73 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 84.93%.

2) Condition 2: Mixture weight by volume (% , PVA:coal) of 10.0:3 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.28 mg/l, 0.09 mg/l and 1.77 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 86.93%.

3) Condition 3: Mixture weight by volume (% , PVA:coal) of 10.0:5 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.29 mg/l, 0.09 mg/l and 1.76 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 86.39%.

4) Condition 4: Mixture weight by volume (% , PVA:coal) of 10.0:7 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.30 mg/l, 0.08 mg/l and 1.75 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 86.16%.

5) Condition 5: Mixture weight by volume (% , PVA:coal) of 12.5:0 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.52 mg/l, 0.09 mg/l and 1.53 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 75.73%.

6) Condition 6: Mixture weight by volume (% , PVA:coal) of 12.5:3 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.23 mg/l, 0.07 mg/l and 1.84 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 89.47%.

7) Condition 7: Mixture weight by volume (% , PVA:coal) of 12.5:5 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.30 mg/l, 0.08 mg/l and 1.75 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 85.98%.

8) Condition 8: Mixture weight by volume (% , PVA:coal) of 12.5:7 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.26 mg/l, 0.07 mg/l and 1.80 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 87.90%.

9) Condition 9: Mixture weight by volume (% , PVA:coal) of 15.0:0 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.46 mg/l, 0.08 mg/l and 1.59 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 78.71%.

10) Condition 10: Mixture weight by volume (% , PVA:coal) of 15.0:3 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.33 mg/l, 0.13 mg/l and 1.67 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 84.45%.

11) Condition 11: Mixture weight by volume (% , PVA:coal) of 15.0:5 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.31 mg/l, 0.13 mg/l and 1.69 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 85.27%.

12) Condition 12: Mixture weight by volume (% , PVA:coal) of 15.0:7 at HRT of 1 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.31 mg/l, 0.12 mg/l and 1.70 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 85.84%.

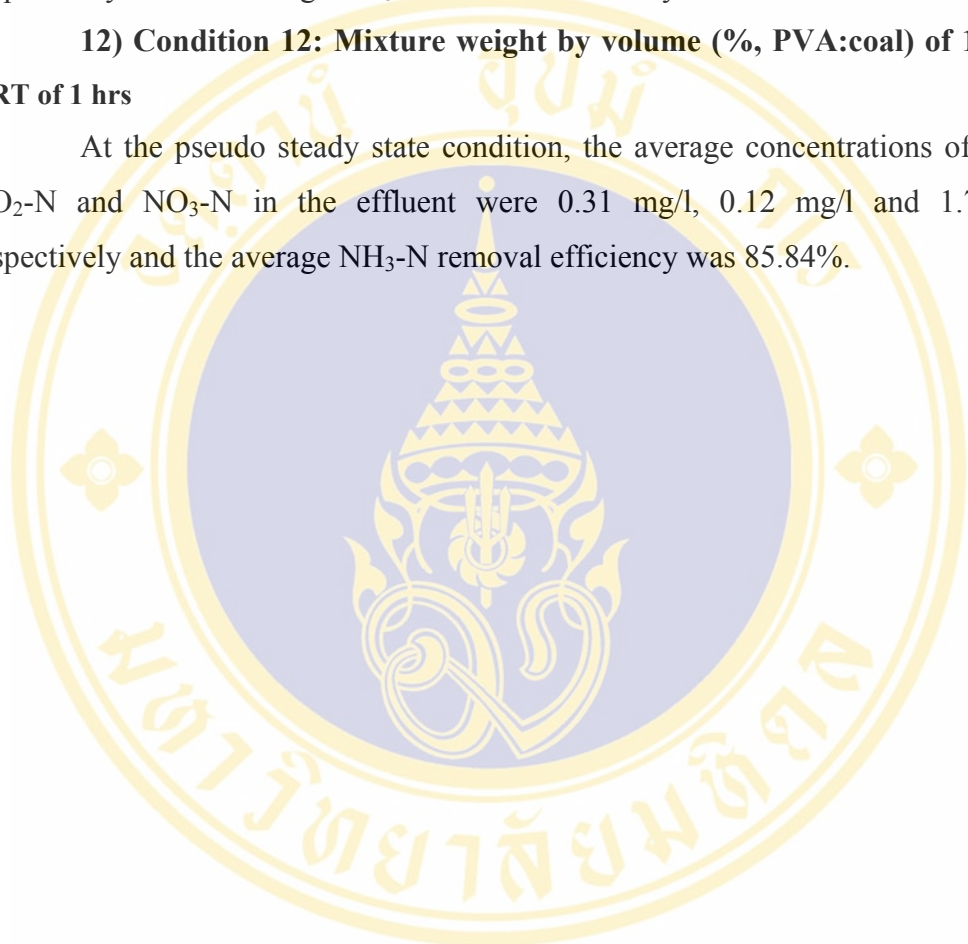


Table 4.2 The characteristics of the influent and the effluent during pseudo steady state condition of 1-12 conditions.

Conditions	Influent				Effluent				NH ₃ -N removal efficiency (%)	COD removal efficiency (%)
	NH ₃ -N mg/l	NO ₂ -N mg/l	NO ₃ -N mg/l	COD mg/l	NH ₃ -N mg/l	NO ₂ -N mg/l	NO ₃ -N mg/l	COD mg/l		
Condition 1: Mixing weight by volume (%PVA:coal) of 10.0:0 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.12	0.03	1.45	27.00	75.62	0.00
Max.	2.47	0.09	0.05	36.80	0.49	0.18	2.05	40.00	93.94	3.33
Mean.	2.13	0.05	0.02	35.40	0.32	0.09	1.73	32.60	84.93	2.58
SD.	0.14	0.02	0.02	0.02	0.09	0.05	0.15	3.58	4.47	1.06
Condition 2: Mixing weight by volume (%PVA:coal) of 10.0:3 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.20	0.03	1.58	29.00	78.03	0.00
Max.	2.47	0.09	0.05	36.80	0.49	0.18	2.06	38.00	90.48	9.09
Mean.	2.13	0.05	0.02	35.40	0.28	0.09	1.77	32.17	86.93	3.51
SD.	0.14	0.02	0.02	0.02	0.07	0.05	0.13	3.06	2.95	2.79
Condition 3: Mixing weight by volume (%PVA:coal) of 10.0:5 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.22	0.04	1.58	29.00	84.34	0.00
Max.	2.47	0.09	0.05	36.80	0.34	0.15	2.01	39.00	89.67	3.33
Mean.	2.13	0.05	0.02	35.40	0.29	0.09	1.76	32.87	86.39	1.49
SD.	0.14	0.02	0.02	0.02	0.04	0.04	0.12	3.18	1.59	1.61
Condition 4: Mixing weight by volume (%PVA:coal) of 10.0:7 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.22	0.05	1.63	30.00	79.22	0.00
Max.	2.47	0.09	0.05	36.80	0.48	0.15	1.97	38.50	89.67	4.05
Mean.	2.13	0.05	0.02	35.40	0.30	0.08	1.75	33.10	86.16	2.07
SD.	0.14	0.02	0.02	0.02	0.08	0.03	0.11	2.67	3.21	1.60
Condition 5: Mixing weight by volume (%PVA:coal) of 12.5:0 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.22	0.04	1.11	27.00	60.20	0.00
Max.	2.47	0.09	0.05	36.80	0.80	0.15	1.81	40.00	88.89	6.67
Mean.	2.13	0.05	0.02	35.40	0.52	0.09	1.53	32.60	75.73	2.81
SD.	0.14	0.02	0.02	0.02	0.14	0.04	0.19	3.58	7.09	2.18
Condition 6: Mixing weight by volume (%PVA:coal) of 12.5:3 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.12	0.04	1.61	30.00	73.59	0.00
Max.	2.47	0.09	0.05	36.80	0.61	0.10	2.05	38.50	94.23	4.05
Mean.	2.13	0.05	0.02	35.40	0.23	0.07	1.84	33.10	89.47	1.70
SD.	0.14	0.02	0.02	0.02	0.15	0.02	0.11	2.67	5.97	1.70
Condition 7: Mixing weight by volume (%PVA:coal) of 12.5:5 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.17	0.05	1.53	28.60	78.48	1.14
Max.	2.47	0.09	0.05	36.80	0.51	0.13	1.96	39.20	91.54	4.67
Mean.	2.13	0.05	0.02	35.40	0.30	0.08	1.75	33.28	85.98	2.60
SD.	0.14	0.02	0.02	0.02	0.10	0.03	0.12	3.51	3.98	1.13
Condition 8: Mixing weight by volume (%PVA:coal) of 12.5:7 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.14	0.04	1.61	27.00	76.68	0.00
Max.	2.47	0.09	0.05	36.80	0.52	0.10	2.08	40.00	93.04	6.67
Mean.	2.13	0.05	0.02	35.40	0.26	0.07	1.80	32.60	87.90	2.81
SD.	0.14	0.02	0.02	0.02	0.13	0.02	0.12	3.58	5.37	1.87
Condition 9: Mixing weight by volume (%PVA:coal) of 15.0:0 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.15	0.05	1.22	29.00	66.67	0.00
Max.	2.47	0.09	0.05	36.80	0.67	0.15	1.93	38.00	93.02	8.33
Mean.	2.13	0.05	0.02	35.40	0.46	0.08	1.59	32.17	78.71	3.38
SD.	0.14	0.02	0.02	0.02	0.17	0.03	0.17	3.06	7.46	2.57
Condition 10: Mixing weight by volume (%PVA:coal) of 15.0:3 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.27	0.10	1.54	28.60	78.03	1.14
Max.	2.47	0.09	0.05	36.80	0.49	0.18	1.98	39.20	87.02	4.67
Mean.	2.13	0.05	0.02	35.40	0.33	0.13	1.67	33.28	84.45	2.41
SD.	0.14	0.02	0.02	0.02	0.06	0.02	0.12	3.51	2.51	1.17
Condition 11: Mixing weight by volume (%PVA:coal) of 15.0:5 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.25	0.10	1.50	29.00	81.43	0.00
Max.	2.47	0.09	0.05	36.80	0.39	0.16	2.08	38.00	89.88	8.33
Mean.	2.13	0.05	0.02	35.40	0.31	0.13	1.69	32.17	85.27	3.38
SD.	0.14	0.02	0.02	0.02	0.03	0.02	0.15	3.06	1.77	2.57
Condition 12: Mixing weight by volume (%PVA:coal) of 15.0:7 in HRT 1 hr.										
Min.	1.95	0.03	0.00	34.00	0.27	0.08	1.50	30.00	82.59	0.00
Max.	2.47	0.09	0.05	36.80	0.37	0.16	2.01	38.50	87.02	4.05
Mean.	2.13	0.05	0.02	35.40	0.31	0.12	1.70	33.10	85.34	1.70
SD.	0.14	0.02	0.02	0.02	0.04	0.02	0.14	2.67	1.29	1.70

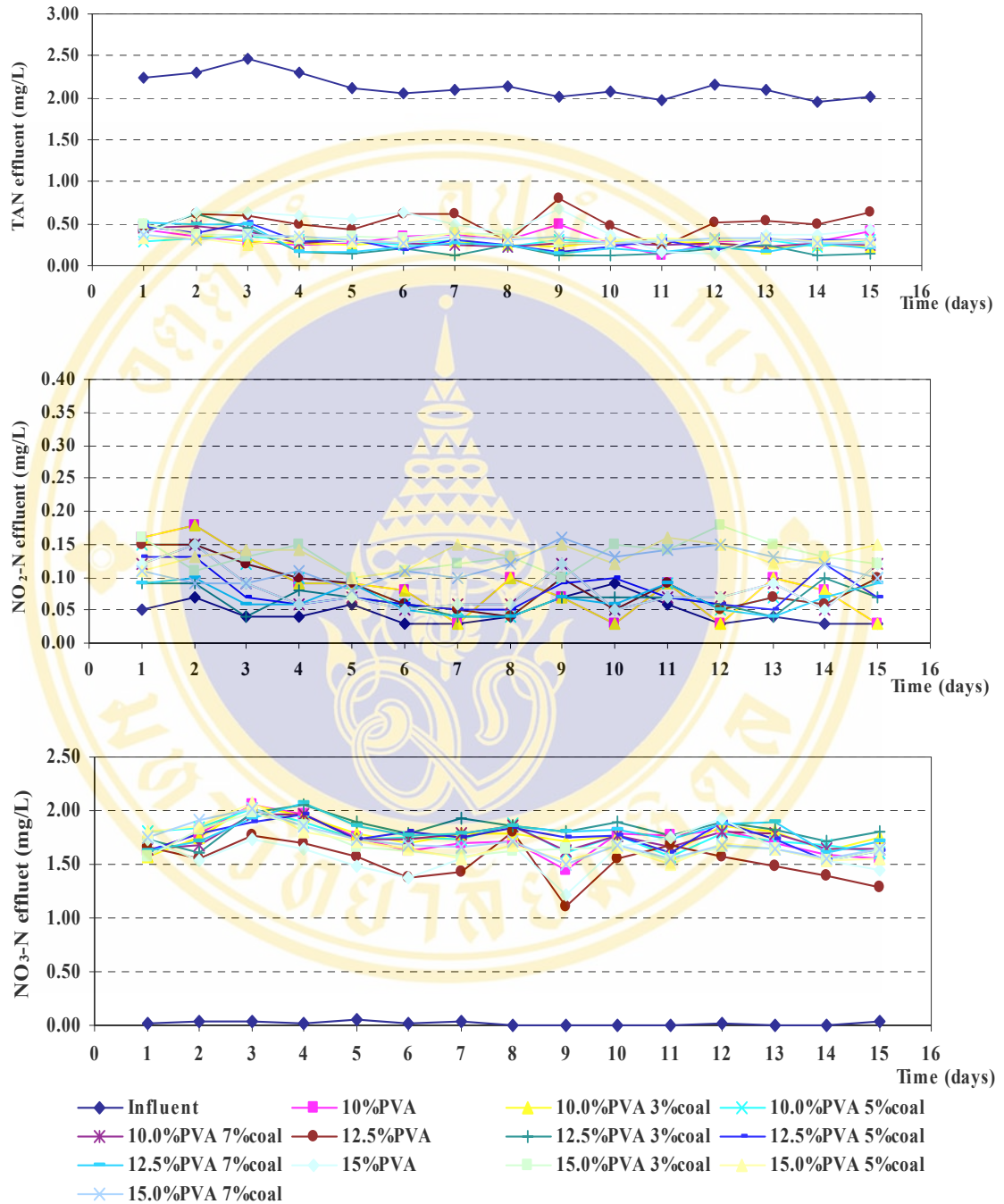


Figure 4.3 The concentrations of NH₃-N in the influent, NH₃-N, NO₂-N and NO₃-N in the effluent and NH₃-N removal efficiency percentages during pseudo steady state condition at HRT 1 hr and various mixture weight by volume (% , PVA:coal)

4.4.2 Group 2: Mixture weight by volume (% , PVA:coal) of 10.0:0, 10.0:3, 10.0:5 10.0:7, 12.5:0, 12.5:3, 12.5:5, 12.5:7, 15.0:0, 15.0:3, 15.0:5 and 15.0:7 at HRT of 2 hrs (Conditions 13-24)

The concentrations of NH₃-N in the influent, NH₃-N, NO₂-N and NO₃-N in the effluent and NH₃-N removal efficiency percentages were summarized in Table 4.3 and illustrated in Figure 4.4 .

1) Condition 13: Mixture weight by volume (% , PVA:coal) of 10.0:0 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.20 mg/l, 0.04 mg/l and 1.53 mg/l, respectively and the average NH₃-N removal efficiency was 90.61%.

2) Condition 14: Mixture weight by volume (% , PVA:coal) of 10.0:3 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.11 mg/l, 0.04 mg/l and 1.75 mg/l, respectively and the average NH₃-N removal efficiency was 94.64%.

3) Condition 15: Mixture weight by volume (% , PVA:coal) of 10.0:5 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.16 mg/l, 0.06 mg/l and 1.68 mg/l, respectively and the average NH₃-N removal efficiency was 92.58%.

4) Condition 16: Mixture weight by volume (% , PVA:coal) of 10.0:7 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.13 mg/l, 0.06 mg/l and 1.74 mg/l, respectively and the average NH₃-N removal efficiency was 93.70%.

5) Condition 17: Mixture weight by volume (% , PVA:coal) of 12.5:0 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.45 mg/l, 0.06 mg/l and 1.37 mg/l, respectively and the average NH₃-N removal efficiency was 78.93%.

6) Condition 18: Mixture weight by volume (% , PVA:coal) of 12.5:3 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.15 mg/l, 0.08 mg/l and 1.75 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 93.01%.

7) Condition 19: Mixture weight by volume (% , PVA:coal) of 12.5:5 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.14 mg/l, 0.08 mg/l and 1.75 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 93.37%.

8) Condition 20: Mixture weight by volume (% , PVA:coal) of 12.5:7 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.13 mg/l, 0.08 mg/l and 1.74 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 93.69%.

9) Condition 21: Mixture weight by volume (% , PVA:coal) of 15.0:0 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.33 mg/l, 0.06 mg/l and 1.42 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 84.27%.

10) Condition 22: Mixture weight by volume (% , PVA:coal) of 15.0:3 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.19 mg/l, 0.12 mg/l and 1.61 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 90.96%.

11) Condition 23: Mixture weight by volume (% , PVA:coal) of 15.0:5 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.20 mg/l, 0.13 mg/l and 1.64 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 90.87%.

12) Condition 24: Mixture weight by volume (% , PVA:coal) of 15.0:7 at HRT of 2 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.20 mg/l, 0.11 mg/l and 1.60 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 90.69%.



Table 4.3 The characteristics of the influent and the effluent during pseudo steady state condition of 13-24 conditions.

Conditions	Influent				Effluent				NH ₃ -N removal efficiency (%)	COD removal efficiency (%)
	NH ₃ -N mg/l	NO ₂ -N mg/l	NO ₃ -N mg/l	COD mg/l	NH ₃ -N mg/l	NO ₂ -N mg/l	NO ₃ -N mg/l	COD mg/l		
Condition 13: Mixing weight by volume (%PVA:coal) of 10.0:0 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.14	0.01	1.53	27.00	81.03	0.00
Max.	2.40	0.05	0.09	36.80	0.37	0.08	2.22	38.00	93.75	4.76
Mean.	2.14	0.01	0.04	35.40	0.20	0.04	1.89	31.63	90.61	1.80
SD.	0.12	0.02	0.03	0.02	0.07	0.02	0.16	3.25	3.68	2.17
Condition 14: Mixing weight by volume (%PVA:coal) of 10.0:3 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.09	0.01	1.75	29.00	92.31	0.00
Max.	2.40	0.05	0.09	36.80	0.15	0.08	2.27	38.00	95.83	3.33
Mean.	2.14	0.01	0.04	35.40	0.11	0.04	1.98	31.44	94.64	1.62
SD.	0.12	0.02	0.03	0.02	0.02	0.02	0.13	2.87	1.15	1.26
Condition 15: Mixing weight by volume (%PVA:coal) of 10.0:5 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.10	0.03	1.68	29.00	89.76	0.00
Max.	2.40	0.05	0.09	36.80	0.21	0.10	2.26	36.00	95.83	5.26
Mean.	2.14	0.01	0.04	35.40	0.16	0.06	1.92	31.13	92.58	2.46
SD.	0.12	0.02	0.03	0.02	0.04	0.02	0.14	2.23	1.86	1.99
Condition 16: Mixing weight by volume (%PVA:coal) of 10.0:7 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.05	0.03	1.74	30.00	89.76	0.00
Max.	2.40	0.05	0.09	36.80	0.21	0.10	2.24	37.50	97.65	3.13
Mean.	2.14	0.01	0.04	35.40	0.13	0.06	1.94	31.81	93.70	1.14
SD.	0.12	0.02	0.03	0.02	0.05	0.02	0.14	2.36	2.20	1.10
Condition 17: Mixing weight by volume (%PVA:coal) of 12.5:0 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.29	0.03	1.37	27.00	71.30	0.00
Max.	2.40	0.05	0.09	36.80	0.62	0.10	1.89	38.00	85.85	4.76
Mean.	2.14	0.01	0.04	35.40	0.45	0.06	1.62	31.63	78.93	1.80
SD.	0.12	0.02	0.03	0.02	0.10	0.02	0.15	3.25	4.69	2.17
Condition 18: Mixing weight by volume (%PVA:coal) of 12.5:3 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.07	0.03	1.75	30.00	90.00	0.00
Max.	2.40	0.05	0.09	36.80	0.22	0.12	2.17	37.50	96.71	6.67
Mean.	2.14	0.01	0.04	35.40	0.15	0.08	1.90	31.81	93.01	1.98
SD.	0.12	0.02	0.03	0.02	0.05	0.03	0.12	2.36	2.14	2.14
Condition 19: Mixing weight by volume (%PVA:coal) of 12.5:5 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.08	0.04	1.75	29.00	90.24	0.00
Max.	2.40	0.05	0.09	36.80	0.20	0.12	2.20	39.00	96.28	4.76
Mean.	2.14	0.01	0.04	35.40	0.14	0.08	1.92	32.48	93.37	1.87
SD.	0.12	0.02	0.03	0.02	0.04	0.03	0.13	3.81	2.07	2.11
Condition 20: Mixing weight by volume (%PVA:coal) of 12.5:7 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.08	0.03	1.74	27.00	92.46	0.00
Max.	2.40	0.05	0.09	36.80	0.18	0.12	2.12	38.00	96.26	10.00
Mean.	2.14	0.01	0.04	35.40	0.13	0.08	1.92	31.63	93.69	3.05
SD.	0.12	0.02	0.03	0.02	0.03	0.03	0.11	3.25	1.17	3.47
Condition 21: Mixing weight by volume (%PVA:coal) of 15.0:0 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.21	0.03	1.42	29.00	76.92	0.00
Max.	2.40	0.05	0.09	36.80	0.47	0.10	2.04	38.00	90.48	3.33
Mean.	2.14	0.01	0.04	35.40	0.33	0.06	1.74	31.44	84.27	1.62
SD.	0.12	0.02	0.03	0.02	0.10	0.02	0.16	2.87	4.56	1.26
Condition 22: Mixing weight by volume (%PVA:coal) of 15.0:3 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.14	0.09	1.61	29.00	87.80	0.00
Max.	2.40	0.05	0.09	36.80	0.25	0.18	2.16	39.00	94.17	4.76
Mean.	2.14	0.01	0.04	35.40	0.19	0.12	1.82	32.48	90.96	1.87
SD.	0.12	0.02	0.03	0.02	0.03	0.02	0.14	3.81	1.84	2.11
Condition 23: Mixing weight by volume (%PVA:coal) of 15.0:5 in HRT 2 hr.										
Min.	1.95	0.00	0.00	34.00	0.15	0.1	1.64	29.00	88.64	0.00
Max.	2.40	0.05	0.09	36.80	0.25	0.17	2.05	38.00	93.12	3.33
Mean.	2.14	0.01	0.04	35.40	0.20	0.13	1.81	31.44	90.87	1.62
SD.	0.12	0.02	0.03	0.02	0.03	0.02	0.11	2.87	1.17	1.26
Condition 24: Mixing weight by volume (%PVA:coal) of 15.0:7 in HRT 2 hr.										
Min.	1.95	0.00	0.00	29.50	0.16	0.09	1.6	30.00	89.09	0.00
Max.	2.40	0.05	0.09	35.80	0.24	0.14	2.08	37.50	92.59	3.13
Mean.	2.14	0.01	0.04	32.00	0.20	0.11	1.83	31.81	90.69	1.14
SD.	0.12	0.02	0.03	0.02	0.03	0.02	0.13	2.36	1.21	1.10

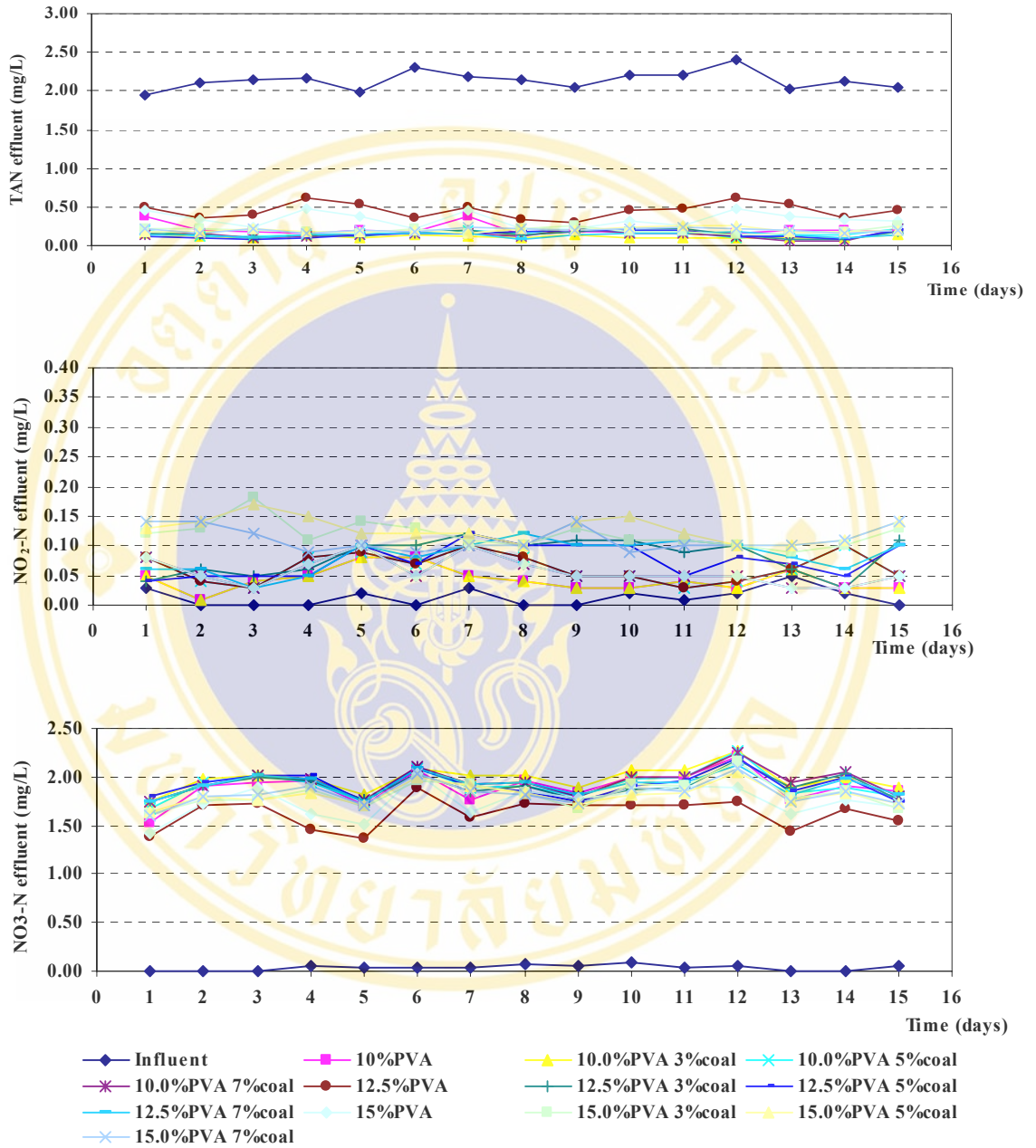


Figure 4.4 The concentrations of NH₃-N in the influent, NH₃-N, NO₂-N and NO₃-N in the effluent and NH₃-N removal efficiency percentages during pseudo steady state condition at HRT 2 hr and various mixture weight by volume (% , PVA:coal)

4.4.3 Group 3: Mixture weight by volume (% , PVA:coal) of 10.0:0, 10.0:3, 10.0:5 10.0:7, 12.5:0, 12.5:3, 12.5:5, 12.5:7, 15.0:0, 15.0:3, 15.0:5 and 15.0:7 at HRT of 4 hrs (Conditions 25-36)

The concentrations of NH₃-N in the influent, NH₃-N, NO₂-N and NO₃-N in the effluent and NH₃-N removal efficiency percentages were summarized in Table 4.4 and illustrated in Figure 4.5.

1) Condition 25: Mixture weight by volume (% , PVA:coal) of 10.0:0 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.18 mg/l, 0.06 mg/l and 1.84 mg/l, respectively and the average NH₃-N removal efficiency was 91.09%.

2) Condition 26: Mixture weight by volume (% , PVA:coal) of 10.0:3 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.10 mg/l, 0.05 mg/l and 1.94 mg/l, respectively and the average NH₃-N removal efficiency was 95.36%.

3) Condition 27: Mixture weight by volume (% , PVA:coal) of 10.0:5 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.09 mg/l, 0.05 mg/l and 1.95 mg/l, respectively and the average NH₃-N removal efficiency was 95.62%.

4) Condition 28: Mixture weight by volume (% , PVA:coal) of 10.0:7 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.11 mg/l, 0.05 mg/l and 1.93 mg/l, respectively and the average NH₃-N removal efficiency was 94.95%.

5) Condition 29: Mixture weight by volume (% , PVA:coal) of 12.5:0 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.24 mg/l, 0.07 mg/l and 1.78 mg/l, respectively and the average NH₃-N removal efficiency was 88.53%.

6) Condition 30: Mixture weight by volume (% , PVA:coal) of 12.5:3 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.09 mg/l, 0.05 mg/l and 1.95 mg/l, respectively and the average NH₃-N removal efficiency was 95.68%.

7) Condition 31: Mixture weight by volume (% , PVA:coal) of 12.5:5 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.10 mg/l, 0.04 mg/l and 1.95 mg/l, respectively and the average NH₃-N removal efficiency was 95.38%.

8) Condition 32: Mixture weight by volume (% , PVA:coal) of 12.5:7 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.10 mg/l, 0.05 mg/l and 1.93 mg/l, respectively and the average NH₃-N removal efficiency was 95.34%.

9) Condition 33: Mixture weight by volume (% , PVA:coal) of 15.0:0 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.19 mg/l, 0.06 mg/l and 1.84 mg/l, respectively and the average NH₃-N removal efficiency was 90.92%.

10) Condition 34: Mixture weight by volume (% , PVA:coal) of 15.0:3 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.10 mg/l, 0.14 mg/l and 1.85 mg/l, respectively and the average NH₃-N removal efficiency was 95.06%.

11) Condition 35: Mixture weight by volume (% , PVA:coal) of 15.0:5 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent were 0.11 mg/l, 0.12 mg/l and 1.86 mg/l, respectively and the average NH₃-N removal efficiency was 94.76%.

12) Condition 36: Mixture weight by volume (% , PVA:coal) of 15.0:7 at HRT of 4 hrs

At the pseudo steady state condition, the average concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ in the effluent were 0.11 mg/l, 0.10 mg/l and 1.88 mg/l, respectively and the average $\text{NH}_3\text{-N}$ removal efficiency was 94.79%.



Table 4.4 The characteristics of the influent and the effluent during pseudo steady state condition of 25-36 conditions.

Conditions	Influent				Effluent				NH ₃ -N removal efficiency (%)	COD removal efficiency (%)
	NH ₃ -N	NO ₂ -N	NO ₃ -N	COD	NH ₃ -N	NO ₂ -N	NO ₃ -N	COD		
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l		
Condition 25: Mixing weight by volume (%PVA:coal) of 10.0:0 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.05	0.02	1.08	30	55.88	0.00
Max.	2.21	0.09	0.09	36.80	0.90	0.14	2.10	40.00	97.69	4.76
Mean.	2.09	0.05	0.06	35.40	0.18	0.06	1.84	34.25	91.09	1.66
SD.	0.09	0.02	0.02	0.02	0.21	0.04	0.25	3.65	10.31	1.88
Condition 26: Mixing weight by volume (%PVA:coal) of 10.0:3 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.05	0.02	1.79	29	90.23	0.00
Max.	2.21	0.09	0.09	36.80	0.21	0.14	2.11	38.00	97.69	9.09
Mean.	2.09	0.05	0.06	35.40	0.10	0.05	1.94	33.31	95.36	3.95
SD.	0.09	0.02	0.02	0.02	0.04	0.04	0.11	3.58	1.72	3.29
Condition 27: Mixing weight by volume (%PVA:coal) of 10.0:5 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.05	0.01	1.81	30.00	93.49	0.00
Max.	2.21	0.09	0.09	36.80	0.14	0.17	2.09	39.00	97.71	5.26
Mean.	2.09	0.05	0.06	35.40	0.09	0.05	1.95	34.13	95.62	1.55
SD.	0.09	0.02	0.02	0.02	0.03	0.04	0.09	3.27	1.35	1.95
Condition 28: Mixing weight by volume (%PVA:coal) of 10.0:7 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.06	0.01	1.66	31.00	87.91	-3.33
Max.	2.21	0.09	0.09	36.80	0.26	0.18	2.10	38.50	97.29	4.05
Mean.	2.09	0.05	0.06	35.40	0.11	0.05	1.93	34.13	94.95	1.49
SD.	0.09	0.02	0.02	0.02	0.05	0.04	0.12	3.04	2.39	2.39
Condition 29: Mixing weight by volume (%PVA:coal) of 12.5:0 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.08	0.01	1.51	30.00	78.79	0.00
Max.	2.21	0.09	0.09	36.80	0.42	0.18	2.05	40.00	96.08	4.76
Mean.	2.09	0.05	0.06	35.40	0.24	0.07	1.78	34.25	88.53	1.66
SD.	0.09	0.02	0.02	0.02	0.10	0.05	0.13	3.65	4.77	1.88
Condition 30: Mixing weight by volume (%PVA:coal) of 12.5:3 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.06	0.01	1.83	31.00	90.70	-3.33
Max.	2.21	0.09	0.09	36.80	0.20	0.11	2.11	38.50	97.22	4.05
Mean.	2.09	0.05	0.06	35.40	0.09	0.05	1.95	34.13	95.68	1.49
SD.	0.09	0.02	0.02	0.02	0.04	0.03	0.09	3.04	1.81	2.39
Condition 31: Mixing weight by volume (%PVA:coal) of 12.5:5 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.06	0.01	1.82	29.00	92.09	0.00
Max.	2.21	0.09	0.09	36.80	0.17	0.12	2.09	39.20	97.22	6.06
Mean.	2.09	0.05	0.06	35.40	0.10	0.04	1.95	33.75	95.38	2.77
SD.	0.09	0.02	0.02	0.02	0.03	0.03	0.10	3.79	1.52	2.04
Condition 32: Mixing weight by volume (%PVA:coal) of 12.5:7 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.06	0.01	1.77	30.00	87.44	0.00
Max.	2.21	0.09	0.09	36.80	0.27	0.13	2.10	40.00	97.22	4.76
Mean.	2.09	0.05	0.06	35.40	0.10	0.05	1.93	34.25	95.34	1.66
SD.	0.09	0.02	0.02	0.02	0.05	0.04	0.11	3.65	2.34	1.88
Condition 33: Mixing weight by volume (%PVA:coal) of 15.0:0 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.08	0.02	1.47	29.00	77.27	0.00
Max.	2.21	0.09	0.09	36.80	0.45	0.10	2.10	38.00	96.08	9.09
Mean.	2.09	0.05	0.06	35.40	0.19	0.06	1.84	33.31	90.92	3.95
SD.	0.09	0.02	0.02	0.02	0.11	0.02	0.18	3.58	5.47	3.29
Condition 34: Mixing weight by volume (%PVA:coal) of 15.0:3 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.08	0.10	1.72	29.00	92.09	0.00
Max.	2.21	0.09	0.09	36.80	0.17	0.20	2.02	39.20	96.38	6.06
Mean.	2.09	0.05	0.06	35.40	0.10	0.14	1.85	33.75	95.08	2.77
SD.	0.09	0.02	0.02	0.02	0.03	0.03	0.09	3.79	1.18	2.04
Condition 35: Mixing weight by volume (%PVA:coal) of 15.0:5 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.08	0.09	1.73	29.00	93.66	0.00
Max.	2.21	0.09	0.09	36.80	0.14	0.18	2.00	38.00	96.33	9.09
Mean.	2.09	0.05	0.06	35.40	0.11	0.12	1.86	33.31	94.76	3.95
SD.	0.09	0.02	0.02	0.02	0.02	0.02	0.09	3.58	0.79	3.29
Condition 36: Mixing weight by volume (%PVA:coal) of 15.0:7 in HRT 4 hr.										
Min.	1.98	0.01	0.03	34.00	0.09	0.06	1.78	31.00	94.12	-3.33
Max.	2.21	0.09	0.09	36.80	0.13	0.12	2.02	38.50	95.52	4.05
Mean.	2.09	0.05	0.06	35.40	0.11	0.10	1.88	34.13	94.79	1.49
SD.	0.09	0.02	0.02	0.02	0.01	0.02	0.08	3.04	0.41	2.39

