Chapter 1 Introduction

1.1 Background Information

The activated sludge process is currently one of the most popular and efficient biological wastewater treatment systems. Traditionally, biological reactor consumes organic pollutant then generates energy and excess biomass with a ratio of 65: 35 based on lactose (Ramalho, 1986). The excessive amount of waste activated sludge (WAS) needs to be costly treated prior to be disposed in a landfill. The current situation of land scarcity and strict environmental regulations has seriously limited the use of activated sludge process in the developed nations such as United Kingdom (Cheeseman et al., 2003). Therefore, the current concept and practice is to develop an effective process to minimize and reuse WAS in order to achieve resource recovery. This approach may save treatment cost as well as reducing the secondary pollution. Some studies have confirmed the reuse of processed WAS for bricks (Huang et al., 2001), an adsorbent of copper (Pan et al., 2003), a raw material of Portland cement (Taruya et al., 2002), and even micro-media in an activated sludge process (Kim et al., 2003). The incinerated WAS is extremely stable due to it has been converted to ash (Tay and Show, 1997), which is composed entirely of inorganic materials such as silicon oxide, aluminum oxide, and iron oxide (Pan and Tseng, 2001). Besides, dried and powdered WAS, the final product, which has a rough surface and different particle sizes (Kim et al., 2003), is suitable for further application in both adsorption and other applications.

Kim et al. (2003) proposed the optimal condition for drying sludge is at 500℃ for 30 minutes. During drying sludge at high temperature, it can simultaneously remove organic substances and generate a rough surface with high porosity and better water absorption ability (Wiebusch and Seyfried, 1997). Increasing the sintered temperature can enhance the density and intensity observed with scanning electron microscopy and dispersive X-ray (Monzo et al., 2003). Wasserman and Bentur (1997) proposed that decreasing the bulk density of the aggregate would be expected to increase in porosity, strength and absorption characteristics of the pellets. Properties, strength, density, and absorption are of prime importance in controlling the behavior of the lightweight aggregate pellets. Cheeseman et al. (2005) suggested that the idea aggregate pellet should have (1) a strong but low density, porous, sintered ceramic core；

(2) a dense continuous surface layer； (3) a near-spherical shape to improve fresh concrete property. Another important aspect of the baked WAS is not be recognized as a hazardous waste unless it contains relatively high levels of heavy metals (Cheeseman et al., 2003). Thus, the baked WAS and some supporting material may become immobilized biological cell in this research.

Immobilization is usually conducted under anaeration processing, but K-Hamedaani et al. (2003) showed a practical application of aerated condition in a food factory with a packed bed bioreactor. The immobilization system provides high biomass concentration in the activated sludge process (Chen et al., 1998) and can reduce the excess sludge. It also can increase the efficiency of denitrification at high nitrogen loading rates (Matsumura et al., 1997). It even provides simultaneous nitrification and denitrification (SND) efficiency with real time aeration control system (Helmer and Kunst, 1998). Therefore, the advanced nutrient removal can be performed simultaneously by nitrification and denitrification processes in immobilized system. The addition of porous pellets in the oxic-anoxic process accelerates the overall treatment efficiency since it combines the advantage of both activated sludge and attached biofilm. The compact reactor can also save the space and cost (Takizawa et al., 1996).

Chapter 2 Literature Review

2.1 Characteristics and Reutilization of Waste Activated Sludge

In Taiwan, the annual sludge (dewatered) production from 34 industrial wastewater treatment plants is approximately 0.67 million tons (Weng et al., 2003). Conventionally, most sludge is treated with incineration to be as sewage sludge ash (SSA), but heat generated by combustion is not always utilized because of it contains a high fraction of water content and the heating value is low (Kojima et al., 2002). SSA is often landfilled, as it is not considered hazardous waste, despite having relatively high heavy metals of potential environmental concern (Cheeseman et al., 2003). Moreover, landfill disposal of sludge may no longer be appropriate owing to land scarcity and more stringent environmental control regulations. Therefore, future sludge management will be moving towards minimization and reutilization of sludge as useful resources. Some studies reutilized the SSA as brick material, cement substitute, raw material of Portland cement and even micro media (Table 2-1). This study will be attempted to reutilize the Dou-Liou Industrial Park waste sludge as rebuilt pellets in an immobilized system.

