

Chapter 3

Treatment of Wastewaters from Chemical Industries



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Abstract Chemical industry wastewaters are diverse in composition ranging from pharmaceutical products, polymers, petrochemicals, intermediates, and fertilizers. The wastewaters from these industries contain both organic and inorganic materials. They are further characterized by an abundant organics content and they can contain traces of toxic pollutants as well. As such, care must be taken when handling and treating these wastewaters. Additionally, pretreatment techniques are utilized to separate inorganic matter. Common methods used for treating chemical industry wastewater are trickling filters, rotating biological contactor (RBC), activated sludge, or lagoons. Several case studies will be investigated throughout this paper to discuss various methods for treating these types of wastewaters.

Keywords Oxidation · Anaerobic treatment · Aerobic treatment · Pretreatment · Chemical industry wastewater treatment · Biological treatment

1 Environmental Practices of the Early Chemical Processing Industry

Today, harsh chemicals continue to be released into the environment, poisoning both plants and animal species. These chemicals derive from many sources. However, one of the most prominent of them is in the chemical industry. Even with EPA regulations in place, the amount of wastewater generated from these industries remains high. One of the main factors for this high amount of wastewater production is the result of a long-lasting industrial production model and of a slowly changing industrial mindset toward environmentalism.

The issue of corporate environmentalism didn't become a major concern until the late 1900s. It was until this time that changes toward more sustainable production models were adopted by the US chemical industry. To understand the mindset of chemical industries towards environmental issues prior to this time period, it is essential to understand the relationship between organizations and institutions evolved. Several federal lawsuits were analyzed to better understand the organizational structure of the U.S. industry. There were four historical stages that outline environmental management within the US chemical industry [1].

The first stage took place between 1962 and 1970. During this time, environmental issues were a low priority for booming industries. Approximately five environmental articles appeared in *Chemical Week*. Although there were no federal environmental cases filed, the concern about environmental issues emerged in coming years. The first environmental event that received significant coverage was the publication of *Silent Spring* by Rachel Carson. Her book identified that there was a persistent presence of DDT in the food chain posing a hazard to all living organisms including humans. While Rachel Carson's book was compelling, the journal dismissed her findings and deemed them as unrealistic. The journal ultimately concluded that her data and methods lacked credibility. In 1964, over a million mass

deaths of fish washed up on the Mississippi River. During this period of time, it was predicted that a non-polluting auto would be available in 1975, which would use fuel that that extracted from shale. This innovation was ignored because the industry did not want to admit that there was a problem that had an impact on chemical wastewater and its processing methods.

The second stage of environmental management occurred between 1971 and 1982. On April 22, 1970, Earth Day was celebrated for the first time and several chemical companies were identified as being the “the handmaidens of Satan”. Because of growing concerns that revolved around environmental issues, President Nixon initiated the second most important event of this decade, which was the establishment of the U.S. Environmental Protection Agency. This time period was marked where nongovernmental organizations (NGOs) and industries fought of legitimate environmental practices. The EPA’s guidelines became more of a compliance with government standards and framework and less of an environmental protection agency. Pollution policies became the main focus soon after the initiation of the EPA. These policies were meant to establish monitoring regulations for industries to implement greater levels of environmental controls. However, these changes would come at a cost. The EPA’s proactivity on pollutant regulation matters led Congress to implement the Toxic Substances Control Act, a legislation established to ensure the implementation of health and safety regulations from chemical industries.

The third stage occurred between 1983 and 1988. During this time, environmentalism became common belief at the institution level. Throughout this period, enforcement and regulation still gained a significant amount of environmental coverage.

The fourth and final stage occurred between 1998 and 1993. During this time several fatal accidents took place, one of which involved a methyl isocyanate release at Union Carbide’s Bhopal India plant killing over 3000 people and injuring more than 300,000 individuals. During this time period, public concern about global warming and the thinning of the ozone layer began to arise. These concerns ultimately led to the establishment of mandates which required companies publicly report all forms of pollution created at their plants beginning in 1987. Other environmental issues that occurred during this time included: the U.N. halting the production of ozone-depleting chemicals and the Exxon Valdez oil spill. The environmental event that potentially made the largest impact on the structure of the chemical industry during this time was the initiation of the Responsible Care Program of the Chemical Manufacturers Association in 1990. This program outlined a set of proactive environmental principles that all members of the trade association would be required to adopt.

By the end of 1993, attention to environmental issues had reached unprecedented levels. What were known as good environmental practices such as recycling and water treatment were now being implemented in the chemical industrial sector. This era saw support and acceptance of corporate environmental responsibilities. These newfound ideals ultimately led companies to change their consumption patterns and minimize the amount of hazardous wastes discharged into the environment.

Political negotiation processes ultimately guide organizational, especially industrial behaviors. Public interest in environmental issues as well as the establishment of key environmental organizations such as the EPA was crucial to pave the path toward cleaner industry practices. These two factors will continue to shift and affect the way that industry develops in the future. Ultimately, a crucial step toward more environmental change is through governmental action. Environmental problems must be solved through changes in the institutional arrangements that govern industry and social actions. As environmental issues evolve, the need to develop new innovations must be considered [1].

One research paper studied the effects of the organizational size of chemical plants on the rate of toxic emissions. The main question is how does human behaviors pollute nature. The environmental consequences of human behavior are tremendous and have been documented in studies that involve global warming, acid rain, loss of animal habitats and species extinctions. Factors that cause pollution, which is related to lifestyle consumption habits, are called econstructuralism [2].

The effects of exploring the environmental factors of econstructuralism, which comprises : urbanization, modernization, class hierarchies, long economic cycles, and the world-system have been considered to be the “most intensive and effective environmental destroyer” of all-organizations and the effects of their structures. New approaches regarding pollution focus on the variations in organizational characteristics focus on the organizational size and toxic emissions of chemical plants. As a result, this study focuses on the emission rates regarding the percent of chemicals used on site by a plant that has released toxins into the environment. The goal is to understand how effectively plants of different sizes manage their chemical waste. This study’s focus is also to debunk the notion that suggest that it is not the chemicals used that lead to pollution but how chemicals are distributed across small or large plants that lead to pollution.

Size has been used to predict numerous organizational outcomes. It is the most studied variable regarding organizational structure. Organizational size matters because there are a growing number of people such as lawyers and lobbyists who believe that extra regulatory burdens that have been placed on large organizations are both unjustified and destructive. For example: the SBREFA for small organizations requires that the EPA and other agencies give small businesses special treatment and exemptions.

In 1986, Congress passed the Emergency Right to Know Provision, which authorized the EPA to collect annual data on the amount and type of toxic chemicals emitted by individual manufacturing facilities. Without a doubt, toxic emissions occurred in the process of extracting raw materials and the transportation of finished products. Therefore, it is important to examine the plant size and the toxic emissions. By researching this information, the study design enables stakeholders to determine the relative importance of facility size and how to evaluate its effects based on the corporate structures, with the hope of finding the links among various structures that have caused pollution.

The problem is that organizations grow and their ability or motivation to adopt new environmental technologies diminishes to the point where the largest plants do

a similarly poor job of containing toxic releases. Research revealing that large organizations abuse their economic power and are less innovative suggests that positive linear relationships exist between size and emission rates.

In the nation's economy chemical industries is one of the most pollution intensive industries. This study involved chemical plants and an analysis of over 2000 cases from their data files. The toxic emissions were the dependent variable and the data was taken from the EPA's Toxics Release Inventory or TRI.

There were limitations to the data from TRI as over 949 cases filed were incompatible and information was missing. Other problems with the data included: (a) plants were excluded if they had greater than 10 full time worker, (b) the data was self-reported, (c) chemical waste of toxicities were weighed in pounds instead of being weighed by pounds of chemical waste emitted. Finally, the EPA was not responsible to collect data on quality control on toxic emissions. However, TRI has become the core database for many industrial pollution research studies in the future.

Based on the data, the results show that large chemical plants emit toxins at a significantly higher rate than do small plants, especially if they are embedded in a wider corporate structure. However, the effect of plant size fails to achieve statistical significance. Unfortunately the type of pollution that was examined, which was toxic emissions by manufacturers, is largely unregulated by the EPA.

The environmental groups should continue to insist that the toxic emissions of large chemical plants be closely monitored and that selective incentives be put in place that encourage more regularity constrains. Also, organizational characteristics or conditions on how effective chemical plants manage their toxins in poor or minority neighborhoods should be included. Overall, organizational size has proven to be a strong predictor of industrial organizations that link pollution as contributors to organizational and environmental systems.

It was suggested that in the future researchers study the impact of organization structures on the adaptation of green production designs and technology [2].

2 Overview of the Chemical Processing Industry

The chemical industry describes industries that produce industrial chemicals [3]. The chemical industry is one of the largest industries in the world, producing over 50,000 compounds [4]. The industry constitutes 7% of global income and 9% of international trade. It also produces 11% of the total manufacturing value added to the United States.

Within the chemical industry there are three major subsectors: petroleum, coal, and basic chemicals; resin, rubber, artificial fibers, agricultural and pharmaceutical manufacturing; and paint, adhesive cleaning, and other chemicals. Resource consumption within these sub industries can provide useful insight for identifying limiting resources. From the petroleum refining sector, crude oil and natural gas are consumed in the highest quantities. Furthermore, the majority of the power generated from chemical processing industries is from renewable energy sources such as

hydro potential, geothermal, and wind. However, large amounts of fossil fuels such as coal, crude oil and natural gas were used to generate energy, while SO₂, NO₂, and CO₂ were identified as the most widely produced emissions [5].