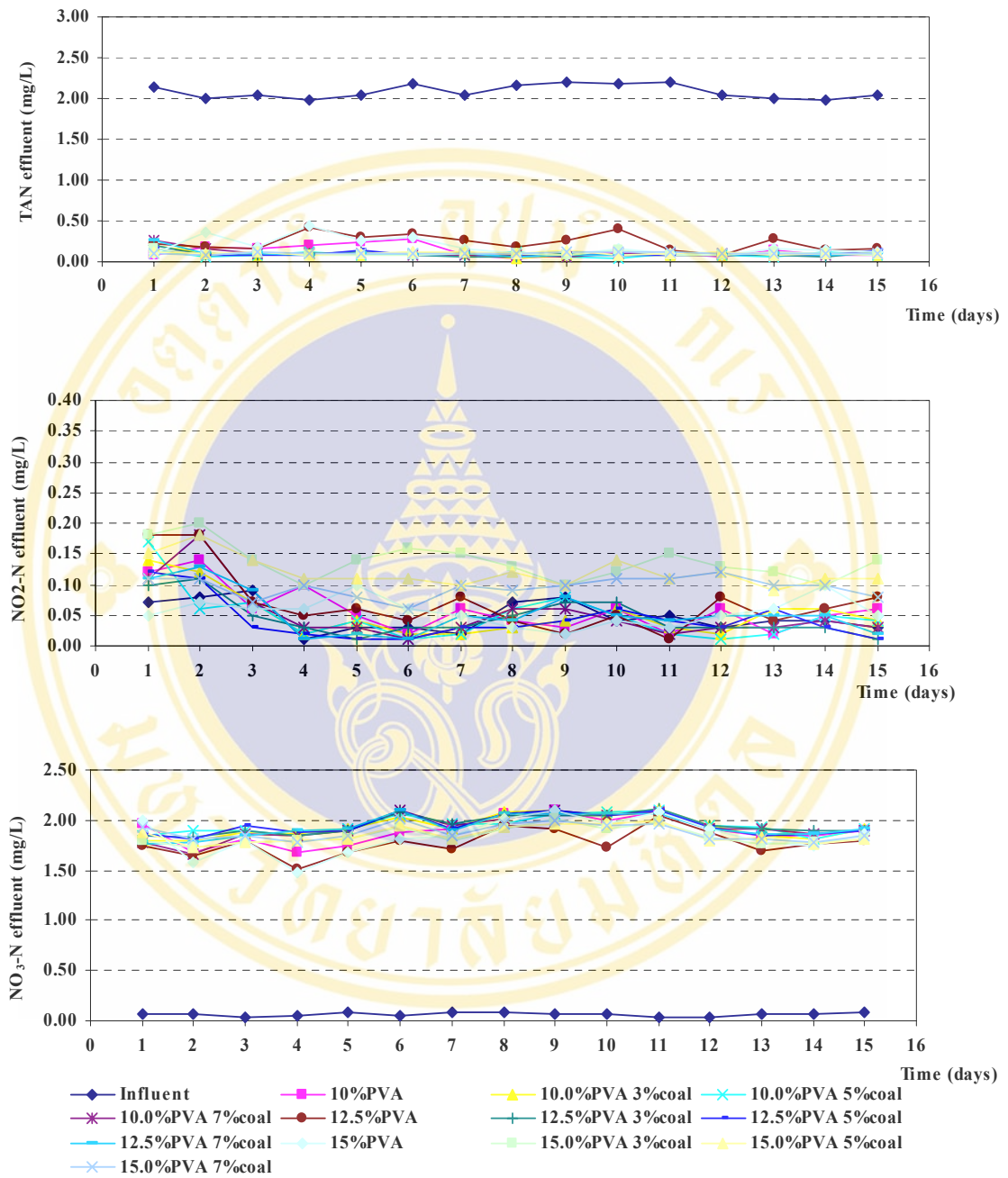


Figure 4.5 The concentrations of NH₃-N, NO₂-N and NO₃-N in the effluent, and NH₃-N removal efficiency percentages during pseudo steady state condition at HRT 4 hr and various mixture weight by volume (% , PVA:coal)

4.4.4 Overall experimental results of nitrification reactors

The overview of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ concentrations in the influent and effluent and $\text{NH}_3\text{-N}$ removal efficiency percentages were illustrated in Figure 4.6

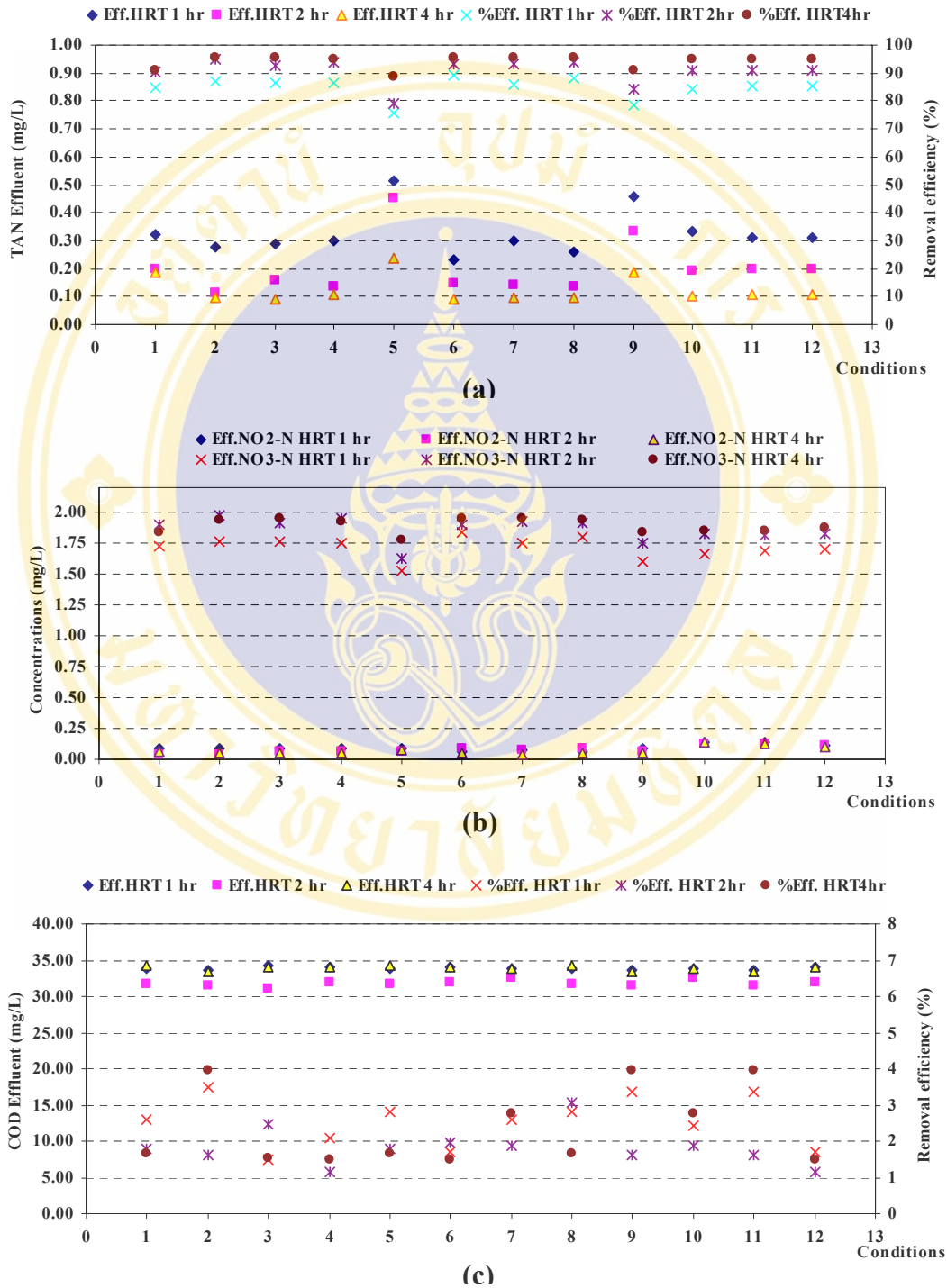


Figure 4.6 The concentrations of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and COD in the influent and effluent and $\text{NH}_3\text{-N}$ removal efficiency percentages throughout the experiment; (a): $\text{NH}_3\text{-N}$, (b): $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$, (c): COD

4.5 System controlled operating profiles

4.5.1 DO Profiles

The average DO concentration in the nitrification bioreactors was 5-7 mg/l. as presented in Figure 4.7.

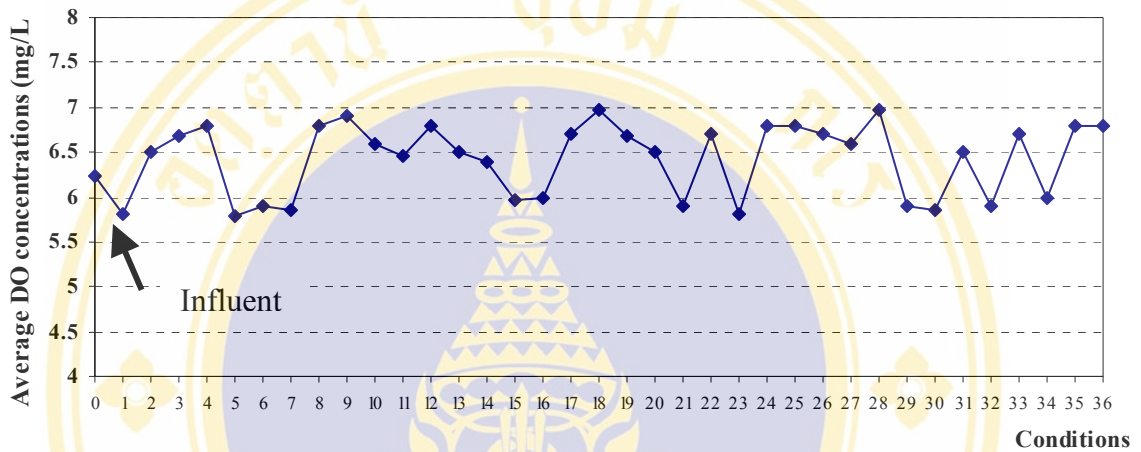


Figure 4.7 Profiles of average DO of all experiments in nitrification bioreactors

4.5.2 pH Profile

The average pH of all experiments in the influent and in the nitrification bioreactors were 7.95 and 8.21 respectively as presented in Figure 4.8.

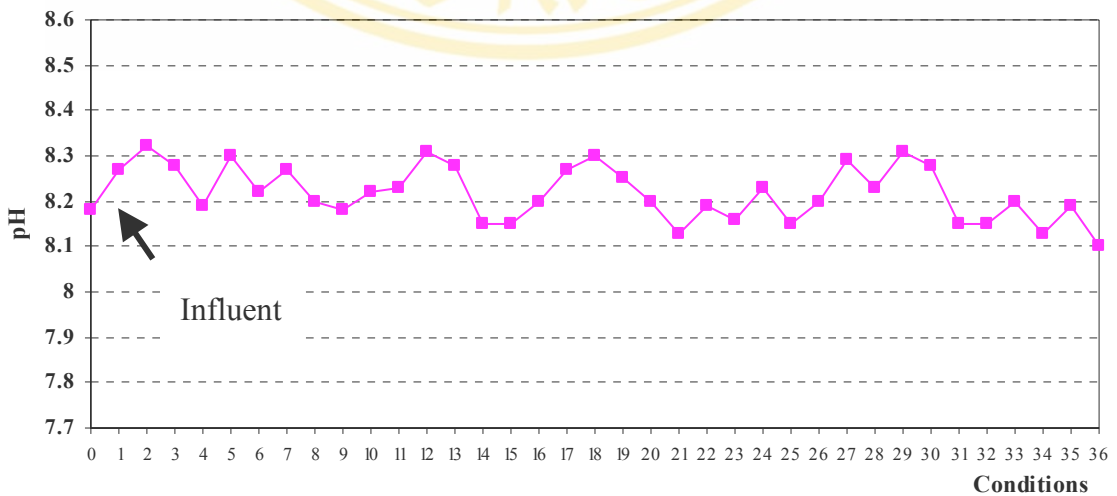


Figure 4.8 Profiles of average pH of all experiments in the nitrification bioreactors

4.6 Statistical analysis for effects of mixture weight by volume (% , PVA : coal) on NH₃-N, NO₂-N, NO₃-N and COD concentrations in the effluent and NH₃-N removal efficiency

4.6.1 Effects of mixture weight by volume (% , PVA : coal) on NH₃-N, NO₂-N, NO₃-N and COD concentration in effluent and NH₃-N removal efficiencies

Statistical analysis for the effects of weight by volume (% , PVA : coal) on NH₃-N, NO₂-N, NO₃-N and COD concentration in effluent and NH₃-N removal efficiencies under pseudo steady state were summarized in Table 4.5, 4.6, and 4.7, as illustrated in Figure 4.9 further described as followed:

4.6.1.1 Effects of mixture weight by volume (% , PVA : coal) on NH₃-N, NO₂-N, NO₃-N and COD concentrations in the effluent and NH₃-N removal efficiency at HRT 1 hr.

The average NH₃-N, NO₂-N, and COD concentrations in the effluent operated at mixture weight by volume (% , PVA : coal) of conditions 1-12 as followed in Table 3.1.

The NH₃-N removal efficiency at mixture weight by volume (% , PVA : coal) of conditions 1-12 were significantly difference ($p < 0.05$). The NH₃-N removal efficiency at mixture weight by volume (% , PVA : coal) of condition 1,5,9 were lower than other condition ($p < 0.05$). The removal efficiency of other conditions, which PVA in gel beads were combined with coal ash, were not significantly difference ($p < 0.05$).The optimum mixture weight by volume (% , PVA : coal) were 10.0:3, 10.0:5 and 10.0:7. The removal efficiency were 78.03%-90.48% and the average NO₂-N and COD concentrations in effluent at mixture weight by volume (% , PVA : coal) of conditions 1-12 were not significantly difference ($p < 0.05$) and the concentration in effluent were safe for aquaculture.

4.6.1.2 Effects of mixture weight by volume (% , PVA : coal) on NH₃-N, NO₂-N, NO₃-N and COD concentrations in the effluent and NH₃-N removal efficiency at HRT 2 hr.

The average NH₃-N, NO₂-N, and COD concentrations in the effluent operated at mixture weight by volume (% , PVA : coal) of conditions 13-24 as followed as Table 3.1.

The NH₃-N removal efficiency at mixture weight by volume (% , PVA : coal) of conditions 13-24 were significantly difference ($p < 0.05$). The NH₃-N removal efficiency at mixture weight by volume (% , PVA : coal) of condition 13,17,21 were lower than other condition ($p < 0.05$). The removal efficiency of other conditions, which PVA in gel beads were combined with coal ash, were not significantly difference ($p < 0.05$). The optimum mixture weight by volume (% , PVA : coal) were 10.0:3, 10.0:5 and 10.0:7. The removal efficiency were 89.76%-97.65% and the average NO₂-N and COD concentrations in effluent at mixture weight by volume (% , PVA : coal) of conditions 13-24 were not significantly difference ($p < 0.05$) and the concentration in effluent were safe for aquaculture.

4.6.1.3 Effects of mixture weight by volume (% , PVA : coal) on NH₃-N, NO₂-N, NO₃-N and COD concentrations in the effluent and NH₃-N removal efficiency at HRT 4 hr.

The average NH₃-N, NO₂-N, and COD concentrations in the effluent operated at mixture weight by volume (% , PVA : coal) of conditions 25-36 as followed as Table 3.1.

The NH₃-N removal efficiency at mixture weight by volume (% , PVA : coal) of conditions 25-36 were significantly difference ($p < 0.05$). The NH₃-N removal efficiency at mixture weight by volume (% , PVA : coal) of condition 13,17,21 were lower than other condition ($p < 0.05$). The removal efficiency of other conditions, which PVA in gel beads were combined with coal ash, were not significantly difference ($p < 0.05$). The optimum mixture weight by volume (% , PVA : coal) were 10.0:3, 10.0:5 and 10.0:7. The removal efficiency were 87.91%-97.71% and the average NO₂-N and COD concentrations in effluent at mixture weight by volume (% , PVA : coal) of conditions 25-36 were not significantly difference ($p < 0.05$) and the concentration in effluent were safe for aquaculture.

Table 4.5 Statistical analysis of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and COD concentrations in the effluents and $\text{NH}_3\text{-N}$, COD removal efficiency at HRT 1 hr. of conditions 1-12. As follow in Table 3.1

Variables	Statistical Test	Multiple Comparison
Independent Variables : mixture weight by volume (% , PVA : coal)		
Dependent Variables: Effluent		
$\text{NO}_2\text{-N}$	NS ^a	Equal for all conditions ^b
$\text{NO}_3\text{-N}$	NS ^a	Equal for all conditions ^b
Dependent Variables: % Removal Efficiency		
$\text{NH}_3\text{-N}$	DS ^a	Condition 1, 5, 9
COD	NS ^a	Equal for all conditions ^b

Table 4.6 Statistical analysis of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and COD concentrations in the effluent and $\text{NH}_3\text{-N}$, COD removal efficiency at HRT 2 hrs. of conditions 13-24. As follow in Table 3.1

Variables	Statistical Test	Multiple Comparison
Independent Variables : mixture weight by volume (% , PVA : coal)		
Dependent Variables: Effluent		
$\text{NO}_2\text{-N}$	NS ^a	Equal for all conditions ^b
$\text{NO}_3\text{-N}$	NS ^a	Equal for all conditions ^b
Dependent Variables: % Removal Efficiency		
$\text{NH}_3\text{-N}$	DS ^a	Condition 13, 17, 21
COD	NS ^a	Equal for all conditions ^b

Table 4.7 Statistical analysis of NH₃-N, NO₂-N, NO₃-N and COD concentrations in the effluent and NH₃-N, COD removal efficiency at HRT 4 hrs. of conditions 25-36. As follow in Table 3.1

Variables	Statistical Test	Multiple Comparison
Independent Variables : mixture weight by volume (% PVA : coal)		
Dependent Variables: Effluent		
NO ₂ -N	NS ^a	Equal for all conditions ^b
NO ₃ -N	NS ^a	Equal for all conditions ^b
Dependent Variables: % Removal Efficiency		
NH ₃ -N	DS ^a	Condition 25, 29, 33
COD	NS ^a	Equal for all conditions ^b

Remarks: DS = Significant differences among the level, $\alpha = 0.05$

NS = No significant differences among the level, $\alpha = 0.05$

^a One-Way ANOVA for Compared Mean and Normal Distribution

^b Post Hoc Tests: Tukey HSD for Multiple Comparisons, Normal Distribution and Equal Variance

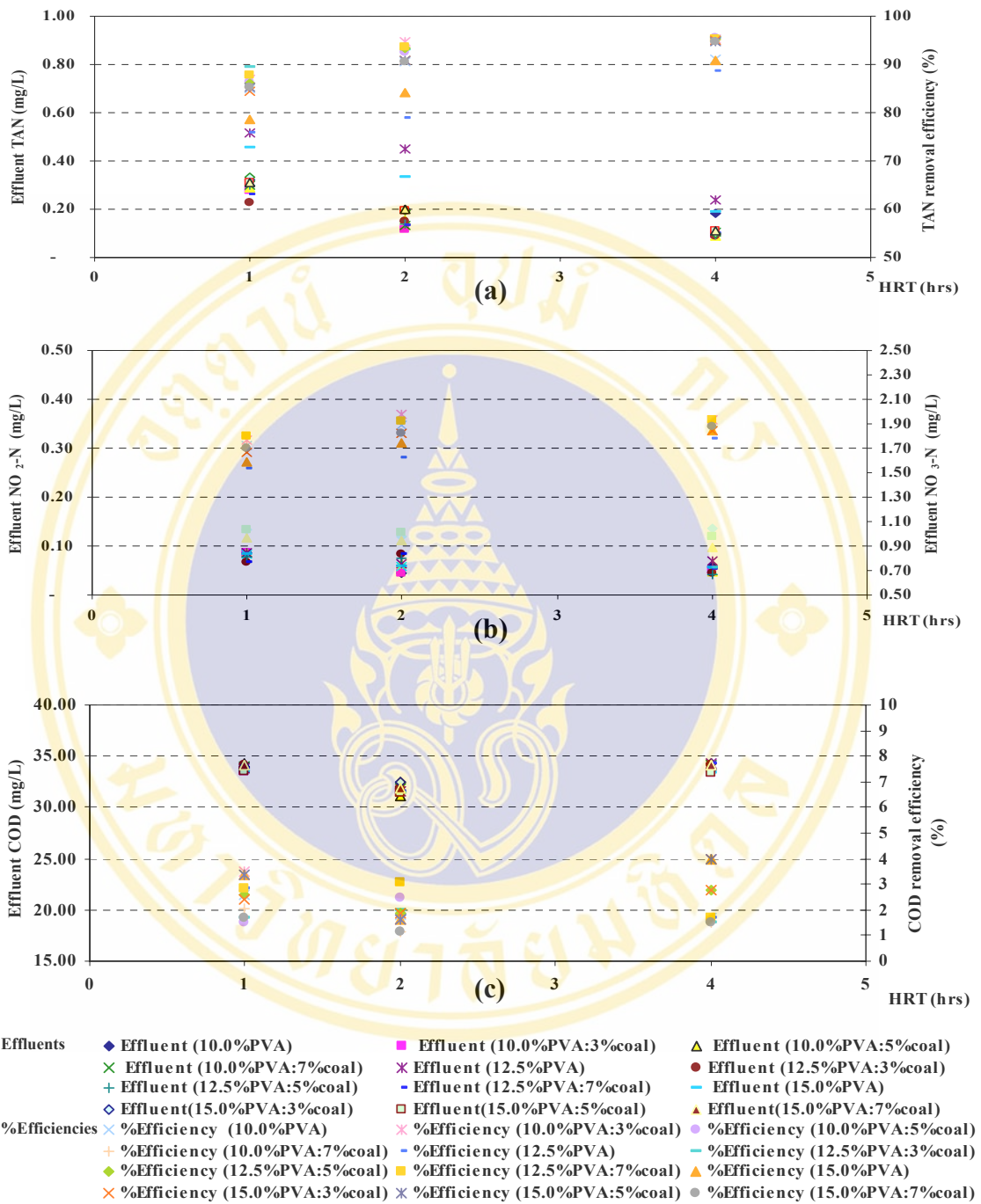


Figure 4.9 The comparisons of average concentrations in the effluent and removal efficiency of each condition; (a): NH₃-N, (b): NO₂-N and NO₃-N, (c): COD

From the results analysis presented in Table 4.5, 4.6 and 4.7, they were illustrated that the mixture ratio weight by volume (% PVA : coal) of 10.0% PVA : 3, 5, 7% coal was the optimum mixture ratio weight by volume when operated at 1, 2 and 4 hrs. The average NH₃-N concentrations in the effluent were 0.29, 0.13 and 0.10 mg/l and the NH₃-N removal efficiencies were 86.49%, 93.64%, and 95.30%, respectively.

The NH₃-N removal rate (when operated with PVA-coal gel beads in bioreactors at 10% v/v) was used to compare the optimum mixture ratio weight by volume (% PVA : coal) and HRT. The NH₃-N removal rate were summarized in Table 4.9, as illustrated in Figure 4.10 and further described as followed:

Table 4.8 The NH₃-N removal efficiency (%) and the removal rate* (g/m³-day) of the best mixture ratio weight by volume (% PVA : coal) at various of HRTs.

Mixture ratio weight by volume (% PVA : coal)	HRT (hrs)	NH ₃ -N removal efficiencies (%)	NH ₃ -N removal rate* (g/m ³ -day)
10.0 : 3, 5, 7	1	86.49	44.46
10.0 : 3, 5, 7	2	93.64	24.26
10.0 : 3, 5, 7	4	95.30	11.96

* The NH₃-N removal rate (g/m³-day) when operated with PVA-coal gel beads in bioreactors at 10% (v/v)

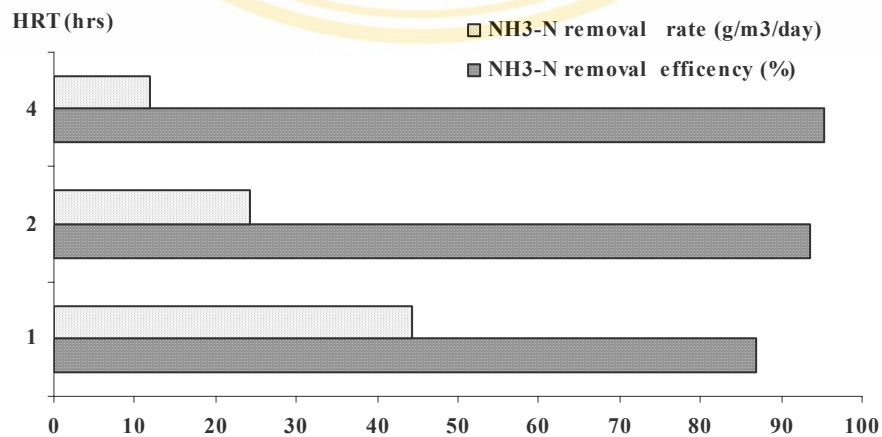


Figure 4.10 The NH₃-N removal efficiencies (%) and the removal rate* (g/m³-day) of the best mixture ratio weight by volume (% PVA : coal) at various of HRTs.

From Table 4.8 and Figure 4.10, it was illustrated that the mixture ratio weight by volume (% PVA : coal) of 10.0 : 3, 5, 7 were the optimum mixture ratio for HRT 1, 2 and 4 hrs. The NH₃-N removal rate of HRT 1, 2 and 4 hrs were significantly different ($p < 0.05$). The NH₃-N removal rate of the mixture ratio weight by volume (% PVA : coal) of 10.0 : 3, 5, 7 at HRT 1 hr. was higher than those of at HRT 2 hrs. ($44.46 \text{ g/m}^3\text{-day} > 24.26 \text{ g/m}^3\text{-day}$) but the NH₃-N removal efficiency when operated at HRT 2 and 4 hrs. were higher than those of at HRT 1 hr. ($95.30\% > 93.64\% > 86.49\%$). But the NH₃-N removal rate when operating at HRT 4 hrs. was lower than operating at HRT 2 hrs. ($11.9 \text{ g/m}^3\text{-day} < 24.26 \text{ g/m}^3\text{-day}$). So the optimum operating condition was the mixture ratio weight by volume (% PVA : coal) of 10.0 : 3, 5, 7 at HRT 2 hr., which the NH₃-N removal efficiency was 93.64 % and the NH₃-N removal rate was $24.26 \text{ g/m}^3\text{-day}$.

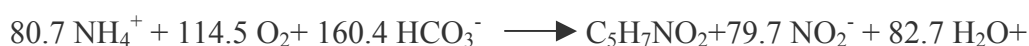
CHAPTER V

DISCUSSION

5.1 Establishment of nitrifying bacteria from the activated sludge of wastewater treatment

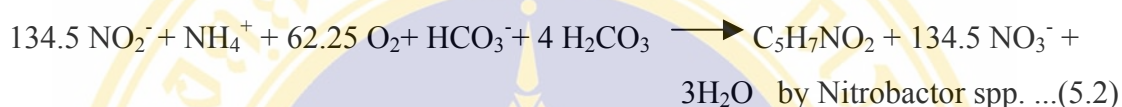
Enrichment for nitrifying bacteria was achieved by incubating activated sludge from Sri-phraya wastewater treatment plant in Bangkok in Nitrite-formation medium and Nitrate-formation medium. Both media were used to ensure the growth of nitrifying bacteria (*Nitrosomonas* spp. and *Nitrobacter* spp.). Since they needed nitrite for growth and increase the numbers. Most of wastewater from shrimp recirculating aquaculture had salinity about 5 – 25 g/l sea water of about 20 g/l was then used for acclimation freshwater nitrifying bacteria to saline water.

For Nitrite-formation medium, the decreasing of ammonia-nitrogen ($\text{NH}_3\text{-N}$) concentration from 119 mg/l to 15 mg/l was observed. The pH was reduced from 8.45 to 6.67. The number of nitrifying bacteria was increased significantly after incubating activated sludge for 6 days. During the establishment of nitrifying bacteria period, pH was reduced due to *Nitrosomonas* spp. change ammonia to nitrite. Hence it will release acid and reduce pH of medium as shown in Equation 5.1.



The pH of medium was increased up to suitable range (7.5-8.5) by adding base solution (NaOH) for growth of nitrifying bacteria. The nitrite-nitrogen ($\text{NO}_2\text{-N}$) concentration was decreased and the nitrate- nitrogen ($\text{NO}_3\text{-N}$) concentration was increased though out the establishment of nitrifying period because of *Nitrobacter* spp.

For Nitrate-formation medium, the increasing of pH from 7.89 to 8.40 and the decrease of nitrite-nitrogen (NO₂-N) concentration from 214 mg/l to 63 mg/l were observed. Nitrobactor spp. took time to increase a number of cells longer than that of Nitrosomonas spp. (Nitrobactor spp. took 15 days and Nitrosomonas spp. took 6 days). This could be due to Nitrobactor spp. needs more time to acclimate than that of Nitrosomonas spp. The reaction of Nitrobactor spp. converting nitrite to nitrate could be illustrated as shown in Equation 5.2.



5.2 Immobilization of nitrifying bacteria by PVA-boric acid method

5.2.1 Preparation of nitrifying bacteria for immobilization

Each 2 liters of nitrifying bacteria which was established in Nitrite-formation medium and Nitrate-formation medium in ratio 1:1 (v/v) were centrifuged at 4,400 rpm and room temperature of 4 °C for 20 min to concentrate nitrifying bacteria cells. The low temperature could help protect destroying of nitrifying cell from the heat.

5.2.2 Immobilization of nitrifying bacteria

The method of immobilized nitrifying bacteria in PVA-coal by PVA-boric acid method. Starting from melted PVA at 60 °C with sodium alginate, The final concentration of mixture must be 10.0, 12.5 and 15.0% (w/v) PVA, 1.6% (w/v) sodium alginate, and was mixed by coal ash, which showed physical characteristic in Figure 2.10, follow as experiment designed and the concentrated nitrifying bacteria was mixed thoroughly with PVA solution at the ratio of 30 : 70 (v/v), which different from other researches. The mixture was dropped by syringe containing cooled boric acid solution, the mixture of saturated boric acid, and 2% calcium chloride (CaCl₂) solution, then refrigerated them for 24 hrs at 4 °C and further stirred to ensure

complete a gelation inside the beads, then the beads were removed and rinsed with seawater, 20 g/l.

5.3 Acclimatization of PVA-coal immobilized nitrifying bacteria gel beads

The PVA-immobilized nitrifying bacteria gel beads were filled in the glass bottle, which contained with the synthetic wastewater to recover nitrifying bacteria activities after cell immobilization because nitrifying bacteria were damaged due to centrifugation, shear stress by stirring, and the toxicities of the boric acid solution. This PVA-coal immobilized nitrifying bacteria gel beads took 9 days to recover nitrifying bacteria activities which was less than those experimented by Eun-Ju Park, Jae-Koan Seo and Mi-Ryung Kim, 2000, taking 15 days. It may be due to this study used seawater, 20 ppt, to enrich nitrifying bacteria during the establishment of nitrifying bacteria period difference from the experiment of Eun-Ju Park, Jae-Koan Seo and Mi-Ryung Kim, which used freshwater. So the nitrifying bacteria of this study showed a shorter acclimatization period.

5.4 The optimum ratio of mixture weight by volume (% , PVA:coal) and hydraulic retention time (HRT) for a removal of ammonia-nitrogen (NH₃-N) with the PVA-coal immobilized nitrifying bacteria gel beads in the continuous nitrification bioreactor

5.4.1 NH₃-N removal efficiency

The experiment was operated 15 days with the continuous nitrification bioreactor under difference of mixture ratio weight by volume (% , PVA: coal) as shown in Table 3.1 and hydraulic retention time (HRTs) of about 1, 2 and 4 hrs prior to evaluating the NH₃-N removal efficiency of the PVA-coal immobilized nitrifying bacteria gel beads. The synthetic wastewater contained 2 mg/l ammonia-

nitrogen ($\text{NH}_3\text{-N}$), according to the upper range of ammonia level found in an intensive aquaculture system (Huifeng Shan. et al (2003)), which was imitated an influent recirculating aquaculture wastewater. The aims of this study were to investigate the $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and COD in the effluent and $\text{NH}_3\text{-N}$ and COD removal efficiencies using the mixture of PVA and coal to immobilize nitrifying bacteria. After immobilization nitrifying bacteria for various mixture ratio, weight by volume (% , PVA:coal) in PVA-coal gel beads, performance evaluation was conducted in the nitrification reactor.

Most of studies utilized 20% (w/v) PVA immobilized nitrifying bacteria to remove nutrients in wastewater by Kuo-Cheng Chen. et al (1998), Sung-Koo Kim. et al (2000) and Tansakul P. (2004) but this study tried to vary the lower ratio (w/v) of PVA than that of the previous researches (10.0%, 12.5% and 15.0%) to reduce processing cost. Evaluation of coal with PVA in PVA-coal gel beads was made for the $\text{NH}_3\text{-N}$ removal efficiencies. As shown in the results, the ammonia removal efficiency was decreased with the hydraulic retention time (HRT). The $\text{NH}_3\text{-N}$ in effluents through out the nitrification bioreactors, operated with the mixture of PVA and coal in gel beads, were decreased below those of using only PVA in gel beads, which were significantly difference ($p < 0.05$). Moreover, there were not significantly difference ($p < 0.05$) at the ratio of coal ash (3, 5 and 7%) for all HRTs (1, 2 and 4 hrs.). The most effective mixture ratio, weight by volume (% , PVA:coal) were at (10.0% : 3, 5, 7%) at HRT 1, 2, and 4 hrs with the average $\text{NH}_3\text{-N}$ concentrations in effluents and removal efficiency of about 0.29 mg/l (86.49%), 0.13 mg/l (93.64%), and 0.10 mg/l (95.30%), respectively. The ammonia removal efficiency decreased with a further decrease in the hydraulic retention time (HRT) due to at a higher flow rate (low HRT), the influent ammonia-nitrogen does not have sufficient contact time to convert to nitrate. The optimum ratio mixture weight by volume (% , PVA:coal) of 10.0 : 3, 5, 7 with 2 hrs of HRT, it gave the ammonia-nitrogen removal rate of 24.26 $\text{g/m}^3\text{-day}$ and the effluents $\text{NH}_3\text{-N}$ concentration were not harmful to aquatic lives (safety level for aquatic lives are must lower than 1 mg/l for $\text{NH}_3\text{-N}$).

5.4.2 The effluents NO₂-N and NO₃-N concentrations

From the results, the effluents NO₂-N and NO₃-N concentrations through out the nitrification bioreactors of all conditions (condition 1-36) were not over safety level (safe level concentration of NO₂-N and NO₃-N for aquaculture were 1 and 10 mg/l, respectively). The average effluents NO₂-N and NO₃-N concentrations of all concentrations were not significantly difference ($p < 0.05$). Because of the effluents NO₂-N concentrations were decreased by Nitrifying bacteria (*Nitrobactor spp.*), which converted nitrite to nitrate, in gel beads. Base on the nature of the nitrification process, the experiment finding in research of William P. Barber and David C. [73], and previous work and photographic investigation, it was possible to gain an insight into the biopellet structure. A layered structure was proposed and consisted of three regions: outer ammonia oxidation zone; inner nitrite oxidization zone; and a core anoxic region. It was likely that ammonia oxidizers would populate the surface region of the pellet since their substrates-un-ionised ammonia and DO were readily available in the bulk region. Subsequently, nitrite would be produced inside the particle and diffuse into a deeper layer where it could be further oxidized by bacteria such as *Nitrobactor* to produce nitrate and nitrogen gas.

5.4.3 The COD in the effluents and removal efficiency

The COD removal efficiencies were not significantly difference ($p < 0.05$) for all conditions. In this study, they were operated by immobilization of autotrophic nitrifying bacteria, which was established in nitrite-formation medium for *Nitrosomonas spp.* and nitrate-formation medium for *nitrobactor spp.* with the short period of bacteria to contact with wastewater and autotrophic nitrifying bacteria used carbon from bicarbonate (HCO₃⁻) in synthetic wastewater, which was prepared by dilution of brine water to 20 g/l (Alkalinity 200 mg/l). Heterotrophic bacteria was rarely growth in the gel beads. William P. Barber and David C. [73] implied that the immobilization of the nitrifier provided some protection against heterotrophic bacteria.