Table 2-1 Utilization of Sewage sludge ash (SSA)

References	Form of SSA	Function
This study., 2005	Pellets	Immobilized cells
Weng et al., 2003	Powder	Brick material
Pan and Tseng., 2001	Agglomeration	Fine aggregate, Pozzolanic material
Taruya et al., 2002	Cake	Raw material of Portland cement
Pan et al., 2003	Powder	Copper adsorbent
Kim et al., 2003	Powder	Micro-media

2.2 Mechanism of immobilized system

2.2.1 Formation of attached biofilm on bio-carriers

Traditionally, the porous materials (bio-carriers) were applied to immobilized bioreactor systems, such as trickling filters, fluidized bed reactor and rotating biological contactors (RBCs). In this study, the rebuilt WAS pellets were utilized as bio-carriers in the activated sludge reactor. The immobilized system in the bioreactor is composed of support material and attached growth biomass. The formation of immobilized system is complex (Figure 2-1) as a result of a combination of factors, such as bacterial growth, substrate consumption, attachment, external-internal mass transfer of substrates and products, cell death, shear loss (biofilm loss because of erosion), sloughing (fragments disrupting from the biofilm), structure of the support material, competition between bacterial species, and effects of predators (Wijffels. and Tramper., 1995).

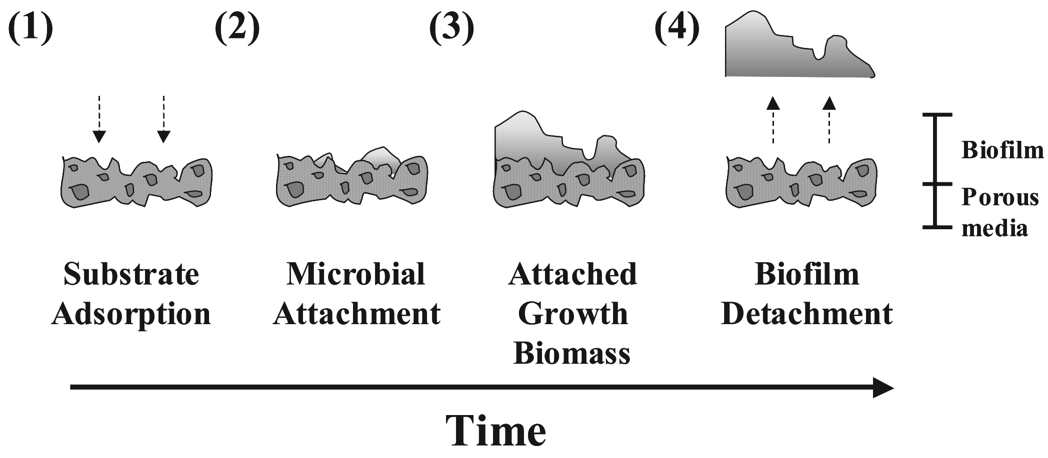

Figure 2-1 Schematic presentation of the formation of a biofilm

The biofilm formation process included as follows:

1. Substrate adsorption: substrate adsorbed into the support material.
2. Microbial attachment: Microbial in the bulk were attached onto the surface of support material (bio-carriers).
3. Attached growth biomass: Substrate utilized with the attached growth biomass. The biofilm thickness can be increased and become matured gradually.
4. Biofilm detachment: When the biofilm become matured for a long time, the biofilm is peeled out owing to the inner starvation zone formed.

Other conditions such as concentration of substrate, temperature, pH, turbulence and diffusion rate all will influence the biofilm formation (Wijffels. and Tramper., 1995).

2.2.2 Mass and Oxygen transfer of immobilized system

The biofilm can be aerobic on the surface, anoxic in the middle and anaerobic at the point of attachment to the pellet (Figure 2-2). The concentration gradients of dissolved oxygen (DO) and organic substrate are similar, being highest at the external surface of the biofilm and lowest at the surface of pellet (Semmens et al., 2003).