2.1 Energy Consumption

The US chemical industry utilizes a very energy-intensive process to generate chemical products.

Furthermore, the chemical industry consumes some of the largest amounts of energy in the industrial sector in the United States. The industry produces 11% of products and consumes 20% of energy from the industrial sector. Three of the most energy-intensive products from the chemical sector are ethylene, nitrogenous fertilizer, and chloride and caustic soda. Ethylene is mainly produced from the petrochemical industry and uses a total of 520 PJ (LVH) of fuel excluding feedstock and 26 GJ/tonne ethylene (LVH). Nitrogenous fertilizer production uses a total of 268 PJ of fuel without feedstock and 368 PJ (LVH) of fuel with feedstock. This fertilizer production uses 14 PJ of electricity and uses 16 GJ/tonne (LVH). Chlorine is produced from electrolysis reactions in a salt solution. Chlorine production requires 173 PJ of electricity and 38 PJ of fuel. The primary energy consumption of chlorine was reported to be 47.8 GJ/tonnes [4].

CO₂ emission consists of 20% of the total energy use from the chemical industry in 1994. Overall, emissions grew at an annual rate of 2.9% and value added grew at an annual rate of 4.6%.

Several subsections within the chemical industry can be very intensive processes. Sections of the chemical industry that produced that largest amount of energy in the chemical industry were: unspecified industrial organic chemicals, unspecified industrial inorganic chemicals, plastic materials and resins, nitrogenous fertilizers, industrial gases, and alkalis and chlorine. Overall, unspecified organic chemical production required the largest amount of energy in 1994.

Ethylene and steam cracking derivatives consist of products within this category. These chemicals are used to create plastic, resins, and fibers and detergents. Ethylene is of particular concern. In 1994, ethylene was known as the fourth most produced chemical. Ethylene production has continued to grow annually. Today, the United States produces 28% of ethylene around the world. Additionally, unspecified inorganic chemical production was listed as the second largest energy-intensive process in 1994. Chemicals which fall within this range include: sulfuric and hydrochloric acid, potassium fertilizers, alumina, and aluminum oxide. Among these chemicals, hydrochloric acid and potassium fertilizers were produced in highest quantities, being identified on the top 40 chemicals produced in the United States in 1994.

Plastic and resin subsection produced lower energy requirements. However, this section was responsible for the highest carbon dioxide emissions. Chemicals falling within this category include polyethylene, polypropylene, polystyrene, and polyvinyl chloride (PVC). Industrial gases accounted for 6% of CO₂ emission from the

chemical industry. Within the industrial gas section, nitrogen and oxygen are chemicals which are produced in the greatest quantity. Both chemicals accounted for 85% of energy consumption within the industrial gas sector. Oxygen requires 2 GJ/tonne of energy. Ammonia from the nitrogenous fertilizer subsection produces the most energy from this subsection. Ammonia production alone accounts for 85% of energy consumption from this sector. Ammonia production continues to grow annually [4].

3 Characteristics of Chemical Industry Wastewaters

Chemicals comprise pharmaceuticals, polymers, bulk petrochemicals and intermediates, derivatives of basic industrials, inorganic and organics, and fertilizers. The concentration of organics and inorganics present in chemical wastewaters varies and depends on type of industry. Chemical wastewaters can also contain toxics, mutagens, carcinogens, and other nonbiodegradable substances. These characteristics result in a high-strength wastewater. Certain chemicals such as surfactant, emulsifiers, and petroleum hydrocarbons present a challenge, as they reduce the performance efficiency of many treatment systems [3, 6].

Many of the chemicals from the chemical industry are toxic and consist of heavy metals. Certain chemicals such as chromium, mercury, lead, and arsenic appear in chemical wastewaters in high concentrations. Operations such as electroplating, metal or surface finishing, and solid state water processing are used to treat wastewater from the chemical industry with high concentrations of toxics [3].

Oil and grease are frequently found as pollutants in wastewaters. Oil and grease rich wastewaters are typically classified as containing animal and vegetable oils, fatty acids, petroleum hydrocarbons, surfactants, phenolic compounds, and naphthenic acids. Wastewaters can contain free, dispersed, and emulsified oils and greases. Free oils have droplet sizes greater than 150 mm, whereas dispersed oils have a size of 20–150 mm and emulsified oils have a size of less than 20 mm. The amount of oils and grease in wastewater can be determined by extracting them using a solvent, typically freon or hexane. Large quantities (up to 200,000 mg/L) of oil and grease are commonly found in chemical industry wastewaters. However, discharge limits for oil and grease effluent are listed as 48 mg/L for old facilities and 29 mg/L for new facilities.

Because of these characteristics, strict standards have been placed on wastewater. Treatment of chemical processing industry wastewaters must be extremely efficient in order to meet the required EPA effluent standards [3].

4 Pretreatment (Physicochemical Methods)

Physicochemical treatment methods have been proven to be effective for reducing oil concentrations in wastewater. These methods include: gravity separation and skimming, dissolved air flotation, de-emulsification, coagulation, and flocculation.

Gravity separation is an effective, low-cost oil-water separation technique. This method is primarily used to remove free oils from wastewaters, and is ineffective at removing smaller oil particles. American Petroleum Institute oil-water separators are common separators.

Dissolved air flotation (DAF) is another oil-separation method that can be used to improve separation for smaller particles such as emulsified oils. DAF units utilize chemicals and or thermal energy to reduce smaller particles into larger particles. Before the DAF process can be implemented, oils must be chemically pretreated and settled. In addition, the wastewater must be heated to reduce viscosity, improve density differences and weaken oil films. Acidification, cationic polymer/ alum addition, and pH raising are primary chemical processes which are used to produce floc during the DAF process. Lastly, the floc is separated from water, thickened, and dewatered.

Coagulation and flocculation can also be used to remove oils from wastewaters. Coagulation describes the process of adding inorganic and organic compounds such as aluminum sulfate, aluminum hydroxide chloride, or high molecular weight cationic polymers to wastewater in order to accelerate the sedimentation process. The implementation of coagulation allows for settled solids to be removed as sludge and floating solids to be removed as scum. The goal objective is to remove 90% of organic compounds. These processes are typically used in a reservoir, sedimentation tank, or clarifier, and are implemented as the first stage of treatment. The main design parameters for this process are retention time, temperature, tank size, and equipment used [3].

4.1 Adsorption

Adsorption describes the process when molecules of dissolved compounds collect on and adhere to the surface of an adsorbent solid. Furthermore, it occurs when attractive forces at a carbon surface overcome the attractive forces of the liquid. While processes such as precipitation, coagulations, and sequestration can be used to remove toxics in high concentrations, adsorption is a useful process for removing low concentrations of toxic heavy metals. Three adsorption techniques which are readily used for wastewater treatment are granular activated carbon (GAC), fixed biofilm reactors, and electrosorption [3].

4.2 GAC

GAC methods are efficient adsorbents due to their high surface area to volume ratio. One gram of activated carbon typically requires a surface area equivalent of 1000 m². Materials that can be used for adsorption include peat, wool, silk, water hyacinth, and agricultural and industrial solid wastes [3].

4.3 Fixed Biofilm Reactor

Fixed biofilm reactors are trickling filters or attached growth reactors. It is the most effective during the secondary treatment process. To prevent clogging biofilms primarily implement media and microbes to treat wastewater. In this type of reactor, microorganisms such as bacteria and protozoa grow on the media as a slime layer when wastewater is passed through the filter. This layer becomes thicker with time, as more wastewater is filtered through the filter. As this layer thickens, oxygen is prevented from reaching the total depth of the slime layer, creating anaerobic conditions deeper in the layer. Slough is generated from anaerobic products and is carried off in effluent. In order to ensure the best effluent quality and remove slough, fixed biofilm reactors should be followed by secondary sedimentation tanks. This method may be beneficial compared to a conventional activated sludge system due to its low process control requirements. Challenges that arise from using this system include excess organic loading, implementation of incorrectly sized media, clogging, non-uniform media, and breaking media [3].

4.4 Electrosorption

Electrosorption is defined as potential polarization-induced adsorption on the surface of electrodes. After polarization, polar molecules can be removed from the solution and adsorbed onto an electrode surface. Common electrodes used during this process include activated carbon fiber cloth with high specific surface area and high conductivity. When these types of electrodes are used, consideration to the surface chemistry must be made. Additionally, electrosorption can be enhanced by increasing their adsorption capacity. This can be done by implementing modification processes which boost the feasible removal rates and adsorption capacities. One such example entails the immobilization of a chelating agent on the adsorbent surface. Electrosorption's low energy requirements make it a variable and efficient alternative to other treatment methods. However, this system can be largely limited by the type and performance of the electrode material [3].

4.5 Membranes

Membrane technology is commonly implemented for wastewater treatment methods. Several types of membranes exist today, including MF (microfiltration), UF (ultrafiltration), NF (nanofiltration), and RO (reverse osmosis). Polymeric UF and MF technologies have an average shelf life of 3–5 years. However, their use is widely dependent on the application and frequency of use. Membranes are most effective for treating stable emulsions, specifically for water-soluble oily wastewa-

ter. The operation for membrane technology utilizes a semi-batch recycle where wastewater feed is added to the tank at the same rate at which the permeate is withdrawn, thus keeping a constant water level throughout the system. Any oil and grease collected are recycled to the process tank. The system operates in cycles. In the first stage, the wastewater is treated in the membrane until the concentration of oils, greases, and suspended solids reaches a set value, usually this occurs when the concentration volume reaches 3–5% of its initial feed volume. Once this concentration is reached, the feed is stopped and the system is cleaned.