As show in Figure 5.2, Mass balance of NH₃-N, NO₂-N, NO₃-N and COD in the influent and effluents were illustrated.

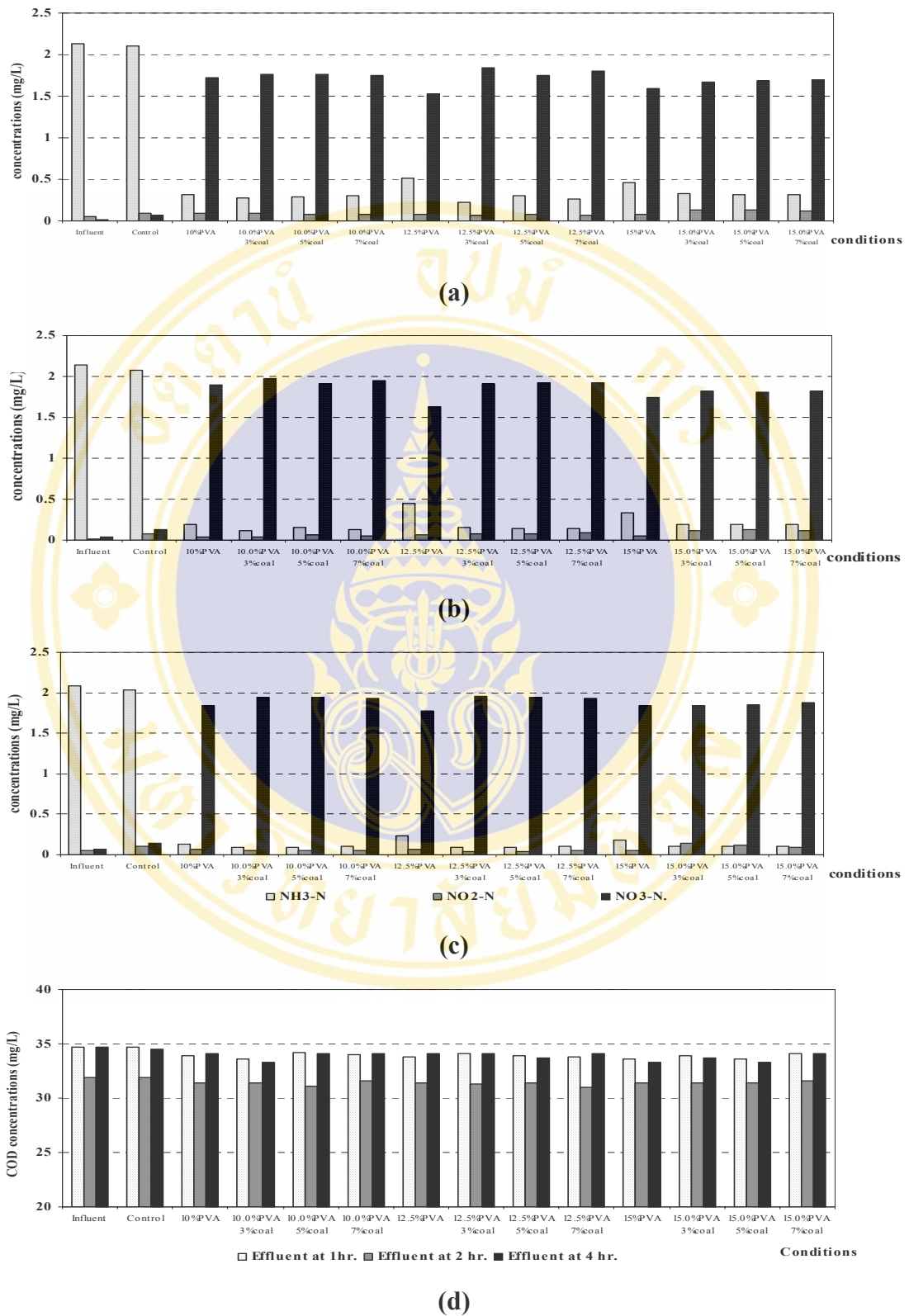


Figure 5.1 Mass balances of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$; (a): operated at 1 hr, (b): operated at 2 hrs, (c): operated at 4 hrs, and COD; (d): operated at various conditions, Control : No gel beads (No PVA/coal)

5.5 System controlled operating conditions

5.5.1 DO

Average DO concentrations of all conditions in nitrification bioreactors were over 5.0 mg/l. These results were agreed with those of several researches. It was found that the DO concentration of 4 mg/l was required for a successful nitrification reaction. Nitrifying bacteria were especially sensitive to the low oxygen concentrations. The DO concentrations above 1 mg/l were essential for nitrification to occur. If DO levels dropped below this value, oxygen became the limiting nitrification (slow or decreases) [65]. In this experiment, the nitrification reactors were filled with saturated aeration air diffuser, for a complete nitrification reaction and flowed over the bioreactors of beads. As shown in Figure 5.3



Figure 5.2 The DO concentration in nitrification bioreactor.

5.5.2 pH

The average pH of all conditions in the nitrification bioreactors were 7.95-8.21. These values were in ranges of 7.2-9.0, which were at the optimum pH for maximum rate of nitrification reaction and suitable for shrimp production. [65]

5.6 The optimum operating condition

NH₃-N, NO₂-N, NO₃-N and COD concentrations in effluent of all conditions were less than those of the aquaculture, industrial effluent and drinking water standards of foreign country and of Thailand as presented in Table 5.1.

Table 5.1 Effluent standards of foreign country and of Thailand.

Standard, country, organization	NH₃-N (mg/l)	NO₃-N (mg/l)	COD (mg/l)
Aquaculture wastewater effluent std., Thailand [69]	<1	<5	<70
Drinking water std., WHO [70]		<10	
National effluent standard, Japan [71,72]		< 10	<120

In the selection of the optimum operating condition, the maximum removal efficiency and removal rate were used as criteria. The NH₃-N was a specific parameter in removal efficiency evaluation of nitrification reaction in PVA-coal gel beads. The NO₂-N, NO₃-N and COD served as general parameters in effluent and removal efficiency evaluation of wastewater treatment system. Difference of COD removal efficiency in this study had very low, not significant difference ($p < 0.05$). At the ratio of mixture weight by volume (% PVA : coal) of 10.0:3, 5, 7 and HRT of 2 hrs. were the optimum operating condition which the average NH₃-N, NO₂-N, NO₃-N and COD concentrations in effluent and NH₃-N and COD removal efficiency in range of 0.29 mg/l, 0.05 mg/l, 1.78 mg/l, 31.37 mg/l, 89.76-97.65% and 1.14-2.46%, respectively. Table 5.2 presented details of the optimum operating condition.

5.7 Actual shrimp culture wastewater

From the results, the optimum condition was operated in nitrification reactor containing the actual shrimp culture wastewater. The PVA-coal gel beads, (% PVA : coal) of about 10.0 : 3, 5, 7 removed the $\text{NH}_3\text{-N}$ and $\text{NO}_2\text{-N}$ in actual shrimp culture wastewater to safety water quality level for shrimp culture. The $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and COD in the effluents and $\text{NH}_3\text{-N}$ removal efficiency were about 0.15 mg/l, 0.03 mg/l, 1.80 mg/l, 35.47 mg/l, 92.31% and 1.64%, respectively. The COD concentration was hardly decreased because the immobilization of the nitrifying bacteria, which was autotrophic bacteria, that used carbon source for bicarbonate (HCO_3^-) provided some protection against heterotrophic bacteria and. [73] Table 5.3 presented the details of the influent and effluent qualities of the actual shrimp culture wastewater through out the nitrification bioreactor, which was operated under the optimum condition.

Table 5.2 Summary of the effluent and removal efficiency under optimum operating condition.

Parameters	Operating condition
Ratio of mixture (% PVA : coal)	10.0 : 3, 5, 7
HRT (hrs.)	2
Flow rate; Q_{in} (L/day)	36
Effluent Quality (mg/l)	
$\text{NH}_3\text{-N}$	0.29
$\text{NO}_2\text{-N}$	0.05
$\text{NO}_3\text{-N}$	1.78
COD	31.37
Removal Efficiency (%)	
$\text{NH}_3\text{-N}$	89.76-97.65
COD	1.14-2.46

Table 5.3 The influent and effluent qualities of actual shrimp culture wastewater operated through out the nitrification bioreactor under the optimum condition.

Parameters	shrimp culture wastewater (Influent)				shrimp culture wastewater (Effluent)			
	Min.	Max.	Mean.	SD	Min.	Max.	Mean.	SD
NH ₃ -N (mg/l)	1.89	2.12	2.00	0.08	0.13	0.18	0.15	0.01
NO ₂ -N (mg/l)	0.20	0.30	0.26	0.03	0.01	0.05	0.03	0.02
NO ₃ -N (mg/l)	0.30	0.55	0.40	0.10	1.71	1.93	1.80	0.07
COD (mg/l)	32.00	36.00	35.40	1.40	32.00	36.00	35.47	1.25

The NH₃-N removal efficiency of PVA-coal gel beads declined as operated at the optimum condition in actual shrimp culture wastewater (decreasing from 94.64% to 92.31%). This was due to the clogging problem of suspended solid in wastewater at the surface of gel bead, so oxygen gas was limited to diffuse into the inner and surface of gel beads. Quantity of alkalinity (bicarbonate, HCO₃⁻) concentration was to adequate for a successful nitrification. In this research, bicarbonate concentration of synthetic wastewater was about 200 mg/l. Bicarbonate served as carbon source of autotrophic bacteria and was used to adjust the pH in ammonia oxidizing reaction by nitrosomonas spp.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The PVA-coal nitrifying bacteria immobilization was evaluated for the optimum operating condition (the ratio of mixture weight by volume: %, PVA:coal and HRT) to remove ammonia-nitrogen in shrimp culture wastewater recirculation system. The following conclusions have been drawn from the results of this experimental research.

6.1.1 Shrimp culture and synthetic wastewater characteristics

Synthetic wastewater in this study was used as shrimp culture wastewater. Because this study was a continuously experiment, which was used at maximum volume around 450 L per day. The average characteristics of synthetic wastewater, which was used as shrimp culture wastewater was NH₃-N 2 mg/l, COD 35.40 mg/l, salinity 20 g/l. NO₂-N and NO₃-N assumed as zero (0.05 mg/l and 0.02 mg/l, respectively). Shrimp culture wastewater used in this study was collected from the Charoen Pokphand Foods Co., Ltd., Samuth-Sakorn. The average concentration of NH₃-N 2 mg/l (max), COD 34.50 mg/l, NO₂-N 0.19 mg/l, NO₃-N 1.03 mg/l, salinity 20 g/l and suspended solid 16.8 mg/l.

6.1.2 Performance of Nitrifying bacteria during establishment period

The Nitrite-formation and nitrate-formation medium were obtained after establishment of about a month. The performance of nitrifying bacteria (*nitrosomonas spp.* and *nitrobactor spp.*) in both of medium were obtained continuously decreasing of NH₃-N concentration in nitrite-formation medium and

$\text{NO}_2\text{-N}$ concentration in nitrate-formation medium with high removal efficiency of $\text{NH}_3\text{-N}$ and $\text{NO}_2\text{-N}$ (>80%). The mixed liquor suspended solid (MLSS) concentration in the medium was about 35-40 mg/l.

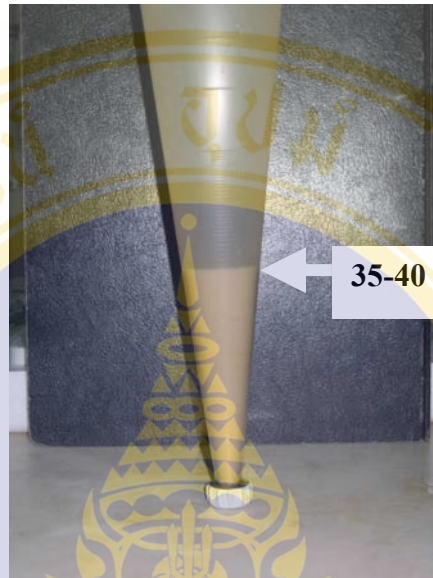


Figure 6.1 The MLSS concentration in the medium (35-40 mg/l)

6.1.3 The performances of PVA-coal nitrifying bacteria gel beads during acclimatization period

Pseudo steady state condition of PVA-coal nitrifying bacteria gel beads in glass bottles were obtained after seeding and acclimatization of about 9 days and were continuously operated until reaching steady state. At the steady state condition, the performances of PVA-coal nitrifying bacteria gel beads obtained low concentration and high removal efficiency of $\text{NH}_3\text{-N}$ over 80%.

6.1.4 Optimum operating condition

The optimum operating condition of the PVA-coal nitrifying bacteria gel beads in nitrification bioreactor to remove ammonia-nitrogen in shrimp culture synthetic wastewater recirculation system was at the ratio of mixture weight by

volume (% PVA : coal) of 10.0 : 3, 5, 7 and HRT of 2 hrs., which yielded $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and COD in effluent and $\text{NH}_3\text{-N}$ and COD removal efficiency of 0.11 mg/l, 0.04 mg/l, 1.98 mg/l, 31.44 mg/l, 94.64% and 1.62%, respectively. And about of 0.15 mg/l, 0.03 mg/l, 1.80 mg/l, 35.47 mg/l, 92.31 %, respectively for actual shrimp culture wastewater.

6.2 Recommendations

Further studies should be performed as follows:

- 1) Using PVA-coal nitrifying bacteria gel beads in nitrification bioreactor to remove ammonia-nitrogen in shrimp culture wastewater recirculation system at pilot scale level should be investigated.
- 2) The optimum volume of PVA-coal nitrifying bacteria gel beads, less than 10% v/v, in nitrification bioreactor should be investigated.
- 3) The ammonia-nitrogen removal efficiency under different of ammonia-nitrogen concentration in influent should be investigated.
- 4) Immobilization of nitrifying and denitrifying bacteria in PVA-coal gel beads to remove nitrogen waste in wastewater should be investigated.
- 5) The Microbial population development and distribution in the inner and surface of gel beads should be investigated.
- 6) Further study on the long life utilization of gel beads and how to recover it back to original usage.
- 7) Further study on physical characteristic of PVA-coal gel beads under different of coal ash (% w/v)

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APPENDIX A

Experimental Results

Table A-1 The NH₃-N in the effluent and NH₃-N removal efficiencies of Group 1

Condition		Condition 1			Condition 2		Condition 3		Condition 4		Condition 5		Condition 6	
TAN	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	
Days	(mg/L)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	
1	2.23	0.44	80.27	0.49	81.17	0.28	82.96	0.46	78.03	0.42	87.44	0.41	79.37	
2	2.31	0.35	84.85	0.38	73.59	0.32	72.73	0.48	83.55	0.61	86.15	0.61	79.22	
3	2.47	0.29	88.26	0.28	76.11	0.34	74.09	0.42	88.66	0.59	86.23	0.45	83.00	
4	2.30	0.24	89.57	0.26	78.26	0.31	73.91	0.27	88.70	0.50	86.52	0.17	88.26	
5	2.11	0.27	87.20	0.24	79.15	0.29	73.93	0.31	88.63	0.44	86.26	0.14	85.31	
6	2.05	0.35	82.93	0.28	70.24	0.24	69.27	0.27	86.34	0.61	88.29	0.20	86.83	
7	2.10	0.37	82.38	0.28	70.48	0.31	76.67	0.25	86.67	0.62	85.24	0.13	88.10	
8	2.13	0.31	85.45	0.25	86.85	0.22	81.22	0.22	88.26	0.28	89.67	0.24	89.67	
9	2.01	0.49	75.62	0.23	60.20	0.31	66.67	0.26	88.56	0.80	84.58	0.13	87.06	
10	2.08	0.27	87.02	0.28	77.40	0.27	82.21	0.27	86.54	0.47	87.02	0.12	87.02	
11	1.98	0.12	93.94	0.28	88.89	0.31	91.92	0.25	85.86	0.22	84.34	0.14	87.37	
12	2.15	0.29	86.51	0.26	75.81	0.31	93.02	0.27	87.91	0.52	85.58	0.20	87.44	
13	2.10	0.31	85.24	0.20	74.29	0.31	82.38	0.22	90.48	0.54	85.24	0.24	89.52	
14	1.95	0.28	85.64	0.25	74.87	0.22	81.54	0.26	87.18	0.49	88.72	0.13	86.67	
15	2.01	0.42	79.10	0.23	68.66	0.31	78.11	0.25	88.56	0.63	84.58	0.14	87.56	
Min.	1.95	0.12	75.62	0.20	60.20	0.22	66.67	0.22	78.03	0.22	84.34	0.12	79.22	
Max.	2.47	0.49	93.94	0.49	88.89	0.34	93.02	0.48	90.48	0.80	89.67	0.61	89.67	
Mean.	2.13	0.32	84.93	0.28	75.73	0.29	78.71	0.30	86.93	0.52	86.39	0.23	86.16	
SD.	0.14	0.09	4.47	0.07	7.09	0.04	7.46	0.08	2.95	0.14	1.59	0.15	3.21	

Condition		Condition 7			Condition 8		Condition 9		Condition 10		Condition 11		Condition 12	
TAN	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	
Days	(mg/L)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	
1	2.23	0.48	81.61	0.52	78.48	0.38	76.68	0.49	78.03	0.32	85.65	0.37	83.41	
2	2.31	0.40	73.59	0.50	82.68	0.63	78.35	0.38	83.55	0.32	86.15	0.31	86.58	
3	2.47	0.51	81.78	0.49	79.35	0.64	80.16	0.36	85.43	0.25	89.88	0.37	85.02	
4	2.30	0.28	92.61	0.16	87.83	0.60	93.04	0.30	86.96	0.35	84.78	0.34	85.22	
5	2.11	0.31	93.36	0.16	85.31	0.55	92.42	0.35	83.41	0.29	86.26	0.30	85.78	
6	2.05	0.19	90.24	0.23	90.73	0.63	88.78	0.32	84.39	0.29	85.85	0.27	86.83	
7	2.10	0.30	93.81	0.27	85.71	0.49	87.14	0.40	80.95	0.39	81.43	0.34	83.81	
8	2.13	0.24	88.73	0.24	88.73	0.40	88.73	0.38	82.16	0.32	84.98	0.30	85.92	
9	2.01	0.17	93.53	0.14	91.54	0.67	93.03	0.27	86.57	0.32	84.08	0.35	82.59	
10	2.08	0.22	94.23	0.20	89.42	0.37	90.38	0.27	87.02	0.30	85.58	0.27	87.02	
11	1.98	0.31	92.93	0.16	84.34	0.16	91.92	0.30	84.85	0.32	83.84	0.29	85.35	
12	2.15	0.19	90.70	0.23	91.16	0.15	89.30	0.31	85.58	0.30	86.05	0.32	85.12	
13	2.10	0.31	88.57	0.16	85.24	0.37	92.38	0.30	85.71	0.33	84.29	0.32	84.76	
14	1.95	0.30	93.33	0.27	84.62	0.36	86.15	0.28	85.64	0.29	85.13	0.27	86.15	
15	2.01	0.31	93.03	0.20	84.58	0.44	90.05	0.27	86.57	0.30	85.07	0.27	86.57	
Min.	1.95	0.17	73.59	0.14	78.48	0.15	76.68	0.27	78.03	0.25	81.43	0.27	82.59	
Max.	2.47	0.51	94.23	0.52	91.54	0.67	93.04	0.49	87.02	0.39	89.88	0.37	87.02	
Mean.	2.13	0.30	89.47	0.26	85.98	0.46	87.90	0.33	84.45	0.31	85.27	0.31	85.34	
SD.	0.14	0.10	5.97	0.13	3.98	0.17	5.37	0.06	2.51	0.03	1.77	0.04	1.29	

Table A-2 The NH₃-N in the effluent and NH₃-N removal efficiencies of Group 2

Condition		Condition 13			Condition14		Condition 15		Condition 16		Condition 17		Condition 18	
TAN	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	
Days	(mg/L)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	
1	1.95	0.37	81.03	0.49	74.87	0.45	76.92	0.15	92.31	0.19	90.26	0.13	93.33	
2	2.10	0.19	90.95	0.36	82.86	0.33	84.29	0.11	94.76	0.12	94.29	0.15	92.86	
3	2.15	0.17	92.09	0.39	81.86	0.24	88.84	0.09	95.81	0.11	94.88	0.10	95.35	
4	2.16	0.15	93.06	0.62	71.30	0.47	78.24	0.14	93.52	0.13	93.98	0.12	94.44	
5	1.99	0.20	89.95	0.53	73.37	0.38	80.90	0.10	94.97	0.15	92.46	0.13	93.47	
6	2.31	0.17	92.64	0.35	84.85	0.22	90.48	0.14	93.94	0.16	93.07	0.15	93.51	
7	2.18	0.37	83.03	0.49	77.52	0.45	79.36	0.12	94.50	0.20	90.83	0.15	93.12	
8	2.14	0.14	93.46	0.34	84.11	0.21	90.19	0.09	95.79	0.15	92.99	0.12	94.39	
9	2.05	0.18	91.22	0.29	85.85	0.22	89.27	0.14	93.17	0.21	89.76	0.21	89.76	
10	2.20	0.17	92.27	0.45	79.55	0.31	85.91	0.10	95.45	0.18	91.82	0.16	92.73	
11	2.20	0.16	92.73	0.47	78.64	0.25	88.64	0.10	95.45	0.18	91.82	0.16	92.73	
12	2.40	0.15	93.75	0.62	74.17	0.47	80.42	0.10	95.83	0.10	95.83	0.11	95.42	
13	2.03	0.20	90.15	0.53	73.89	0.38	81.28	0.09	95.57	0.13	93.60	0.06	97.04	
14	2.13	0.19	91.08	0.36	83.10	0.33	84.51	0.10	95.31	0.14	93.43	0.05	97.65	
15	2.05	0.17	91.71	0.45	78.05	0.31	84.88	0.14	93.17	0.21	89.76	0.21	89.76	
Min.	1.95	0.14	81.03	0.29	71.30	0.21	76.92	0.09	92.31	0.10	89.76	0.05	89.76	
Max.	2.40	0.37	93.75	0.62	85.85	0.47	90.48	0.15	95.83	0.21	95.83	0.21	97.65	
Mean.	2.14	0.20	90.61	0.45	78.93	0.33	84.27	0.11	94.64	0.16	92.58	0.13	93.70	
SD.	0.12	0.07	3.68	0.10	4.69	0.10	4.56	0.02	1.15	0.04	1.86	0.05	2.20	

Condition		Condition 19			Condition 20		Condition 21		Condition 22		Condition 23		Condition 24	
TAN	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	
Days	(mg/L)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	
1	1.95	0.16	91.8	0.12	93.8	0.14	92.8	0.22	88.7	0.18	90.8	0.21	89.2	
2	2.10	0.14	93.33	0.10	95.24	0.14	93.33	0.21	90.00	0.17	91.90	0.16	92.38	
3	2.15	0.10	95.35	0.08	96.28	0.10	95.35	0.20	90.70	0.22	89.77	0.22	89.77	
4	2.16	0.14	93.52	0.10	95.37	0.13	93.98	0.18	91.67	0.18	91.67	0.16	92.59	
5	1.99	0.12	93.97	0.14	92.96	0.15	92.46	0.16	91.96	0.17	91.46	0.19	90.45	
6	2.31	0.17	92.64	0.15	93.51	0.15	93.51	0.22	90.48	0.19	91.77	0.18	92.21	
7	2.18	0.20	90.83	0.16	92.66	0.15	93.12	0.15	93.12	0.15	93.12	0.23	89.45	
8	2.14	0.13	93.93	0.18	91.59	0.08	96.26	0.21	90.19	0.21	90.19	0.22	89.72	
9	2.05	0.18	91.22	0.20	90.24	0.14	93.17	0.25	87.80	0.19	90.73	0.19	90.73	
10	2.20	0.22	90.00	0.19	91.36	0.15	93.18	0.17	92.27	0.23	89.55	0.22	90.00	
11	2.20	0.22	90.00	0.19	91.36	0.15	93.18	0.18	91.82	0.25	88.64	0.24	89.09	
12	2.40	0.13	94.58	0.12	95.00	0.18	92.50	0.14	94.17	0.25	89.58	0.22	90.83	
13	2.03	0.08	96.06	0.11	94.58	0.13	93.60	0.16	92.12	0.17	91.63	0.19	90.64	
14	2.13	0.07	96.71	0.08	96.24	0.09	95.77	0.18	91.55	0.18	91.55	0.16	92.49	
15	2.05	0.18	91.22	0.20	90.24	0.14	93.17	0.25	87.80	0.19	90.73	0.19	90.73	
Min.	1.95	0.07	90.00	0.08	90.24	0.08	92.46	0.14	87.80	0.15	88.64	0.16	89.09	
Max.	2.40	0.22	96.71	0.20	96.28	0.18	96.26	0.25	94.17	0.25	93.12	0.24	92.59	
Mean.	2.14	0.15	93.01	0.14	93.37	0.13	93.69	0.19	90.96	0.20	90.87	0.20	90.69	
SD.	0.12	0.05	2.14	0.04	2.07	0.03	1.17	0.03	1.84	0.03	1.17	0.03	1.21	

Table A-3 The NH₃-N in the effluent and NH₃-N removal efficiencies of Group 3

Condition		Condition 25			Condition 26		Condition 27		Condition 28		Condition 29		Condition 30	
TAN	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	
Days	(mg/L)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	
1	2.15	0.07	96.74	0.22	89.77	0.11	94.88	0.21	90.23	0.14	93.49	0.26	87.91	
2	2.01	0.19	90.55	0.18	91.04	0.36	82.09	0.10	95.02	0.06	97.01	0.17	91.54	
3	2.04	0.16	92.16	0.17	91.67	0.18	91.18	0.09	95.59	0.08	96.08	0.10	95.10	
4	1.98	0.20	89.90	0.42	78.79	0.45	77.27	0.10	94.95	0.12	93.94	0.10	94.95	
5	2.04	0.24	88.24	0.31	84.80	0.26	87.25	0.08	96.08	0.09	95.59	0.11	94.61	
6	2.18	0.28	87.16	0.34	84.40	0.30	86.24	0.13	94.04	0.11	94.95	0.07	96.79	
7	2.05	0.07	96.59	0.26	87.32	0.16	92.20	0.11	94.63	0.07	96.59	0.07	96.59	
8	2.16	0.05	97.69	0.18	91.67	0.11	94.91	0.05	97.69	0.13	93.98	0.08	96.30	
9	2.21	0.08	96.38	0.27	87.78	0.09	95.93	0.07	96.83	0.06	97.29	0.06	97.29	
10	2.18	0.12	94.50	0.41	81.19	0.17	92.20	0.08	96.33	0.05	97.71	0.10	95.41	
11	2.21	0.11	95.02	0.15	93.21	0.10	95.48	0.07	96.83	0.10	95.48	0.11	95.02	
12	2.04	0.06	97.06	0.08	96.08	0.08	96.08	0.08	96.08	0.09	95.59	0.10	95.10	
13	2.01	0.15	92.54	0.28	86.07	0.17	91.54	0.10	95.02	0.06	97.01	0.07	96.52	
14	1.98	0.08	95.96	0.15	92.42	0.14	92.93	0.10	94.95	0.12	93.94	0.07	96.46	
15	2.04	0.90	55.88	0.17	91.67	0.13	93.63	0.08	96.08	0.09	95.59	0.11	94.61	
Min.	1.98	0.05	55.88	0.08	78.79	0.08	77.27	0.05	90.23	0.05	93.49	0.06	87.91	
Max.	2.21	0.90	97.69	0.42	96.08	0.45	96.08	0.21	97.69	0.14	97.71	0.26	97.29	
Mean.	2.09	0.18	91.09	0.24	88.53	0.19	90.92	0.10	95.36	0.09	95.62	0.11	94.95	
SD.	0.09	0.21	10.31	0.10	4.77	0.11	5.47	0.04	1.72	0.03	1.35	0.05	2.39	

Condition		Condition 31			Condition 32		Condition 33		Condition 34		Condition 35		Condition 36	
TAN	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	
Days	(mg/L)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	(mg/L)	(%)	
1	2.15	0.20	90.70	0.17	92.09	0.27	87.44	0.17	92.09	0.12	94.42	0.11	94.88	
2	2.01	0.07	96.52	0.08	96.02	0.10	95.02	0.09	95.52	0.10	95.02	0.09	95.52	
3	2.04	0.09	95.59	0.07	96.57	0.10	95.10	0.12	94.12	0.12	94.12	0.12	94.12	
4	1.98	0.10	94.95	0.08	95.96	0.07	96.46	0.09	95.45	0.08	95.96	0.10	94.95	
5	2.04	0.13	93.63	0.14	93.14	0.10	95.10	0.08	96.08	0.11	94.61	0.11	94.61	
6	2.18	0.07	96.79	0.08	96.33	0.07	96.79	0.09	95.87	0.12	94.50	0.10	95.41	
7	2.05	0.06	97.07	0.11	94.63	0.10	95.12	0.10	95.12	0.13	93.66	0.10	95.12	
8	2.16	0.06	97.22	0.06	97.22	0.06	97.22	0.11	94.91	0.11	94.91	0.11	94.91	
9	2.21	0.10	95.48	0.08	96.38	0.07	96.83	0.09	95.93	0.14	93.67	0.12	94.57	
10	2.18	0.07	96.79	0.08	96.33	0.07	96.79	0.14	93.58	0.08	96.33	0.12	94.50	
11	2.21	0.07	96.83	0.08	96.38	0.11	95.02	0.08	96.38	0.10	95.48	0.13	94.12	
12	2.04	0.07	96.57	0.08	96.08	0.07	96.57	0.08	96.08	0.12	94.12	0.11	94.61	
13	2.01	0.07	96.52	0.11	94.53	0.10	95.02	0.12	94.03	0.09	95.52	0.10	95.02	
14	1.98	0.06	96.97	0.08	95.96	0.07	96.46	0.10	94.95	0.11	94.44	0.10	94.95	
15	2.04	0.13	93.63	0.14	93.14	0.10	95.10	0.08	96.08	0.11	94.61	0.11	94.61	
Min.	1.98	0.06	90.70	0.06	92.09	0.06	87.44	0.08	92.09	0.08	93.66	0.09	94.12	
Max.	2.21	0.20	97.22	0.17	97.22	0.27	97.22	0.17	96.38	0.14	96.33	0.13	95.52	
Mean.	2.09	0.09	95.68	0.10	95.38	0.10	95.34	0.10	95.08	0.11	94.76	0.11	94.79	
SD.	0.09	0.04	1.81	0.03	1.52	0.05	2.34	0.03	1.18	0.02	0.79	0.01	0.41	

Table A-4 The COD in the effluent and COD removal efficiencies of Group 1

Conditions	Condition 1			Condition 2		Condition 3		Condition 4		Condition 5		Condition 6	
COD	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.
Days	mg/L	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)
1	33.00	32.00	3.03	30.00	9.09	32.00	3.03	33.00	0.00	32.00	3.03	33.00	0.00
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	33.00	32.00	3.03	32.00	3.03	32.00	3.03	32.00	3.03	33.00	0.00	33.00	0.00
4	-	-	-	-	-	-	-	-	-	-	-	-	-
5	37.00	36.00	2.70	36.00	2.70	37.00	0.00	35.50	4.05	36.00	2.70	35.50	4.05
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	34.00	33.00	2.94	33.00	2.94	34.00	0.00	33.00	2.94	32.50	4.41	33.00	2.94
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	30.00	29.00	3.33	29.00	3.33	29.00	3.33	30.00	0.00	28.00	6.67	30.00	0.00
10	-	-	-	-	-	-	-	-	-	-	-	-	-
11	35.00	34.00	2.86	33.00	5.71	35.00	0.00	34.50	1.43	34.00	2.86	34.50	1.43
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	40.00	40.00	0.00	39.50	1.25	39.00	2.50	38.50	3.75	40.00	0.00	38.50	3.75
14	-	-	-	-	-	-	-	-	-	-	-	-	-
15	36.00	35.00	2.78	36.00	0.00	36.00	0.00	35.50	1.39	35.00	2.78	35.50	1.39
Min.	30.00	29.00	0.00	29.00	0.00	29.00	0.00	30.00	0.00	28.00	0.00	30.00	0.00
Max.	40.00	40.00	3.33	39.50	9.09	39.00	3.33	38.50	4.05	40.00	6.67	38.50	4.05
Mean.	34.75	33.88	2.58	33.56	3.51	34.25	1.49	34.00	2.07	33.81	2.81	34.13	1.70
SD.	3.01	3.27	1.06	3.46	2.79	3.20	1.61	2.59	1.60	3.46	2.18	2.50	1.70

Conditions	Condition 7			Condition 8		Condition 9		Condition 10		Condition 11		Condition 12	
COD	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.
Days	mg/L	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)
1	33.00	32.50	1.52	32.00	3.03	33.00	0.00	32.50	1.52	33.00	0.00	33.00	0.00
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	33.00	32.00	3.03	32.50	1.52	32.50	1.52	32.50	1.52	32.50	1.52	33.00	0.00
4	-	-	-	-	-	-	-	-	-	-	-	-	-
5	37.00	36.20	2.16	36.00	2.70	36.00	2.70	36.20	2.16	36.00	2.70	35.50	4.05
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	34.00	33.00	2.94	33.00	2.94	33.00	2.94	33.00	2.94	33.00	2.94	33.00	2.94
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	30.00	28.60	4.67	28.00	6.67	29.00	3.33	28.60	4.67	29.00	3.33	30.00	0.00
10	-	-	-	-	-	-	-	-	-	-	-	-	-
11	35.00	34.60	1.14	34.00	2.86	33.00	5.71	34.60	1.14	33.00	5.71	34.50	1.43
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	40.00	39.20	2.00	40.00	0.00	39.00	2.50	39.20	2.00	39.00	2.50	38.50	3.75
14	-	-	-	-	-	-	-	-	-	-	-	-	-
15	36.00	34.80	3.33	35.00	2.78	33.00	8.33	34.80	3.33	33.00	8.33	35.50	1.39
Min.	30.00	28.60	1.14	28.00	0.00	29.00	0.00	28.60	1.14	29.00	0.00	30.00	0.00
Max.	40.00	39.20	4.67	40.00	6.67	39.00	8.33	39.20	4.67	39.00	8.33	38.50	4.05
Mean.	34.75	33.86	2.60	33.81	2.81	33.56	3.38	33.93	2.41	33.56	3.38	34.13	1.70
SD.	3.01	3.14	1.13	3.46	1.87	2.90	2.57	3.11	1.17	2.90	2.57	2.50	1.70

Table A-5 The COD in the effluent and COD removal efficiencies of Group 2

Conditions	Condition 13		Condition 14		Condition 15		Condition 16		Condition 17		Condition 18		
COD	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.
Days	mg/L	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)
1	30.00	30.00	0.00	30.00	0.00	29.00	3.33	30.00	0.00	30.00	0.00	28.00	6.67
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	32.00	32.00	0.00	31.50	1.56	32.00	0.00	31.00	3.13	32.00	0.00	31.00	3.13
4	-	-	-	-	-	-	-	-	-	-	-	-	-
5	31.50	30.00	4.76	31.00	1.59	31.00	1.59	31.00	1.59	30.00	4.76	31.00	1.59
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	31.50	30.00	4.76	31.00	1.59	31.00	1.59	31.00	1.59	30.00	4.76	31.00	1.59
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	30.00	29.00	3.33	29.00	3.33	29.00	3.33	30.00	0.00	29.00	3.33	30.00	0.00
10	-	-	-	-	-	-	-	-	-	-	-	-	-
11	30.00	30.00	0.00	29.00	3.33	30.00	0.00	30.00	0.00	30.00	0.00	30.00	0.00
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	38.00	38.00	0.00	38.00	0.00	36.00	5.26	37.50	1.32	38.00	0.00	37.50	1.32
14	-	-	-	-	-	-	-	-	-	-	-	-	-
15	32.50	32.00	1.54	32.00	1.54	31.00	4.62	32.00	1.54	32.00	1.54	32.00	1.54
Min.	30.00	29.00	0.00	29.00	0.00	29.00	0.00	30.00	0.00	29.00	0.00	28.00	0.00
Max.	38.00	38.00	4.76	38.00	3.33	36.00	5.26	37.50	3.13	38.00	4.76	37.50	6.67
Mean.	31.94	31.38	1.80	31.44	1.62	31.13	2.46	31.56	1.14	31.38	1.80	31.31	1.98
SD.	2.64	2.88	2.17	2.87	1.26	2.23	1.99	2.50	1.10	2.88	2.17	2.76	2.14