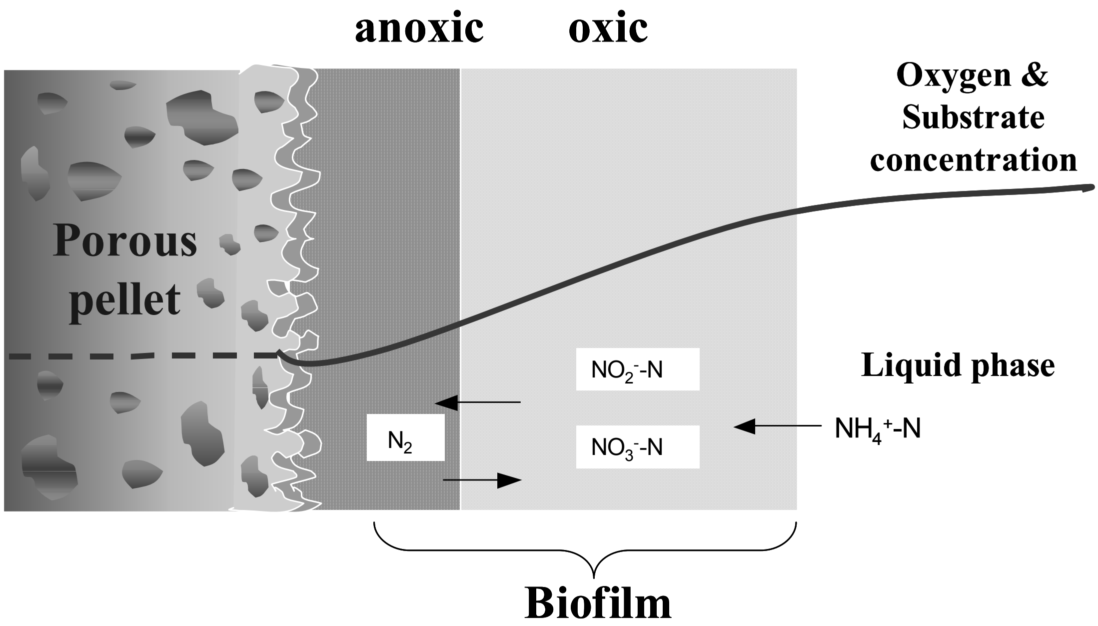

Figure 2-2 Diagram of oxygen and mass transfer of immobilized system under nitrogen removal reaction

The diffusion reaction theory shows that the growth rate of biofilm is dependent on substrate loading rate applied to the biofilm system. Therefore, the substrate loading rate may represent the capability of biofilm growth, and can be regarded as the growth force of biofilm culture (Liu et al., 2003). Hibiya et al., (2004) proposed the effective internal diffusion coefficient of the biofilms changed with its density and thickness.

2.3 Simultaneous nitrification and denitrification (SND) process in the immobilized system

In this study, the suspended growth activated sludge and the attached growth biofilm are both used for the immobilized system. The purpose of the combination is to conduct the SND efficiency in the AS (activated sludge) with rebuilt pellets reactor.

2.3.1 SND of suspended growth activated reactor

In conventional biological nutrient removal (BNR) systems, nitrogen removal is accomplished with a two-stage treatment, aerobic nitrification (NH_4^+-N + $2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$) and anoxic denitrification ($NO_3^- \rightarrow OH^- + 1/2N_2$) (Rodgers and Zhan., 2004). And this system needs to divide into two kinds of reactors to remove the nutrient from wastewater. More studies have been showing that nitrification and denitrification can occur concurrently in the same reactor under aerobic condition (Keller et al., 1997； Zeng et al., 2003), which is called as simultaneous nitrification and denitrification (SND). SND system is a point of interest for designers and operators of wastewater treatment plants due to it may have significant advantages over the conventional separated nitrification and denitrification processes. Under an SND system, the nitrogen (N) removal can be achieved with partial oxidation of ammonium to nitrite, which is then directly reduced to N_2 gas (Liou, 2004; Yoo et al., 1999). This process, termed SND via nitrite, saves 40% of the COD requirement compared with conventional denitrification via nitrate. It can achieve higher denitrification rates and a lower yield during aerobic growth (Zeng et al., 2003).

2.3.2 SND of attached growth biofilm reactor

The immobilized system can be utilized with some support materials (such as zeolite, plastic pellet, activated carbon) as micro-media to offer the growth of the attached biofilm. When the biofilm becomes matured, two different layer of biofilm classified to aerobic and anoxic zone close to the surface of support material. During this processes, oxidation of organic compound, nitrification and denitrification may occurred in the same environment (Sørensen and Nielsen., 1996). The aerobic zone can offer nitrification process (NH_4^+-N converted to NO_3^--N and NO_2^--N) occurred in the biofilm and anoxic zone can apply the space of dentrification process (NO_3^--N and NO_2^--N converted to N_2)

simultaneously (Hibiya et al., 2003). Under the immobilized system, it can remain high biomass concentrations and stability in operation (Su and Ouyang., 1996) and conduct the efficiency of simultaneous nitrification and denitrification (SND).