The main advantages of using a membrane system include its wide range of applications, its ability to treat wastewater uniformly, small number of chemicals needed for treatment, reuse of waste streams in the plant, lower energy costs than thermal treatment methods, and the system's low operation requirements. Overall, these systems are appealing to operators due to their efficiency in treating wastewater to appropriate discharge standards. However, several limitations with using membranes include: scale-up, high capital costs for large effluent volumes, some membranes, polymeric membranes, can become easily degraded or fouled during use. In these cases, membranes need to be replaced more frequently, which will increase operating costs of treatment of wastewater [3].

5 Biological Treatment Methods

Biological treatment is a necessary step in wastewater treatment that mainly deals with organic removal. Typically, biological treatment utilizes microbes to feed on organics in the wastewater, and thus reduce the organic concentration significantly. Biological treatment processes can be aerobic, anaerobic, or anoxic. Furthermore, biological treatment can occur using suspended growth reactors or attached growth reactors. Chemical industrial wastewater can be treated by biological oxidation methods such as trickling filters, rotating biological contactors (RBCs), activated sludge, or lagoons [6].

5.1 Aerobic Treatment

Aerobic treatment utilizes microbes under oxygenated conditions to destroy biodegradable organics. Biodegradable organics are sources of biodegradable oxygen demand (BOD). Aerobic treatment is the primary treatment method for removing BOD from domestic wastewater. Additionally, aerobic treatment can be used on industrial wastewaters. This treatment method is simple, inexpensive, and efficient. Several factors can affect the efficiency of treatment. The factors include temperature, moisture, pH, nutrient rate, and aeration rate. Aeration takes place ten times faster than anaerobic reactions, and as a result, they are designed with small volume and open. One of the major disadvantages of using aerobic treatment processes is

the large quantity of sludge produced as the result of a high biomass yield (amount of cells produced per unit mass of biodegradable organic matter).

There are a number of reactions which microorganisms use to degrade organic pollutants. One such pathway involves the attack of xenobiotics by organic acids produced by microorganisms. Another reaction involves the production of noxious compounds (H_2S) and chelating agents which increase solubility of xenobiotics, and further allow them to be degraded.

Chemical industry wastewater can induce toxic effects on microorganisms. The chemicals from these wastewaters can inhibit growth of the microorganisms and affect the degradation process. Two aeration methods – a membrane bioreactor and a phase partitioning system – are viable biotreatment methods that can be used to treat highly toxic, high-strength chemical industry wastewaters [3].

5.1.1 Membrane Bioreactors

Membranes are more commonly used for small-scale activated sludge operations. Membrane systems can be beneficial systems than activated sludge systems due to their reduced footprint and efficient treatment. There are two main configurations for these types of reactors: a submerged membrane and an external membrane.

A study was conducted in which a membrane bioreactor was used to treat 3-chloronitrobenzene [1]. The wastewater was pumped into the system at a flow rate of 64 mL/h. The results found that the membrane was able to remove 99% of pollutants found in the wastewater. Further, the carbon from the wastewater was completely degraded to CO_2 . An important consideration to ensure proper functioning of these systems, is their operating conditions. Membrane reactors, if not operated correctly, can become subject to fouling. Fouling is a common problem with membrane technology. Coating can occur in hydrophobic membranes, when free oils accumulate. This coating results in a poor flux. In order to overcome these effects, these types of membranes must be constructed in a tubular manner, which allows for better mixing conditions. Membranes are also sensitive to pressure, temperature and pH changes. As a result, these systems need to be monitored and maintained frequently.

5.1.2 Two Phase Partitioning System

Two phase partitioning systems are aerated systems which use nonbiodegradable, non-volatile solvents to treat. These systems are self-regulating. Xenobiotics are produced from this system at the same rate as the consumption rate of microorganisms. These systems operate under conditions which limit the exposure of microorganisms to organic pollutants, which ultimately reduces the toxic effects on the microbes and increases the rates of xenobiotics. However, care must be taken when using this system, as the interaction of microflora from the system and metal ions from the wastewater can increase the number of reactions needed before effluent discharge.

The degradation of xenobiotics was observed in the following case study. In the study, benzene was to be treated in a two phase partitioning system using *Alcaligenes xylosoxidans* Y234. It was found that 63.8% of benzene was degraded within a day while 36.2% was stripped using aeration processes. However, benzene is known to be toxic and hard to degrade at high concentrations. To combat these conditions, the stripping effect was adjusted to allow for 99.7% degradation of benzene. The results from this case study emphasize the effectiveness of two-phase systems for treating toxics and, therefore, emphasize the usefulness of these systems for treating chemical industry wastewaters [3].

5.1.3 Sequencing Batch Reactors

A sequencing batch reactor describes a process in which a reactor conducts each stage (aeration, oxidation, sludge settling, and recycling) of an activated sludge process. Batch reactors are operated in a periodic, discontinuous process and can be used to treat low-to-medium-strength wastewaters or specific organic pollutants. They have many applications ranging from landfill leachate treatment to domestic and industrial treatment and contaminated soil treatment. Before a new stage can begin, the reactor is emptied of all contents except a layer of activated sludge on the bottom. Then the reactor is filled with wastewater where it is mixed and aerated. The mixing is stopped only once the satisfied level of degradation of the pollutant is achieved. Sludge is allowed to settle. The top layer is discharged as effluent. One major advantage of SBRs is that they can adapt to changing wastewater flow rates. Additionally, the settling times for sequencing batch reactors can also easily be adjusted to better allow for complete settling before discharging. However, each step in the process requires a separate reactor [3].

5.2 *Anaerobic Treatment*

Anaerobic digestion is a sequential process which involves the complete breakdown of organics to carbon and methane. Methanogenic microbes are used to degrade BOD in anaerobic systems. Anaerobic digester or stabilizers are capable of degrading many toxic organics under methanogenic conditions. They can be applied to a variety of applications including automobile industry wastewater as well as sulfate bearing and hypersaline chemical wastewater. Unlike aerobic systems, anaerobic systems are closed off to the environment to induce an oxygen-free environment. Anaerobic systems are more advantageous to use compared to aerobic treatment for treating hazardous, high-strength wastes. They produce better removal of color, halogens, and heavy metals than aerobic systems. These systems pose numerous benefits, including the ability to lower sludge production rate, operate at higher influent BOD and toxic levels, and produce useful by-products such as methane gas.

These systems are designed to have a vent in order to filter gaseous methane and carbon dioxide produced from the system. Conversely, the capital and operating costs of these systems are higher than those of conventional aerobic systems. Anaerobic systems are limited by low flow rates.

Anaerobic reactors typically operate under a 10 to 20-day hydraulic and solids retention time and at a temperature of 35 °C. There are four main steps which occur during an anaerobic process: hydrolysis/liquefaction, acidogenesis, acetogenesis, and methanogenesis. Coupling is a necessary design consideration to prevent accumulation of intermediates and ensure a balanced digestion process. Anaerobic reactors can be numerous configurations ranging from Upflow Anaerobic sludge blankets (USAB), and Anaerobic Sequencing Batch Reactor (ASBR) which both have applications in industrial treatment. These two processes will be discussed further [3].

5.2.1 Upflow Anaerobic Sludge Blankets (USAB)

This type of reactor has been used to treat many types of industrial waste including chemical industry wastewaters. There are four main criteria for designing a USAB: sludge bed, sludge blanket, gas-sludge-liquid separator, and a settlement compartment. Mixing occurs in the reactor from upflow forces caused from influent wastewater flow [3].

5.2.2 Anaerobic Sequencing Batch Reactor (ASBR)

ASBRs are high-rate reactors which generate granular biomass as a result of treatment. One major advantage of using this system is that it can maintain a higher biomass within the reactor. These reactors have also proven to be simple, efficient, and applicable for a wide range of effluents. Treatment in these reactors occurs in five separate stages: filling, reaction, settling, decanting, and idling [3].

5.3 Combined Treatment

Combined or integrated treatment systems use both aerobic and anaerobic procedures microorganisms to treat wastewater. Combined systems are commonly implemented for high-strength wastewaters and in cases where the incoming wastewater has a BOD of above 1000 mg/L. Combined systems can take place in a single or multiple steps. Single-stage processes occur when bacteria are stationed in fixed film bioreactors. These combined systems are especially good for treating saline wastewater for nutrient COD, N and P removal [3].

6 Chemical Treatment Methods

Chemical oxidation is defined as the process by which electrons are transferred from one substance to another [1]. COD is used as a key parameter to indicate oxidation efficiency. Usually oxidation processes are implemented on wastewaters with a COD less than 5000 mg/L. Wet oxidation or incineration can be applied in cases where COD contents are higher than 20,000 mg/L. There are two main types of chemical oxidation processes: classical oxidations and advanced oxidation [3].

6.1 Classical Oxidation

Classical oxidation describes the process by which an oxidant is added to an oxidant, wastewater and oxidation occurs. Five commonly used oxidants are chlorine, potassium permanganate, oxygen, hydrogen peroxide and ozone. Chlorine can be used in cases where water evaporation is needed. While inexpensive and easy to use, large amounts of chlorine are needed for effective treatment. Carcinogenic byproducts are also produced from chlorine; therefore, care must be taken during the application process. Potassium permanganate is an expensive oxidant that can be used for a wide range of pHs. However, by-products produced from this oxidant require additional clarification or filtration. Like potassium permanganate, the use of oxygen as an oxidant requires large installation costs.