Conditions	Condition 19		Condition 20		Condition 21		Condition 22		Condition 23		Condition 24		
COD	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.
Days	mg/L	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)
1	30.00	30.00	0.00	29.00	3.33	30.00	0.00	30.00	0.00	30.00	0.00	30.00	0.00
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	32.00	32.00	0.00	32.00	0.00	31.50	1.56	32.00	0.00	31.50	1.56	31.00	3.13
4	-	-	-	-	-	-	-	-	-	-	-	-	-
5	31.50	30.00	4.76	30.00	4.76	31.00	1.59	30.00	4.76	31.00	1.59	31.00	1.59
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	31.50	30.00	4.76	30.00	4.76	31.00	1.59	30.00	4.76	31.00	1.59	31.00	1.59
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	30.00	30.00	0.00	27.00	10.00	29.00	3.33	30.00	0.00	29.00	3.33	30.00	0.00
10	-	-	-	-	-	-	-	-	-	-	-	-	-
11	30.00	29.00	3.33	30.00	0.00	29.00	3.33	29.00	3.33	29.00	3.33	30.00	0.00
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	38.00	37.80	0.53	38.00	0.00	38.00	0.00	37.80	0.53	38.00	0.00	37.50	1.32
14	-	-	-	-	-	-	-	-	-	-	-	-	-
15	32.50	32.00	1.54	32.00	1.54	32.00	1.54	32.00	1.54	32.00	1.54	32.00	1.54
Min.	30.00	29.00	0.00	27.00	0.00	29.00	0.00	29.00	0.00	29.00	0.00	30.00	0.00
Max.	38.00	37.80	4.76	38.00	10.00	38.00	3.33	37.80	4.76	38.00	3.33	37.50	3.13
Mean.	31.94	31.35	1.87	31.00	3.05	31.44	1.62	31.35	1.87	31.44	1.62	31.56	1.14
SD.	2.64	2.81	2.11	3.25	3.47	2.87	1.26	2.81	2.11	2.87	1.26	2.50	1.10

Table A-6 The COD in the effluent and COD removal efficiencies of Group 3

Conditions		Condition 25			Condition 26		Condition 27		Condition 28		Condition 29		Condition 30	
COD	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	
Days	mg/L	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	
1	31.50	30.00	4.76	31.00	1.59	31.00	1.59	31.00	1.59	30.00	4.76	31.00	1.59	
2	-	-	-	-	-	-	-	-	-	-	-	-	-	
3	30.00	30.00	0.00	29.00	3.33	30.00	0.00	31.00	-3.33	30.00	0.00	31.00	-3.33	
4	-	-	-	-	-	-	-	-	-	-	-	-	-	
5	38.00	38.00	0.00	38.00	0.00	36.00	5.26	37.50	1.32	38.00	0.00	37.50	1.32	
6	-	-	-	-	-	-	-	-	-	-	-	-	-	
7	32.00	32.00	0.00	31.50	1.56	32.00	0.00	31.00	3.13	32.00	0.00	31.00	3.13	
8	-	-	-	-	-	-	-	-	-	-	-	-	-	
9	37.00	36.00	2.70	36.00	2.70	37.00	0.00	35.50	4.05	36.00	2.70	35.50	4.05	
10	-	-	-	-	-	-	-	-	-	-	-	-	-	
11	40.00	40.00	0.00	38.00	5.00	39.00	2.50	38.50	3.75	40.00	0.00	38.50	3.75	
12	-	-	-	-	-	-	-	-	-	-	-	-	-	
13	36.00	35.00	2.78	33.00	8.33	36.00	0.00	35.50	1.39	35.00	2.78	35.50	1.39	
14	-	-	-	-	-	-	-	-	-	-	-	-	-	
15	33.00	32.00	3.03	30.00	9.09	32.00	3.03	33.00	0.00	32.00	3.03	33.00	0.00	
Min.	30.00	30.00	0.00	29.00	0.00	30.00	0.00	31.00	-3.33	30.00	0.00	31.00	-3.33	
Max.	40.00	40.00	4.76	38.00	9.09	39.00	5.26	38.50	4.05	40.00	4.76	38.50	4.05	
Mean.	34.69	34.13	1.66	33.31	3.95	34.13	1.55	34.13	1.49	34.13	1.66	34.13	1.49	
SD.	3.56	3.72	1.88	3.58	3.29	3.27	1.95	3.04	2.39	3.72	1.88	3.04	2.39	

Conditions		Condition 31			Condition 32		Condition 33		Condition 34		Condition 35		Condition 36	
COD	Inf.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	Eff.	Rem.	
Days	mg/L	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	mg/L	(%)	
1	31.50	30.00	4.76	30.00	4.76	31.00	1.59	30.00	4.76	31.00	1.59	31.00	1.59	
2	-	-	-	-	-	-	-	-	-	-	-	-	-	
3	30.00	29.00	3.33	30.00	0.00	29.00	3.33	29.00	3.33	29.00	3.33	31.00	-3.33	
4	-	-	-	-	-	-	-	-	-	-	-	-	-	
5	38.00	37.80	0.53	38.00	0.00	38.00	0.00	37.80	0.53	38.00	0.00	37.50	1.32	
6	-	-	-	-	-	-	-	-	-	-	-	-	-	
7	32.00	32.00	0.00	32.00	0.00	31.50	1.56	32.00	0.00	31.50	1.56	31.00	3.13	
8	-	-	-	-	-	-	-	-	-	-	-	-	-	
9	37.00	36.20	2.16	36.00	2.70	36.00	2.70	36.20	2.16	36.00	2.70	35.50	4.05	
10	-	-	-	-	-	-	-	-	-	-	-	-	-	
11	40.00	39.20	2.00	40.00	0.00	38.00	5.00	39.20	2.00	38.00	5.00	38.50	3.75	
12	-	-	-	-	-	-	-	-	-	-	-	-	-	
13	36.00	34.80	3.33	35.00	2.78	33.00	8.33	34.80	3.33	33.00	8.33	35.50	1.39	
14	-	-	-	-	-	-	-	-	-	-	-	-	-	
15	33.00	31.00	6.06	32.00	3.03	30.00	9.09	31.00	6.06	30.00	9.09	33.00	0.00	
Min.	30.00	29.00	0.00	30.00	0.00	29.00	0.00	29.00	0.00	29.00	0.00	31.00	-3.33	
Max.	40.00	39.20	6.06	40.00	4.76	38.00	9.09	39.20	6.06	38.00	9.09	38.50	4.05	
Mean.	34.69	33.75	2.77	34.13	1.66	33.31	3.95	33.75	2.77	33.31	3.95	34.13	1.49	
SD.	3.56	3.79	2.04	3.72	1.88	3.58	3.29	3.79	2.04	3.58	3.29	3.04	2.39	

Table A-7 The NO₂-N and NO₃-N in the effluent of Group 1

Days	Influents		Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6	Influents		Condition 7	Condition 8	Condition 9	Condition 10	Condition 11	Condition 12		
			Effluents		Effluents		Effluents				Effluents		Effluents		Effluents		Effluents	
	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	0.05	0.02	0.16	1.63	0.15	1.66	0.12	1.73	0.16	1.58	0.15	1.80	0.12	1.65				
2	0.07	0.03	0.18	1.78	0.15	1.55	0.15	1.53	0.18	1.75	0.15	1.84	0.15	1.68				
3	0.04	0.03	0.13	2.05	0.12	1.76	0.09	1.74	0.13	2.06	0.12	2.01	0.09	1.96				
4	0.04	0.02	0.09	1.97	0.10	1.70	0.06	1.64	0.09	1.95	0.10	1.89	0.06	1.97				
5	0.06	0.05	0.09	1.75	0.09	1.58	0.07	1.49	0.09	1.78	0.09	1.73	0.07	1.73				
6	0.03	0.01	0.08	1.62	0.06	1.38	0.05	1.37	0.08	1.69	0.06	1.75	0.05	1.73				
7	0.03	0.04	0.03	1.70	0.05	1.43	0.06	1.55	0.03	1.79	0.05	1.74	0.06	1.79				
8	0.04	0.00	0.10	1.72	0.04	1.81	0.06	1.67	0.10	1.78	0.04	1.87	0.06	1.85				
9	0.07	0.00	0.07	1.45	0.10	1.11	0.12	1.22	0.07	1.71	0.10	1.60	0.12	1.63				
10	0.09	0.00	0.03	1.78	0.05	1.56	0.05	1.66	0.03	1.77	0.05	1.76	0.05	1.76				
11	0.06	0.00	0.09	1.77	0.09	1.67	0.07	1.75	0.09	1.61	0.09	1.58	0.07	1.66				
12	0.03	0.01	0.03	1.83	0.05	1.58	0.07	1.93	0.03	1.86	0.05	1.79	0.07	1.81				
13	0.04	0.00	0.10	1.69	0.07	1.49	0.09	1.64	0.10	1.80	0.07	1.72	0.09	1.79				
14	0.03	0.00	0.08	1.59	0.06	1.40	0.05	1.54	0.08	1.62	0.06	1.67	0.05	1.64				
15	0.03	0.04	0.03	1.56	0.10	1.28	0.12	1.45	0.03	1.75	0.10	1.60	0.12	1.64				
Min.	0.03	0.00	0.03	1.45	0.04	1.11	0.05	1.22	0.03	1.58	0.04	1.58	0.05	1.63				
Max.	0.09	0.05	0.18	2.05	0.15	1.81	0.15	1.93	0.18	2.06	0.15	2.01	0.15	1.97				
Mean.	0.05	0.02	0.09	1.73	0.09	1.53	0.08	1.59	0.09	1.77	0.09	1.76	0.08	1.75				
SD.	0.02	0.02	0.05	0.15	0.04	0.19	0.03	0.17	0.05	0.13	0.04	0.12	0.03	0.11				

Days	Influents		Condition 7	Condition 8	Condition 9	Condition 10	Condition 11	Condition 12	Influents		Condition 7	Condition 8	Condition 9	Condition 10	Condition 11	Condition 12
			Effluents		Effluents		Effluents				Effluents		Effluents		Effluents	
	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N	NO ₂ -N	NO ₃ -N
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	0.05	0.02	0.09	1.73	0.13	1.62	0.09	1.62	0.16	1.58	0.11	1.80	0.11	1.75		
2	0.07	0.03	0.09	1.61	0.13	1.78	0.10	1.71	0.11	1.82	0.13	1.86	0.09	1.91		
3	0.04	0.03	0.04	1.98	0.07	1.89	0.06	1.92	0.13	1.98	0.14	2.08	0.09	2.01		
4	0.04	0.02	0.08	2.05	0.06	1.96	0.06	2.08	0.15	1.85	0.14	1.81	0.11	1.85		
5	0.06	0.05	0.07	1.90	0.07	1.73	0.09	1.86	0.10	1.66	0.10	1.72	0.08	1.73		
6	0.03	0.01	0.06	1.79	0.06	1.80	0.05	1.77	0.11	1.62	0.11	1.65	0.11	1.67		
7	0.03	0.04	0.04	1.93	0.05	1.75	0.04	1.79	0.12	1.58	0.15	1.56	0.10	1.66		
8	0.04	0.00	0.04	1.85	0.05	1.84	0.04	1.85	0.13	1.62	0.13	1.68	0.12	1.71		
9	0.07	0.00	0.07	1.81	0.09	1.75	0.07	1.80	0.10	1.64	0.15	1.54	0.16	1.50		
10	0.09	0.00	0.07	1.89	0.10	1.76	0.06	1.82	0.15	1.66	0.12	1.66	0.13	1.68		
11	0.06	0.00	0.07	1.77	0.07	1.60	0.09	1.73	0.14	1.54	0.16	1.50	0.14	1.55		
12	0.03	0.01	0.06	1.89	0.06	1.90	0.05	1.87	0.18	1.66	0.15	1.70	0.15	1.68		
13	0.04	0.00	0.04	1.82	0.05	1.74	0.04	1.90	0.15	1.65	0.12	1.65	0.13	1.65		
14	0.03	0.00	0.10	1.72	0.12	1.53	0.07	1.61	0.13	1.54	0.13	1.53	0.12	1.56		
15	0.03	0.04	0.07	1.80	0.07	1.63	0.09	1.72	0.12	1.62	0.15	1.56	0.10	1.64		
Min.	0.03	0.00	0.04	1.61	0.05	1.53	0.04	1.61	0.10	1.54	0.10	1.50	0.08	1.50		
Max.	0.09	0.05	0.10	2.05	0.13	1.96	0.10	2.08	0.18	1.98	0.16	2.08	0.16	2.01		
Mean.	0.05	0.02	0.07	1.84	0.08	1.75	0.07	1.80	0.13	1.67	0.13	1.69	0.12	1.70		
SD.	0.02	0.02	0.02	0.11	0.03	0.12	0.02	0.12	0.02	0.12	0.02	0.15	0.02	0.14		

Table A-8 The NO₂-N and NO₃-N in the effluent of Group 2

Days	Influents		Condition 13	Condition 14	Condition 15	Condition 16	Condition 17	Condition 18						
			Effluents		Effluents		Effluents		Effluents					
	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L
1	0.03	0.00	0.05	1.53	0.08	1.38	0.08	1.42	0.05	1.75	0.08	1.68	0.08	1.74
2	0.00	0.00	0.01	1.90	0.04	1.70	0.05	1.72	0.01	1.98	0.04	1.94	0.05	1.90
3	0.00	0.00	0.04	1.94	0.03	1.73	0.03	1.88	0.04	2.02	0.03	2.01	0.03	2.02
4	0.00	0.05	0.05	1.96	0.08	1.46	0.07	1.62	0.05	1.97	0.08	1.95	0.07	1.97
5	0.02	0.04	0.08	1.71	0.09	1.37	0.10	1.51	0.08	1.81	0.09	1.75	0.10	1.76
6	0.00	0.04	0.08	2.06	0.07	1.89	0.05	2.04	0.08	2.09	0.07	2.08	0.05	2.11
7	0.03	0.04	0.05	1.76	0.10	1.59	0.10	1.63	0.05	2.01	0.10	1.88	0.10	1.93
8	0.00	0.08	0.04	1.96	0.08	1.72	0.07	1.86	0.04	2.01	0.08	1.91	0.07	1.95
9	0.00	0.05	0.03	1.84	0.05	1.71	0.05	1.78	0.03	1.88	0.05	1.79	0.05	1.79
10	0.02	0.09	0.03	2.00	0.05	1.70	0.05	1.84	0.03	2.07	0.05	1.97	0.05	1.99
11	0.01	0.04	0.04	2.00	0.03	1.70	0.05	1.90	0.04	2.06	0.03	1.99	0.05	1.99
12	0.02	0.05	0.03	2.22	0.04	1.74	0.05	1.88	0.03	2.27	0.04	2.26	0.05	2.24
13	0.05	0.00	0.06	1.77	0.06	1.44	0.03	1.62	0.06	1.88	0.06	1.84	0.03	1.94
14	0.02	0.00	0.03	1.91	0.10	1.67	0.03	1.77	0.03	2.00	0.10	1.89	0.03	2.05
15	0.00	0.05	0.03	1.85	0.05	1.55	0.05	1.69	0.03	1.88	0.05	1.79	0.05	1.79
Min.	0.00	0.00	0.01	1.53	0.03	1.37	0.03	1.42	0.01	1.75	0.03	1.68	0.03	1.74
Max.	0.05	0.09	0.08	2.22	0.10	1.89	0.10	2.04	0.08	2.27	0.10	2.26	0.10	2.24
Mean.	0.01	0.04	0.04	1.89	0.06	1.62	0.06	1.74	0.04	1.98	0.06	1.92	0.06	1.94
SD.	0.02	0.03	0.02	0.16	0.02	0.15	0.02	0.16	0.02	0.13	0.02	0.14	0.02	0.14

Days	Influents		Condition 19	Condition 20	Condition 21	Condition 22	Condition 23	Condition 24						
			Effluents		Effluents		Effluents		Effluents					
	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L		
1	0.03	0.00	0.04	1.75	0.04	1.79	0.06	1.75	0.12	1.61	0.13	1.64	0.14	1.60
2	0.00	0.00	0.06	1.90	0.05	1.95	0.06	1.90	0.13	1.76	0.14	1.79	0.14	1.80
3	0.00	0.00	0.05	2.00	0.05	2.02	0.03	2.02	0.18	1.77	0.17	1.76	0.12	1.81
4	0.00	0.05	0.06	1.96	0.05	2.01	0.05	1.98	0.11	1.87	0.15	1.83	0.09	1.91
5	0.02	0.04	0.10	1.77	0.10	1.75	0.10	1.74	0.14	1.69	0.12	1.70	0.10	1.70
6	0.00	0.04	0.10	2.04	0.07	2.09	0.08	2.08	0.13	1.96	0.12	2.00	0.09	2.04
7	0.03	0.04	0.12	1.86	0.12	1.90	0.10	1.93	0.11	1.92	0.12	1.91	0.10	1.85
8	0.00	0.08	0.10	1.91	0.10	1.86	0.12	1.94	0.10	1.83	0.10	1.83	0.10	1.82
9	0.00	0.05	0.11	1.76	0.10	1.75	0.10	1.81	0.13	1.67	0.14	1.72	0.14	1.72
10	0.02	0.09	0.11	1.87	0.10	1.91	0.10	1.95	0.11	1.92	0.15	1.82	0.09	1.89
11	0.01	0.04	0.09	1.89	0.05	1.96	0.11	1.94	0.11	1.91	0.12	1.83	0.10	1.86
12	0.02	0.05	0.10	2.17	0.08	2.20	0.10	2.12	0.10	2.16	0.10	2.05	0.10	2.08
13	0.05	0.00	0.06	1.89	0.07	1.85	0.08	1.82	0.09	1.78	0.10	1.76	0.10	1.74
14	0.02	0.00	0.03	2.03	0.05	2.00	0.06	1.98	0.10	1.85	0.11	1.84	0.11	1.86
15	0.00	0.05	0.11	1.76	0.10	1.75	0.10	1.81	0.13	1.67	0.14	1.72	0.14	1.72
Min.	0.00	0.00	0.03	1.75	0.04	1.75	0.03	1.74	0.09	1.61	0.10	1.64	0.09	1.60
Max.	0.05	0.09	0.12	2.17	0.12	2.20	0.12	2.12	0.18	2.16	0.17	2.05	0.14	2.08
Mean.	0.01	0.04	0.08	1.90	0.08	1.92	0.08	1.92	0.12	1.82	0.13	1.81	0.11	1.83
SD.	0.02	0.03	0.03	0.12	0.03	0.13	0.03	0.11	0.02	0.14	0.02	0.11	0.02	0.13

Table A-9 The NO₂-N and NO₃-N in the effluent of Group 3

Days	Influents		Condition 25	Condition 26	Condition 27	Condition 28	Condition 29	Condition 30						
			Effluents		Effluents		Effluents		Effluents					
	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L
1	0.07	0.07	0.12	1.96	0.18	1.75	0.05	1.99	0.14	1.80	0.17	1.84	0.11	1.78
2	0.08	0.07	0.14	1.68	0.18	1.65	0.07	1.58	0.12	1.79	0.06	1.89	0.18	1.66
3	0.09	0.03	0.06	1.82	0.07	1.80	0.06	1.80	0.07	1.88	0.07	1.89	0.07	1.87
4	0.01	0.05	0.10	1.68	0.05	1.51	0.06	1.47	0.02	1.86	0.02	1.84	0.03	1.85
5	0.03	0.08	0.05	1.75	0.06	1.67	0.10	1.68	0.04	1.92	0.04	1.91	0.03	1.90
6	0.03	0.05	0.02	1.88	0.04	1.80	0.06	1.82	0.02	2.03	0.01	2.06	0.01	2.10
7	0.02	0.09	0.06	1.92	0.08	1.71	0.05	1.84	0.02	1.92	0.02	1.96	0.03	1.95
8	0.07	0.09	0.04	2.07	0.04	1.94	0.03	2.02	0.03	2.08	0.06	1.97	0.06	2.02
9	0.08	0.06	0.03	2.10	0.02	1.92	0.02	2.10	0.04	2.10	0.08	2.07	0.06	2.09
10	0.04	0.07	0.06	2.00	0.05	1.72	0.04	1.97	0.06	2.04	0.05	2.08	0.04	2.04
11	0.05	0.03	0.02	2.08	0.01	2.05	0.03	2.08	0.03	2.11	0.02	2.09	0.02	2.08
12	0.03	0.03	0.06	1.92	0.08	1.88	0.05	1.91	0.02	1.94	0.01	1.94	0.03	1.91
13	0.04	0.06	0.02	1.84	0.04	1.69	0.06	1.78	0.06	1.85	0.02	1.93	0.03	1.91
14	0.04	0.07	0.05	1.85	0.06	1.77	0.10	1.74	0.06	1.82	0.05	1.81	0.04	1.87
15	0.03	0.08	0.06	1.08	0.08	1.79	0.05	1.86	0.04	1.92	0.04	1.91	0.03	1.90
Min.	0.01	0.03	0.02	1.08	0.01	1.51	0.02	1.47	0.02	1.79	0.01	1.81	0.01	1.66
Max.	0.09	0.09	0.14	2.10	0.18	2.05	0.10	2.10	0.14	2.11	0.17	2.09	0.18	2.10
Mean.	0.05	0.06	0.06	1.84	0.07	1.78	0.06	1.84	0.05	1.94	0.05	1.95	0.05	1.93
SD.	0.02	0.02	0.04	0.25	0.05	0.13	0.02	0.18	0.04	0.11	0.04	0.09	0.04	0.12

Days	Influents		Condition 31	Condition 32	Condition 33	Condition 34	Condition 35	Condition 36						
			Effluents		Effluents		Effluents		Effluents					
	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L
1	0.07	0.07	0.10	1.85	0.12	1.86	0.11	1.77	0.18	1.80	0.15	1.88	0.11	1.93
2	0.08	0.07	0.11	1.83	0.11	1.82	0.13	1.78	0.20	1.72	0.18	1.73	0.11	1.81
3	0.09	0.03	0.05	1.90	0.03	1.94	0.09	1.85	0.14	1.78	0.14	1.78	0.07	1.85
4	0.01	0.05	0.03	1.85	0.02	1.88	0.01	1.90	0.10	1.79	0.11	1.79	0.10	1.78
5	0.03	0.08	0.01	1.90	0.01	1.89	0.02	1.92	0.14	1.82	0.11	1.82	0.08	1.85
6	0.03	0.05	0.03	2.08	0.01	2.09	0.01	2.10	0.16	1.93	0.11	1.95	0.06	2.02
7	0.02	0.09	0.03	1.96	0.03	1.91	0.05	1.90	0.15	1.80	0.10	1.82	0.10	1.85
8	0.07	0.09	0.05	2.05	0.03	2.07	0.04	2.06	0.13	1.92	0.12	1.93	0.09	1.96
9	0.08	0.06	0.07	2.04	0.04	2.09	0.08	2.06	0.10	2.02	0.10	1.97	0.10	1.99
10	0.04	0.07	0.07	2.04	0.06	2.04	0.05	2.06	0.12	1.92	0.14	1.96	0.11	1.95
11	0.05	0.03	0.03	2.11	0.04	2.09	0.04	2.06	0.15	1.98	0.11	2.00	0.11	1.97
12	0.03	0.03	0.03	1.94	0.03	1.93	0.05	1.92	0.13	1.83	0.12	1.80	0.12	1.81
13	0.04	0.06	0.03	1.91	0.06	1.84	0.05	1.86	0.12	1.77	0.09	1.83	0.10	1.81
14	0.04	0.07	0.03	1.89	0.03	1.87	0.05	1.86	0.10	1.78	0.11	1.76	0.10	1.78
15	0.03	0.08	0.01	1.90	0.01	1.89	0.02	1.92	0.14	1.82	0.11	1.82	0.08	1.85
Min.	0.01	0.03	0.01	1.83	0.01	1.82	0.01	1.77	0.10	1.72	0.09	1.73	0.06	1.78
Max.	0.09	0.09	0.11	2.11	0.12	2.09	0.13	2.10	0.20	2.02	0.18	2.00	0.12	2.02
Mean.	0.05	0.06	0.05	1.95	0.04	1.95	0.05	1.93	0.14	1.85	0.12	1.86	0.10	1.88
SD.	0.02	0.02	0.03	0.09	0.03	0.10	0.04	0.11	0.03	0.09	0.02	0.09	0.02	0.08

APPENDIX B

Results of Statistical Analysis

Table B-1 Descriptive analysis for NH₃-N removal efficiencies of conditions in Group1 (HRT 1 hr.)

Descriptive Statistics

%TAN removal efficiency (HRT1)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	1.2513	.50640	.13075	.50	2.05
10.0%PVA	84.9320	4.46875	1.15383	75.62	93.94
10.0%PVA 3%coal	86.9287	2.95286	.76242	78.03	90.48
10.0%PVA 5%coal	86.3907	1.59171	.41098	84.34	89.67
10.0%PVA 7%coal	86.1600	3.20803	.82831	79.22	89.67
12.5%PVA	75.7313	7.08989	1.83060	60.20	88.89
12.5%PVA 3%coal	89.4700	5.97056	1.54159	73.59	94.23
12.5%PVA 5%coal	85.9813	3.98024	1.02769	78.48	91.54
12.5%PVA 7%coal	87.9007	5.37343	1.38741	76.68	93.04
15.0%PVA	78.7087	7.45923	1.92596	66.67	93.02
15.0%PVA 3% coal	84.4547	2.50571	.64697	78.03	87.02
15.0%PVA 5%coal	85.2680	1.76762	.45640	81.43	89.88
15.0%PVA 7%coal	85.3420	1.29309	.33387	82.59	87.02
Total	78.3476	22.97026	1.64493	.50	94.23

Table B-2 Descriptive analysis for NH₃-N removal efficiencies of conditions in Group2 (HRT 2 hrs)

Descriptives Statistics

%TAN removal efficiency (HRT2)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	2.5040	1.50521	.38864	.45	7.04
10.0%PVA	90.6080	3.67758	.94955	81.03	93.75
10.0%PVA 3%coal	94.6367	1.14553	.29577	92.31	95.83
10.0%PVA 5%coal	92.5853	1.85985	.48021	89.76	95.83
10.0%PVA 7%coal	93.7040	2.19837	.56762	89.76	97.65
12.5%PVA	78.9327	4.69109	1.21123	71.30	85.85
12.5%PVA 3%coal	93.0100	2.13758	.55192	90.00	96.71
12.5%PVA 5%coal	93.3653	2.07170	.53491	90.24	96.28
12.5%PVA 7%coal	93.6933	1.16536	.30089	92.46	96.26
15.0%PVA	84.2753	4.56166	1.17782	76.92	90.48
15.0%PVA 3% coal	90.9580	1.84051	.47522	87.80	94.17
15.0%PVA 5%coal	90.8707	1.16688	.30129	88.64	93.12
15.0%PVA 7%coal	90.6873	1.21279	.31314	89.09	92.59
Total	83.8331	24.03906	1.72147	.45	97.65

Table B-3 Descriptive analysis for NH₃-N removal efficiencies of conditions in Group3 (HRT 4 hrs)

Descriptives Statistics

%TAN removal efficiency (HRT4)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	2.2407	2.50154	.64590	.00	9.50
10.0%PVA	91.0913	10.31093	2.66227	55.88	97.69
10.0%PVA 3%coal	95.3567	1.72086	.44432	90.23	97.69
10.0%PVA 5%coal	95.6160	1.35003	.34858	93.49	97.71
10.0%PVA 7%coal	94.9467	2.38748	.61644	87.91	97.29
12.5%PVA	88.5253	4.77527	1.23297	78.79	96.08
12.5%PVA 3%coal	95.6840	1.80760	.46672	90.70	97.22
12.5%PVA 5%coal	95.3840	1.51947	.39233	92.09	97.22
12.5%PVA 7%coal	95.3360	2.34398	.60521	87.44	97.22
15.0%PVA	90.9207	5.47003	1.41235	77.27	96.08
15.0%PVA 3% coal	95.0793	1.18408	.30573	92.09	96.38
15.0%PVA 5%coal	94.7580	.78553	.20282	93.66	96.33
15.0%PVA 7%coal	94.7933	.40357	.10420	94.12	95.52
Total	86.9025	24.87624	1.78142	.00	97.71

Table B-4 Descriptive analysis COD removal efficiencies of conditions in Group1 (HRT 1 hr.)

Descriptives Statistics

%COD removal efficiency (HRT1)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
10%PVA	2.5838	1.06141	.37527	.00	3.33
10%PVA3%COAL	3.5063	2.79407	.98785	.00	9.09
10%PVA5%COAL	1.4863	1.60487	.56741	.00	3.33
10%PVA7%COAL	2.0738	1.59745	.56478	.00	4.05
12.5%PVA	2.8063	2.18160	.77131	.00	6.67
12.5%PVA3%COAL	1.6950	1.69459	.59913	.00	4.05
12.5%PVA5%COAL	2.5988	1.13199	.40022	1.14	4.67
12.5%PVA7%COAL	2.8125	1.87238	.66198	.00	6.67
15%PVA	3.3788	2.57039	.90877	.00	8.33
15%PVA3%COAL	2.4100	1.17489	.41539	1.14	4.67
15%PVA5%COAL	3.3788	2.57039	.90877	.00	8.33
15%PVA7%COAL	1.6950	1.69459	.59913	.00	4.05
Total	2.5354	1.91867	.19582	.00	9.09

Table B-5 Descriptive analysis COD removal efficiencies of conditions in Group2 (HRT 2 hrs.)**Descriptives Statistics**

%COD removal efficiency (HRT2)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
10%PVA	1.7990	2.16844	.76666	.00	4.76
10%PVA3%COAL	1.6174	1.26041	.44562	.00	3.33
10%PVA5%COAL	2.4646	1.98743	.70266	.00	5.26
10%PVA7%COAL	1.1442	1.09732	.38796	.00	3.13
12.5%PVA	1.7990	2.16844	.76666	.00	4.76
12.5%PVA3%COAL	1.9776	2.14013	.75665	.00	6.67
12.5%PVA5%COAL	1.8652	2.11368	.74730	.00	4.76
12.5%PVA7%COAL	3.0495	3.47309	1.22792	.00	10.00
15%PVA	1.6174	1.26041	.44562	.00	3.33
15%PVA3%COAL	1.8652	2.11368	.74730	.00	4.76
15%PVA5%COAL	1.6174	1.26041	.44562	.00	3.33
15%PVA7%COAL	1.1442	1.09732	.38796	.00	3.13
Total	1.8301	1.91030	.19497	.00	10.00

Table B-6 Descriptive analysis COD removal efficiencies of conditions in Group3 (HRT 4 hrs.)**Descriptives Statistics**

%COD removal efficiency (HRT4)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
10%PVA	1.6591	1.88447	.66626	.00	4.76
10%PVA3%COAL	3.9513	3.28560	1.16163	.00	9.09
10%PVA5%COAL	1.5476	1.94542	.68781	.00	5.26
10%PVA7%COAL	1.4860	2.38716	.84399	-3.33	4.05
12.5%PVA	1.6591	1.88447	.66626	.00	4.76
12.5%PVA3%COAL	1.4860	2.38716	.84399	-3.33	4.05
12.5%PVA5%COAL	2.7722	2.03890	.72086	.00	6.06
12.5%PVA7%COAL	1.6591	1.88447	.66626	.00	4.76
15%PVA	3.9513	3.28560	1.16163	.00	9.09
15%PVA3%COAL	2.7722	2.03890	.72086	.00	6.06
15%PVA5%COAL	3.9513	3.28560	1.16163	.00	9.09
15%PVA7%COAL	1.4860	2.38716	.84399	-3.33	4.05
Total	2.3651	2.52259	.25746	-3.33	9.09

Table B-7 Descriptive analysis NO₂-N removal efficiency of conditions in Group1 (HRT 1 hrs.)

Descriptives Statistics

%NO₂-N removal efficiency (HRT1)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	-115.0000	62.89220	16.23870	-250.00	-33.00
10.0%PVA	-92.9333	92.58854	23.90626	-225.00	67.00
10.0%PVA 3%coal	-92.9333	92.58854	23.90626	-225.00	67.00
10.0%PVA 5%coal	-93.6667	76.33167	19.70875	-233.00	44.00
10.0%PVA 7%coal	-88.8000	77.82141	20.09340	-300.00	44.00
12.5%PVA	-93.6667	76.33167	19.70875	-233.00	44.00
12.5%PVA 3%coal	-54.6667	68.94270	17.80093	-233.00	22.00
12.5%PVA 5%coal	-79.6667	76.01096	19.62595	-300.00	-11.00
12.5%PVA 7%coal	-52.6667	57.00084	14.71755	-200.00	33.00
15.0%PVA	-88.8000	77.82141	20.09340	-300.00	44.00
15.0%PVA 3% coal	-219.1333	126.64679	32.70006	-500.00	-43.00
15.0%PVA 5%coal	-220.8000	123.85833	31.98008	-400.00	-33.00
15.0%PVA 7%coal	-176.4000	104.39745	26.95531	-400.00	-29.00
Total	-113.0103	101.01939	7.23415	-500.00	67.00

Table B-8 Descriptive analysis NO₂-N removal efficiency of conditions in Group2 (HRT 2 hrs.)

Descriptives Statistics

%NO₂-N removal efficiency (HRT2)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	-150.9333	158.78218	40.99738	-400.00	.00
10.0%PVA	-71.4000	102.92077	26.57403	-300.00	.00
10.0%PVA 3%coal	-71.4000	102.92077	26.57403	-300.00	.00
10.0%PVA 5%coal	-125.8000	139.25373	35.95516	-400.00	.00
10.0%PVA 7%coal	-116.2000	147.12250	37.98686	-400.00	40.00
12.5%PVA	-125.8000	139.25373	35.95516	-400.00	.00
12.5%PVA 3%coal	-176.8667	243.08460	62.76417	-800.00	.00
12.5%PVA 5%coal	-146.0000	167.61734	43.27861	-400.00	.00
12.5%PVA 7%coal	-197.3333	271.46051	70.09080	-1000.00	.00
15.0%PVA	-116.2000	147.12250	37.98686	-400.00	40.00
15.0%PVA 3% coal	-257.6000	291.48776	75.26182	-1000.00	.00
15.0%PVA 5%coal	-288.8667	322.29420	83.21601	-1100.00	.00
15.0%PVA 7%coal	-233.3333	257.36457	66.45125	-900.00	.00
Total	-159.8256	208.72766	14.94730	-1100.00	40.00

Table B-9 Descriptive analysis NO₂-N removal efficiency of conditions in Group3 (HRT 4 hrs.)

Descriptives Statistics

%NO₂-N removal efficiency (HRT4)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	-188.5333	194.67587	50.26509	-800.00	-33.00
10.0%PVA	-87.0667	237.34648	61.28260	-900.00	63.00
10.0%PVA 3%coal	-15.4000	52.52999	13.56319	-100.00	57.00
10.0%PVA 5%coal	-3.6000	59.80062	15.44045	-143.00	67.00
10.0%PVA 7%coal	-14.6000	69.79337	18.02057	-200.00	67.00
12.5%PVA	-86.9333	136.60761	35.27193	-400.00	80.00
12.5%PVA 3%coal	-6.4000	68.44059	17.67128	-200.00	67.00
12.5%PVA 5%coal	4.0667	58.83812	15.19194	-100.00	67.00
12.5%PVA 7%coal	-14.4000	54.69892	14.12320	-150.00	67.00
15.0%PVA	-71.3333	148.08620	38.23569	-500.00	75.00
15.0%PVA 3% coal	-284.9333	236.53102	61.07205	-900.00	-25.00
15.0%PVA 5%coal	-237.4667	235.82435	60.88959	-1000.00	-25.00
15.0%PVA 7%coal	-183.7333	226.16001	58.39426	-900.00	22.00
Total	-91.5641	179.64616	12.86473	-1000.00	80.00

Table B-10 Descriptive analysis NO₃-N effluents of conditions in Group1 (HRT 1 hrs.)