2.3.3 Advantage and disadvantage of immobilized system

The immobilized system compared with traditional activated sludge system has main advantages as follows (Loukidou and Zouboulis., 2001):

1. Higher biomass concentrations in the aeration tank, which correspond to lower wastage of biomass；
2. Elimination of long sludge-settling periods；
3. Co-existence of aerobic and anoxic metabolic (simultaneous nitrification and denitrificaion)activity within the same biomass ecosystem；
4. Up-grading of existing wastewater treatment plants at a minimum cost；and
5. Lower sensitivity to toxicity effects, as well as to other adverse environmental conditions.

The main disadvantage of this system is however, the need for operation at higher concentrations of dissolved oxygen (above DO of 2-3 mg/L) in order to maintain the biofilm activity and high nitrification rats (Loukidou and Zouboulis., 2001).

2.4 Real-time control strategy

Many system-monitoring parameters, e.g. OPR (Oxiadtion Reduction Potential), pH and DO, can possibly be used as indicators of reaction progress for the biological treatment real-time control strategy. Andreottola et al., (2001) operated a SBR system with an on-line control of ORP, pH and DO for treating the high ammonium wastewater from a wood factory. A nearly complete removal of ammonium (99%) was reported at 20℃. The on-line control system allows the applied load to be doubled without causing an obvious decrease in the ammonium removal efficiency.

Using the on-line measured ORP as an indicator, which can provide the biological nitrification/denitrification process information. Under normal loading conditions, the system ORP of a nitrification process continues to rise and then approaches a plateau when the biochemical process is completed (Paul et al., 1998).

2.5 Research Objectives and Approach

This study is to build up the immobilization system with waste activated sludge and pellet in aerobic process.

The primary objectives of this thesis research are shown as following:

1. Develop the technique to apply the waste industrial sludge as immobilized media.
2. Apply the immobilized media in the aerated sludge reactor to conduct SND reactor.
3. Develop a mathematical model for the real-time control of pellet SND process.

Chapter 3 Materials and Methods

3.1 Experiment design and investigation flow chart

Flow chart of this study could be divided into three parts (Figure 3-1). Part (A) Rebuilt WAS pellet as an immobilized media in activated sludge reactor. Part (B) Develop an immobilized system to conduct SND reactor. Part (C) Establish the Nernst equation with the immobilized system experiment.