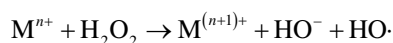
Oxygen is typically the most effective under high temperature and pressure conditions. Hydrogen peroxide has a wide range of applications. It is usually applied either directly or with a ferrous sulfate, iron salt, or a metal catalyst for reactions. In addition to hydrogen peroxide being easy to apply and having a high oxidizing power, it is also the least expensive oxidant option. Unlike many of the other oxidants, hydrogen peroxide does not produce toxic by-products that require additional treatment. Hydrogen peroxide oxidation efficiency is largely dependent on the production of hydroxyl radicals. Ozone is the last major oxidant. Ozone is primarily used during tertiary treatment to treat organic pollutants from industrial and agricultural wastewaters. Insoluble under standard conditions. Large quantities of it are needed for treatment. A disadvantage of using ozone as an oxidant is that it must be produced at the site of treatment. Further, systems must be put in place to capture and trap the ozone after it is used for treatment. As a result of these conditions, the use of ozone is very expensive [3].

6.2 Advanced Oxidation

Advanced oxidation describes oxidation processes which take place near ambient temperatures and produce highly reactive radicals, which are utilized during the treatment process. This process is applicable to groundwater, surface water and

wastewater which contain nonbiodegradable organic pollutants. AOP (advanced oxidation process) processes are mainly applied as a pretreatment technique for industrial wastewaters. The most common types of reagents for advanced oxidation include: UV/O₃, UV/H₂O₂, O₃/H₂O₂, Fe³⁺/UV, UV/TiO₂, and H₂O₂/Fe²⁺ with the Fenton reagent (H₂O₂/Fe²⁺) being the most effective.

The Fenton reaction can be described by the following equation.



where M is described by a transition metal such as Fe or Cu.

The Fenton reaction has seen numerous applications in textile and chemical industrial treatment. Because it does not require energy input to activate the reagent, this method is simpler to use and more cost-effective than other reagents. However, many problematic by-products such as iron III oxide hydroxide and iron salts are produced from the reaction. To combat this, iron sources are added as catalysts.

Overall, API-oil separators are useful treatment methods for wastewater with high oil contents. Combined, aerobic and anaerobic systems are the most efficient at removing both toxic and nontoxic organics from wastewater [3].

7 Natural Treatment Methods

Constructed wetlands are types of natural treatment system that have been used to treat chemical industry wastewater in the past. Constructed wetlands utilize natural processes such as wetland vegetation, soils, and microbes to treat wastewaters. These systems are modeled after natural wetlands. However, unlike their natural counterparts, constructed wetlands take place in a controlled environment. The systems have been used to treat landfill leachate, runoff, food processing wastewaters, industrial wastewaters, agricultural farm wastewater, and mine drainage wastewater. Constructed wetlands can be classified according to their macrophytic growth, which may be emergent, submerged, free floating, or rooted with floating leaves. They could also be classified by the water flow type such as surface flow, sub-surface vertical or horizontal flow. Combined wetlands have been used to improve nitrogen removal performance during treatment.

Plants have an essential role in a constructed wetland environment. Plants roots provide a stable and safe habitat for microorganism growth within the wetland. Plant uptake further enhances the treatment process. Uptake describes a chemical process that occurs in constructed wetlands in which nutrients such as nitrogen and phosphorus are absorbed by plant roots. Plant uptake increases the nutrient removal efficiency of the system, as a whole. Water hyacinth is a plant species that is commonly implemented in constructed wetlands due to its highly efficient uptake ability. However, constructed wetlands that use this plant must be built in tropic, subtropic, or environments that promote yearlong growth, as these climates are the most suitable environments for water hyacinth to thrive in. In order to maintain efficiency, plants must be maintained regularly within the system [3].

8 Case Studies

The effects of treatment of chemical industry wastewaters were investigated in the following case study. Wastewater originating from building and construction chemical factories and plastic shoes manufacturing factories was analyzed. This wastewater was directly discharged into the public sewage system for both observed factories. Hu developed a process for how to select the appropriate treatment process for chemical industrial wastewater based on molecular size and biodegradability of the pollutants. Bury developed a dynamic simulation to chemical-industry wastewater treatment to manage and control the treatment plant. Two methods were utilized for treatment: chemical treatment using coagulation precipitation for the chemical factory and biological treatment using an activated sludge reactor and a rotating biological reactor (RBC) for the manufacturing factories [6].

8.1 Case Study 1: Treatment from Plastic Shoes Manufacturing Factory

The chemical factory produced concrete mixtures, painting and coating materials and bitumen products. The flow effluent coming from this factory ranged between 11 and 15 m³/day.

Chemical coagulation was performed using lime aided with ferric chloride or aided with aluminum sulfate. A continuous treatment system was operated at optimum pH and coagulant dose, both of which we determined using a jar test. For lime aided with ferric chloride, a dosage of 700 mg of lime and 600 mg of ferric chloride. For lime aided with aluminum sulfate, a dosage of 300 mg of lime and 1000 mg of aluminum sulfate was used. The construction cost of the treatment system was \$3,71,017 and operating costs were \$12,315 [6].

Samples from effluent water were collected and physicochemical analyses were conducted. It was found that the building and construction chemical factory wastewater contained high levels of organics. Average values of COD and BOD were given as 2912 and 150 mg/L. The BOD/COD ratio was 6%. Phenol up to 0.3 mg/L was also detected. The oil and grease concentration ranged between 149 and 600 mg/L. The average oil and grease concentration was 371 mg/L. The average total suspended solids (TSS) concentration was 200 mg/L. Using the batch chemical process, an 94% removal efficiency of COD, an 81% removal efficiency of TSS, and an 91% removal efficiency of oil and grease were achieved.

The plastic shoes manufacturing factory melted raw materials and used forming, molding, and painting processes to produce a finished product. Biological treatment was utilized to treat this type of wastewater. A majority of pollution from this industry originated from the painting department. Furthermore, the wastewater from the paint department contained high levels of organics. The construction chemical factory contained an average COD concentration of 15,441 mg/L and a BOD of

7776 mg/L. The average phenol concentration was 0.93 mg/L. Domestic wastewater was mixed with this chemical industry wastewater at a ratio of 1:3. The domestic wastewater allowed for the addition of nutrients such as nitrogen and phosphorus. After mixing, the effluent from the factory had an average COD and BOD of 5239 and 2615 mg/L respectively. Due to the high BOD/COD ratio, biological treatment was chosen as the appropriate treatment method for this kind of waste.

Activated sludge processes were conducted in a batch reactor in a laboratory. Two-liter plexiglass columns were used to conduct the reaction. The aeration was conducted by filling the columns with inoculated (with activated domestic sludge) wastewater from the chemical processing industry. The columns were aerated daily. At the end of each cycle, the sludge was allowed to settle in the columns. The column was then drained and refilled. This process was repeated until a large amount of sludge was produced from the system. The aeration time was determined by conducting an experiment in another column. For this experiment, sludge and pre-treated wastewater were allowed to settle for a detention time ranging between 1 and 24 h and an MLSS of 3 g/L. The minimum dissolved oxygen (DO) concentration was given as 2 mg/L. Samples were taken an hour after settlement. The rotating biological reactor operated under continuous flow conditions where the effluent was filtered into the reactor with an organic load of 7.8 kg BOD/m³ for 4 months. The construction cost of the activated sludge system was \$54,912 and the operation cost was \$19,912. The construction cost of the rotating biological reactor was \$54,035 and the operation cost was \$10,614.

From this study, it was found that the highest BOD removal occurred at a retention time of 24 hrs. After activated sludge treatment, the average COD, BOD, TSS, and oil and grease concentration values were 376, 131, 12, and 26 mg/L, all of which were compatible with effluent limits. An RBC treatment process was also used. After RBC treatment, the average wastewater COD and BOD concentration values were 474 and 277 mg/L. The average suspended solids residual value was 76 mg/L. The oil and grease residual value was 16 mg/L. The average removal rate of suspended solids and oil and grease was 88% and 93% respectively. The wastewater treated from this reactor was also within discharge limits.

While both biological treatment systems were effective for treating wastewater and reducing pollutant concentration to acceptable limits, the RBC system was recommended due to its easy operating requirements and lower cost [6].

8.2 Case Study 2: Treatment of PVCs

Another case study from Zhejiang province, China examined the treatment of wastewater rich in polychlorinated biphenyls (PCBs). PCBs are toxic organic pollutants which are highly resistant to biodegradation, biological accumulation, and long-range transport. As a result of these characteristics, PCBs present numerous environmental challenges and health risks ranging from neurological disorders, reproductive toxicity, endocrine disruption, cancer, deformity. Additionally, PCBs

can be harmful in both high and low concentrations. While PCB production has been banned since the late 1900s, these pollutants still remain in the environment. Many PCBs originated from the waste incineration process, from the chemical processes, or from dyeing processes. Wastewater treatment plants can also act as another source of PCB. While the PCB concentration is expected to decrease during treatment, as it was reduced from 1000 to 250 ng/L in Greece, PCB concentration can sometimes increase during the treatment processes as it did in Sweden (0.3–1 ng/L) and Lithuania (9–34 ng/L). Furthermore, the number and variety of pollutants can impact the characteristics of PCBs in wastewater [7].