Descriptives Statistics

%NO₃-N increasing (HRT1)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	.0613	.02200	.00568	.03	.09
10.0%PVA	1.7260	.15315	.03954	1.45	2.05
10.0%PVA 3%coal	1.7667	.12562	.03244	1.58	2.06
10.0%PVA 5%coal	1.7567	.11800	.03047	1.58	2.01
10.0%PVA 7%coal	1.7527	.11074	.02859	1.63	1.97
12.5%PVA	1.5307	.18763	.04845	1.11	1.81
12.5%PVA 3%coal	1.8360	.11018	.02845	1.61	2.05
12.5%PVA 5%coal	1.7520	.11965	.03089	1.53	1.96
12.5%PVA 7%coal	1.8033	.12040	.03109	1.61	2.08
15.0%PVA	1.5940	.17361	.04483	1.22	1.93
15.0%PVA 3% coal	1.6680	.12249	.03163	1.54	1.98
15.0%PVA 5%coal	1.6867	.15365	.03967	1.50	2.08
15.0%PVA 7%coal	1.7033	.13563	.03502	1.50	2.01
Total	1.5875	.46684	.03343	.03	2.08

Table B-11 Descriptive analysis NO₃-N effluents of conditions in Group2 (HRT 2 hrs.)**Descriptives Statistics**%NO₃-N increasing (HRT2)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	.0607	.02434	.00628	.02	.09
10.0%PVA	1.8940	.16300	.04209	1.53	2.22
10.0%PVA 3%coal	1.9787	.12716	.03283	1.75	2.27
10.0%PVA 5%coal	1.9153	.14317	.03697	1.68	2.26
10.0%PVA 7%coal	1.9447	.13685	.03533	1.74	2.24
12.5%PVA	1.6233	.15188	.03921	1.37	1.89
12.5%PVA 3%coal	1.9040	.12076	.03118	1.75	2.17
12.5%PVA 5%coal	1.9193	.13280	.03429	1.75	2.20
12.5%PVA 7%coal	1.9180	.11353	.02931	1.74	2.12
15.0%PVA	1.7440	.16487	.04257	1.42	2.04
15.0%PVA 3% coal	1.8247	.14147	.03653	1.61	2.16
15.0%PVA 5%coal	1.8133	.10965	.02831	1.64	2.05
15.0%PVA 7%coal	1.8267	.12596	.03252	1.60	2.08
Total	1.7205	.50541	.03619	.02	2.27

Table B-12 Descriptive analysis NO₃-N effluents of conditions in Group3 (HRT 4 hrs.)**Descriptives Statistics**%NO₃-N increasing (HRT4)

	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	.1427	.03035	.00784	.10	.18
10.0%PVA	1.8420	.24926	.06436	1.08	2.10
10.0%PVA 3%coal	1.9373	.10951	.02828	1.79	2.11
10.0%PVA 5%coal	1.9460	.09179	.02370	1.81	2.09
10.0%PVA 7%coal	1.9287	.12223	.03156	1.66	2.10
12.5%PVA	1.7767	.13318	.03439	1.51	2.05
12.5%PVA 3%coal	1.9500	.09103	.02350	1.83	2.11
12.5%PVA 5%coal	1.9473	.09960	.02572	1.82	2.09
12.5%PVA 7%coal	1.9347	.10776	.02782	1.77	2.10
15.0%PVA	1.8427	.17886	.04618	1.47	2.10
15.0%PVA 3% coal	1.8453	.08684	.02242	1.72	2.02
15.0%PVA 5%coal	1.8560	.08551	.02208	1.73	2.00
15.0%PVA 7%coal	1.8807	.08102	.02092	1.78	2.02
Total	1.7562	.48504	.03473	.10	2.11

Table B-13 Comparison of NH₃-N removal efficiencies of conditions in Group1 (HRT 1 hr.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	99013.135	12	8251.095	448.587	0
Within Groups	3347.623	182	18.394		
Total	102360.758	194			

Multiple Comparisons (Tukey HSD)					
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.
% NH ₃ -N Removal Efficiency	Control	10.0%PVA	-83.68067(*)	1.56604	0
		10.0%PVA 3%coal	-85.67733(*)	1.56604	0
		10.0%PVA 5%coal	-85.13933(*)	1.56604	0
		10.0%PVA 7%coal	-84.90867(*)	1.56604	0
		12.5%PVA	-74.48000(*)	1.56604	0
		12.5%PVA 3%coal	-88.21867(*)	1.56604	0
		12.5%PVA 5%coal	-84.73000(*)	1.56604	0
		12.5%PVA 7%coal	-86.64933(*)	1.56604	0
		15.0%PVA	-77.45733(*)	1.56604	0
		15.0%PVA 3% coal	-83.20333(*)	1.56604	0
	15.0%PVA 5%coal	-84.01667(*)	1.56604	0	
	15.0%PVA 7%coal	-84.09067(*)	1.56604	0	
	10.0%PVA	Control	83.68067(*)	1.56604	0
		10.0%PVA 3%coal	-1.99667	1.56604	0.988
		10.0%PVA 5%coal	-1.45867	1.56604	0.999
		10.0%PVA 7%coal	-1.228	1.56604	1
		12.5%PVA	9.20067(*)	1.56604	0
		12.5%PVA 3%coal	-4.538	1.56604	0.169
		12.5%PVA 5%coal	-1.04933	1.56604	1
		12.5%PVA 7%coal	-2.96867	1.56604	0.796
15.0%PVA		6.22333(*)	1.56604	0.007	
15.0%PVA 3% coal		0.47733	1.56604	1	
15.0%PVA 5%coal	-0.336	1.56604	1		
15.0%PVA 7%coal	-0.41	1.56604	1		
10.0%PVA 3%coal	Control	85.67733(*)	1.56604	0	
	10.0%PVA	1.99667	1.56604	0.988	
	10.0%PVA 5%coal	0.538	1.56604	1	
	10.0%PVA 7%coal	0.76867	1.56604	1	
	12.5%PVA	11.19733(*)	1.56604	0	
	12.5%PVA 3%coal	-2.54133	1.56604	0.921	
	12.5%PVA 5%coal	0.94733	1.56604	1	
	12.5%PVA 7%coal	-0.972	1.56604	1	
	15.0%PVA	8.22000(*)	1.56604	0	
	15.0%PVA 3% coal	2.474	1.56604	0.934	
15.0%PVA 5%coal	1.66067	1.56604	0.998		
15.0%PVA 7%coal	1.58667	1.56604	0.998		
10.0%PVA 5%coal	Control	85.13933(*)	1.56604	0	
	10.0%PVA	1.45867	1.56604	0.999	
	10.0%PVA 3%coal	-0.538	1.56604	1	
	10.0%PVA 7%coal	0.23067	1.56604	1	

	12.5%PVA	10.65933(*)	1.56604	0
	12.5%PVA 3%coal	-3.07933	1.56604	0.753
	12.5%PVA 5%coal	0.40933	1.56604	1
	12.5%PVA 7%coal	-1.51	1.56604	0.999
	15.0%PVA	7.68200(*)	1.56604	0
	15.0%PVA 3% coal	1.936	1.56604	0.99
	15.0%PVA 5%coal	1.12267	1.56604	1
	15.0%PVA 7%coal	1.04867	1.56604	1
10.0%PVA 7%coal	Control	84.90867(*)	1.56604	0
	10.0%PVA	1.228	1.56604	1
	10.0%PVA 3%coal	-0.76867	1.56604	1
	10.0%PVA 5%coal	-0.23067	1.56604	1
	12.5%PVA	10.42867(*)	1.56604	0
	12.5%PVA 3%coal	-3.31	1.56604	0.654
	12.5%PVA 5%coal	0.17867	1.56604	1
	12.5%PVA 7%coal	-1.74067	1.56604	0.996
	15.0%PVA	7.45133(*)	1.56604	0
	15.0%PVA 3% coal	1.70533	1.56604	0.997
	15.0%PVA 5%coal	0.892	1.56604	1
	15.0%PVA 7%coal	0.818	1.56604	1
12.5%PVA	Control	74.48000(*)	1.56604	0
	10.0%PVA	-9.20067(*)	1.56604	0
	10.0%PVA 3%coal	-11.19733(*)	1.56604	0
	10.0%PVA 5%coal	-10.65933(*)	1.56604	0
	10.0%PVA 7%coal	-10.42867(*)	1.56604	0
	12.5%PVA 3%coal	-13.73867(*)	1.56604	0
	12.5%PVA 5%coal	-10.25000(*)	1.56604	0
	12.5%PVA 7%coal	-12.16933(*)	1.56604	0
	15.0%PVA	-2.97733	1.56604	0.793
	15.0%PVA 3% coal	-8.72333(*)	1.56604	0
	15.0%PVA 5%coal	-9.53667(*)	1.56604	0
	15.0%PVA 7%coal	-9.61067(*)	1.56604	0
12.5%PVA 3%coal	Control	88.21867(*)	1.56604	0
	10.0%PVA	4.538	1.56604	0.169
	10.0%PVA 3%coal	2.54133	1.56604	0.921
	10.0%PVA 5%coal	3.07933	1.56604	0.753
	10.0%PVA 7%coal	3.31	1.56604	0.654
	12.5%PVA	13.73867(*)	1.56604	0
	12.5%PVA 5% coal	3.48867	1.56604	0.572
	12.5%PVA 7%coal	1.56933	1.56604	0.999
	15.0%PVA	10.76133(*)	1.56604	0
	15.0%PVA 3% coal	5.01533	1.56604	0.078
	15.0%PVA 5%coal	4.202	1.56604	0.27
	15.0%PVA 7%coal	4.128	1.56604	0.297
12.5%PVA 5%coal	Control	84.73000(*)	1.56604	0
	10.0%PVA	1.04933	1.56604	1
	10.0%PVA 3%coal	-0.94733	1.56604	1
	10.0%PVA 5%coal	-0.40933	1.56604	1
	10.0%PVA 7%coal	-0.17867	1.56604	1
	12.5%PVA	10.25000(*)	1.56604	0
	12.5%PVA 3%coal	-3.48867	1.56604	0.572

	12.5%PVA 7% coal	-1.91933	1.56604	0.991	
	15.0%PVA	7.27267(*)	1.56604	0	
	15.0%PVA 3% coal	1.52667	1.56604	0.999	
	15.0%PVA 5% coal	0.71333	1.56604	1	
	15.0%PVA 7% coal	0.63933	1.56604	1	
12.5%PVA 7% coal	Control	86.64933(*)	1.56604	0	
	10.0%PVA	2.96867	1.56604	0.796	
	10.0%PVA 3% coal	0.972	1.56604	1	
	10.0%PVA 5% coal	1.51	1.56604	0.999	
	10.0%PVA 7% coal	1.74067	1.56604	0.996	
	12.5%PVA	12.16933(*)	1.56604	0	
	12.5%PVA 3% coal	-1.56933	1.56604	0.999	
	12.5%PVA 5% coal	1.91933	1.56604	0.991	
	15.0%PVA	9.19200(*)	1.56604	0	
	15.0%PVA 3% coal	3.446	1.56604	0.592	
	15.0%PVA 5% coal	2.63267	1.56604	0.9	
	15.0%PVA 7% coal	2.55867	1.56604	0.917	
	15.0%PVA	Control	77.45733(*)	1.56604	0
		10.0%PVA	-6.22333(*)	1.56604	0.007
		10.0%PVA 3% coal	-8.22000(*)	1.56604	0
		10.0%PVA 5% coal	-7.68200(*)	1.56604	0
		10.0%PVA 7% coal	-7.45133(*)	1.56604	0
12.5%PVA		2.97733	1.56604	0.793	
12.5%PVA 3% coal		-10.76133(*)	1.56604	0	
12.5%PVA 5% coal		-7.27267(*)	1.56604	0	
12.5%PVA 7% coal		-9.19200(*)	1.56604	0	
15.0%PVA 3% coal		-5.74600(*)	1.56604	0.019	
15.0%PVA 5% coal		-6.55933(*)	1.56604	0.003	
15.0%PVA 7% coal		-6.63333(*)	1.56604	0.002	
15.0%PVA 3% coal		Control	83.20333(*)	1.56604	0
	10.0%PVA	-0.47733	1.56604	1	
	10.0%PVA 3% coal	-2.474	1.56604	0.934	
	10.0%PVA 5% coal	-1.936	1.56604	0.99	
	10.0%PVA 7% coal	-1.70533	1.56604	0.997	
	12.5%PVA	8.72333(*)	1.56604	0	
	12.5%PVA 3% coal	-5.01533	1.56604	0.078	
	12.5%PVA 5% coal	-1.52667	1.56604	0.999	
	12.5%PVA 7% coal	-3.446	1.56604	0.592	
	15.0%PVA	5.74600(*)	1.56604	0.019	
	15.0%PVA 5% coal	-0.81333	1.56604	1	
	15.0%PVA 7% coal	-0.88733	1.56604	1	
	15.0%PVA 5% coal	Control	84.01667(*)	1.56604	0
10.0%PVA		0.336	1.56604	1	
10.0%PVA 3% coal		-1.66067	1.56604	0.998	
10.0%PVA 5% coal		-1.12267	1.56604	1	
10.0%PVA 7% coal		-0.892	1.56604	1	
12.5%PVA		9.53667(*)	1.56604	0	
12.5%PVA 3% coal		-4.202	1.56604	0.27	
12.5%PVA 5% coal		-0.71333	1.56604	1	
12.5%PVA 7% coal		-2.63267	1.56604	0.9	
15.0%PVA		6.55933(*)	1.56604	0.003	

	15.0%PVA 3% coal	0.81333	1.56604	1
	15.0%PVA 7% coal	-0.074	1.56604	1
15.0% PVA 7% coal	Control	84.09067(*)	1.56604	0
	10.0%PVA	0.41	1.56604	1
	10.0%PVA 3% coal	-1.58667	1.56604	0.998
	10.0%PVA 5% coal	-1.04867	1.56604	1
	10.0%PVA 7% coal	-0.818	1.56604	1
	12.5%PVA	9.61067(*)	1.56604	0
	12.5%PVA 3% coal	-4.128	1.56604	0.297
	12.5%PVA 5% coal	-0.63933	1.56604	1
	12.5%PVA 7% coal	-2.55867	1.56604	0.917
	15.0%PVA	6.63333(*)	1.56604	0.002
	15.0%PVA 3% coal	0.88733	1.56604	1
	15.0%PVA 5% coal	0.074	1.56604	1

* The mean difference is significant at the .05 level

Tests of Between-Subjects Effects

Dependent Variable: %TAN removal efficiency (HRT1)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	99013.135	12	8251.095	448.587	.000
Intercept	883802.626	1	883802.626	48049.640	.000
PVA	69606.991	3	23202.330	1261.440	.000
COAL	1514.915	3	504.972	27.454	.000
PVA * COAL	698.621	6	116.437	6.330	.000
Error	3347.623	182	18.394		
Total	1299339.565	195			
Corrected Total	102360.758	194			

Table B-14 Comparison of NH₃-N removal efficiencies of conditions in Group2 (HRT 2hrs.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	110922.902	12	9243.575	1419.592	0
Within Groups	1185.08	182	6.511		
Total	112107.982	194			

Multiple Comparisons (Tukey HSD)					
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.
% NH ₃ -N Removal Efficiency	Control	10.0%PVA	-88.10400(*)	0.932	0.000
		10.0%PVA 3%coal	-92.13267(*)	0.932	0.000
		10.0%PVA 5%coal	-90.08133(*)	0.932	0.000
		10.0%PVA 7%coal	-91.20000(*)	0.932	0.000
		12.5%PVA	-76.42867(*)	0.932	0.000
		12.5%PVA 3%coal	-90.50600(*)	0.932	0.000
		12.5%PVA 5%coal	-90.86133(*)	0.932	0.000
		12.5%PVA 7%coal	-91.18933(*)	0.932	0.000
		15.0%PVA	-81.77133(*)	0.932	0.000
		15.0%PVA 3% coal	-88.45400(*)	0.932	0.000
	15.0%PVA 5%coal	-88.36667(*)	0.932	0.000	
	15.0%PVA 7%coal	-88.18333(*)	0.932	0.000	
	10.0%PVA	Control	88.10400(*)	0.932	0.000
		10.0%PVA 3%coal	-4.02867(*)	0.932	0.002
		10.0%PVA 5%coal	-1.97733	0.932	0.648
		10.0%PVA 7%coal	-3.096	0.932	0.055
		12.5%PVA	11.67533(*)	0.932	0.000
		12.5%PVA 3%coal	-2.402	0.932	0.331
		12.5%PVA 5%coal	-2.75733	0.932	0.146
		12.5%PVA 7%coal	-3.08533	0.932	0.057
15.0%PVA		6.33267(*)	0.932	0.000	
15.0%PVA 3% coal		-0.35	0.932	1.000	
15.0%PVA 5%coal	-0.26267	0.932	1.000		
15.0%PVA 7%coal	-0.07933	0.932	1.000		
10.0%PVA 3%coal	Control	92.13267(*)	0.932	0.000	
	10.0%PVA	4.02867(*)	0.932	0.002	
	10.0%PVA 5%coal	2.05133	0.932	0.591	
	10.0%PVA 7%coal	0.93267	0.932	0.999	
	12.5%PVA	15.70400(*)	0.932	0.000	
	12.5%PVA 3%coal	1.62667	0.932	0.873	
	12.5%PVA 5%coal	1.27133	0.932	0.978	
	12.5%PVA 7%coal	0.94333	0.932	0.998	
	15.0%PVA	10.36133(*)	0.932	0.000	
	15.0%PVA 3% coal	3.67867(*)	0.932	0.007	
15.0%PVA 5%coal	3.76600(*)	0.932	0.005		
15.0%PVA 7%coal	3.94933(*)	0.932	0.002		
10.0%PVA 5%coal	Control	90.08133(*)	0.932	0.000	
	10.0%PVA	1.97733	0.932	0.648	
	10.0%PVA 3%coal	-2.05133	0.932	0.591	
	10.0%PVA 7%coal	-1.11867	0.932	0.993	

	12.5%PVA	13.65267(*)	0.932	0.000
	12.5%PVA 3%coal	-0.42467	0.932	1.000
	12.5%PVA 5%coal	-0.78	0.932	1.000
	12.5%PVA 7%coal	-1.108	0.932	0.993
	15.0%PVA	8.31000(*)	0.932	0.000
	15.0%PVA 3% coal	1.62733	0.932	0.873
	15.0%PVA 5%coal	1.71467	0.932	0.827
	15.0%PVA 7%coal	1.898	0.932	0.707
10.0%PVA 7%coal	Control	91.20000(*)	0.932	0.000
	10.0%PVA	3.096	0.932	0.055
	10.0%PVA 3%coal	-0.93267	0.932	0.999
	10.0%PVA 5%coal	1.11867	0.932	0.993
	12.5%PVA	14.77133(*)	0.932	0.000
	12.5%PVA 3%coal	0.694	0.932	1.000
	12.5%PVA 5%coal	0.33867	0.932	1.000
	12.5%PVA 7%coal	0.01067	0.932	1.000
	15.0%PVA	9.42867(*)	0.932	0.000
	15.0%PVA 3% coal	2.746	0.932	0.151
	15.0%PVA 5%coal	2.83333	0.932	0.119
	15.0%PVA 7%coal	3.01667	0.932	0.071
12.5%PVA	Control	76.42867(*)	0.932	0.000
	10.0%PVA	-11.67533(*)	0.932	0.000
	10.0%PVA 3%coal	-15.70400(*)	0.932	0.000
	10.0%PVA 5%coal	-13.65267(*)	0.932	0.000
	10.0%PVA 7%coal	-14.77133(*)	0.932	0.000
	12.5%PVA 3%coal	-14.07733(*)	0.932	0.000
	12.5%PVA 5%coal	-14.43267(*)	0.932	0.000
	12.5%PVA 7%coal	-14.76067(*)	0.932	0.000
	15.0%PVA	-5.34267(*)	0.932	0.000
	15.0%PVA 3% coal	-12.02533(*)	0.932	0.000
	15.0%PVA 5%coal	-11.93800(*)	0.932	0.000
	15.0%PVA 7%coal	-11.75467(*)	0.932	0.000
12.5%PVA 3%coal	Control	90.50600(*)	0.932	0.000
	10.0%PVA	2.402	0.932	0.331
	10.0%PVA 3%coal	-1.62667	0.932	0.873
	10.0%PVA 5%coal	0.42467	0.932	1.000
	10.0%PVA 7%coal	-0.694	0.932	1.000
	12.5%PVA	14.07733(*)	0.932	0.000
	12.5%PVA 5% coal	-0.35533	0.932	1.000
	12.5%PVA 7%coal	-0.68333	0.932	1.000
	15.0%PVA	8.73467(*)	0.932	0.000
	15.0%PVA 3% coal	2.052	0.932	0.591
	15.0%PVA 5%coal	2.13933	0.932	0.523
	15.0%PVA 7%coal	2.32267	0.932	0.386
12.5%PVA 5%coal	Control	90.86133(*)	0.932	0.000
	10.0%PVA	2.75733	0.932	0.146
	10.0%PVA 3%coal	-1.27133	0.932	0.978
	10.0%PVA 5%coal	0.78	0.932	1.000
	10.0%PVA 7%coal	-0.33867	0.932	1.000
	12.5%PVA	14.43267(*)	0.932	0.000
	12.5%PVA 3%coal	0.35533	0.932	1.000

	12.5%PVA 7% coal	-0.328	0.932	1.000	
	15.0%PVA	9.09000(*)	0.932	0.000	
	15.0%PVA 3% coal	2.40733	0.932	0.328	
	15.0%PVA 5% coal	2.49467	0.932	0.274	
	15.0%PVA 7% coal	2.678	0.932	0.179	
12.5%PVA 7% coal	Control	91.18933(*)	0.932	0.000	
	10.0%PVA	3.08533	0.932	0.057	
	10.0%PVA 3% coal	-0.94333	0.932	0.998	
	10.0%PVA 5% coal	1.108	0.932	0.993	
	10.0%PVA 7% coal	-0.01067	0.932	1.000	
	12.5%PVA	14.76067(*)	0.932	0.000	
	12.5%PVA 3% coal	0.68333	0.932	1.000	
	12.5%PVA 5% coal	0.328	0.932	1.000	
	15.0%PVA	9.41800(*)	0.932	0.000	
	15.0%PVA 3% coal	2.73533	0.932	0.155	
	15.0%PVA 5% coal	2.82267	0.932	0.123	
	15.0%PVA 7% coal	3.006	0.932	0.073	
	15.0%PVA	Control	81.77133(*)	0.932	0.000
		10.0%PVA	-6.33267(*)	0.932	0.000
		10.0%PVA 3% coal	-10.36133(*)	0.932	0.000
		10.0%PVA 5% coal	-8.31000(*)	0.932	0.000
		10.0%PVA 7% coal	-9.42867(*)	0.932	0.000
12.5%PVA		5.34267(*)	0.932	0.000	
12.5%PVA 3% coal		-8.73467(*)	0.932	0.000	
12.5%PVA 5% coal		-9.09000(*)	0.932	0.000	
12.5%PVA 7% coal		-9.41800(*)	0.932	0.000	
15.0%PVA 3% coal		-6.68267(*)	0.932	0.000	
15.0%PVA 5% coal		-6.59533(*)	0.932	0.000	
15.0%PVA 7% coal		-6.41200(*)	0.932	0.000	
15.0%PVA 3% coal		Control	88.45400(*)	0.932	0.000
	10.0%PVA	0.35	0.932	1.000	
	10.0%PVA 3% coal	-3.67867(*)	0.932	0.007	
	10.0%PVA 5% coal	-1.62733	0.932	0.873	
	10.0%PVA 7% coal	-2.746	0.932	0.151	
	12.5%PVA	12.02533(*)	0.932	0.000	
	12.5%PVA 3% coal	-2.052	0.932	0.591	
	12.5%PVA 5% coal	-2.40733	0.932	0.328	
	12.5%PVA 7% coal	-2.73533	0.932	0.155	
	15.0%PVA	6.68267(*)	0.932	0.000	
	15.0%PVA 5% coal	0.08733	0.932	1.000	
	15.0%PVA 7% coal	0.27067	0.932	1.000	
	15.0%PVA 5% coal	Control	88.36667(*)	0.932	0.000
10.0%PVA		0.26267	0.932	1.000	
10.0%PVA 3% coal		-3.76600(*)	0.932	0.005	
10.0%PVA 5% coal		-1.71467	0.932	0.827	
10.0%PVA 7% coal		-2.83333	0.932	0.119	
12.5%PVA		11.93800(*)	0.932	0.000	
12.5%PVA 3% coal		-2.13933	0.932	0.523	
12.5%PVA 5% coal		-2.49467	0.932	0.274	
12.5%PVA 7% coal		-2.82267	0.932	0.123	
15.0%PVA		6.59533(*)	0.932	0.000	

	15.0%PVA 3% coal	-0.08733	0.932	1.000
	15.0%PVA 7%coal	0.18333	0.932	1.000
15.0%PVA 7%coal	Control	88.18333(*)	0.932	0.000
	10.0%PVA	0.07933	0.932	1.000
	10.0%PVA 3%coal	-3.94933(*)	0.932	0.002
	10.0%PVA 5%coal	-1.898	0.932	0.707
	10.0%PVA 7%coal	-3.01667	0.932	0.071
	12.5%PVA	11.75467(*)	0.932	0.000
	12.5%PVA 3%coal	-2.32267	0.932	0.386
	12.5%PVA 5%coal	-2.678	0.932	0.179
	12.5%PVA 7%coal	-3.006	0.932	0.073
	15.0%PVA	6.41200(*)	0.932	0.000
	15.0%PVA 3% coal	-0.27067	0.932	1.000
	15.0%PVA 5%coal	-0.18333	0.932	1.000

Tests of Between-Subjects Effects

Dependent Variable: %TAN removal efficiency (HRT2)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	110922.902(a)	12	9243.575	1419.592	.000
Intercept	1016780.344	1	1016780.344	156153.181	.000
PVA	76306.198	3	25435.399	3906.270	.000
COAL	2172.173	3	724.058	111.198	.000
PVA * COAL	792.166	6	132.028	20.276	.000
Error	1185.080	182	6.511		
Total	1482566.692	195			
Corrected Total	112107.982	194			

a R Squared = .989 (Adjusted R Squared = .989)

Table B-15 Comparison of NH₃-N removal efficiencies of conditions in Group 3 (HRT 4 hrs.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	117406.012	12	9783.834	672.842	0
Within Groups	2646.473	182	14.541		
Total	120052.485	194			

Multiple Comparisons (Tukey HSD)					
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.
% NH ₃ -N Removal Efficiency	Control	10.0% PVA	-88.85067(*)	1.392	0.000
		10.0% PVA 3% coal	-93.11600(*)	1.392	0.000
		10.0% PVA 5% coal	-93.37533(*)	1.392	0.000
		10.0% PVA 7% coal	-92.70600(*)	1.392	0.000
		12.5% PVA	-86.28467(*)	1.392	0.000
		12.5% PVA 3% coal	-93.44333(*)	1.392	0.000
		12.5% PVA 5% coal	-93.14333(*)	1.392	0.000
		12.5% PVA 7% coal	-93.09533(*)	1.392	0.000
		15.0% PVA	-88.68000(*)	1.392	0.000
		15.0% PVA 3% coal	-92.83867(*)	1.392	0.000
		15.0% PVA 5% coal	-92.51733(*)	1.392	0.000
	15.0% PVA 7% coal	-92.55267(*)	1.392	0.000	
	10.0% PVA	Control	88.85067(*)	1.392	0.000
		10.0% PVA 3% coal	-4.26533	1.392	0.113
		10.0% PVA 5% coal	-4.52467	1.392	0.068
		10.0% PVA 7% coal	-3.85533	1.392	0.226
		12.5% PVA	2.566	1.392	0.825
		12.5% PVA 3% coal	-4.59267	1.392	0.059
		12.5% PVA 5% coal	-4.29267	1.392	0.107
		12.5% PVA 7% coal	-4.24467	1.392	0.117
		15.0% PVA	0.17067	1.392	1.000
15.0% PVA 3% coal		-3.988	1.392	0.183	
15.0% PVA 5% coal	-3.66667	1.392	0.298		
15.0% PVA 7% coal	-3.702	1.392	0.284		
10.0% PVA 3% coal	Control	93.11600(*)	1.392	0.000	
	10.0% PVA	4.26533	1.392	0.113	
	10.0% PVA 5% coal	-0.25933	1.392	1.000	
	10.0% PVA 7% coal	0.41	1.392	1.000	
	12.5% PVA	6.83133(*)	1.392	0.000	
	12.5% PVA 3% coal	-0.32733	1.392	1.000	
	12.5% PVA 5% coal	-0.02733	1.392	1.000	
	12.5% PVA 7% coal	0.02067	1.392	1.000	
	15.0% PVA	4.436	1.392	0.081	
	15.0% PVA 3% coal	0.27733	1.392	1.000	
	15.0% PVA 5% coal	0.59867	1.392	1.000	
15.0% PVA 7% coal	0.56333	1.392	1.000		
10.0% PVA 5% coal	Control	93.37533(*)	1.392	0.000	
	10.0% PVA	4.52467	1.392	0.068	
	10.0% PVA 3% coal	0.25933	1.392	1.000	
	10.0% PVA 7% coal	0.66933	1.392	1.000	
	12.5% PVA	7.09067(*)	1.392	0.000	

12.5%PVA 3% coal		-0.068	1.392	1.000
12.5%PVA 5% coal		0.232	1.392	1.000
12.5%PVA 7% coal		0.28	1.392	1.000
15.0%PVA		4.69533(*)	1.392	0.048
15.0%PVA 3% coal		0.53667	1.392	1.000
15.0%PVA 5% coal		0.858	1.392	1.000
15.0%PVA 7% coal		0.82267	1.392	1.000
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10.0%PVA 7% coal	Control	92.70600(*)	1.392	0.000
	10.0%PVA	3.85533	1.392	0.226
	10.0%PVA 3% coal	-0.41	1.392	1.000
	10.0%PVA 5% coal	-0.66933	1.392	1.000
	12.5%PVA	6.42133(*)	1.392	0.001
	12.5%PVA 3% coal	-0.73733	1.392	1.000
	12.5%PVA 5% coal	-0.43733	1.392	1.000
	12.5%PVA 7% coal	-0.38933	1.392	1.000
	15.0%PVA	4.026	1.392	0.172
	15.0%PVA 3% coal	-0.13267	1.392	1.000
	15.0%PVA 5% coal	0.18867	1.392	1.000
	15.0%PVA 7% coal	0.15333	1.392	1.000
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12.5%PVA	Control	86.28467(*)	1.392	0.000
	10.0%PVA	-2.566	1.392	0.825
	10.0%PVA 3% coal	-6.83133(*)	1.392	0.000
	10.0%PVA 5% coal	-7.09067(*)	1.392	0.000
	10.0%PVA 7% coal	-6.42133(*)	1.392	0.001
	12.5%PVA 3% coal	-7.15867(*)	1.392	0.000
	12.5%PVA 5% coal	-6.85867(*)	1.392	0.000
	12.5%PVA 7% coal	-6.81067(*)	1.392	0.000
	15.0%PVA	-2.39533	1.392	0.884
	15.0%PVA 3% coal	-6.55400(*)	1.392	0.000
	15.0%PVA 5% coal	-6.23267(*)	1.392	0.001
	15.0%PVA 7% coal	-6.26800(*)	1.392	0.001
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12.5%PVA 3% coal	Control	93.44333(*)	1.392	0.000
	10.0%PVA	4.59267	1.392	0.059
	10.0%PVA 3% coal	0.32733	1.392	1.000
	10.0%PVA 5% coal	0.068	1.392	1.000
	10.0%PVA 7% coal	0.73733	1.392	1.000
	12.5%PVA	7.15867(*)	1.392	0.000
	12.5%PVA 5% coal	0.3	1.392	1.000
	12.5%PVA 7% coal	0.348	1.392	1.000
	15.0%PVA	4.76333(*)	1.392	0.041
	15.0%PVA 3% coal	0.60467	1.392	1.000
	15.0%PVA 5% coal	0.926	1.392	1.000
	15.0%PVA 7% coal	0.89067	1.392	1.000
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12.5%PVA 5% coal	Control	93.14333(*)	1.392	0.000
	10.0%PVA	4.29267	1.392	0.107
	10.0%PVA 3% coal	0.02733	1.392	1.000
	10.0%PVA 5% coal	-0.232	1.392	1.000
	10.0%PVA 7% coal	0.43733	1.392	1.000
	12.5%PVA	6.85867(*)	1.392	0.000
	12.5%PVA 3% coal	-0.3	1.392	1.000
	12.5%PVA 7% coal	0.048	1.392	1.000

	15.0%PVA	4.46333	1.392	0.077
	15.0%PVA 3% coal	0.30467	1.392	1.000
	15.0%PVA 5%coal	0.626	1.392	1.000
	15.0%PVA 7%coal	0.59067	1.392	1.000
12.5%PVA 7%coal	Control	93.09533(*)	1.392	0.000
	10.0%PVA	4.24467	1.392	0.117
	10.0%PVA 3% coal	-0.02067	1.392	1.000
	10.0%PVA 5%coal	-0.28	1.392	1.000
	10.0%PVA 7%coal	0.38933	1.392	1.000
	12.5%PVA	6.81067(*)	1.392	0.000
	12.5%PVA 3%coal	-0.348	1.392	1.000
	12.5%PVA 5%coal	-0.048	1.392	1.000
	15.0%PVA	4.41533	1.392	0.085
	15.0%PVA 3% coal	0.25667	1.392	1.000
	15.0%PVA 5%coal	0.578	1.392	1.000
	15.0%PVA 7%coal	0.54267	1.392	1.000
15.0%PVA	Control	88.68000(*)	1.392	0.000
	10.0%PVA	-0.17067	1.392	1.000
	10.0%PVA 3%coal	-4.436	1.392	0.081
	10.0%PVA 5%coal	-4.69533(*)	1.392	0.048
	10.0%PVA 7%coal	-4.026	1.392	0.172
	12.5%PVA	2.39533	1.392	0.884
	12.5%PVA 3% coal	-4.76333(*)	1.392	0.041
	12.5%PVA 5%coal	-4.46333	1.392	0.077
	12.5%PVA 7%coal	-4.41533	1.392	0.085
	15.0%PVA 3% coal	-4.15867	1.392	0.137
	15.0%PVA 5%coal	-3.83733	1.392	0.233
	15.0%PVA 7%coal	-3.87267	1.392	0.220
15.0%PVA 3% coal	Control	92.83867(*)	1.392	0.000
	10.0%PVA	3.988	1.392	0.183
	10.0%PVA 3% coal	-0.27733	1.392	1.000
	10.0%PVA 5%coal	-0.53667	1.392	1.000
	10.0%PVA 7%coal	0.13267	1.392	1.000
	12.5%PVA	6.55400(*)	1.392	0.000
	12.5%PVA 3%coal	-0.60467	1.392	1.000
	12.5%PVA 5%coal	-0.30467	1.392	1.000
	12.5%PVA 7%coal	-0.25667	1.392	1.000
	15.0%PVA	4.15867	1.392	0.137
	15.0%PVA 5% coal	0.32133	1.392	1.000
	15.0%PVA 7%coal	0.286	1.392	1.000
15.0%PVA 5%coal	Control	92.51733(*)	1.392	0.000
	10.0%PVA	3.66667	1.392	0.298
	10.0%PVA 3% coal	-0.59867	1.392	1.000
	10.0%PVA 5% coal	-0.858	1.392	1.000
	10.0%PVA 7% coal	-0.18867	1.392	1.000
	12.5%PVA	6.23267(*)	1.392	0.001
	12.5%PVA 3% coal	-0.926	1.392	1.000
	12.5%PVA 5% coal	-0.626	1.392	1.000
	12.5%PVA 7% coal	-0.578	1.392	1.000
	15.0%PVA	3.83733	1.392	0.233
	15.0%PVA 3% coal	-0.32133	1.392	1.000

	15.0%PVA 7% coal	-0.03533	1.392	1.000
15.0%PVA 7% coal	Control	92.55267(*)	1.392	0.000
	10.0%PVA	3.702	1.392	0.284
	10.0%PVA 3% coal	-0.56333	1.392	1.000
	10.0%PVA 5% coal	-0.82267	1.392	1.000
	10.0%PVA 7% coal	-0.15333	1.392	1.000
	12.5%PVA	6.26800(*)	1.392	0.001
	12.5%PVA 3% coal	-0.89067	1.392	1.000
	12.5%PVA 5% coal	-0.59067	1.392	1.000
	12.5%PVA 7% coal	-0.54267	1.392	1.000
	15.0%PVA	3.87267	1.392	0.220
	15.0%PVA 3% coal	-0.286	1.392	1.000
	15.0%PVA 5% coal	0.03533	1.392	1.000

Tests of Between-Subjects Effects

Dependent Variable: %TAN removal efficiency (HRT4)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	117406.012(a)	12	9783.834	672.842	.000
Intercept	1083729.669	1	1083729.669	74528.938	.000
PVA	87006.723	3	29002.241	1994.507	.000
COAL	859.434	3	286.478	19.701	.000
PVA * COAL	64.201	6	10.700	.736	.621
Error	2646.473	182	14.541		
Total	1592699.860	195			
Corrected Total	120052.485	194			

a R Squared = .978 (Adjusted R Squared = .977)