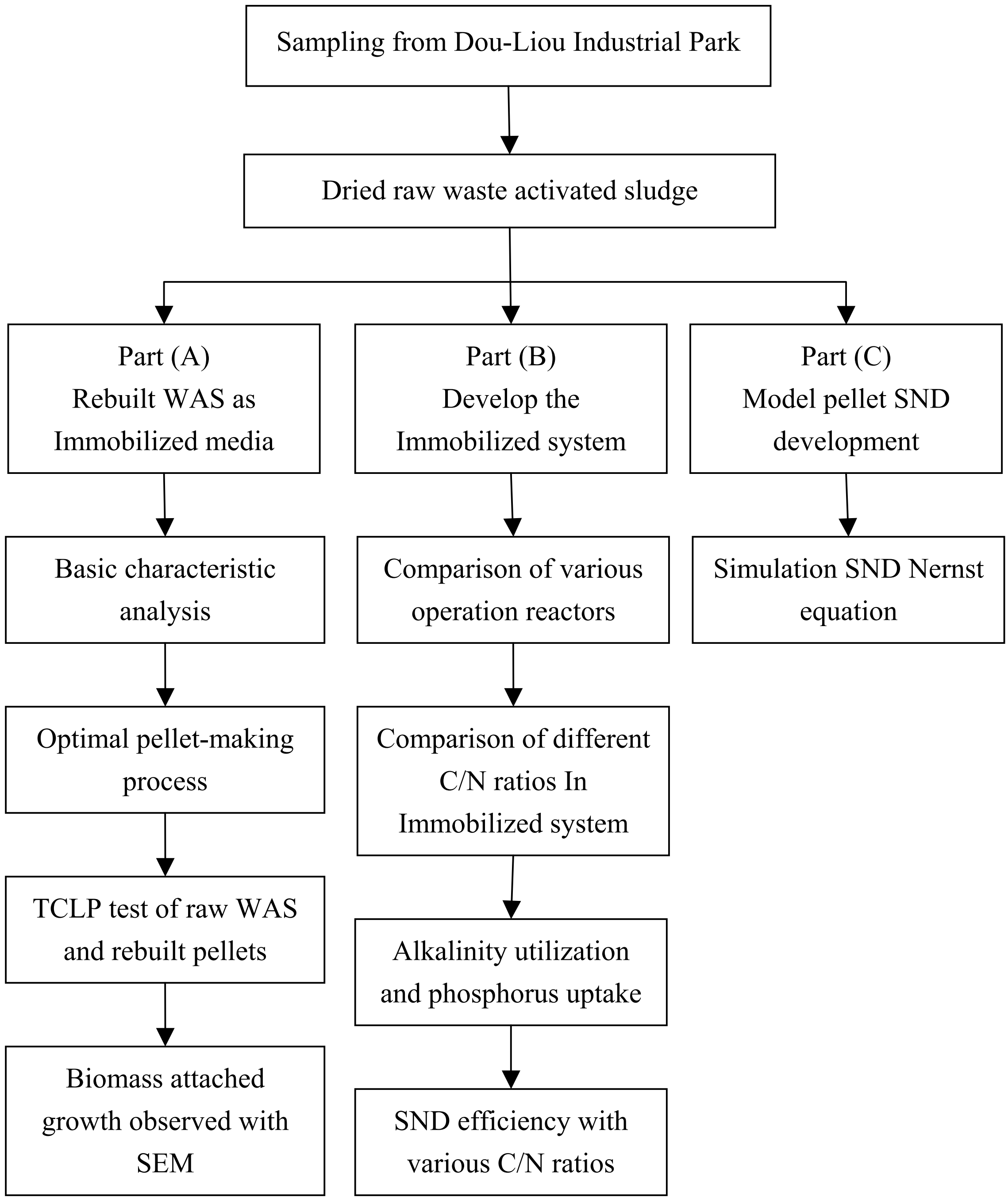

Figure 3-1 The flow chart of immobilized system study included three parts of (A) Rebuilt WAS as immobilized media, (B) Develop the immobilized system and (C) Develop pellet SND model

3.2 Rebuilt WAS pellet as immobilized media

3.2.1 Waste activated sludge sampling and its basic characteristics analysis

The waste activated sludge (WAS) was collected from the Dou-Liou Industrial Park (DLIP) wastewater treatment plant located in the mid-Taiwan treating 7,086 CMD industrial discharges from more than 176 factories in the secondary biological treatment. The system generates 7,660 Kg WAS daily that is dewatered with belt press filter before being sended to a sanitary landfill for disposal. The moisture content of raw WAS is determined with oven dried at 105℃ for 3 days (NIEA R205.01C). Ash content is obtained from baking with 1100℃ box furnace at 800℃ for 3 hrs. The flammable content is determined with Eq. 3.1.

$$\text{Flammable content }\% = 100 - \text{Moisture content }\% - \text{Ash content }\% \quad (3.1)$$

3.2.2 Preparation of rebuilt WAS pellets

The fresh WAS sample was baked and then mixed with red soil and chemical additive (A) with the addition of few water to yield a final consistency suitable for the mixture processed into uniform spherical pellets of 7-8 mm in diameter. In order to obtain the best rebuilt pellets, the rebuilt pellets were composed of WAS, red soil and chemical additive (A) with different mixed ratio based on weight from 5:5:1 to 8:5:1. Meanwhile another type of the pellets were also mixed of WAS and red soil with various proportion from 5:5 to 8:5. The optimal formula of mixture ratio could be obtained with two kinds of mixture forms. The pellet was then dried at 105℃ for one day. The temperature was then baked at an increment of 100℃ until the final baking temperature of 800℃ was reached. The sample was baked for 1 hour at every temperature level and baked at 800℃ for 30minutes. After cooling down at 25℃ room temperature, the rebuilt pellets diameter were 6-8mm.

3.2.3 Toxicity Characteristics Leaching Procedure (TCLP) of raw WAS and rebuilt pellets

Owing to its potential function of as-immobilized cells in activated sludge, the rebuilt pellets and WAS must be free from toxicity as determined using the leaching test. The toxic characteristics leaching procedure (TCLP) was used to determine the effect of sludge metal