For this particular case study, the treatment of PCBs from wastewaters consisting of 70% industrial wastewater from the chemical industry and 30% of domestic wastewater was investigated. The chemical industry wastewater consisted of 13.6% of wastewater from the dyeing sector. This industry was responsible for producing pharmaceuticals and intermediates, pigments and dyes, textile dyeing and finishing, biochemical, inorganic chemicals, and other specialty chemicals. Specifically, indicator PCBs, dioxin-like PCB congeners and three lightly chlorinated biphenyls and total PCBs were analyzed. The treatment plant used was fed an average daily load of 90,000–120,000 m³. The wastewater was first pretreated using grit and grease chambers and mixing regulation tank. The treatment system consists of primary sedimentation, anaerobic/aerobic biochemical treatment secondary sedimentation, and a high-density clarifier.

Samples were taken after each stage of the treatment process in October and November of 2010. After collection, wastewater samples were filtered through 1 L glass fiber filters and spiked with 200 ng of 13 carbon surrogate standards and extracted three times under ultrasonic conditions using a liquid-liquid extraction method. PCBs were analyzed by isotope dilution methods. Quantification of the PCBs was determined by using an Agilent 6890A gas chromatograph with a 5795X inert mass spectrometer with an electron impact ion source [6]. One microliter of extract solution was injected into a DB-5MS capillary column with a 0.25 μm film thickness. The injector temperature was 280 °C and the source temperature was 250 °C.

PCB concentrations from each stage of the treatment process were analyzed. PCB-11 was the most abundant, accounting for more than 66.1% of polychlorinated biphenols, found in the wastewater. The concentration of PCB-11 found in the raw wastewater was 10321.6 pg/L. Other PCBs present in this wastewater included PCB-15 (241.6 pg/L), PCB-52 (249.6 pg/L), PCB-28 (173.5 pg/L), and PCB-77 (114.4 pg/L), PCB-126, PCB-169, PCB-189. The PCB concentrations of PCB-28, PCB-52, and PCB-77 increased after the anaerobic hydrolysis unit by 270%, 35.7%, and 52.3%, respectively. This effect may be caused by the release of PCBs from solid to liquid phase. These dissolved PCBs pose less of a risk than nondissolved PCBs. The distribution of PCBs within the system varied from stage to stage. Distribution was affected by factors such as solute concentration, the amount of solids available for sorption, and the competition between pollutants for sorption sites of particles.

Two methods utilized for reducing the PCB concentration from this wastewater were adsorbing PCBs onto a solid surface and dissolving the PCBs into the wastewater. The adsorption of other hydrophobic chemicals was strongly dependent on the sorptive behavior. Adsorption is typically affected by the octanol water coefficients (K_{ow}). There was a low correlation between the log K_{ow} value and the removal efficiency percentage for primary sedimentation, anaerobic hydrolysis, aerobic bioprocess, and the high-density clarifier. It was also found that other processes such as advection, volatilization, biotransformation, oxidation and coagulation are useful for removing less hydrophobic compounds.

Mean removals of PCBs were calculated by using the equation.

$$R(\%) = \frac{(C_{in} - C_{out})}{C_{in}} * 100$$

where C_{in} describes the amount of influent PCBs from a treatment stage and C_{out} describes the amount of effluent PCBs from a treatment stage. The removal efficiencies were the highest in the aerobic bio-process and the high-density clarifier. Mono-CBs, and Hexa-CB removal efficiency was greater than 90%. The removal of Penta-CB and Hepta-CB was greater than 80%. The lowest removal occurred during anaerobic hydrolysis. This low efficiency may have been the result of selective adsorption of PAC flocculants and anaerobic sludge. Specifically, Di-Cb and Nona-CB were isomers that had the lowest removal. The treatment system removed a total of 23.2% of PCBs. Additionally, the removal of Octa-Cb, Nona-Cb during primary sedimentation and of TriOCb and Tetra-CB during anaerobic hydrolysis was less than zero (indicating the increase of PCBs). Overall, the removal of most PCBs isomers during treatment was above 40% and the removal efficiency was 23.2%. However, the removal of Di-CB, Nona-CB, and Deca-CB in the aerobic stage and the removal of Di-CB, and Tetra-CB in the high-density clarifier was below 40%.

PCB levels from the sludge were much higher than effluent limits. Partitioning between the dissolved and adsorbed phases indicated that Di-PB were the most dominant isomers in the wastewater, accounting for 70% of the PCBs present. 89.8–97.4% of Di-CBs were absorbed on the particles and sludge in the influent and effluent of each treatment stage [7].

8.3 Case Study 2: Treatment Organics Using Activated Sludge

Currently, there are at least 114 organic pollutants that pose a threat to the environment. It is important to better understand the physical, biological, and chemical characteristics of these compounds in order to better treat them. To best determine the removability of a specific compound, it is essential to obtain more data during the treatment process. Existing design treatment models are derived from substrate

mass balance of substrate removal from biological consumption. However, these models do not account for natural chemical reactions such as stripping and adsorption. More accurate models that consider these chemical reactions need to be developed [8].

In this case study, the performance of the activated sludge process was investigated. The main objective of this study was to gain insight into the behavior of specific organic compounds found in industrial wastewaters. Biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), and total organic carbon TOC concentrations were used as primary parameters to characterize the wastewaters from this case study. These parameters are used to compare treatment to effluent limits. A continuous flow activated sludge system was used to treat a mixture of synthetic wastewater from chemical, plastic, petrochemical, and petroleum industries. The wastewater contained ethylene glycol, ethyl alcohol, glucose, glutamic acid, acetic acid, phenol, ammonium, sulfate, phosphoric acid, and salts. The CSTR reactors were constructed as stainless steel with a 3.0-1 activated sludge volume and a 3.23-1 settling volume. Each compartment of the reactors was fitted with air-tight stainless steel covers. Air flow meters were also used to control influent air and off gas.

System operation consisted of a pumped influent wastewater feed stream and an exit stream that transferred the effluent stream to collection tanks. The feed was filtered into the activated sludge tanks from a feed tank. The hydraulic retention time within the activated sludge system was 8 h. Effluent then flowed by gravity from the settling compartment to the collection tanks.

Two types of studies were conducted. The first was a nonbiological study designed to determine stripping characteristics of a specific chemical in the absence of biological activity. The second study used biological treatment to determine the treatability and fate determination of the same organic compounds during biological activated sludge treatment [8].

In the first study, the reactors were filled with distilled water before feed wastewater was pumped into the tanks. Total organic carbon levels and pollutant concentration levels of each organic compound were observed as a function of time. Samples were then collected and analyzed for each specific organic compound under investigation. The percentage of each compound stripped from wastewater was determined. Overall, stripping had a high effect on three compounds, a moderate effect on four compounds, and no effect on five compounds. BOD₅, TOC, COD, and concentrations. A total of 15% of benzene was stripped, 17% of ethyl acetate, and 24% of 1,2-dichlorobenzene.

In the second study, activated sludge was collected from local municipal sludge treatment plants to be used for seeding. The sludge was then acclimated to wastewater containing pollutants. Three activated sludge systems were used. Each system was operated at a different mean cell residence time: 2, 4, and 6 days. The hydraulic retention time of all reactors was 8 h. Samples were taken over a 60-day period and analyzed. The BOD₅, TOC, COD, and concentrations of specific compounds were studied. TOC analysis was performed using a TOC analyzer and procedures were in compliance with the Federal Register. All other parameters were analyzed accord-

ing to US EPA procedures. Other parameters such as pH, dissolved oxygen, oxygen uptake rates, effluent solids sludge settling characteristics, and population dynamics were also monitored [8].

Gaudy, Lawrence, and McCarty biokinetic models were used to determine the treatability and fate of specific organic compounds. Constants used for these models were determined in terms of BOD₅, TOC, and COD for control, a base mix with the addition of one specific compound, and for the base mix for the addition of three specific compounds. These constants were also corrected for the stripping of the specific organic compound from the biological system. Each system was operated to control the solids retention time by wasting sludge daily according to the following equation.

$$F_w = \frac{\frac{VX}{\theta_c} - FX_e}{X - X_e}$$

where F_w is the sludge waste flow rate (d^{-1}), θ_c is the mean cell residence time (d), V is the reactor volume (L), F is the influent flow rate (L/day), X_e is the suspended solids effluent (mg/L), and X is the mixed liquor or volatile suspended solids (mg/L).

The performance efficiency of one particular compound, benzene, was determined over a two-week operation period. Observation of this data indicates that the effluent level remained stable after 2 weeks. Additionally, the effluent benzene concentration remained below 50 $\mu\text{g/L}$ and the effluent soluble BOD₅ was 1.0 mg/L.

The influent, effluent, and treated efficiency values for the BOD₅, TOC, and COD of 12 specific organic compounds were also determined. These values were also determined for combined compounds including volatile organic compounds, base-neutral extractable organic compounds, and acid extractable organic compounds. Overall, removal efficiencies for both types of systems (specific and combined) were high. Among individual compounds, the effluent concentration varied [8].