Table B-16 Comparison of COD removal efficiencies of conditions in Group 1 (HRT 1 hr.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	42.109	11	3.828	1.045	0.415
Within Groups	307.614	84	3.662		
Total	349.723	95			

Multiple Comparisons (Tukey HSD)							
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.		
% COD Removal Efficiency	Control	10.0%PVA	-0.9225	0.957	0.998		
		10.0%PVA 3%coal	1.0975	0.957	0.991		
		10.0%PVA 5%coal	0.51	0.957	1.000		
		10.0%PVA 7%coal	-0.2225	0.957	1.000		
		12.5%PVA	0.88875	0.957	0.999		
		12.5%PVA 3%coal	-0.015	0.957	1.000		
		12.5%PVA 5%coal	-0.22875	0.957	1.000		
		12.5%PVA 7%coal	-0.795	0.957	1.000		
		15.0%PVA	0.17375	0.957	1.000		
		15.0%PVA 3% coal	-0.795	0.957	1.000		
		15.0%PVA 5%coal	0.88875	0.957	0.999		
		15.0%PVA 7%coal	0.9225	0.957	0.998		
		10.0%PVA	Control	10.0%PVA	2.02	0.957	0.616
				10.0%PVA 3%coal	1.4325	0.957	0.937
				10.0%PVA 5%coal	0.7	0.957	1.000
10.0%PVA 7%coal	1.81125			0.957	0.760		
12.5%PVA	0.9075			0.957	0.998		
12.5%PVA 3%coal	0.69375			0.957	1.000		
12.5%PVA 5%coal	0.1275			0.957	1.000		
12.5%PVA 7%coal	1.09625			0.957	0.991		
15.0%PVA	0.1275			0.957	1.000		
15.0%PVA 3% coal	1.81125			0.957	0.760		
15.0%PVA 5%coal	-1.0975			0.957	0.991		
15.0%PVA 7%coal	-2.02			0.957	0.616		
10.0%PVA 3%coal	Control			10.0%PVA	-0.5875	0.957	1.000
				10.0%PVA 3%coal	-1.32	0.957	0.964
				10.0%PVA 5%coal	-0.20875	0.957	1.000
		10.0%PVA 7%coal	-1.1125	0.957	0.990		
		12.5%PVA	-1.32625	0.957	0.963		
		12.5%PVA 3%coal	-1.8925	0.957	0.707		
		12.5%PVA 5%coal	-0.92375	0.957	0.998		
		12.5%PVA 7%coal	-1.8925	0.957	0.707		
		15.0%PVA	-0.20875	0.957	1.000		
		15.0%PVA 3% coal	-0.51	0.957	1.000		
		15.0%PVA 5%coal	-1.4325	0.957	0.937		
		15.0%PVA 7%coal	0.5875	0.957	1.000		
		10.0%PVA 5%coal	Control	10.0%PVA	-0.7325	0.957	1.000
				10.0%PVA 3%coal	0.37875	0.957	1.000
				10.0%PVA 5%coal	-0.525	0.957	1.000
10.0%PVA 7%coal	-0.73875			0.957	1.000		

	12.5%PVA	-1.305	0.957	0.967
	12.5%PVA 3%coal	-0.33625	0.957	1.000
	12.5%PVA 5%coal	-1.305	0.957	0.967
	12.5%PVA 7%coal	0.37875	0.957	1.000
	15.0%PVA	0.2225	0.957	1.000
	15.0%PVA 3% coal	-0.7	0.957	1.000
	15.0%PVA 5%coal	1.32	0.957	0.964
	15.0%PVA 7%coal	0.7325	0.957	1.000
10.0%PVA 7%coal	Control	1.11125	0.957	0.990
	10.0%PVA	0.2075	0.957	1.000
	10.0%PVA 3%coal	-0.00625	0.957	1.000
	10.0%PVA 5%coal	-0.5725	0.957	1.000
	12.5%PVA	0.39625	0.957	1.000
	12.5%PVA 3%coal	-0.5725	0.957	1.000
	12.5%PVA 5%coal	1.11125	0.957	0.990
	12.5%PVA 7%coal	-0.88875	0.957	0.999
	15.0%PVA	-1.81125	0.957	0.760
	15.0%PVA 3% coal	0.20875	0.957	1.000
	15.0%PVA 5%coal	-0.37875	0.957	1.000
	15.0%PVA 7%coal	-1.11125	0.957	0.990
12.5%PVA	Control	-0.90375	0.957	0.998
	10.0%PVA	-1.1175	0.957	0.990
	10.0%PVA 3%coal	-1.68375	0.957	0.834
	10.0%PVA 5%coal	-0.715	0.957	1.000
	10.0%PVA 7%coal	-1.68375	0.957	0.834
	12.5%PVA 3%coal	0	0.957	1.000
	12.5%PVA 5%coal	0.015	0.957	1.000
	12.5%PVA 7%coal	-0.9075	0.957	0.998
	15.0%PVA	1.1125	0.957	0.990
	15.0%PVA 3% coal	0.525	0.957	1.000
	15.0%PVA 5%coal	-0.2075	0.957	1.000
	15.0%PVA 7%coal	0.90375	0.957	0.998
12.5%PVA 3%coal	Control	-0.21375	0.957	1.000
	10.0%PVA	-0.78	0.957	1.000
	10.0%PVA 3%coal	0.18875	0.957	1.000
	10.0%PVA 5%coal	-0.78	0.957	1.000
	10.0%PVA 7%coal	0.90375	0.957	0.998
	12.5%PVA	0.22875	0.957	1.000
	12.5%PVA 5% coal	-0.69375	0.957	1.000
	12.5%PVA 7%coal	1.32625	0.957	0.963
	15.0%PVA	0.73875	0.957	1.000
	15.0%PVA 3% coal	0.00625	0.957	1.000
	15.0%PVA 5%coal	1.1175	0.957	0.990
	15.0%PVA 7%coal	0.21375	0.957	1.000
12.5%PVA 5%coal	Control	-0.56625	0.957	1.000
	10.0%PVA	0.4025	0.957	1.000
	10.0%PVA 3%coal	-0.56625	0.957	1.000
	10.0%PVA 5%coal	1.1175	0.957	0.990
	10.0%PVA 7%coal	0.795	0.957	1.000
	12.5%PVA	-0.1275	0.957	1.000
	12.5%PVA 3%coal	1.8925	0.957	0.707

	12.5%PVA 7% coal	1.305	0.957	0.967	
	15.0%PVA	0.5725	0.957	1.000	
	15.0%PVA 3% coal	1.68375	0.957	0.834	
	15.0%PVA 5% coal	0.78	0.957	1.000	
	15.0%PVA 7% coal	0.56625	0.957	1.000	
12.5%PVA 7% coal	Control	0.96875	0.957	0.997	
	10.0%PVA	0	0.957	1.000	
	10.0%PVA 3% coal	1.68375	0.957	0.834	
	10.0%PVA 5% coal	-0.17375	0.957	1.000	
	10.0%PVA 7% coal	-1.09625	0.957	0.991	
	12.5%PVA	0.92375	0.957	0.998	
	12.5%PVA 3% coal	0.33625	0.957	1.000	
	12.5%PVA 5% coal	-0.39625	0.957	1.000	
	15.0%PVA	0.715	0.957	1.000	
	15.0%PVA 3% coal	-0.18875	0.957	1.000	
	15.0%PVA 5% coal	-0.4025	0.957	1.000	
	15.0%PVA 7% coal	-0.96875	0.957	0.997	
	15.0%PVA	Control	-0.96875	0.957	0.997
		10.0%PVA	0.715	0.957	1.000
		10.0%PVA 3% coal	0.795	0.957	1.000
10.0%PVA 5% coal		-0.1275	0.957	1.000	
10.0%PVA 7% coal		1.8925	0.957	0.707	
12.5%PVA		1.305	0.957	0.967	
12.5%PVA 3% coal		0.5725	0.957	1.000	
12.5%PVA 5% coal		1.68375	0.957	0.834	
12.5%PVA 7% coal		0.78	0.957	1.000	
15.0%PVA 3% coal		0.56625	0.957	1.000	
15.0%PVA 5% coal		0	0.957	1.000	
15.0%PVA 7% coal		0.96875	0.957	0.997	
15.0%PVA 3% coal		Control	1.68375	0.957	0.834
		10.0%PVA	-0.88875	0.957	0.999
		10.0%PVA 3% coal	-1.81125	0.957	0.760
	10.0%PVA 5% coal	0.20875	0.957	1.000	
	10.0%PVA 7% coal	-0.37875	0.957	1.000	
	12.5%PVA	-1.11125	0.957	0.990	
	12.5%PVA 3% coal	0	0.957	1.000	
	12.5%PVA 5% coal	-0.90375	0.957	0.998	
	12.5%PVA 7% coal	-1.1175	0.957	0.990	
	15.0%PVA	-1.68375	0.957	0.834	
	15.0%PVA 5% coal	-0.715	0.957	1.000	
	15.0%PVA 7% coal	-1.68375	0.957	0.834	
	15.0%PVA 5% coal	Control	92.51733(*)	1.392	0.000
		10.0%PVA	3.66667	1.392	0.298
		10.0%PVA 3% coal	-0.59867	1.392	1.000
10.0%PVA 5% coal		-0.858	1.392	1.000	
10.0%PVA 7% coal		-0.18867	1.392	1.000	
12.5%PVA		6.23267(*)	1.392	0.001	
12.5%PVA 3% coal		-0.926	1.392	1.000	
12.5%PVA 5% coal		-0.626	1.392	1.000	
12.5%PVA 7% coal		-0.578	1.392	1.000	
15.0%PVA		3.83733	1.392	0.233	

	15.0%PVA 3% coal	-0.32133	1.392	1.000
	15.0%PVA 7%coal	-0.03533	1.392	1.000
15.0%PVA 7%coal	Control	92.55267(*)	1.392	0.000
	10.0%PVA	3.702	1.392	0.284
	10.0%PVA 3%coal	-0.56333	1.392	1.000
	10.0%PVA 5%coal	-0.82267	1.392	1.000
	10.0%PVA 7%coal	-0.15333	1.392	1.000
	12.5%PVA	6.26800(*)	1.392	0.001
	12.5%PVA 3%coal	-0.89067	1.392	1.000
	12.5%PVA 5%coal	-0.59067	1.392	1.000
	12.5%PVA 7%coal	-0.54267	1.392	1.000
	15.0%PVA	3.87267	1.392	0.220
	15.0%PVA 3% coal	-0.286	1.392	1.000
	15.0%PVA 5%coal	0.03533	1.392	1.000

Tests of Between-Subjects Effects

Dependent Variable: %COD removal efficiency (HRT1)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	42.109(a)	11	3.828	1.045	.415
Intercept	617.120	1	617.120	168.517	.000
PVA	1.628	2	.814	.222	.801
COAL	6.460	3	2.153	.588	.625
PVA * COAL	34.022	6	5.670	1.548	.173
Error	307.614	84	3.662		
Total	966.844	96			
Corrected Total	349.723	95			

a. R Squared = .120 (Adjusted R Squared = .005)

Table B-17 Comparison of COD removal efficiencies of conditions in Group 2 (HRT 2 hrs.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	23.937	11	2.176	0.566	0.851
Within Groups	322.743	84	3.842		
Total	346.679	95			

Multiple Comparisons (Tukey HSD)						
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	
% NH ₃ -N Removal Efficiency	Control	10.0%PVA	0.18167	0.980	1.000	
		10.0%PVA 3% coal	-0.66553	0.980	1.000	
		10.0%PVA 5% coal	0.6548	0.980	1.000	
		10.0%PVA 7% coal	0	0.980	1.000	
		12.5%PVA	-0.17853	0.980	1.000	
		12.5%PVA 3% coal	-0.06621	0.980	1.000	
		12.5%PVA 5% coal	-1.25042	0.980	0.980	
		12.5%PVA 7% coal	0.18167	0.980	1.000	
		15.0%PVA	-0.06621	0.980	1.000	
		15.0%PVA 3% coal	0.18167	0.980	1.000	
		15.0%PVA 5% coal	0.6548	0.980	1.000	
		15.0%PVA 7% coal	-0.18167	0.980	1.000	
		10.0%PVA	Control	-0.8472	0.980	0.999
			10.0%PVA 3% coal	0.47313	0.980	1.000
			10.0%PVA 5% coal	-0.18167	0.980	1.000
	10.0%PVA 7% coal		-0.3602	0.980	1.000	
	12.5%PVA		-0.24788	0.980	1.000	
	12.5%PVA 3% coal		-1.43209	0.980	0.947	
	12.5%PVA 5% coal		0	0.980	1.000	
	12.5%PVA 7% coal		-0.24788	0.980	1.000	
	15.0%PVA		0	0.980	1.000	
	15.0%PVA 3% coal		0.47313	0.980	1.000	
	15.0%PVA 5% coal		0.66553	0.980	1.000	
	15.0%PVA 7% coal		0.8472	0.980	0.999	
	10.0%PVA 3% coal		Control	1.32033	0.980	0.970
			10.0%PVA	0.66553	0.980	1.000
			10.0%PVA 5% coal	0.48699	0.980	1.000
		10.0%PVA 7% coal	0.59932	0.980	1.000	
		12.5%PVA	-0.58489	0.980	1.000	
		12.5%PVA 3% coal	0.8472	0.980	0.999	
		12.5%PVA 5% coal	0.59932	0.980	1.000	
		12.5%PVA 7% coal	0.8472	0.980	0.999	
		15.0%PVA	1.32033	0.980	0.970	
15.0%PVA 3% coal		-0.6548	0.980	1.000		
15.0%PVA 5% coal		-0.47313	0.980	1.000		
15.0%PVA 7% coal		-1.32033	0.980	0.970		
10.0%PVA 5% coal		Control	-0.6548	0.980	1.000	
		10.0%PVA	-0.83333	0.980	0.999	
		10.0%PVA 3% coal	-0.72101	0.980	1.000	
	10.0%PVA 7% coal	-1.90522	0.980	0.728		

	12.5%PVA	-0.47313	0.980	1.000
	12.5%PVA 3% coal	-0.72101	0.980	1.000
	12.5%PVA 5% coal	-0.47313	0.980	1.000
	12.5%PVA 7% coal	0	0.980	1.000
	15.0%PVA	0	0.980	1.000
	15.0%PVA 3% coal	0.18167	0.980	1.000
	15.0%PVA 5% coal	-0.66553	0.980	1.000
	15.0%PVA 7% coal	0.6548	0.980	1.000
10.0%PVA 7% coal	Control	-0.17853	0.980	1.000
	10.0%PVA	-0.06621	0.980	1.000
	10.0%PVA 3% coal	-1.25042	0.980	0.980
	10.0%PVA 5% coal	0.18167	0.980	1.000
	12.5%PVA	-0.06621	0.980	1.000
	12.5%PVA 3% coal	0.18167	0.980	1.000
	12.5%PVA 5% coal	0.6548	0.980	1.000
	12.5%PVA 7% coal	0.17853	0.980	1.000
	15.0%PVA	0.3602	0.980	1.000
	15.0%PVA 3% coal	-0.48699	0.980	1.000
	15.0%PVA 5% coal	0.83333	0.980	0.999
	15.0%PVA 7% coal	0.17853	0.980	1.000
12.5%PVA	Control	0.11233	0.980	1.000
	10.0%PVA	-1.07189	0.980	0.994
	10.0%PVA 3% coal	0.3602	0.980	1.000
	10.0%PVA 5% coal	0.11233	0.980	1.000
	10.0%PVA 7% coal	0.3602	0.980	1.000
	12.5%PVA 3% coal	0.83333	0.980	0.999
	12.5%PVA 5% coal	0.06621	0.980	1.000
	12.5%PVA 7% coal	0.24788	0.980	1.000
	15.0%PVA	-0.59932	0.980	1.000
	15.0%PVA 3% coal	0.72101	0.980	1.000
	15.0%PVA 5% coal	0.06621	0.980	1.000
	15.0%PVA 7% coal	-0.11233	0.980	1.000
12.5%PVA 3% coal	Control	-1.18421	0.980	0.987
	10.0%PVA	0.24788	0.980	1.000
	10.0%PVA 3% coal	0	0.980	1.000
	10.0%PVA 5% coal	0.24788	0.980	1.000
	10.0%PVA 7% coal	0.72101	0.980	1.000
	12.5%PVA	1.25042	0.980	0.980
	12.5%PVA 5% coal	1.43209	0.980	0.947
	12.5%PVA 7% coal	0.58489	0.980	1.000
	15.0%PVA	1.90522	0.980	0.728
	15.0%PVA 3% coal	1.25042	0.980	0.980
	15.0%PVA 5% coal	1.07189	0.980	0.994
	15.0%PVA 7% coal	1.18421	0.980	0.987
12.5%PVA 5% coal	Control	1.43209	0.980	0.947
	10.0%PVA	1.18421	0.980	0.987
	10.0%PVA 3% coal	1.43209	0.980	0.947
	10.0%PVA 5% coal	1.90522	0.980	0.728
	10.0%PVA 7% coal	-0.18167	0.980	1.000
	12.5%PVA	0	0.980	1.000
	12.5%PVA 3% coal	-0.8472	0.980	0.999

	12.5%PVA 7% coal	0.47313	0.980	1.000	
	15.0%PVA	-0.18167	0.980	1.000	
	15.0%PVA 3% coal	-0.3602	0.980	1.000	
	15.0%PVA 5% coal	-0.24788	0.980	1.000	
	15.0%PVA 7% coal	-1.43209	0.980	0.947	
12.5%PVA 7% coal	Control	-0.24788	0.980	1.000	
	10.0%PVA	0	0.980	1.000	
	10.0%PVA 3% coal	0.47313	0.980	1.000	
	10.0%PVA 5% coal	0.06621	0.980	1.000	
	10.0%PVA 7% coal	0.24788	0.980	1.000	
	12.5%PVA	-0.59932	0.980	1.000	
	12.5%PVA 3% coal	0.72101	0.980	1.000	
	12.5%PVA 5% coal	0.06621	0.980	1.000	
	15.0%PVA	-0.11233	0.980	1.000	
	15.0%PVA 3% coal	0	0.980	1.000	
	15.0%PVA 5% coal	-1.18421	0.980	0.987	
	15.0%PVA 7% coal	0.24788	0.980	1.000	
	15.0%PVA	Control	0.24788	0.980	1.000
		10.0%PVA	0.72101	0.980	1.000
		10.0%PVA 3% coal	-0.18167	0.980	1.000
10.0%PVA 5% coal		0	0.980	1.000	
10.0%PVA 7% coal		-0.8472	0.980	0.999	
12.5%PVA		0.47313	0.980	1.000	
12.5%PVA 3% coal		-0.18167	0.980	1.000	
12.5%PVA 5% coal		-0.3602	0.980	1.000	
12.5%PVA 7% coal		-0.24788	0.980	1.000	
15.0%PVA 3% coal		-1.43209	0.980	0.947	
15.0%PVA 5% coal		0	0.980	1.000	
15.0%PVA 7% coal		-0.24788	0.980	1.000	
15.0%PVA 3% coal		Control	0.47313	0.980	1.000
		10.0%PVA	-0.6548	0.980	1.000
		10.0%PVA 3% coal	-0.47313	0.980	1.000
	10.0%PVA 5% coal	-1.32033	0.980	0.970	
	10.0%PVA 7% coal	0	0.980	1.000	
	12.5%PVA	-0.6548	0.980	1.000	
	12.5%PVA 3% coal	-0.83333	0.980	0.999	
	12.5%PVA 5% coal	-0.72101	0.980	1.000	
	12.5%PVA 7% coal	-1.90522	0.980	0.728	
	15.0%PVA	-0.47313	0.980	1.000	
	15.0%PVA 5% coal	-0.72101	0.980	1.000	
	15.0%PVA 7% coal	-0.47313	0.980	1.000	
	15.0%PVA 5% coal	Control	92.51733(*)	1.392	0.000
		10.0%PVA	3.66667	1.392	0.298
		10.0%PVA 3% coal	-0.59867	1.392	1.000
10.0%PVA 5% coal		-0.858	1.392	1.000	
10.0%PVA 7% coal		-0.18867	1.392	1.000	
12.5%PVA		6.23267(*)	1.392	0.001	
12.5%PVA 3% coal		-0.926	1.392	1.000	
12.5%PVA 5% coal		-0.626	1.392	1.000	
12.5%PVA 7% coal		-0.578	1.392	1.000	
15.0%PVA		3.83733	1.392	0.233	

	15.0%PVA 3% coal	-0.32133	1.392	1.000
	15.0%PVA 7% coal	-0.03533	1.392	1.000
15.0%PVA 7% coal	Control	92.55267(*)	1.392	0.000
	10.0%PVA	3.702	1.392	0.284
	10.0%PVA 3% coal	-0.56333	1.392	1.000
	10.0%PVA 5% coal	-0.82267	1.392	1.000
	10.0%PVA 7% coal	-0.15333	1.392	1.000
	12.5%PVA	6.26800(*)	1.392	0.001
	12.5%PVA 3% coal	-0.89067	1.392	1.000
	12.5%PVA 5% coal	-0.59067	1.392	1.000
	12.5%PVA 7% coal	-0.54267	1.392	1.000
	15.0%PVA	3.87267	1.392	0.220
	15.0%PVA 3% coal	-0.286	1.392	1.000
	15.0%PVA 5% coal	0.03533	1.392	1.000

Tests of Between-Subjects Effects

Dependent Variable: %COD removal efficiency (HRT2)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	23.937(a)	11	2.176	.566	.851
Intercept	321.514	1	321.514	83.680	.000
PVA	6.249	2	3.125	.813	.447
COAL	.822	3	.274	.071	.975
PVA * COAL	16.865	6	2.811	.732	.625
Error	322.743	84	3.842		
Total	668.193	96			
Corrected Total	346.679	95			

a R Squared = .069 (Adjusted R Squared = -.053)

Table B-18 Comparison of COD removal efficiencies of conditions in Group 3 (HRT 4 hrs.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	98.892	11	8.99	1.494	0.149
Within Groups	505.636	84	6.019		
Total	604.528	95			

Multiple Comparisons (Tukey HSD)						
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	
% NH ₃ -N Removal Efficiency	Control	10.0%PVA	-2.29217	1.227	0.775	
		10.0%PVA 3% coal	0.11149	1.227	1.000	
		10.0%PVA 5% coal	0.17312	1.227	1.000	
		10.0%PVA 7% coal	0	1.227	1.000	
		12.5%PVA	0.17312	1.227	1.000	
		12.5%PVA 3% coal	-1.11312	1.227	0.999	
		12.5%PVA 5% coal	0	1.227	1.000	
		12.5%PVA 7% coal	-2.29217	1.227	0.775	
		15.0%PVA	-1.11312	1.227	0.999	
		15.0%PVA 3% coal	-2.29217	1.227	0.775	
		15.0%PVA 5% coal	0.17312	1.227	1.000	
		15.0%PVA 7% coal	2.29217	1.227	0.775	
		10.0%PVA	Control	2.40366	1.227	0.719
			10.0%PVA 3% coal	2.4653	1.227	0.686
			10.0%PVA 5% coal	2.29217	1.227	0.775
	10.0%PVA 7% coal		2.4653	1.227	0.686	
	12.5%PVA		1.17905	1.227	0.998	
	12.5%PVA 3% coal		2.29217	1.227	0.775	
	12.5%PVA 5% coal		0	1.227	1.000	
	12.5%PVA 7% coal		1.17905	1.227	0.998	
	15.0%PVA		0	1.227	1.000	
15.0%PVA 3% coal	2.4653		1.227	0.686		
10.0%PVA 3% coal	Control	0.06163	1.227	1.000		
	10.0%PVA	-0.11149	1.227	1.000		
	10.0%PVA 5% coal	0.06163	1.227	1.000		
	10.0%PVA 7% coal	-1.22461	1.227	0.997		
	12.5%PVA	-0.11149	1.227	1.000		
	12.5%PVA 3% coal	-2.40366	1.227	0.719		
	12.5%PVA 5% coal	-1.22461	1.227	0.997		
	12.5%PVA 7% coal	-2.40366	1.227	0.719		
	15.0%PVA	0.06163	1.227	1.000		
	15.0%PVA 3% coal	-0.17312	1.227	1.000		
	15.0%PVA 5% coal	-2.4653	1.227	0.686		
	15.0%PVA 7% coal	-0.06163	1.227	1.000		
	10.0%PVA 5% coal	Control	-0.17312	1.227	1.000	
		10.0%PVA	0	1.227	1.000	
		10.0%PVA 3% coal	-1.28624	1.227	0.996	
10.0%PVA 7% coal		-0.17312	1.227	1.000		

	12.5%PVA	-2.4653	1.227	0.686
	12.5%PVA 3% coal	-1.28624	1.227	0.996
	12.5%PVA 5% coal	-2.4653	1.227	0.686
	12.5%PVA 7% coal	0	1.227	1.000
	15.0%PVA	0	1.227	1.000
	15.0%PVA 3% coal	-2.29217	1.227	0.775
	15.0%PVA 5% coal	0.11149	1.227	1.000
	15.0%PVA 7% coal	0.17312	1.227	1.000
10.0%PVA 7% coal	Control	0.17312	1.227	1.000
	10.0%PVA	-1.11312	1.227	0.999
	10.0%PVA 3% coal	0	1.227	1.000
	10.0%PVA 5% coal	-2.29217	1.227	0.775
	12.5%PVA	-1.11312	1.227	0.999
	12.5%PVA 3% coal	-2.29217	1.227	0.775
	12.5%PVA 5% coal	0.17312	1.227	1.000
	12.5%PVA 7% coal	-0.17312	1.227	1.000
	15.0%PVA	-2.4653	1.227	0.686
	15.0%PVA 3% coal	-0.06163	1.227	1.000
	15.0%PVA 5% coal	0	1.227	1.000
	15.0%PVA 7% coal	-0.17312	1.227	1.000
12.5%PVA	Control	-1.28624	1.227	0.996
	10.0%PVA	-0.17312	1.227	1.000
	10.0%PVA 3% coal	-2.4653	1.227	0.686
	10.0%PVA 5% coal	-1.28624	1.227	0.996
	10.0%PVA 7% coal	-2.4653	1.227	0.686
	12.5%PVA 3% coal	0	1.227	1.000
	12.5%PVA 5% coal	1.11312	1.227	0.999
	12.5%PVA 7% coal	-1.17905	1.227	0.998
	15.0%PVA	1.22461	1.227	0.997
	15.0%PVA 3% coal	1.28624	1.227	0.996
	15.0%PVA 5% coal	1.11312	1.227	0.999
	15.0%PVA 7% coal	1.28624	1.227	0.996
12.5%PVA 3% coal	Control	1.11312	1.227	0.999
	10.0%PVA	-1.17905	1.227	0.998
	10.0%PVA 3% coal	0	1.227	1.000
	10.0%PVA 5% coal	-1.17905	1.227	0.998
	10.0%PVA 7% coal	1.28624	1.227	0.996
	12.5%PVA	0	1.227	1.000
	12.5%PVA 5% coal	-2.29217	1.227	0.775
	12.5%PVA 7% coal	0.11149	1.227	1.000
	15.0%PVA	0.17312	1.227	1.000
	15.0%PVA 3% coal	0	1.227	1.000
	15.0%PVA 5% coal	0.17312	1.227	1.000
	15.0%PVA 7% coal	-1.11312	1.227	0.999
12.5%PVA 5% coal	Control	-2.29217	1.227	0.775
	10.0%PVA	-1.11312	1.227	0.999
	10.0%PVA 3% coal	-2.29217	1.227	0.775
	10.0%PVA 5% coal	0.17312	1.227	1.000
	10.0%PVA 7% coal	2.29217	1.227	0.775
	12.5%PVA	0	1.227	1.000
	12.5%PVA 3% coal	2.40366	1.227	0.719

	12.5%PVA 7% coal	2.4653	1.227	0.686
	15.0%PVA	2.29217	1.227	0.775
	15.0%PVA 3% coal	2.4653	1.227	0.686
	15.0%PVA 5% coal	1.17905	1.227	0.998
	15.0%PVA 7% coal	2.29217	1.227	0.775
12.5%PVA 7% coal	Control	1.17905	1.227	0.998
	10.0%PVA	0	1.227	1.000
	10.0%PVA 3% coal	2.4653	1.227	0.686
	10.0%PVA 5% coal	1.11312	1.227	0.999
	10.0%PVA 7% coal	-1.17905	1.227	0.998
	12.5%PVA	1.22461	1.227	0.997
	12.5%PVA 3% coal	1.28624	1.227	0.996
	12.5%PVA 5% coal	1.11312	1.227	0.999
	15.0%PVA	1.28624	1.227	0.996
	15.0%PVA 3% coal	0	1.227	1.000
	15.0%PVA 5% coal	1.11312	1.227	0.999
	15.0%PVA 7% coal	-1.17905	1.227	0.998
15.0%PVA	Control	-1.17905	1.227	0.998
	10.0%PVA	1.28624	1.227	0.996
	10.0%PVA 3% coal	2.29217	1.227	0.775
	10.0%PVA 5% coal	0	1.227	1.000
	10.0%PVA 7% coal	2.40366	1.227	0.719
	12.5%PVA	2.4653	1.227	0.686
	12.5%PVA 3% coal	2.29217	1.227	0.775
	12.5%PVA 5% coal	2.4653	1.227	0.686
	12.5%PVA 7% coal	1.17905	1.227	0.998
	15.0%PVA 3% coal	2.29217	1.227	0.775
	15.0%PVA 5% coal	0	1.227	1.000
	15.0%PVA 7% coal	1.17905	1.227	0.998
15.0%PVA 3% coal	Control	2.4653	1.227	0.686
	10.0%PVA	-0.17312	1.227	1.000
	10.0%PVA 3% coal	-2.4653	1.227	0.686
	10.0%PVA 5% coal	-0.06163	1.227	1.000
	10.0%PVA 7% coal	0	1.227	1.000
	12.5%PVA	-0.17312	1.227	1.000
	12.5%PVA 3% coal	0	1.227	1.000
	12.5%PVA 5% coal	-1.28624	1.227	0.996
	12.5%PVA 7% coal	-0.17312	1.227	1.000
	15.0%PVA	-2.4653	1.227	0.686
	15.0%PVA 5% coal	-1.28624	1.227	0.996
	15.0%PVA 7% coal	-2.4653	1.227	0.686
15.0%PVA 5% coal	Control	92.51733(*)	1.392	0.000
	10.0%PVA	3.66667	1.392	0.298
	10.0%PVA 3% coal	-0.59867	1.392	1.000
	10.0%PVA 5% coal	-0.858	1.392	1.000
	10.0%PVA 7% coal	-0.18867	1.392	1.000
	12.5%PVA	6.23267(*)	1.392	0.001
	12.5%PVA 3% coal	-0.926	1.392	1.000
	12.5%PVA 5% coal	-0.626	1.392	1.000
	12.5%PVA 7% coal	-0.578	1.392	1.000
	15.0%PVA	3.83733	1.392	0.233

	15.0%PVA 3% coal	-0.32133	1.392	1.000
	15.0%PVA 7% coal	-0.03533	1.392	1.000
15.0%PVA 7% coal	Control	92.55267(*)	1.392	0.000
	10.0%PVA	3.702	1.392	0.284
	10.0%PVA 3% coal	-0.56333	1.392	1.000
	10.0%PVA 5% coal	-0.82267	1.392	1.000
	10.0%PVA 7% coal	-0.15333	1.392	1.000
	12.5%PVA	6.26800(*)	1.392	0.001
	12.5%PVA 3% coal	-0.89067	1.392	1.000
	12.5%PVA 5% coal	-0.59067	1.392	1.000
	12.5%PVA 7% coal	-0.54267	1.392	1.000
	15.0%PVA	3.87267	1.392	0.220
	15.0%PVA 3% coal	-0.286	1.392	1.000
	15.0%PVA 5% coal	0.03533	1.392	1.000

Tests of Between-Subjects Effects

Dependent Variable: %COD removal efficiency (HRT4)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	98.892(a)	11	8.990	1.494	.149
Intercept	536.985	1	536.985	89.208	.000
PVA	23.016	2	11.508	1.912	.154
COAL	23.271	3	7.757	1.289	.284
PVA * COAL	52.605	6	8.767	1.457	.203
Error	505.636	84	6.019		
Total	1141.513	96			
Corrected Total	604.528	95			

a R Squared = .164 (Adjusted R Squared = .054)

Table B-19 Comparison of NO₂-N removal efficiency of conditions in Group 1 (HRT 1 hrs.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	566802.913	12	47233.576	6.084	0
Within Groups	1412951.067	182	7763.467		
Total	1979753.979	194			

Multiple Comparisons (Tukey HSD)						
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	
% NH ₃ -N Removal Efficiency	Control	10.0%PVA	-22.06667	32.173	1.000	
		10.0%PVA 3% coal	-22.06667	32.173	1.000	
		10.0%PVA 5% coal	-21.33333	32.173	1.000	
		10.0%PVA 7% coal	-26.2	32.173	1.000	
		12.5%PVA	-21.33333	32.173	1.000	
		12.5%PVA 3% coal	-60.33333	32.173	0.807	
		12.5%PVA 5% coal	-35.33333	32.173	0.997	
		12.5%PVA 7% coal	-62.33333	32.173	0.771	
		15.0%PVA	-26.2	32.173	1.000	
		15.0%PVA 3% coal	104.13333	32.173	0.071	
		15.0%PVA 5% coal	105.8	32.173	0.061	
		15.0%PVA 7% coal	61.4	32.173	0.788	
		10.0%PVA	Control	22.06667	32.173	1.000
			10.0%PVA 3% coal	0	32.173	1.000
			10.0%PVA 5% coal	0.73333	32.173	1.000
	10.0%PVA 7% coal		-4.13333	32.173	1.000	
	12.5%PVA		0.73333	32.173	1.000	
	12.5%PVA 3% coal		-38.26667	32.173	0.993	
	12.5%PVA 5% coal		-13.26667	32.173	1.000	
	12.5%PVA 7% coal		-40.26667	32.173	0.989	
	15.0%PVA		-4.13333	32.173	1.000	
	15.0%PVA 3% coal		126.20000(*)	32.173	0.008	
	10.0%PVA 3% coal	Control	22.06667	32.173	1.000	
		10.0%PVA	0	32.173	1.000	
		10.0%PVA 5% coal	0.73333	32.173	1.000	
		10.0%PVA 7% coal	-4.13333	32.173	1.000	
		12.5%PVA	0.73333	32.173	1.000	
12.5%PVA 3% coal		-38.26667	32.173	0.993		
12.5%PVA 5% coal		-13.26667	32.173	1.000		
12.5%PVA 7% coal		-40.26667	32.173	0.989		
15.0%PVA		-4.13333	32.173	1.000		
15.0%PVA 3% coal		126.20000(*)	32.173	0.008		
15.0%PVA 5% coal		127.86667(*)	32.173	0.007		
15.0%PVA 7% coal		83.46667	32.173	0.322		
10.0%PVA 5% coal	Control	21.33333	32.173	1.000		
	10.0%PVA	-0.73333	32.173	1.000		
	10.0%PVA 3% coal	-0.73333	32.173	1.000		
	10.0%PVA 7% coal	-4.86667	32.173	1.000		

	12.5%PVA	0	32.173	1.000
	12.5%PVA 3% coal	-39	32.173	0.992
	12.5%PVA 5% coal	-14	32.173	1.000
	12.5%PVA 7% coal	-41	32.173	0.988
	15.0%PVA	-4.86667	32.173	1.000
	15.0%PVA 3% coal	125.46667(*)	32.173	0.009
	15.0%PVA 5% coal	127.13333(*)	32.173	0.007
	15.0%PVA 7% coal	82.73333	32.173	0.335
10.0%PVA 7% coal	Control	26.2	32.173	1.000
	10.0%PVA	4.13333	32.173	1.000
	10.0%PVA 3% coal	4.13333	32.173	1.000
	10.0%PVA 5% coal	4.86667	32.173	1.000
	12.5%PVA	4.86667	32.173	1.000
	12.5%PVA 3% coal	-34.13333	32.173	0.998
	12.5%PVA 5% coal	-9.13333	32.173	1.000
	12.5%PVA 7% coal	-36.13333	32.173	0.996
	15.0%PVA	0	32.173	1.000
	15.0%PVA 3% coal	130.33333(*)	32.173	0.005
	15.0%PVA 5% coal	132.00000(*)	32.173	0.004
	15.0%PVA 7% coal	87.6	32.173	0.249
12.5%PVA	Control	21.33333	32.173	1.000
	10.0%PVA	-0.73333	32.173	1.000
	10.0%PVA 3% coal	-0.73333	32.173	1.000
	10.0%PVA 5% coal	0	32.173	1.000
	10.0%PVA 7% coal	-4.86667	32.173	1.000
	12.5%PVA 3% coal	-39	32.173	0.992
	12.5%PVA 5% coal	-14	32.173	1.000
	12.5%PVA 7% coal	-41	32.173	0.988
	15.0%PVA	-4.86667	32.173	1.000
	15.0%PVA 3% coal	125.46667(*)	32.173	0.009
	15.0%PVA 5% coal	127.13333(*)	32.173	0.007
	15.0%PVA 7% coal	82.73333	32.173	0.335
12.5%PVA 3% coal	Control	60.33333	32.173	0.807
	10.0%PVA	38.26667	32.173	0.993
	10.0%PVA 3% coal	38.26667	32.173	0.993
	10.0%PVA 5% coal	39	32.173	0.992
	10.0%PVA 7% coal	34.13333	32.173	0.998
	12.5%PVA	39	32.173	0.992
	12.5%PVA 5% coal	25	32.173	1.000
	12.5%PVA 7% coal	-2	32.173	1.000
	15.0%PVA	34.13333	32.173	0.998
	15.0%PVA 3% coal	164.46667(*)	32.173	0.000
	15.0%PVA 5% coal	166.13333(*)	32.173	0.000
	15.0%PVA 7% coal	121.73333(*)	32.173	0.013
12.5%PVA 5% coal	Control	35.33333	32.173	0.997
	10.0%PVA	13.26667	32.173	1.000
	10.0%PVA 3% coal	13.26667	32.173	1.000
	10.0%PVA 5% coal	14	32.173	1.000
	10.0%PVA 7% coal	9.13333	32.173	1.000
	12.5%PVA	14	32.173	1.000
	12.5%PVA 3% coal	-25	32.173	1.000

	12.5%PVA 7% coal	-27	32.173	1.000	
	15.0%PVA	9.13333	32.173	1.000	
	15.0%PVA 3% coal	139.46667(*)	32.173	0.002	
	15.0%PVA 5% coal	141.13333(*)	32.173	0.001	
	15.0%PVA 7% coal	96.73333	32.173	0.130	
12.5%PVA 7% coal	Control	62.33333	32.173	0.771	
	10.0%PVA	40.26667	32.173	0.989	
	10.0%PVA 3% coal	40.26667	32.173	0.989	
	10.0%PVA 5% coal	41	32.173	0.988	
	10.0%PVA 7% coal	36.13333	32.173	0.996	
	12.5%PVA	41	32.173	0.988	
	12.5%PVA 3% coal	2	32.173	1.000	
	12.5%PVA 5% coal	27	32.173	1.000	
	15.0%PVA	36.13333	32.173	0.996	
	15.0%PVA 3% coal	166.46667(*)	32.173	0.000	
	15.0%PVA 5% coal	168.13333(*)	32.173	0.000	
	15.0%PVA 7% coal	123.73333(*)	32.173	0.010	
	15.0%PVA	Control	26.2	32.173	1.000
		10.0%PVA	4.13333	32.173	1.000
		10.0%PVA 3% coal	4.13333	32.173	1.000
		10.0%PVA 5% coal	4.86667	32.173	1.000
10.0%PVA 7% coal		0	32.173	1.000	
12.5%PVA		4.86667	32.173	1.000	
12.5%PVA 3% coal		-34.13333	32.173	0.998	
12.5%PVA 5% coal		-9.13333	32.173	1.000	
12.5%PVA 7% coal		-36.13333	32.173	0.996	
15.0%PVA 3% coal		130.33333(*)	32.173	0.005	
15.0%PVA 5% coal		132.00000(*)	32.173	0.004	
15.0%PVA 7% coal		87.6	32.173	0.249	
15.0%PVA 3% coal		Control	-104.13333	32.173	0.071
	10.0%PVA	-126.20000(*)	32.173	0.008	
	10.0%PVA 3% coal	-126.20000(*)	32.173	0.008	
	10.0%PVA 5% coal	-125.46667(*)	32.173	0.009	
	10.0%PVA 7% coal	-130.33333(*)	32.173	0.005	
	12.5%PVA	-125.46667(*)	32.173	0.009	
	12.5%PVA 3% coal	-164.46667(*)	32.173	0.000	
	12.5%PVA 5% coal	-139.46667(*)	32.173	0.002	
	12.5%PVA 7% coal	-166.46667(*)	32.173	0.000	
	15.0%PVA	-130.33333(*)	32.173	0.005	
	15.0%PVA 5% coal	1.66667	32.173	1.000	
	15.0%PVA 7% coal	-42.73333	32.173	0.982	
	15.0%PVA 5% coal	Control	-105.8	32.173	0.061
10.0%PVA		-127.86667(*)	32.173	0.007	
10.0%PVA 3% coal		-127.86667(*)	32.173	0.007	
10.0%PVA 5% coal		-127.13333(*)	32.173	0.007	
10.0%PVA 7% coal		-132.00000(*)	32.173	0.004	
12.5%PVA		-127.13333(*)	32.173	0.007	
12.5%PVA 3% coal		-166.13333(*)	32.173	0.000	
12.5%PVA 5% coal		-141.13333(*)	32.173	0.001	
12.5%PVA 7% coal		-168.13333(*)	32.173	0.000	
15.0%PVA		-132.00000(*)	32.173	0.004	

	15.0%PVA 3% coal	-1.66667	32.173	1.000
	15.0%PVA 7% coal	-44.4	32.173	0.976
15.0%PVA 7% coal	Control	-61.4	32.173	0.788
	10.0%PVA	-83.46667	32.173	0.322
	10.0%PVA 3% coal	-83.46667	32.173	0.322
	10.0%PVA 5% coal	-82.73333	32.173	0.335
	10.0%PVA 7% coal	-87.6	32.173	0.249
	12.5%PVA	-82.73333	32.173	0.335
	12.5%PVA 3% coal	-121.73333(*)	32.173	0.013
	12.5%PVA 5% coal	-96.73333	32.173	0.130
	12.5%PVA 7% coal	-123.73333(*)	32.173	0.010
	15.0%PVA	-87.6	32.173	0.249
	15.0%PVA 3% coal	42.73333	32.173	0.982
	15.0%PVA 5% coal	44.4	32.173	0.976

Tests of Between-Subjects Effects

Dependent Variable: %NO₂-N removal efficiency (HRT1)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	566802.913(a)	12	47233.576	6.084	.000
Intercept	2282366.605	1	2282366.605	293.988	.000
COAL	41497.644	3	13832.548	1.782	.152
PVA	382669.744	3	127556.581	16.430	.000
PVA * COAL	148626.389	6	24771.065	3.191	.005
Error	1412951.067	182	7763.467		
Total	4470161.000	195			
Corrected Total	1979753.979	194			

a R Squared = .286 (Adjusted R Squared = .239)

Table B-20 Comparison of NO₂-N removal efficiency of conditions in Group 2 (HRT 2 hrs.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	830134.605	12	69177.884	1.652	0.081
Within Groups	7621909.467	182	41878.623		
Total	8452044.072	194			

Multiple Comparisons (Tukey HSD)						
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	
% NH ₃ -N Removal Efficiency	Control	10.0%PVA	-79.53333	74.725	0.998	
		10.0%PVA 3% coal	-79.53333	74.725	0.998	
		10.0%PVA 5% coal	-25.13333	74.725	1.000	
		10.0%PVA 7% coal	-34.73333	74.725	1.000	
		12.5%PVA	-25.13333	74.725	1.000	
		12.5%PVA 3% coal	25.93333	74.725	1.000	
		12.5%PVA 5% coal	-4.93333	74.725	1.000	
		12.5%PVA 7% coal	46.4	74.725	1.000	
		15.0%PVA	-34.73333	74.725	1.000	
		15.0%PVA 3% coal	106.66667	74.725	0.969	
		15.0%PVA 5% coal	137.93333	74.725	0.824	
		15.0%PVA 7% coal	82.4	74.725	0.997	
		10.0%PVA	Control	79.53333	74.725	0.998
			10.0%PVA 3% coal	0	74.725	1.000
			10.0%PVA 5% coal	54.4	74.725	1.000
	10.0%PVA 7% coal		44.8	74.725	1.000	
	12.5%PVA		54.4	74.725	1.000	
	12.5%PVA 3% coal		105.46667	74.725	0.971	
	12.5%PVA 5% coal		74.6	74.725	0.999	
	12.5%PVA 7% coal		125.93333	74.725	0.898	
	15.0%PVA		44.8	74.725	1.000	
	15.0%PVA 3% coal		186.2	74.725	0.386	
	10.0%PVA 3% coal	Control	79.53333	74.725	0.998	
		10.0%PVA	0	74.725	1.000	
10.0%PVA 5% coal		54.4	74.725	1.000		
10.0%PVA 7% coal		44.8	74.725	1.000		
12.5%PVA		54.4	74.725	1.000		
12.5%PVA 3% coal		105.46667	74.725	0.971		
12.5%PVA 5% coal		74.6	74.725	0.999		
12.5%PVA 7% coal		125.93333	74.725	0.898		
15.0%PVA		44.8	74.725	1.000		
15.0%PVA 3% coal		186.2	74.725	0.386		
10.0%PVA 5% coal	Control	25.13333	74.725	1.000		
	10.0%PVA	-54.4	74.725	1.000		
	10.0%PVA 3% coal	-54.4	74.725	1.000		
	10.0%PVA 7% coal	-9.6	74.725	1.000		

	12.5%PVA	0	74.725	1.000
	12.5%PVA 3% coal	51.06667	74.725	1.000
	12.5%PVA 5% coal	20.2	74.725	1.000
	12.5%PVA 7% coal	71.53333	74.725	0.999
	15.0%PVA	-9.6	74.725	1.000
	15.0%PVA 3% coal	131.8	74.725	0.865
	15.0%PVA 5% coal	163.06667	74.725	0.605
	15.0%PVA 7% coal	107.53333	74.725	0.967
10.0%PVA 7% coal	Control	34.73333	74.725	1.000
	10.0%PVA	-44.8	74.725	1.000
	10.0%PVA 3% coal	-44.8	74.725	1.000
	10.0%PVA 5% coal	9.6	74.725	1.000
	12.5%PVA	9.6	74.725	1.000
	12.5%PVA 3% coal	60.66667	74.725	1.000
	12.5%PVA 5% coal	29.8	74.725	1.000
	12.5%PVA 7% coal	81.13333	74.725	0.997
	15.0%PVA	0	74.725	1.000
	15.0%PVA 3% coal	141.4	74.725	0.798
	15.0%PVA 5% coal	172.66667	74.725	0.512
	15.0%PVA 7% coal	117.13333	74.725	0.937
12.5%PVA	Control	25.13333	74.725	1.000
	10.0%PVA	-54.4	74.725	1.000
	10.0%PVA 3% coal	-54.4	74.725	1.000
	10.0%PVA 5% coal	0	74.725	1.000
	10.0%PVA 7% coal	-9.6	74.725	1.000
	12.5%PVA 3% coal	51.06667	74.725	1.000
	12.5%PVA 5% coal	20.2	74.725	1.000
	12.5%PVA 7% coal	71.53333	74.725	0.999
	15.0%PVA	-9.6	74.725	1.000
	15.0%PVA 3% coal	131.8	74.725	0.865
	15.0%PVA 5% coal	163.06667	74.725	0.605
	15.0%PVA 7% coal	107.53333	74.725	0.967
12.5%PVA 3% coal	Control	-25.93333	74.725	1.000
	10.0%PVA	-105.46667	74.725	0.971
	10.0%PVA 3% coal	-105.46667	74.725	0.971
	10.0%PVA 5% coal	-51.06667	74.725	1.000
	10.0%PVA 7% coal	-60.66667	74.725	1.000
	12.5%PVA	-51.06667	74.725	1.000
	12.5%PVA 5% coal	-30.86667	74.725	1.000
	12.5%PVA 7% coal	20.46667	74.725	1.000
	15.0%PVA	-60.66667	74.725	1.000
	15.0%PVA 3% coal	80.73333	74.725	0.997
	15.0%PVA 5% coal	112	74.725	0.955
	15.0%PVA 7% coal	56.46667	74.725	1.000
12.5%PVA 5% coal	Control	4.93333	74.725	1.000
	10.0%PVA	-74.6	74.725	0.999
	10.0%PVA 3% coal	-74.6	74.725	0.999
	10.0%PVA 5% coal	-20.2	74.725	1.000
	10.0%PVA 7% coal	-29.8	74.725	1.000
	12.5%PVA	-20.2	74.725	1.000
	12.5%PVA 3% coal	30.86667	74.725	1.000

	12.5%PVA 7% coal	51.33333	74.725	1.000	
	15.0%PVA	-29.8	74.725	1.000	
	15.0%PVA 3% coal	111.6	74.725	0.956	
	15.0%PVA 5% coal	142.86667	74.725	0.786	
	15.0%PVA 7% coal	87.33333	74.725	0.994	
12.5%PVA 7% coal	Control	-46.4	74.725	1.000	
	10.0%PVA	-125.93333	74.725	0.898	
	10.0%PVA 3% coal	-125.93333	74.725	0.898	
	10.0%PVA 5% coal	-71.53333	74.725	0.999	
	10.0%PVA 7% coal	-81.13333	74.725	0.997	
	12.5%PVA	-71.53333	74.725	0.999	
	12.5%PVA 3% coal	-20.46667	74.725	1.000	
	12.5%PVA 5% coal	-51.33333	74.725	1.000	
	15.0%PVA	-81.13333	74.725	0.997	
	15.0%PVA 3% coal	60.26667	74.725	1.000	
	15.0%PVA 5% coal	91.53333	74.725	0.991	
	15.0%PVA 7% coal	36	74.725	1.000	
	15.0%PVA	Control	34.73333	74.725	1.000
		10.0%PVA	-44.8	74.725	1.000
		10.0%PVA 3% coal	-44.8	74.725	1.000
10.0%PVA 5% coal		9.6	74.725	1.000	
10.0%PVA 7% coal		0	74.725	1.000	
12.5%PVA		9.6	74.725	1.000	
12.5%PVA 3% coal		60.66667	74.725	1.000	
12.5%PVA 5% coal		29.8	74.725	1.000	
12.5%PVA 7% coal		81.13333	74.725	0.997	
15.0%PVA 3% coal		141.4	74.725	0.798	
15.0%PVA 5% coal		172.66667	74.725	0.512	
15.0%PVA 7% coal		117.13333	74.725	0.937	
15.0%PVA 3% coal		Control	-106.66667	74.725	0.969
		10.0%PVA	-186.2	74.725	0.386
		10.0%PVA 3% coal	-186.2	74.725	0.386
	10.0%PVA 5% coal	-131.8	74.725	0.865	
	10.0%PVA 7% coal	-141.4	74.725	0.798	
	12.5%PVA	-131.8	74.725	0.865	
	12.5%PVA 3% coal	-80.73333	74.725	0.997	
	12.5%PVA 5% coal	-111.6	74.725	0.956	
	12.5%PVA 7% coal	-60.26667	74.725	1.000	
	15.0%PVA	-141.4	74.725	0.798	
	15.0%PVA 5% coal	31.26667	74.725	1.000	
	15.0%PVA 7% coal	-24.26667	74.725	1.000	
	15.0%PVA 5% coal	Control	-137.93333	74.725	0.824
		10.0%PVA	-217.46667	74.725	0.165
		10.0%PVA 3% coal	-217.46667	74.725	0.165
10.0%PVA 5% coal		-163.06667	74.725	0.605	
10.0%PVA 7% coal		-172.66667	74.725	0.512	
12.5%PVA		-163.06667	74.725	0.605	
12.5%PVA 3% coal		-112	74.725	0.955	
12.5%PVA 5% coal		-142.86667	74.725	0.786	
12.5%PVA 7% coal		-91.53333	74.725	0.991	
15.0%PVA		-172.66667	74.725	0.512	

	15.0%PVA 3% coal	-31.26667	74.725	1.000
	15.0%PVA 7%coal	-55.53333	74.725	1.000
15.0%PVA 7%coal	Control	-82.4	74.725	0.997
	10.0%PVA	-161.93333	74.725	0.616
	10.0%PVA 3%coal	-161.93333	74.725	0.616
	10.0%PVA 5%coal	-107.53333	74.725	0.967
	10.0%PVA 7%coal	-117.13333	74.725	0.937
	12.5%PVA	-107.53333	74.725	0.967
	12.5%PVA 3%coal	-56.46667	74.725	1.000
	12.5%PVA 5%coal	-87.33333	74.725	0.994
	12.5%PVA 7%coal	-36	74.725	1.000
	15.0%PVA	-117.13333	74.725	0.937
	15.0%PVA 3% coal	24.26667	74.725	1.000
	15.0%PVA 5%coal	55.53333	74.725	1.000

Tests of Between-Subjects Effects

Dependent Variable: %NO₂-N removal efficiency (HRT2)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	830134.605(a)	12	69177.884	1.652	.081
Intercept	4683322.765	1	4683322.765	111.831	.000
COAL	196956.733	3	65652.244	1.568	.199
PVA	514354.050	3	171451.350	4.094	.008
PVA * COAL	141829.333	6	23638.222	.564	.758
Error	7621909.467	182	41878.623		
Total	13433170.000	195			
Corrected Total	8452044.072	194			

Table B-21 Comparison of NO₂-N removal efficiency of conditions in Group 3 (HRT 4 hrs.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1782644.482	12	148553.707	6.037	0
Within Groups	4478267.467	182	24605.865		
Total	6260911.949	194			

Multiple Comparisons (Tukey HSD)						
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	
% NH ₃ -N Removal Efficiency	Control	10.0%PVA	-101.46667	57.278	0.861	
		10.0%PVA 3% coal	-173.13333	57.278	0.125	
		10.0%PVA 5% coal	-184.93333	57.278	0.072	
		10.0%PVA 7% coal	-173.93333	57.278	0.121	
		12.5%PVA	-101.6	57.278	0.860	
		12.5%PVA 3% coal	-182.13333	57.278	0.083	
		12.5%PVA 5% coal	-192.60000(*)	57.278	0.049	
		12.5%PVA 7% coal	-174.13333	57.278	0.120	
		15.0%PVA	-117.2	57.278	0.701	
		15.0%PVA 3% coal	96.4	57.278	0.899	
		15.0%PVA 5% coal	48.93333	57.278	1.000	
		15.0%PVA 7% coal	-4.8	57.278	1.000	
		10.0%PVA	Control	101.46667	57.278	0.861
			10.0%PVA 3% coal	-71.66667	57.278	0.989
			10.0%PVA 5% coal	-83.46667	57.278	0.963
	10.0%PVA 7% coal		-72.46667	57.278	0.988	
	12.5%PVA		-0.13333	57.278	1.000	
	12.5%PVA 3% coal		-80.66667	57.278	0.972	
	12.5%PVA 5% coal		-91.13333	57.278	0.931	
	12.5%PVA 7% coal		-72.66667	57.278	0.988	
	15.0%PVA		-15.73333	57.278	1.000	
	15.0%PVA 3% coal		197.86667(*)	57.278	0.037	
	15.0%PVA 5% coal		150.4	57.278	0.303	
	15.0%PVA 7% coal		96.66667	57.278	0.897	
	10.0%PVA 3% coal		Control	173.13333	57.278	0.125
			10.0%PVA	71.66667	57.278	0.989
			10.0%PVA 5% coal	-11.8	57.278	1.000
		10.0%PVA 7% coal	-0.8	57.278	1.000	
		12.5%PVA	71.53333	57.278	0.990	
		12.5%PVA 3% coal	-9	57.278	1.000	
		12.5%PVA 5% coal	-19.46667	57.278	1.000	
		12.5%PVA 7% coal	-1	57.278	1.000	
		15.0%PVA	55.93333	57.278	0.999	
15.0%PVA 3% coal		269.53333(*)	57.278	0.000		
15.0%PVA 5% coal		222.06667(*)	57.278	0.009		
15.0%PVA 7% coal		168.33333	57.278	0.154		
10.0%PVA 5% coal		Control	184.93333	57.278	0.072	
		10.0%PVA	83.46667	57.278	0.963	
		10.0%PVA 3% coal	11.8	57.278	1.000	
	10.0%PVA 7% coal	11	57.278	1.000		

	12.5%PVA	83.33333	57.278	0.964
	12.5%PVA 3% coal	2.8	57.278	1.000
	12.5%PVA 5% coal	-7.66667	57.278	1.000
	12.5%PVA 7% coal	10.8	57.278	1.000
	15.0%PVA	67.73333	57.278	0.994
	15.0%PVA 3% coal	281.33333(*)	57.278	0.000
	15.0%PVA 5% coal	233.86667(*)	57.278	0.004
	15.0%PVA 7% coal	180.13333	57.278	0.091
10.0%PVA 7% coal	Control	173.93333	57.278	0.121
	10.0%PVA	72.46667	57.278	0.988
	10.0%PVA 3% coal	0.8	57.278	1.000
	10.0%PVA 5% coal	-11	57.278	1.000
	12.5%PVA	72.33333	57.278	0.988
	12.5%PVA 3% coal	-8.2	57.278	1.000
	12.5%PVA 5% coal	-18.66667	57.278	1.000
	12.5%PVA 7% coal	-0.2	57.278	1.000
	15.0%PVA	56.73333	57.278	0.999
	15.0%PVA 3% coal	270.33333(*)	57.278	0.000
	15.0%PVA 5% coal	222.86667(*)	57.278	0.009
	15.0%PVA 7% coal	169.13333	57.278	0.149
12.5%PVA	Control	101.6	57.278	0.860
	10.0%PVA	0.13333	57.278	1.000
	10.0%PVA 3% coal	-71.53333	57.278	0.990
	10.0%PVA 5% coal	-83.33333	57.278	0.964
	10.0%PVA 7% coal	-72.33333	57.278	0.988
	12.5%PVA 3% coal	-80.53333	57.278	0.972
	12.5%PVA 5% coal	-91	57.278	0.931
	12.5%PVA 7% coal	-72.53333	57.278	0.988
	15.0%PVA	-15.6	57.278	1.000
	15.0%PVA 3% coal	198.00000(*)	57.278	0.037
	15.0%PVA 5% coal	150.53333	57.278	0.301
	15.0%PVA 7% coal	96.8	57.278	0.896
12.5%PVA 3% coal	Control	182.13333	57.278	0.083
	10.0%PVA	80.66667	57.278	0.972
	10.0%PVA 3% coal	9	57.278	1.000
	10.0%PVA 5% coal	-2.8	57.278	1.000
	10.0%PVA 7% coal	8.2	57.278	1.000
	12.5%PVA	80.53333	57.278	0.972
	12.5%PVA 5% coal	-10.46667	57.278	1.000
	12.5%PVA 7% coal	8	57.278	1.000
	15.0%PVA	64.93333	57.278	0.996
	15.0%PVA 3% coal	278.53333(*)	57.278	0.000
	15.0%PVA 5% coal	231.06667(*)	57.278	0.005
	15.0%PVA 7% coal	177.33333	57.278	0.104
12.5%PVA 5% coal	Control	192.60000(*)	57.278	0.049
	10.0%PVA	91.13333	57.278	0.931
	10.0%PVA 3% coal	19.46667	57.278	1.000
	10.0%PVA 5% coal	7.66667	57.278	1.000
	10.0%PVA 7% coal	18.66667	57.278	1.000
	12.5%PVA	91	57.278	0.931
	12.5%PVA 3% coal	10.46667	57.278	1.000

	12.5%PVA 7% coal	18.46667	57.278	1.000	
	15.0%PVA	75.4	57.278	0.984	
	15.0%PVA 3% coal	289.00000(*)	57.278	0.000	
	15.0%PVA 5% coal	241.53333(*)	57.278	0.003	
	15.0%PVA 7% coal	187.8	57.278	0.063	
12.5%PVA 7% coal	Control	174.13333	57.278	0.120	
	10.0%PVA	72.66667	57.278	0.988	
	10.0%PVA 3% coal	1	57.278	1.000	
	10.0%PVA 5% coal	-10.8	57.278	1.000	
	10.0%PVA 7% coal	0.2	57.278	1.000	
	12.5%PVA	72.53333	57.278	0.988	
	12.5%PVA 3% coal	-8	57.278	1.000	
	12.5%PVA 5% coal	-18.46667	57.278	1.000	
	15.0%PVA	56.93333	57.278	0.999	
	15.0%PVA 3% coal	270.53333(*)	57.278	0.000	
	15.0%PVA 5% coal	223.06667(*)	57.278	0.009	
	15.0%PVA 7% coal	169.33333	57.278	0.147	
	15.0%PVA	Control	117.2	57.278	0.701
		10.0%PVA	15.73333	57.278	1.000
		10.0%PVA 3% coal	-55.93333	57.278	0.999
		10.0%PVA 5% coal	-67.73333	57.278	0.994
		10.0%PVA 7% coal	-56.73333	57.278	0.999
12.5%PVA		15.6	57.278	1.000	
12.5%PVA 3% coal		-64.93333	57.278	0.996	
12.5%PVA 5% coal		-75.4	57.278	0.984	
12.5%PVA 7% coal		-56.93333	57.278	0.999	
15.0%PVA 3% coal		213.60000(*)	57.278	0.015	
15.0%PVA 5% coal		166.13333	57.278	0.168	
15.0%PVA 7% coal		112.4	57.278	0.756	
15.0%PVA 3% coal		Control	-96.4	57.278	0.899
	10.0%PVA	-197.86667(*)	57.278	0.037	
	10.0%PVA 3% coal	-269.53333(*)	57.278	0.000	
	10.0%PVA 5% coal	-281.33333(*)	57.278	0.000	
	10.0%PVA 7% coal	-270.33333(*)	57.278	0.000	
	12.5%PVA	-198.00000(*)	57.278	0.037	
	12.5%PVA 3% coal	-278.53333(*)	57.278	0.000	
	12.5%PVA 5% coal	-289.00000(*)	57.278	0.000	
	12.5%PVA 7% coal	-270.53333(*)	57.278	0.000	
	15.0%PVA	-213.60000(*)	57.278	0.015	
	15.0%PVA 5% coal	-47.46667	57.278	1.000	
	15.0%PVA 7% coal	-101.2	57.278	0.863	
	15.0%PVA 5% coal	Control	-48.93333	57.278	1.000
10.0%PVA		-150.4	57.278	0.303	
10.0%PVA 3% coal		-222.06667(*)	57.278	0.009	
10.0%PVA 5% coal		-233.86667(*)	57.278	0.004	
10.0%PVA 7% coal		-222.86667(*)	57.278	0.009	
12.5%PVA		-150.53333	57.278	0.301	
12.5%PVA 3% coal		-231.06667(*)	57.278	0.005	
12.5%PVA 5% coal		-241.53333(*)	57.278	0.003	
12.5%PVA 7% coal		-223.06667(*)	57.278	0.009	
15.0%PVA		-166.13333	57.278	0.168	

	15.0%PVA 3% coal	47.46667	57.278	1.000
	15.0%PVA 7% coal	-53.73333	57.278	0.999
15.0%PVA 7% coal	Control	4.8	57.278	1.000
	10.0%PVA	-96.66667	57.278	0.897
	10.0%PVA 3% coal	-168.33333	57.278	0.154
	10.0%PVA 5% coal	-180.13333	57.278	0.091
	10.0%PVA 7% coal	-169.13333	57.278	0.149
	12.5%PVA	-96.8	57.278	0.896
	12.5%PVA 3% coal	-177.33333	57.278	0.104
	12.5%PVA 5% coal	-187.8	57.278	0.063
	12.5%PVA 7% coal	-169.33333	57.278	0.147
	15.0%PVA	-112.4	57.278	0.756
	15.0%PVA 3% coal	101.2	57.278	0.863
	15.0%PVA 5% coal	53.73333	57.278	0.999

Tests of Between-Subjects Effects

Dependent Variable: %NO₂-N removal efficiency (HRT4)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1782644.482(a)	12	148553.707	6.037	.000
Intercept	1721496.480	1	1721496.480	69.963	.000
COAL	23987.217	3	7995.739	.325	.807
PVA	1235315.522	3	411771.841	16.735	.000
PVA * COAL	498755.900	6	83125.983	3.378	.004
Error	4478267.467	182	24605.865		
Total	7895789.000	195			
Corrected Total	6260911.949	194			

a R Squared = .285 (Adjusted R Squared = .238)

Table B-22 Comparison of NO₃-N effluents of conditions in Group 1 (HRT 1 hrs.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	39.071	12	3.256	184.664	0
Within Groups	3.209	182	0.018		
Total	42.28	194			

Multiple Comparisons (Tukey HSD)					
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.
% NH ₃ -N Removal Efficiency	Control	10.0%PVA	-1.66467(*)	0.048	0.000
		10.0%PVA 3%coal	-1.70533(*)	0.048	0.000
		10.0%PVA 5%coal	-1.69533(*)	0.048	0.000
		10.0%PVA 7%coal	-1.69133(*)	0.048	0.000
		12.5%PVA	-1.46933(*)	0.048	0.000
		12.5%PVA 3%coal	-1.77467(*)	0.048	0.000
		12.5%PVA 5%coal	-1.69067(*)	0.048	0.000
		12.5%PVA 7%coal	-1.74200(*)	0.048	0.000
		15.0%PVA	-1.53267(*)	0.048	0.000
		15.0%PVA 3% coal	-1.60667(*)	0.048	0.000
		15.0%PVA 5%coal	-1.62533(*)	0.048	0.000
		15.0%PVA 7%coal	-1.64200(*)	0.048	0.000
	10.0%PVA	Control	1.66467(*)	0.048	0.000
		10.0%PVA 3%coal	-0.04067	0.048	1.000
		10.0%PVA 5%coal	-0.03067	0.048	1.000
		10.0%PVA 7%coal	-0.02667	0.048	1.000
		12.5%PVA	.19533(*)	0.048	0.005
		12.5%PVA 3%coal	-0.11	0.048	0.543
		12.5%PVA 5%coal	-0.026	0.048	1.000
		12.5%PVA 7%coal	-0.07733	0.048	0.929
		15.0%PVA	0.132	0.048	0.250
		15.0%PVA 3% coal	0.058	0.048	0.993
		15.0%PVA 5%coal	0.03933	0.048	1.000
		15.0%PVA 7%coal	0.02267	0.048	1.000
	10.0%PVA 3%coal	Control	1.70533(*)	0.048	0.000
		10.0%PVA	0.04067	0.048	1.000
		10.0%PVA 5%coal	0.01	0.048	1.000
		10.0%PVA 7%coal	0.014	0.048	1.000
		12.5%PVA	.23600(*)	0.048	0.000
		12.5%PVA 3%coal	-0.06933	0.048	0.968
		12.5%PVA 5%coal	0.01467	0.048	1.000
		12.5%PVA 7%coal	-0.03667	0.048	1.000
		15.0%PVA	.17267(*)	0.048	0.027
		15.0%PVA 3% coal	0.09867	0.048	0.708
		15.0%PVA 5%coal	0.08	0.048	0.911
		15.0%PVA 7%coal	0.06333	0.048	0.985
	10.0%PVA 5%coal	Control	1.69533(*)	0.048	0.000
		10.0%PVA	0.03067	0.048	1.000
		10.0%PVA 3%coal	-0.01	0.048	1.000
		10.0%PVA 7%coal	0.004	0.048	1.000
		12.5%PVA	.22600(*)	0.048	0.000

	12.5%PVA 3% coal	-0.07933	0.048	0.916
	12.5%PVA 5% coal	0.00467	0.048	1.000
	12.5%PVA 7% coal	-0.04667	0.048	0.999
	15.0%PVA	0.16267	0.048	0.050
	15.0%PVA 3% coal	0.08867	0.048	0.833
	15.0%PVA 5% coal	0.07	0.048	0.966
	15.0%PVA 7% coal	0.05333	0.048	0.997
10.0%PVA 7% coal	Control	1.69133(*)	0.048	0.000
	10.0%PVA	0.02667	0.048	1.000
	10.0%PVA 3% coal	-0.014	0.048	1.000
	10.0%PVA 5% coal	-0.004	0.048	1.000
	12.5%PVA	.22200(*)	0.048	0.001
	12.5%PVA 3% coal	-0.08333	0.048	0.885
	12.5%PVA 5% coal	0.00067	0.048	1.000
	12.5%PVA 7% coal	-0.05067	0.048	0.998
	15.0%PVA	0.15867	0.048	0.064
	15.0%PVA 3% coal	0.08467	0.048	0.873
	15.0%PVA 5% coal	0.066	0.048	0.979
	15.0%PVA 7% coal	0.04933	0.048	0.998
12.5%PVA	Control	1.46933(*)	0.048	0.000
	10.0%PVA	-.19533(*)	0.048	0.005
	10.0%PVA 3% coal	-.23600(*)	0.048	0.000
	10.0%PVA 5% coal	-.22600(*)	0.048	0.000
	10.0%PVA 7% coal	-.22200(*)	0.048	0.001
	12.5%PVA 3% coal	-.30533(*)	0.048	0.000
	12.5%PVA 5% coal	-.22133(*)	0.048	0.001
	12.5%PVA 7% coal	-.27267(*)	0.048	0.000
	15.0%PVA	-0.06333	0.048	0.985
	15.0%PVA 3% coal	-0.13733	0.048	0.197
	15.0%PVA 5% coal	-0.156	0.048	0.075
	15.0%PVA 7% coal	-.17267(*)	0.048	0.027
12.5%PVA 3% coal	Control	1.77467(*)	0.048	0.000
	10.0%PVA	0.11	0.048	0.543
	10.0%PVA 3% coal	0.06933	0.048	0.968
	10.0%PVA 5% coal	0.07933	0.048	0.916
	10.0%PVA 7% coal	0.08333	0.048	0.885
	12.5%PVA	.30533(*)	0.048	0.000
	12.5%PVA 5% coal	0.084	0.048	0.879
	12.5%PVA 7% coal	0.03267	0.048	1.000
	15.0%PVA	.24200(*)	0.048	0.000
	15.0%PVA 3% coal	.16800(*)	0.048	0.036
	15.0%PVA 5% coal	0.14933	0.048	0.108
	15.0%PVA 7% coal	0.13267	0.048	0.243
12.5%PVA 5% coal	Control	1.69067(*)	0.048	0.000
	10.0%PVA	0.026	0.048	1.000
	10.0%PVA 3% coal	-0.01467	0.048	1.000
	10.0%PVA 5% coal	-0.00467	0.048	1.000
	10.0%PVA 7% coal	-0.00067	0.048	1.000
	12.5%PVA	.22133(*)	0.048	0.001
	12.5%PVA 3% coal	-0.084	0.048	0.879
	12.5%PVA 7% coal	-0.05133	0.048	0.998