8.4 Case Study 4: Treatment Coal Chemistry Wastewater

Coal chemical industry wastewater can also pose a variety of environmental challenges. Coal is a readily used material to produce oil and natural gases. In order to produce these products, combustion, gasification and cooling and washing must be used. These processing techniques are highly energy-intensive and they produce large amounts of wastewater. Coal chemistry wastewater is characterized by high concentrations of COD and toxics. Toxic organic compounds which are commonly found in these wastewater include phenol, cyanogens, oils and ammonia nitrogen. Organics such as polycyclic aromatic hydrocarbons and heterocyclic compounds

containing nitrogen and sulfur are also common. For this study, influent COD concentrations were found to be between 300 and 5000 mg/L and influent ammonia nitrogen concentrations were found to be between 150 and 400 mg/L [9].

Characterization of these types of wastewaters is also influenced by coal quality and the gasification process. Low-temperature gasification wastewaters contained polycyclic aromatic compounds such as benzene, phenol, and polyhydric phenols, heterocyclic compounds, and refractory organics. These wastewaters are highly saline and alkaline. Furthermore, treatment efficiency of these waters is determined by the phenol ammonia recovery method utilized, the selection of extractant, and the pretreatment method used. However, wastewater can also change based on coal quality, which can range from long flame coal to lignitous coal.

Treatment was conducted using biochemical treatment in several stages including pretreatment, treatment and polishing. Pretreatment needs to be conducted to remove oils from the wastewater. Systems that can be used to pretreat coal wastewater include regulation tanks, oil-water separators, and air flotation devices. Conventional biochemical treatment uses the activated sludge process which consists of an oxidation ditch, SBR, A/O common activated sludge reactor, and an MBR. Using hydrolysis or anaerobic treatment before biological treatment may further enhance treatment. Secondary biological treatment is needed to treat small amounts of ammonia nitrogen and organic substances that pass through primary treatment. Lastly, tertiary treatment implements a biological aerated filter (BAF), contact oxidation, filtration, ozonation, biological/ activated carbon, disinfection, membrane treatment, a biological oxidation pond, and other combined processes. Ozone and hydrogen peroxide are needed during this stage of treatment to improve biodegradability.

Phenol and ammonia was recovered from the wastewater. Slow degradation of coal chemical wastewater is a common challenge during treatment. The sludge produced by the sewage treatment biochemical system is mainly flocculation sludge and biological excess sludge, which is dehydrated by a belt-type pressure filter. The sludge produced by life softening is inorganic sludge, which contains inorganic particles that are more abrasive to the equipment. The screw-type dehydrator and centrifugal dehydrator are widely used along with the use of most imported products.

The pretreatment, and the sludge treatment units of sewage biochemical treatment produce harmful waste gases [8]. The main treatment methods are activated carbon adsorption that puts the gas into the adsorber with activated carbon, liquid absorption, absorption oxidation, and biological deodorization which is a method of deodorizing artificially by natural microorganism that control the biota within a facility. The advantages of activated carbon adsorption are that they have a: quick reaction, short contact time, and a high treatment capacity.

Biochemical wastewater reclamation and desalting process can be softened by petrochemical softening plus walnut shell filter, plus gas water backwash filter, plus ultrafiltration, plus primary reverse osmosis treatment process. Gradual maturity of fouling membrane products and RO membrane desalination are the most widely used treatment processes in the field of water reuse. Ultrafiltration is used to remove residual contaminants in water. The effects of pretreatment facilities are based on

the effects of the membrane treatment process. Air flotation was used to remove oil and small-suspended matter that may contain water and the filters were used to reduce suspended solids. When the wastewater has a certain degree of hardness, lime-softening method is adopted to reduce the hardness of water inflow, and to protect reverse osmosis membrane. The purpose of these processes is to minimize the pollution load of RO membrane and improve the high-efficiency cycle of the equipment. The desalination process is required to meet the needs of industrial reuse of the recirculating of the water system [9].

8.4.1 Standard Treatment of Concentration Treatment of Concentrated Brine

After the enrichment by the membrane method, the amount of concentrated brine is still large and concentrated brine contains a certain amount of organic pollutants. Without treatment, emissions can cause heavy pollution to the local environment. When zero emission requirements exist, it is very uneconomical to evaporate the concentrated brine from the double membrane process, because of its: large size, high equipment investment, and large amount of energy. The concentrated brine process in foreign countries, includes a highly effective reverse osmosis process. It is important that the brine concentration is stable which is beneficial to the safe and long-term operation.

8.4.2 Evaporation Crystallization Process

The concentration of brine is high based on the biochemical treatment process, which is difficult to be recycled. Therefore, the evaporation and crystallization treatments are needed in order to realize the zero discharge of wastewater. Forced circulation technology is used in a crystallizer. The concentrated waste brine passes through a crystallizer or a dryer to crystallize various salts dissolved in the sewage and become solid.

Coal chemical wastewater characteristics involve complex water quality characteristics, large amounts of water, and the inability to deal with this type of wastewater. Because the technology that exists today cannot meet the national environmental protection requirements, it is necessary to develop an integrated and complete process with stable systems that: are shock resistant, have a low treatment cost, and have a good effluent effect in order to achieve near-zero emissions of coal chemical wastewater.

Overall, the biodegradability of coal chemical wastewater is poor. Therefore it is necessary to strengthen the pretreatment technology to improve the biodegradability of the sewage and reduce biological toxicity. Secondly, it is key to select the biological treatment process with strong toxicity resistance and to cultivate and adapt activated sludge for treating coal chemical wastewater. Finally, post-processing

techniques are needed to meet the requirements for water reuse by treating coal chemical wastewater.

By having a zero discharge of the real coal chemical wastewater along with advanced oxidation and membrane assembly process may address the problem of chemical wastewater of coal, but the cost of providing these treatments is still too high. Therefore, further research is needed to reduce the treatment cost and control the membrane fouling assembly process.

8.5 Case Study 5: Treatment Mixed Chemical Wastewater by a Two-Stage A/O Process

Aerobic biological oxidation tank resulted in excellent toxic matter removal. The acute toxicity of the whole system dropped from 0.165 to 0.042 mg HgCl₂/L. The two stage AO system with sludge return system can be used for treating wastewater containing COD, nitrogen and toxic substances.

The mixed wastewater generated from industrial plants which produce chemicals such as fluorochemicals, petrochemicals, coal-chemicals chloro-alkali chemicals and pharmaceuticals, may contain high concentration of COD, nitrogen and toxic substances. By removing the COD nitrogen and toxic matter before discharge, the sewage will not pollute the receiving water bodies that seriously poison the aquatic and terrestrial creatures.

Therefore, treatment of wastewater discharge from a single chemical factory was the basis of this study. Although many wastewater treatments were studied where the processes obtained good COD and nitrogen removal outcomes, the main problems identified were the strict operating requirements and the high running costs. In comparison, bio-treating processes like anaerobic and anoxic/oxic process membrane bioreactor (MBR), biofilm reactor [3, 5] and anaerobic baffled reactor (ABR) [11] are easier to manage, are lower in cost, and are more popular in lab and full-scale experiments and applications. Unfortunately, a high COD and toxic matters on microorganisms are a problem for mixed chemical wastewater treatment systems because the information needed is rarely studied [10]. COD oxidation and nitrification carry out two kinds of microorganism that can inhibit each other under two opposite COD/N ratio conditions. Because of this information, an independent COD oxidation and nitrification system is necessary.

This study focuses on a two-stage A/O process with an independent sludge system, which has a separate COD oxidizer and nitrifiers in two subsystems. Mixed wastewater produced by a chemical group containing high concentrations of COD, nitrogen and toxic matters was treated. The removal efficiency of COD and nitrogen was examined, the acute toxicity of the wastewater from different treating units was appraised (bioassayed), and the system was evaluated [10].

The two-stage A/O system consists of two subsystems. Subsystem one is for COD removal and subsystem two is for nitrogen removal. Each system consists of

a whole A/O system with an anoxic tank, an oxic tank, and a settling tank that finish its removal work independently. The influent flux was maintained at 10 L h and the HRT's had different units. The mixed liquid return was not settled and the sludge return ratios were set at 100–200% to maintain a high usable sludge concentration. The temperature of 25 ± 2 and 30 ± 2 °C was maintained for both subsystems. The two oxic tanks were aerated continuously with rubber diffusers to keep the DO concentration levels at 3–5 mg/L, and the mixing velocity was kept at 60 rpm.

The mixed chemical wastewater used was from the equalizing tank of Juhua wastewater treatment plan (WWTP) Zhejiang province, China. The organic nitrogen in the wastewater was from PVN production. And the $C_6H_{11}NO$ (raw material of PVN) was added to the wastewater to enhance loading rates of NH_4-N . The Org-N/ NH_4N ratio was kept at approximately 1:1. The seed sludge was the condensed sludge of the Juhua water treatment plant. The seed sludge inoculation for both subsystems was at 10,025 and 10,828 mg/L. Sixty-seven days of run passed before the mixed chemical wastewater was adapted. No excess sludge was discharged. DO was determined by an oxygen meter. The pH and temperatures were determined by the pH meter and the concentration of alkalinity was measured by the standard methods.

Marine luminescent bacterium was used to estimate acute toxicity. The bioassays were carried out by adding 2 mL wastewater and 10 mL bacterial suspension to a low-background vitreous tube. After 15 min of exposure, the relatively light units of wastewater were recorded by the luminator. The temperature was constant at 15 °C.