	15.0%PVA	0.158	0.048	0.067
	15.0%PVA 3% coal	0.084	0.048	0.879
	15.0%PVA 5%coal	0.06533	0.048	0.980
	15.0%PVA 7%coal	0.04867	0.048	0.999
12.5%PVA 7%coal	Control	1.74200(*)	0.048	0.000
	10.0%PVA	0.07733	0.048	0.929
	10.0%PVA 3%coal	0.03667	0.048	1.000
	10.0%PVA 5%coal	0.04667	0.048	0.999
	10.0%PVA 7%coal	0.05067	0.048	0.998
	12.5%PVA	.27267(*)	0.048	0.000
	12.5%PVA 3%coal	-0.03267	0.048	1.000
	12.5%PVA 5%coal	0.05133	0.048	0.998
	15.0%PVA	.20933(*)	0.048	0.002
	15.0%PVA 3% coal	0.13533	0.048	0.216
	15.0%PVA 5%coal	0.11667	0.048	0.444
	15.0%PVA 7%coal	0.1	0.048	0.690
15.0%PVA	Control	1.53267(*)	0.048	0.000
	10.0%PVA	-0.132	0.048	0.250
	10.0%PVA 3%coal	-.17267(*)	0.048	0.027
	10.0%PVA 5%coal	-0.16267	0.048	0.050
	10.0%PVA 7%coal	-0.15867	0.048	0.064
	12.5%PVA	0.06333	0.048	0.985
	12.5%PVA 3%coal	-.24200(*)	0.048	0.000
	12.5%PVA 5%coal	-0.158	0.048	0.067
	12.5%PVA 7%coal	-.20933(*)	0.048	0.002
	15.0%PVA 3% coal	-0.074	0.048	0.948
	15.0%PVA 5%coal	-0.09267	0.048	0.787
	15.0%PVA 7%coal	-0.10933	0.048	0.553
15.0%PVA 3% coal	Control	1.60667(*)	0.048	0.000
	10.0%PVA	-0.058	0.048	0.993
	10.0%PVA 3%coal	-0.09867	0.048	0.708
	10.0%PVA 5%coal	-0.08867	0.048	0.833
	10.0%PVA 7%coal	-0.08467	0.048	0.873
	12.5%PVA	0.13733	0.048	0.197
	12.5%PVA 3%coal	-.16800(*)	0.048	0.036
	12.5%PVA 5%coal	-0.084	0.048	0.879
	12.5%PVA 7%coal	-0.13533	0.048	0.216
	15.0%PVA	0.074	0.048	0.948
	15.0%PVA 5%coal	-0.01867	0.048	1.000
	15.0%PVA 7%coal	-0.03533	0.048	1.000
15.0%PVA 5%coal	Control	1.62533(*)	0.048	0.000
	10.0%PVA	-0.03933	0.048	1.000
	10.0%PVA 3%coal	-0.08	0.048	0.911
	10.0%PVA 5%coal	-0.07	0.048	0.966
	10.0%PVA 7%coal	-0.066	0.048	0.979
	12.5%PVA	0.156	0.048	0.075
	12.5%PVA 3%coal	-0.14933	0.048	0.108
	12.5%PVA 5%coal	-0.06533	0.048	0.980
	12.5%PVA 7%coal	-0.11667	0.048	0.444
	15.0%PVA	0.09267	0.048	0.787
	15.0%PVA 3% coal	0.01867	0.048	1.000

	15.0%PVA 7%coal	-0.01667	0.048	1.000
15.0%PVA 7%coal	Control	1.64200(*)	0.048	0.000
	10.0%PVA	-0.02267	0.048	1.000
	10.0%PVA 3%coal	-0.06333	0.048	0.985
	10.0%PVA 5%coal	-0.05333	0.048	0.997
	10.0%PVA 7%coal	-0.04933	0.048	0.998
	12.5%PVA	.17267(*)	0.048	0.027
	12.5%PVA 3%coal	-0.13267	0.048	0.243
	12.5%PVA 5%coal	-0.04867	0.048	0.999
	12.5%PVA 7%coal	-0.1	0.048	0.690
	15.0%PVA	0.10933	0.048	0.553
	15.0%PVA 3% coal	0.03533	0.048	1.000
	15.0%PVA 5%coal	0.01667	0.048	1.000

Tests of Between-Subjects Effects

Dependent Variable: %NO3-N increasing (HRT1)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	39.071(a)	12	3.256	184.664	.000
Intercept	364.271	1	364.271	20659.870	.000
COAL	.590	3	.197	11.157	.000
PVA	27.474	3	9.158	519.412	.000
PVA * COAL	.380	6	.063	3.597	.002
Error	3.209	182	.018		
Total	533.703	195			
Corrected Total	42.280	194			

a. R Squared = .924 (Adjusted R Squared = .919)

Table B-23 Comparison of NO₃-N effluents of conditions in Group 2 (HRT 2 hrs.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	46.394	12	3.866	222.575	0
Within Groups	3.161	182	0.017		
Total	49.556	194			

Multiple Comparisons (Tukey HSD)					
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.
% NH ₃ -N Removal Efficiency	Control	10.0%PVA	-1.83333(*)	0.048	0.000
		10.0%PVA 3%coal	-1.91800(*)	0.048	0.000
		10.0%PVA 5%coal	-1.85467(*)	0.048	0.000
		10.0%PVA 7%coal	-1.88400(*)	0.048	0.000
		12.5%PVA	-1.56267(*)	0.048	0.000
		12.5%PVA 3%coal	-1.84333(*)	0.048	0.000
		12.5%PVA 5%coal	-1.85867(*)	0.048	0.000
		12.5%PVA 7%coal	-1.85733(*)	0.048	0.000
		15.0%PVA	-1.68333(*)	0.048	0.000
		15.0%PVA 3% coal	-1.76400(*)	0.048	0.000
		15.0%PVA 5%coal	-1.75267(*)	0.048	0.000
		15.0%PVA 7%coal	-1.76600(*)	0.048	0.000
	10.0%PVA	Control	1.83333(*)	0.048	0.000
		10.0%PVA 3%coal	-0.08467	0.048	0.867
		10.0%PVA 5%coal	-0.02133	0.048	1.000
		10.0%PVA 7%coal	-0.05067	0.048	0.998
		12.5%PVA	.27067(*)	0.048	0.000
		12.5%PVA 3%coal	-0.01	0.048	1.000
		12.5%PVA 5%coal	-0.02533	0.048	1.000
		12.5%PVA 7%coal	-0.024	0.048	1.000
		15.0%PVA	0.15	0.048	0.098
		15.0%PVA 3% coal	0.06933	0.048	0.966
		15.0%PVA 5%coal	0.08067	0.048	0.902
		15.0%PVA 7%coal	0.06733	0.048	0.973
	10.0%PVA 3%coal	Control	1.91800(*)	0.048	0.000
		10.0%PVA	0.08467	0.048	0.867
		10.0%PVA 5%coal	0.06333	0.048	0.984
10.0%PVA 7%coal		0.034	0.048	1.000	
12.5%PVA		.35533(*)	0.048	0.000	
12.5%PVA 3%coal		0.07467	0.048	0.942	
12.5%PVA 5%coal		0.05933	0.048	0.991	
12.5%PVA 7%coal		0.06067	0.048	0.989	
15.0%PVA		.23467(*)	0.048	0.000	
15.0%PVA 3% coal		0.154	0.048	0.078	
15.0%PVA 5%coal		.16533(*)	0.048	0.040	
15.0%PVA 7%coal		0.152	0.048	0.088	
10.0%PVA 5%coal	Control	1.85467(*)	0.048	0.000	
	10.0%PVA	0.02133	0.048	1.000	
	10.0%PVA 3%coal	-0.06333	0.048	0.984	
	10.0%PVA 7%coal	-0.02933	0.048	1.000	
	12.5%PVA	.29200(*)	0.048	0.000	

	12.5%PVA 3% coal	0.01133	0.048	1.000
	12.5%PVA 5% coal	-0.004	0.048	1.000
	12.5%PVA 7% coal	-0.00267	0.048	1.000
	15.0%PVA	.17133(*)	0.048	0.027
	15.0%PVA 3% coal	0.09067	0.048	0.803
	15.0%PVA 5% coal	0.102	0.048	0.650
	15.0%PVA 7% coal	0.08867	0.048	0.825
10.0%PVA 7% coal	Control	1.88400(*)	0.048	0.000
	10.0%PVA	0.05067	0.048	0.998
	10.0%PVA 3% coal	-0.034	0.048	1.000
	10.0%PVA 5% coal	0.02933	0.048	1.000
	12.5%PVA	.32133(*)	0.048	0.000
	12.5%PVA 3% coal	0.04067	0.048	1.000
	12.5%PVA 5% coal	0.02533	0.048	1.000
	12.5%PVA 7% coal	0.02667	0.048	1.000
	15.0%PVA	.20067(*)	0.048	0.003
	15.0%PVA 3% coal	0.12	0.048	0.385
	15.0%PVA 5% coal	0.13133	0.048	0.246
	15.0%PVA 7% coal	0.118	0.048	0.413
12.5%PVA	Control	1.56267(*)	0.048	0.000
	10.0%PVA	-.27067(*)	0.048	0.000
	10.0%PVA 3% coal	-.35533(*)	0.048	0.000
	10.0%PVA 5% coal	-.29200(*)	0.048	0.000
	10.0%PVA 7% coal	-.32133(*)	0.048	0.000
	12.5%PVA 3% coal	-.28067(*)	0.048	0.000
	12.5%PVA 5% coal	-.29600(*)	0.048	0.000
	12.5%PVA 7% coal	-.29467(*)	0.048	0.000
	15.0%PVA	-0.12067	0.048	0.376
	15.0%PVA 3% coal	-.20133(*)	0.048	0.003
	15.0%PVA 5% coal	-.19000(*)	0.048	0.007
	15.0%PVA 7% coal	-.20333(*)	0.048	0.003
12.5%PVA 3% coal	Control	1.84333(*)	0.048	0.000
	10.0%PVA	0.01	0.048	1.000
	10.0%PVA 3% coal	-0.07467	0.048	0.942
	10.0%PVA 5% coal	-0.01133	0.048	1.000
	10.0%PVA 7% coal	-0.04067	0.048	1.000
	12.5%PVA	.28067(*)	0.048	0.000
	12.5%PVA 5% coal	-0.01533	0.048	1.000
	12.5%PVA 7% coal	-0.014	0.048	1.000
	15.0%PVA	0.16	0.048	0.055
	15.0%PVA 3% coal	0.07933	0.048	0.912
	15.0%PVA 5% coal	0.09067	0.048	0.803
	15.0%PVA 7% coal	0.07733	0.048	0.926
12.5%PVA 5% coal	Control	1.85867(*)	0.048	0.000
	10.0%PVA	0.02533	0.048	1.000
	10.0%PVA 3% coal	-0.05933	0.048	0.991
	10.0%PVA 5% coal	0.004	0.048	1.000
	10.0%PVA 7% coal	-0.02533	0.048	1.000
	12.5%PVA	.29600(*)	0.048	0.000
	12.5%PVA 3% coal	0.01533	0.048	1.000
	12.5%PVA 7% coal	0.00133	0.048	1.000

	15.0%PVA	.17533(*)	0.048	0.020
	15.0%PVA 3% coal	0.09467	0.048	0.753
	15.0%PVA 5%coal	0.106	0.048	0.591
	15.0%PVA 7%coal	0.09267	0.048	0.778
12.5%PVA 7%coal	Control	1.85733(*)	0.048	0.000
	10.0%PVA	0.024	0.048	1.000
	10.0%PVA 3%coal	-0.06067	0.048	0.989
	10.0%PVA 5%coal	0.00267	0.048	1.000
	10.0%PVA 7%coal	-0.02667	0.048	1.000
	12.5%PVA	.29467(*)	0.048	0.000
	12.5%PVA 3%coal	0.014	0.048	1.000
	12.5%PVA 5%coal	-0.00133	0.048	1.000
	15.0%PVA	.17400(*)	0.048	0.022
	15.0%PVA 3% coal	0.09333	0.048	0.770
	15.0%PVA 5%coal	0.10467	0.048	0.611
	15.0%PVA 7%coal	0.09133	0.048	0.795
15.0%PVA	Control	1.68333(*)	0.048	0.000
	10.0%PVA	-0.15	0.048	0.098
	10.0%PVA 3%coal	-.23467(*)	0.048	0.000
	10.0%PVA 5%coal	-.17133(*)	0.048	0.027
	10.0%PVA 7%coal	-.20067(*)	0.048	0.003
	12.5%PVA	0.12067	0.048	0.376
	12.5%PVA 3%coal	-0.16	0.048	0.055
	12.5%PVA 5%coal	-.17533(*)	0.048	0.020
	12.5%PVA 7%coal	-.17400(*)	0.048	0.022
	15.0%PVA 3% coal	-0.08067	0.048	0.902
	15.0%PVA 5%coal	-0.06933	0.048	0.966
	15.0%PVA 7%coal	-0.08267	0.048	0.885
15.0%PVA 3% coal	Control	1.76400(*)	0.048	0.000
	10.0%PVA	-0.06933	0.048	0.966
	10.0%PVA 3%coal	-0.154	0.048	0.078
	10.0%PVA 5%coal	-0.09067	0.048	0.803
	10.0%PVA 7%coal	-0.12	0.048	0.385
	12.5%PVA	.20133(*)	0.048	0.003
	12.5%PVA 3%coal	-0.07933	0.048	0.912
	12.5%PVA 5%coal	-0.09467	0.048	0.753
	12.5%PVA 7%coal	-0.09333	0.048	0.770
	15.0%PVA	0.08067	0.048	0.902
	15.0%PVA 5%coal	0.01133	0.048	1.000
	15.0%PVA 7%coal	-0.002	0.048	1.000
15.0%PVA 5%coal	Control	1.75267(*)	0.048	0.000
	10.0%PVA	-0.08067	0.048	0.902
	10.0%PVA 3%coal	-.16533(*)	0.048	0.040
	10.0%PVA 5%coal	-0.102	0.048	0.650
	10.0%PVA 7%coal	-0.13133	0.048	0.246
	12.5%PVA	.19000(*)	0.048	0.007
	12.5%PVA 3%coal	-0.09067	0.048	0.803
	12.5%PVA 5%coal	-0.106	0.048	0.591
	12.5%PVA 7%coal	-0.10467	0.048	0.611
	15.0%PVA	0.06933	0.048	0.966
	15.0%PVA 3% coal	-0.01133	0.048	1.000

	15.0%PVA 7%coal	-0.01333	0.048	1.000
15.0%PVA 7%coal	Control	1.76600(*)	0.048	0.000
	10.0%PVA	-0.06733	0.048	0.973
	10.0%PVA 3%coal	-0.152	0.048	0.088
	10.0%PVA 5%coal	-0.08867	0.048	0.825
	10.0%PVA 7%coal	-0.118	0.048	0.413
	12.5%PVA	.20333(*)	0.048	0.003
	12.5%PVA 3%coal	-0.07733	0.048	0.926
	12.5%PVA 5%coal	-0.09267	0.048	0.778
	12.5%PVA 7%coal	-0.09133	0.048	0.795
	15.0%PVA	0.08267	0.048	0.885
	15.0%PVA 3% coal	0.002	0.048	1.000
	15.0%PVA 5%coal	0.01333	0.048	1.000

Tests of Between-Subjects Effects

Dependent Variable: %NO3-N increasing (HRT2)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	46.394(a)	12	3.866	222.575	.000
Intercept	427.536	1	427.536	24613.005	.000
COAL	.671	3	.224	12.885	.000
PVA	32.792	3	10.931	629.281	.000
PVA * COAL	.410	6	.068	3.932	.001
Error	3.161	182	.017		
Total	626.788	195			
Corrected Total	49.556	194			

a. R Squared = .936 (Adjusted R Squared = .932)

Table B-24 Comparison of NO₃-N effluents of conditions in Group 3 (HRT 4 hrs.)

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	42.85	12	3.571	232.829	0
Within Groups	2.791	182	0.015		
Total	45.641	194			

Multiple Comparisons (Tukey HSD)						
Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	
% NH ₃ -N Removal Efficiency	Control	10.0%PVA	-1.69933(*)	0.045	0.000	
		10.0%PVA 3%coal	-1.79467(*)	0.045	0.000	
		10.0%PVA 5%coal	-1.80333(*)	0.045	0.000	
		10.0%PVA 7%coal	-1.78600(*)	0.045	0.000	
		12.5%PVA	-1.63400(*)	0.045	0.000	
		12.5%PVA 3%coal	-1.80733(*)	0.045	0.000	
		12.5%PVA 5%coal	-1.80467(*)	0.045	0.000	
		12.5%PVA 7%coal	-1.79200(*)	0.045	0.000	
		15.0%PVA	-1.70000(*)	0.045	0.000	
		15.0%PVA 3% coal	-1.70267(*)	0.045	0.000	
		15.0%PVA 5%coal	-1.71333(*)	0.045	0.000	
		15.0%PVA 7%coal	-1.73800(*)	0.045	0.000	
		10.0%PVA	Control	1.69933(*)	0.045	0.000
			10.0%PVA 3%coal	-0.09533	0.045	0.658
			10.0%PVA 5%coal	-0.104	0.045	0.520
	10.0%PVA 7%coal		-0.08667	0.045	0.784	
	12.5%PVA		0.06533	0.045	0.966	
	12.5%PVA 3%coal		-0.108	0.045	0.457	
	12.5%PVA 5%coal		-0.10533	0.045	0.499	
	12.5%PVA 7%coal		-0.09267	0.045	0.699	
	15.0%PVA		-0.00067	0.045	1.000	
	15.0%PVA 3% coal		-0.00333	0.045	1.000	
	15.0%PVA 5%coal		-0.014	0.045	1.000	
	15.0%PVA 7%coal		-0.03867	0.045	1.000	
	10.0%PVA 3%coal		Control	1.79467(*)	0.045	0.000
			10.0%PVA	0.09533	0.045	0.658
			10.0%PVA 5%coal	-0.00867	0.045	1.000
		10.0%PVA 7%coal	0.00867	0.045	1.000	
		12.5%PVA	.16067(*)	0.045	0.027	
		12.5%PVA 3%coal	-0.01267	0.045	1.000	
12.5%PVA 5%coal		-0.01	0.045	1.000		
12.5%PVA 7%coal		0.00267	0.045	1.000		
15.0%PVA		0.09467	0.045	0.668		
15.0%PVA 3% coal		0.092	0.045	0.709		
15.0%PVA 5%coal		0.08133	0.045	0.848		
15.0%PVA 7%coal		0.05667	0.045	0.989		
10.0%PVA 5%coal		Control	1.80333(*)	0.045	0.000	
		10.0%PVA	0.104	0.045	0.520	
		10.0%PVA 3%coal	0.00867	0.045	1.000	
	10.0%PVA 7%coal	0.01733	0.045	1.000		
	12.5%PVA	.16933(*)	0.045	0.015		

	12.5%PVA 3% coal	-0.004	0.045	1.000
	12.5%PVA 5% coal	-0.00133	0.045	1.000
	12.5%PVA 7% coal	0.01133	0.045	1.000
	15.0%PVA	0.10333	0.045	0.531
	15.0%PVA 3% coal	0.10067	0.045	0.574
	15.0%PVA 5% coal	0.09	0.045	0.738
	15.0%PVA 7% coal	0.06533	0.045	0.966
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10.0%PVA 7% coal	Control	1.78600(*)	0.045	0.000
	10.0%PVA	0.08667	0.045	0.784
	10.0%PVA 3% coal	-0.00867	0.045	1.000
	10.0%PVA 5% coal	-0.01733	0.045	1.000
	12.5%PVA	.15200(*)	0.045	0.049
	12.5%PVA 3% coal	-0.02133	0.045	1.000
	12.5%PVA 5% coal	-0.01867	0.045	1.000
	12.5%PVA 7% coal	-0.006	0.045	1.000
	15.0%PVA	0.086	0.045	0.792
	15.0%PVA 3% coal	0.08333	0.045	0.825
	15.0%PVA 5% coal	0.07267	0.045	0.926
	15.0%PVA 7% coal	0.048	0.045	0.998
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12.5%PVA	Control	1.63400(*)	0.045	0.000
	10.0%PVA	-0.06533	0.045	0.966
	10.0%PVA 3% coal	-.16067(*)	0.045	0.027
	10.0%PVA 5% coal	-.16933(*)	0.045	0.015
	10.0%PVA 7% coal	-.15200(*)	0.045	0.049
	12.5%PVA 3% coal	-.17333(*)	0.045	0.011
	12.5%PVA 5% coal	-.17067(*)	0.045	0.013
	12.5%PVA 7% coal	-.15800(*)	0.045	0.033
	15.0%PVA	-0.066	0.045	0.963
	15.0%PVA 3% coal	-0.06867	0.045	0.950
	15.0%PVA 5% coal	-0.07933	0.045	0.869
	15.0%PVA 7% coal	-0.104	0.045	0.520
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12.5%PVA 3% coal	Control	1.80733(*)	0.045	0.000
	10.0%PVA	0.108	0.045	0.457
	10.0%PVA 3% coal	0.01267	0.045	1.000
	10.0%PVA 5% coal	0.004	0.045	1.000
	10.0%PVA 7% coal	0.02133	0.045	1.000
	12.5%PVA	.17333(*)	0.045	0.011
	12.5%PVA 5% coal	0.00267	0.045	1.000
	12.5%PVA 7% coal	0.01533	0.045	1.000
	15.0%PVA	0.10733	0.045	0.467
	15.0%PVA 3% coal	0.10467	0.045	0.510
	15.0%PVA 5% coal	0.094	0.045	0.679
	15.0%PVA 7% coal	0.06933	0.045	0.947
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12.5%PVA 5% coal	Control	1.80467(*)	0.045	0.000
	10.0%PVA	0.10533	0.045	0.499
	10.0%PVA 3% coal	0.01	0.045	1.000
	10.0%PVA 5% coal	0.00133	0.045	1.000
	10.0%PVA 7% coal	0.01867	0.045	1.000
	12.5%PVA	.17067(*)	0.045	0.013
	12.5%PVA 3% coal	-0.00267	0.045	1.000
	12.5%PVA 7% coal	0.01267	0.045	1.000

	15.0%PVA	0.10467	0.045	0.510
	15.0%PVA 3% coal	0.102	0.045	0.552
	15.0%PVA 5% coal	0.09133	0.045	0.719
	15.0%PVA 7% coal	0.06667	0.045	0.960
12.5%PVA 7% coal	Control	1.79200(*)	0.045	0.000
	10.0%PVA	0.09267	0.045	0.699
	10.0%PVA 3% coal	-0.00267	0.045	1.000
	10.0%PVA 5% coal	-0.01133	0.045	1.000
	10.0%PVA 7% coal	0.006	0.045	1.000
	12.5%PVA	.15800(*)	0.045	0.033
	12.5%PVA 3% coal	-0.01533	0.045	1.000
	12.5%PVA 5% coal	-0.01267	0.045	1.000
	15.0%PVA	0.092	0.045	0.709
	15.0%PVA 3% coal	0.08933	0.045	0.747
	15.0%PVA 5% coal	0.07867	0.045	0.876
	15.0%PVA 7% coal	0.054	0.045	0.993
15.0%PVA	Control	1.70000(*)	0.045	0.000
	10.0%PVA	0.00067	0.045	1.000
	10.0%PVA 3% coal	-0.09467	0.045	0.668
	10.0%PVA 5% coal	-0.10333	0.045	0.531
	10.0%PVA 7% coal	-0.086	0.045	0.792
	12.5%PVA	0.066	0.045	0.963
	12.5%PVA 3% coal	-0.10733	0.045	0.467
	12.5%PVA 5% coal	-0.10467	0.045	0.510
	12.5%PVA 7% coal	-0.092	0.045	0.709
	15.0%PVA 3% coal	-0.00267	0.045	1.000
	15.0%PVA 5% coal	-0.01333	0.045	1.000
	15.0%PVA 7% coal	-0.038	0.045	1.000
15.0%PVA 3% coal	Control	1.70267(*)	0.045	0.000
	10.0%PVA	0.00333	0.045	1.000
	10.0%PVA 3% coal	-0.092	0.045	0.709
	10.0%PVA 5% coal	-0.10067	0.045	0.574
	10.0%PVA 7% coal	-0.08333	0.045	0.825
	12.5%PVA	0.06867	0.045	0.950
	12.5%PVA 3% coal	-0.10467	0.045	0.510
	12.5%PVA 5% coal	-0.102	0.045	0.552
	12.5%PVA 7% coal	-0.08933	0.045	0.747
	15.0%PVA	0.00267	0.045	1.000
	15.0%PVA 5% coal	-0.01067	0.045	1.000
	15.0%PVA 7% coal	-0.03533	0.045	1.000
15.0%PVA 5% coal	Control	1.71333(*)	0.045	0.000
	10.0%PVA	0.014	0.045	1.000
	10.0%PVA 3% coal	-0.08133	0.045	0.848
	10.0%PVA 5% coal	-0.09	0.045	0.738
	10.0%PVA 7% coal	-0.07267	0.045	0.926
	12.5%PVA	0.07933	0.045	0.869
	12.5%PVA 3% coal	-0.094	0.045	0.679
	12.5%PVA 5% coal	-0.09133	0.045	0.719
	12.5%PVA 7% coal	-0.07867	0.045	0.876
	15.0%PVA	0.01333	0.045	1.000
	15.0%PVA 3% coal	0.01067	0.045	1.000

	15.0%PVA 7%coal	-0.02467	0.045	1.000
15.0%PVA 7%coal	Control	1.73800(*)	0.045	0.000
	10.0%PVA	0.03867	0.045	1.000
	10.0%PVA 3%coal	-0.05667	0.045	0.989
	10.0%PVA 5%coal	-0.06533	0.045	0.966
	10.0%PVA 7%coal	-0.048	0.045	0.998
	12.5%PVA	0.104	0.045	0.520
	12.5%PVA 3%coal	-0.06933	0.045	0.947
	12.5%PVA 5%coal	-0.06667	0.045	0.960
	12.5%PVA 7%coal	-0.054	0.045	0.993
	15.0%PVA	0.038	0.045	1.000
	15.0%PVA 3% coal	0.03533	0.045	1.000
	15.0%PVA 5%coal	0.02467	0.045	1.000

Tests of Between-Subjects Effects

Dependent Variable: %NO3-N increasing (HRT4)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	42.850(a)	12	3.571	232.829	.000
Intercept	446.988	1	446.988	29144.955	.000
COAL	.296	3	.099	6.436	.000
PVA	31.779	3	10.593	690.689	.000
PVA * COAL	.139	6	.023	1.509	.177
Error	2.791	182	.015		
Total	647.036	195			
Corrected Total	45.641	194			

a. R Squared = .939 (Adjusted R Squared = .935)

APPENDIX C

Details of shrimp culture wastewater recirculation system at the Charoen Pokphand Foods Co., Ltd.

The shrimp culture wastewater exchange program of Charoen Pokphand Foods Co., Ltd. (Hatchery) has the quality and quantity of effluent follow as Table C-1. The quantity of wastewater was exchanged cover the hatching around 10.5 m³.

Table C-1 The shrimp culture wastewater exchanged program in each stage.

Stage	Zoeal	Mysis	PL1	PL2	PL3	PL4	PL5	PL6	PL7	PL8	PL9	PL10
% Exchange	20	25	30	30	30	40	40	40	40	50	50	50

Synthetic wastewater in this study was used as shrimp culture wastewater. The average chemical characteristics of synthetic wastewater, which used as shrimp culture wastewater, in this study, were NH₃-N 2.13 mg/L, COD 32 mg/L, salinity 20 g/L. NO₂-N and NO₃-N assumed as zero. The details of chemical characteristics of shrimp culture wastewater and synthetic wastewater were presented in Table C-2 and the physical characteristics were following and illustrated in Figure C-1. The mineral compositions in brine water, which was diluted to sea water (20 ppt) for preparation of synthetic wastewater shown as Table C-4.

Table C-2 The Chemical characteristics of the shrimp culture wastewater

Parameters	shrimp culture wastewater				synthetic wastewater			
	Min.	Max.	Mean.	SD	Min.	Max.	Mean.	SD
NH ₃ -N (mg/L)	0.00	2.00	0.71	0.74	1.95	2.47	2.13	0.14
NO ₂ -N (mg/L)	0.00	0.30	0.19	0.13	0.03	0.09	0.05	0.02
NO ₃ -N (mg/L)	0.00	2.50	1.03	0.12	0.00	0.05	0.02	0.02
COD (mg/L)	0.00	65.00	34.50	0.54	29.50	35.80	32.00	0.02

The details of physical characteristics of shrimp culture wastewater

pH	7.5-8.5	
SS	15-20	mg/L

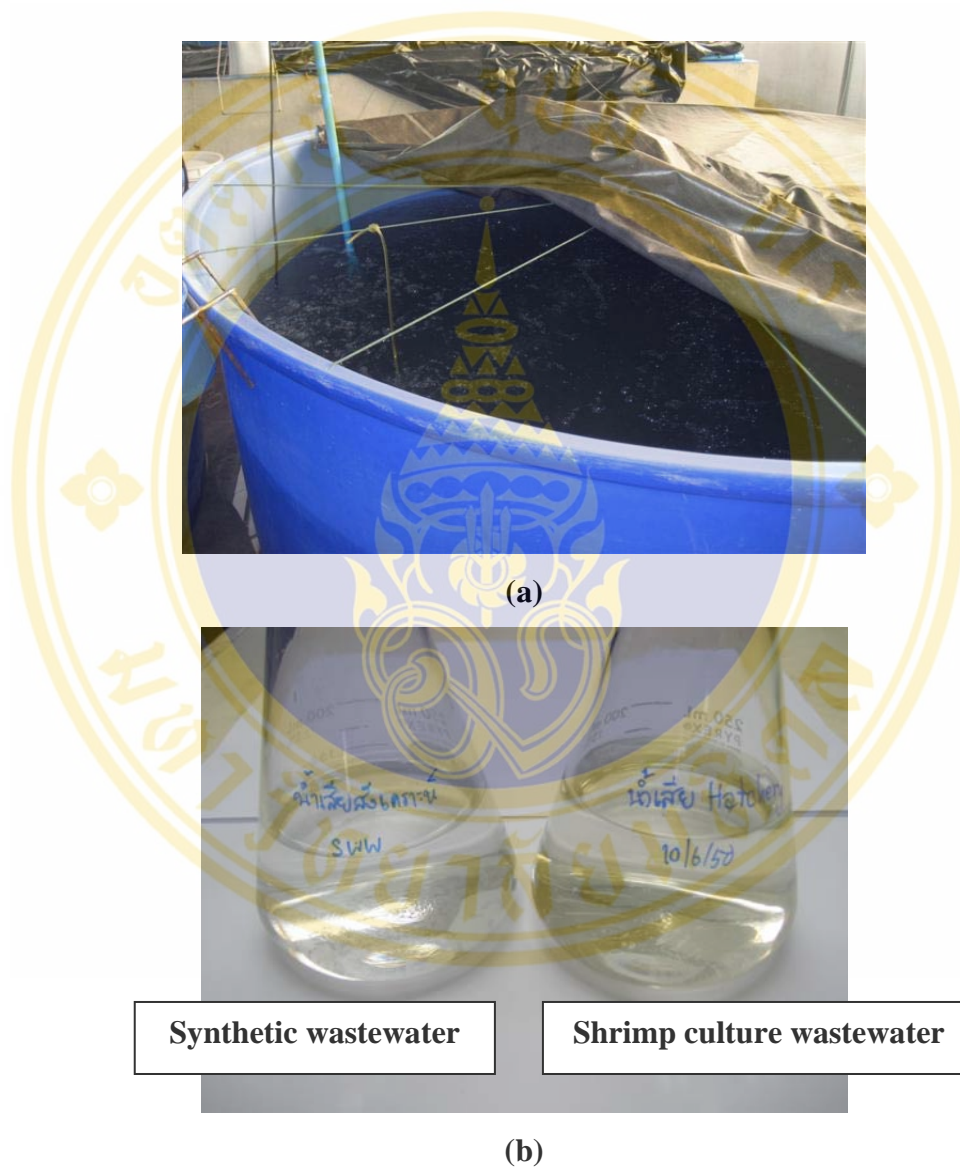


Figure C-1 The details of physical characteristics of shrimp culture wastewater and synthetic wastewater. (a); the shrimp culture tank, (b); the comparison of physical characteristics of shrimp culture wastewater and synthetic wastewater

Actual shrimp culture wastewater was operated with optimum condition of the mixture ratio (% , PVA:coal); 10.0:3 in nitrification bioreactor. The effluent NH₃-N, NO₂-N, NO₃-N and COD in the effluent and NH₃-N removal efficiency of 0.15 mg/L, 0.03 mg/L, 1.80 mg/L, 35.47 mg/L, 92.31 %, respectively. And were summarized in Table C-3

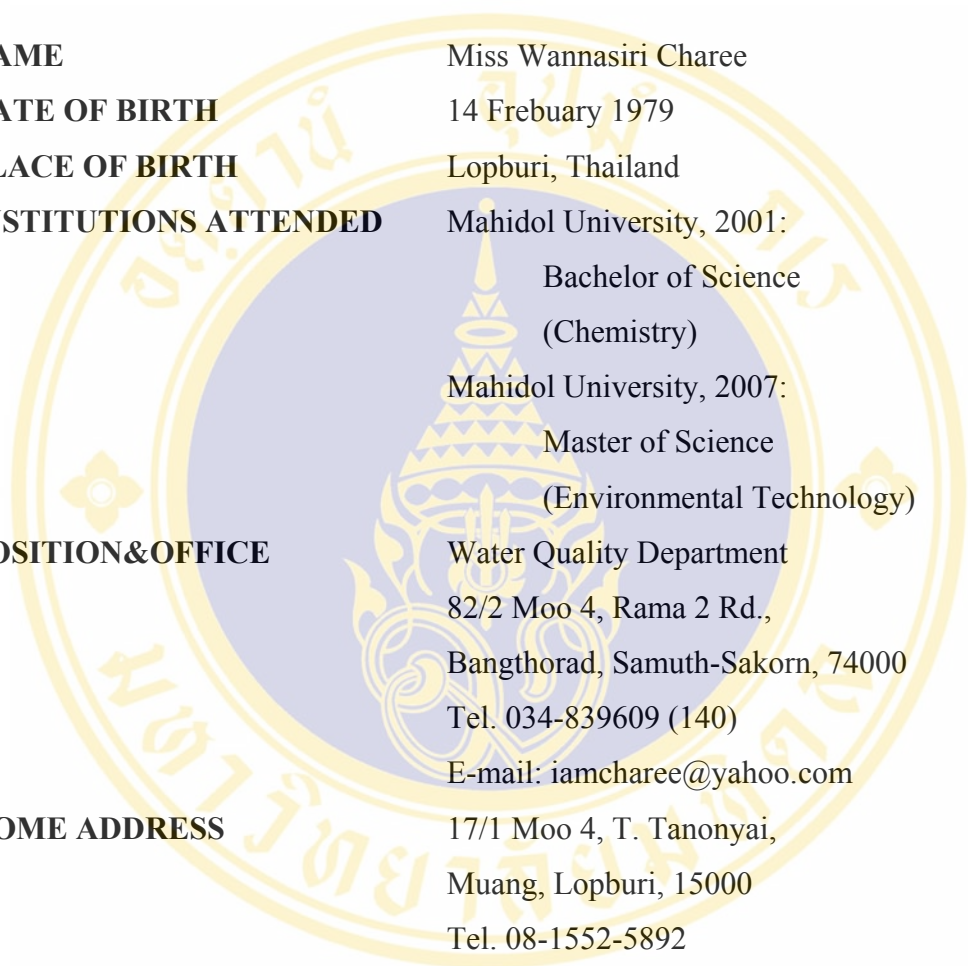
Table C-3 The influent and effluent of actual shrimp culture wastewater were operated through out the nitrification bioreactor with the optimum condition.

periods	Influents				Effluents				NH ₃ -N removal
	NH ₃ -N	NO ₂ -N	NO ₃ -N	COD	NH ₃ -N	NO ₂ -N	NO ₃ -N	COD	
1	2.08	0.21	0.30	32.00	0.15	0.05	1.87	33.00	92.79
2	2.04	0.25	0.30	32.00	0.17	0.04	1.82	32.00	91.67
3	2.10	0.22	0.30	36.00	0.15	0.01	1.93	36.00	92.86
4	2.12	0.24	0.30	35.00	0.18	0.05	1.88	35.00	91.51
5	2.06	0.20	0.30	36.00	0.15	0.05	1.85	36.00	92.72
6	2.04	0.25	0.43	36.00	0.16	0.04	1.83	36.00	92.16
7	2.01	0.30	0.50	36.00	0.17	0.02	1.81	36.00	91.54
8	2.05	0.28	0.50	36.00	0.14	0.03	1.87	36.00	93.17
9	1.95	0.25	0.50	36.00	0.17	0.01	1.76	36.00	91.28
10	1.89	0.26	0.45	36.00	0.13	0.04	1.71	36.00	93.12
11	1.91	0.30	0.55	36.00	0.13	0.05	1.72	36.00	93.19
12	1.95	0.27	0.33	36.00	0.15	0.01	1.78	36.00	92.31
13	1.89	0.29	0.32	36.00	0.15	0.02	1.71	36.00	92.06
14	1.99	0.30	0.45	36.00	0.16	0.01	1.81	36.00	91.96
15	1.94	0.27	0.50	36.00	0.15	0.03	1.75	36.00	92.27
max	2.12	0.30	0.55	36.00	0.18	0.05	1.93	36.00	93.19
min	1.89	0.20	0.30	32.00	0.13	0.01	1.71	32.00	91.28
average	2.00	0.26	0.40	35.40	0.15	0.03	1.80	35.47	92.31
SD	0.08	0.03	0.10	1.40	0.01	0.02	0.07	1.25	0.64

Table C-4 The mineral compositions in brine water.

minerals	Conc. in brine water (mg/l)
Ca_2^+	400
Mg_2^+	1350
Na^+	10500
Cl^-	19000
K^+	380
HCO_3^-	142
P	0.07
SO_4^{2-}	2700

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