Overall, the two-stage A/C system showed excellent performance in COD removal. Average influent COD concentration of subsystem one of days 1–9, 10–19, and 20–52 were around 943.5. With different $C_6H_{11}NO$ additions the COD increases did not make any influence on COD removal efficiency. Subsystem two had a further removal of COD and average removal efficiency was 50.1% based on subsystem one effluent. The average removal efficiency of the whole system was 93.3%. COD was mostly removed by subsystem one with little nitrification. Overall, it was presumed that autotrophic nitrifiers were more sensitive than heterotrophic COD oxidizers and the inhibition of toxic matters was stronger for nitrifiers than COD oxidizers. Therefore, most of the COD was removed, but very little ammonium was oxidized.

The average removal efficiency of subsystem one of KN was only 6.8% and the KN removal loading rate was 0–0.014 kg KN (kg MLVSS day). On the other hand, subsystem two had a further removal of ORG-N at a low influent ORG-N concentration to the organic matter. Average 86.0%. Additional treatment is required to reduce effluent KN to a concentration of 13.6 mg/L KN, 9.9 mg/L NH_4-N and 3.7 mg/L Org-N.

It was suggested that the coagulation process could remove a part of toxic matters. After coagulation, the acute toxicity was dropped to 0.100 mg $HgCl_2$ L. Overall, coagulation just transferred toxic matters from wastewater to deposits while the aerobic biological oxidation changed toxic matters to nontoxic matters like CO_2 , N_2 and H_2O . Therefore, the two-stage A/O process was sufficient. Coagulation made little impact on the acute toxicity of subsystem two effluent.

The two-stage A/O system, which could remove 87.63% COD, 92.1% KN, and eliminate 75% acute toxicity, performed excellently. After comparing the four biological systems, the sludge system was the main difference and each subsystem had an independent sludge system. Organic carbons were removed and the toxic matters were eliminated in subsystem One. As a result, it guaranteed high nitrifying activity in subsystem 2.

The two-stage A/O system removed COD and KN efficiently from the mixed chemical wastewater with two completely independent microorganism subsystems that performed different functions under their own optimal COD/KN ratio. Subsystem One obtained high COD and OR-N removal capability while nitrification was totally inhibited with only 7.6% KN assimilated by microorganism. Subsystem Two had high nitrification capacity because of the low influent COD/KN ratio and the low nitrification toxicity of 92.1%KN removal efficiency was achieved. Subsystem Two also had a further removal of COD and Org-N. Aerobic biological oxidation of oxic tank one showed excellent toxic matter eliminating ability and the two-stage A/O system can eliminate most of the toxic matters effectively. This study used independent functional activated sludge systems, and established the discharge of mixed wastewater treatments by comprehensive chemical groups, which contained high concentrations of COD and toxic matter [10].

8.6 Case Study 6: Treatment of Chemical Wastewater Using Adsorption

Adsorption is a useful method for treating chemical industry wastewater for the removal of heavy metals and dissolved organic compounds and the reduction of BOD, COD, and color. Adsorption has proven to be an effective treatment method for treating wastewater which varies in composition and concentration of pollutants. There are a variety of adsorbents (materials which absorb pollutants on their surface) including granulated or powdered activated carbon, clay bentonite, fly ash, alumina, magnesium oxide, ferric oxide, silica, saw dust, zeolites, anthracite, and volcano ash soils. For this particular case study, adsorption using activated carbon, and other inorganic adsorbents was studied. The wastewater studied originated from a petrochemical industry. The given wastewater was biologically treated before adsorption was applied. Activated and powdered carbon were adsorbents used. Activated carbon was efficient from removing color from the original amber-colored influent. COD and color were parameters which were used to quantify the amount of organic solutes. The system used a three stage adsorption tank with activated carbon implemented in each stage [12].

Eleven different wastewater samples were analyzed in the laboratory. It was found that they contained dye intermediates (H-acid, dihydroxydibenzanthrone, dibenzyl oxybezaldehyde, dibenzanthronyl), benzanthrone crude, ethanol, drug intermediates (diethyl malonate), complex manufacturing vat dyes and their inter-

mediates. The samples were directly taken from processing plant wastewater streams. Each sample was analyzed for pH, color, and COD. The experiments were all conducted at room temperature. 500 mL of the sample was placed in a cylindrical flask where it was mixed with 2.5 g of activated carbon. Every 15 min, 5–10 mL was extracted from the sample and analyzed for pH, color, and COD. After 2 h, mixing was stopped and the experiment was repeated several times using other adsorbents: once using 5 g of bentonite and another time using 5 g of lignite. The performance of each adsorbent was measured to be effective if percent reduction of COD and color was above 40%, moderately effective if the percent reduction of COD and color was between 20 and 40%, and ineffective if the percent reduction of COD and color was below 20%.

Phenols and cyanides were also removed using activated carbon. Phenol concentrations were reduced to less than 0.5 mg/L. Phenols were more easily adsorbed than pyridines. More than 80% of COD was removed from wastewater containing benzene derivatives, carboxylic acids, pesticides, and phenols. The COD was removed by using an activated anthracite adsorbent. Heavy metals were removed using fly ash. The process was maintained at a pH above 8. Organic impurities such as sodium chloride (NaCl), sodium carbonate (Na_2CO_3), sodium nitrate, monochlorobenzene, polyamines, diaminodiphenylmethane, and toluenediamine were also removed. The concentrations of these impurities were 5–15 mg/L for NaCl, 1.5 mg/L for Na_2CO_3 , and 2 mg/L for toluene diamine.

Overall, activated carbon was highly efficient at removing H-acid, dihydroxydibenzanthrone, ethanol, and diethyl malonate and moderately efficient at removing dibenzanthronyl, benzanthrone crude, and vat dyes and their intermediates. Bentonite was ineffective at removing H-acid while lignite was ineffective at removing H-acid and dibenzyl oxybenzaldehyde. While all three adsorbents were effective for removing COD and color from wastewater, activated carbon had better performance than the other adsorbents. One drawback of using activated carbon is that it was ten times more expensive than the other adsorbents used. However, activated carbon as well as lignite provides easy and safe disposal.

COD values at different durations were predicted using the following models.

Weber and Morri's equation

$$C_i - C = m_1 t^{0.5} + c_1$$

Lagergren equation

$$\log(C - C_{\text{eq}}) = m_2 + c_2$$

Rathi Puranik equation

$$\log(\text{CODRT}) = m_1 + c$$

The predicted values were plotted along with the data obtained from wastewater analysis. The Rathi Puranik equation was found to predict the COD with the least amount of error [12].

8.7 Case Study 7: Treatment of Chemical Coking Wastewater Using Combined Anaerobic–Aerobic Treatment

Anaerobic–aerobic systems are efficient systems for reducing high-strength wastewater. Their efficiency was examined in a case study lasting 300 days. During the study, a combined system was analyzed for treating wastewater from the coking industry. Contaminant removal was also studied using a two-dimensional gas chromatography with time-of-flight mass spectrometry with SCN^- and CN^- under stable operation. Microbial communities were assessed by using a Roche 454 pyrosequencing and real-time quantitative polymerase chain reaction (qPCR) [11].

The combined system that was used during this study was a bench-scale sequential anaerobic and aerobic system. The system consisted of an upflow anaerobic sludge blanket reactor (USAB) and a conventional aerobic bioreactor. The hydraulic retention time was 42 h for the USAB and 72 h for the aerobic reactors [10]. Operating temperature ranged between 20 and 25 °C. Dissolved oxygen was kept 2–4 mg/L in the aerobic reactor during the entirety of the study period (300 days). The concentration of suspended solids in the aerobic reactor was maintained between 3000 and 4000 mg/L.

Coking wastewater is produced from the coke industry. This wastewater is characterized by a mixture of organic contaminants such as phenols and toxic compounds such as cyanides that are hazardous to ecosystems and human health. Methods such as ammonia stripping or solvent extraction are commonly used for pretreatment of coking wastewaters while aerobic activated sludge systems are typically implemented to treat these wastewaters. However, anaerobic systems can also be used in tandem with aerobic systems to better help treat high-strength industrial wastewater and reduce toxic compound concentrations.

Choking wastewater was obtained from an equalization tank of a coking facility in Tangshan City, Hebei Province, China. Ammonia and phenol were recovered from the wastewater, giving it a COD ranging between 2500 and 3500 mg/L. Prior to treatment, the raw wastewater was supplemented with 0.2 g/L of potassium phosphate mono-basic (KH_2PO_4) and 1 mg/L of a micronutrient solution [10]. The pH of the influent wastewater was adjusted to 7.5 ± 0.5 using a concentrated hydrochloric acid solution [10]. Seed sludge originated from a full-scale sewage plant in Beijing, China.

Samples used were using grab samples and were taken at influent and effluent locations every 5–7 days. For the determination of organic and inorganic compounds, wastewater samples were collected in triplicate before the termination of bioreactor operation [11]. Aerobic and anaerobic sludge samples were collected on

days 125, 194, 228, 276, and 325, whereas anaerobic sludge samples were collected on days 154 and 261 of the study period. Sludge composite samples were obtained from a mixture of three samples. From these composites, 1 mL was used as anaerobic sludge and 1.5 mL was used as aerobic sludge. The sludge samples were separately placed into 2 mL tubes and placed into a centrifuge at 10,000 rpm for 10 min at 4 °C. After the centrifuge process was completed, the samples were filtered through a filter 0.45 µm in size. COD was measured using the open reflux method. Total, phenol, total nitrogen, ammonia-nitrogen, thiocyanate, and free cyanide were measured using spectrophotometry. The TOC was measured using a TOC analyzer. Sulfate was measured, using ion chromatography. Lastly, DO and pH were measured using a meter.

Overall, the removal efficiency of the anaerobic treatment system ranged between 0 and 84.6%. It was found that anaerobic treatment removed one third of organics consisting of 32.7% of COD and 34.2% of TOC and more than half of the total phenols (54%) from the wastewater.

The hydraulic retention time of the anaerobic system was 42 h. Anaerobic treatment removed an average of 58% of NHCs and 58.6% of phenolic derivatives. The combined system was able to remove 81.8% of COD, 85.6% of total organic carbon (TOC), 99.9% of total phenols, and 85.4% of thiocyanate and cyanide. The COD concentration was reduced to an effluent concentration of 520.1 ± 73.1 mg/L and a TOC concentration of 112.1 ± 21.8 mg/L. These values are fairly high. Additionally, the system removed 98.2% of SCN^- and 85.4% of CN^- . However, the system had minimal effect on nutrients, as the total nitrogen concentration was constant throughout the treatment process. The ammonia-nitrogen concentration and sulfate concentration increased to 149.5 ± 27.1 and 1512.5 ± 320.7 mg/L after treatment.

Microbes within the system were also examined. It was found that *Proteobacteria*, specifically *Betaproteobacteria* (34.4–70.1%), *Alphaproteobacteria* (10.9–31.7%), were present in the combined system (10–11%). Bacteria such as *Betaproteobacteria* (64.2–76%), *Ottowia*, *Soehngenia*, and *Corynebacterium* were the most abundant in the anaerobic stage. Other bacteria with high populations in the anaerobic reactor include *Actinobacteria*, which had an abundance ranging between 3.1 and 14.1% of the total bacteria present in the reactor; *Firmicutes*, which had an abundance ranging between 11.9 and 13.5% of the total bacteria present in the reactor; bacteroids, which had an abundance ranging between 3.3 and 4.7% of the total bacteria present in the reactor. Bacteria such as *Thiobacillus*, *Diaphorobacter*, *Trichosporon*, and *Comamonas* were the most abundant in the aerobic stage.

The archaea and fungi population was low in both the aerobic and anaerobic systems. However, the following archaea appeared in the highest numbers: *Methanosarcina* (41.7–44.3%), *Methanobacterium* (19.8–20.9%), *Methanomethylovorans*, and *Euryarchaeota* (96.2–98.3%), which can further be classified by two subcategories, *Methanomicrobia* (73.0–75.7%) and *Methanobacteria* (20.2–20.9%). Out of the fungi present, phylum *Basidiomycota* was the most abundant fungi in the system. *Trichosporon* was the most abundant yeast present in the aerobic reactor, having an abundance between 62.9–88.3 and 10.2–34.5% of fungi were listed as unclassified.

Ultimately, these results are in agreement with the presented material about combined systems described earlier. Combined systems provide a simple, less energy-intensive alternative for treatment. These systems can be useful for removing pollutants such as phenolics, NHCs, SCN^- , and CN^- in coking wastewater [11].

8.8 Case Study 8: Treatment of Chemical Industry Wastewater Using an MBBR System

This study examined the use of an moving bed biofilm reactor (MBBR) for pretreating complex chemical industry wastewater. Wastewater from the study originated from the Exxon Chemical Baton Rouge Chemical Plant in Louisiana. The plant implemented physical pretreatment, trickling filters and activated sludge to treat the wastewaters. However, the existing treatment system was unable to meet stringent effluent guidelines specified and therefore need to be either replaced or upgraded. Recommendations were made to replace the existing trickling filter unit with an MBBR system to enhance efficiency [13].

MBBR systems have proven to be efficient for treating wastewaters from the food industry, pulp and paper industry, and municipal wastewaters. However, this was one of the first applications of using an MBBR on chemical industry wastewaters. Therefore, a pilot system was developed to establish criteria for full-scale MBBR system design. The biofilm was constructed as a small, 10 mm diameter, 7 mm tall cylinder made of polyethylene with a density of 0.96 g/cm^3 . The cylinder was designed with a cross shape on the interior and longitudinal fins on the exterior surface. Perforated plates sized $5 \text{ mm} \times 25 \text{ mm}$ were used to support the biofilm. The maximum specific growth area was specified as $350 \text{ m}^2/\text{m}^3$. The system was designed with no sludge return to the biofilm reactors. The system was designed with two MBBR units in parallel, with one operating at a medium organic load and a high organics load. The conventional aerated activated sludge plant was then fed effluent from one MBBR at a time. Air flow was controlled manually by using valves.

For the study, wastewater from three streams was collected and analyzed. Phosphoric acid was added to the wastewater to provide ample nutrients for treatment. Daily composite samples were taken from the three points and stored in a refrigerator. Samples were also taken from the activated sludge stage (point 4), the mixed liquor (point 5), and the RAS (point 6). Samples were analyzed for total and filtered BOD_5 , total and filter COD, total Kjeldahl nitrogen (TKN), $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, total suspended solids (TSS), and volatile suspended solids (VSS). Mixed liquor and RAs were analyzed for TSS and VSS.

The organic load of typical MBBR systems is $53 \text{ g BOD}_5/\text{m}^2/\text{day}$ and the BOD fraction ranges between 60 and 80%. Lower organic loads between 10 and $20 \text{ g BOD}_5/\text{m}^2/\text{day}$ have been observed to metabolize organic matter. For this system, MBBR 1 was loaded with a high load and MBBR 2 was loaded with medium loaded wastewater. In previous studies, when MBBR were combined with activated sludge, chemical wastewater effluent was found to have BOD_5 as low as 3.4 mg/L . The

operating average conditions for the systems are as follows. Both MBBR systems were operated at the same pH, 7.9 ± 0.1 .

MBBR 1 operated with a flow of 7.8 ± 0.4 m³/day, an empty bed HRT of 1.9 ± 0.2 h, a DO of 4.3 ± 0.8 mg/L, an ammonia nitrogen concentration of 4.1 ± 3.7 mg/L, and a phosphate phosphorus concentration of 1.1 ± 0.8 mg/L. MBBR 2 operated with a flow of 3.8 ± 0.1 m³/day, an empty bed HRT of 3.8 ± 0.1 h a DO of 4.0 ± 0.5 mg/L, an ammonia nitrogen concentration of 3.1 ± 2.9 mg/L, and a phosphate phosphorus concentration of 1.1 ± 0.9 mg/L. The MBBRs were operated at nearly the same temperature with the temperature of 34.1 ± 1.1 °C for MBBR 1 and 34.2 ± 1.0 °C for MBBR 2.

The average flow into the activated sludge system ranged between 1.4 and 2.8 m³/day between the study period that took place between June 3 and August 15. The activated sludge system was also operated with an average MLSS ranging between 4.9 ± 1.6 and 5.8 ± 2.5 g/L, an average MLVSS ranging between 3.8 ± 1.2 and 4.4 ± 1.8 g/L, an average ammonia nitrogen concentration ranging between 3.0 ± 2.5 and 4.3 ± 0.1 mg/L, and an average phosphate phosphorus concentration ranging between 3.0 ± 0.5 and 4.5 ± 0.7 mg/L.

From analysis, it was found that MBBR 2 has a 10–15% higher removal efficiency of organic matter and a lower sludge production than MBBR 1. Both MBBRs had a BOD removal efficiency 6–8% higher than the COD removal efficiency. A change in influent concentration did not affect the removal efficiency. Of the BOD analyzed, it was found that 60–80% of the BOD was easily removed. Organic loads above 25 g TBOD₅/m²day were observed to have no change on the removal efficiency. The removal efficiency of high loaded wastewater ranged between 70 and 80% BOD removal. For low loads between 10 and 20 g TBOD₅/m²day, 95% of total and filtered BOD₅ was removed. The highest removal rates observed were 40 g TBOD₅/m²day and 35 g FBOD₅/m²day.

From this study it can be concluded that MBBRs can offer a compact alternative for treating chemical industry wastewaters [13].

9 Waste Minimization

While the wastewater treatment process removes harmful chemicals from water after chemical production, other steps can be taken within the chemical industry to reduce the amount of wastewater and the concentrations of pollutants within the wastewater during the manufacturing. Waste minimization during the production process is an important step to avoid waste formation during production [6].

Resource efficiency is an important consideration for sustainability in the chemical industry. Resource efficiency is defined as the use of natural resources in a way that minimizes the amount of resources needed to produce a particular product. Resource efficiency is especially concerned with material use efficiency as well as energy and water efficiency. Proper design and management are essential for the development of efficient systems. One particular method to reduce waste within the chemical industry is to implement green chemistry practices. Implementation of

green practices allows for the design of chemical products all the while minimizing the harmful effects of these products on humans and the environment. Furthermore, green engineering methods can be utilized for better design practices, which can aid in waste reduction [14].

A few key steps for waste minimization in the chemical industry include: (1) determining the cost of the waste, (2) understanding the products and processes utilized, (3) analyzing the performance efficiency and identifying areas where reduction can be made, (4) narrowing options and prioritizing improvement ideas, (5) implementing reuse and recycling methods when possible, and (6) monitor and maintain practices. Ultimately, the best waste management practices account for environmental, economic, and social concerns [14]. In order to produce efficient, sustainable products which account for all of these factors, engineers and other stakeholders must come together to prioritize and implement the best waste management practices. Good communication is essential during this process.

The resource efficiency from the chemical industry was measured in a case study from Finland. The chemical industries from the study consisted of pharmaceutical, oil refining, plastic, and rubber manufacturing industries as well as other chemical product industries. Most of these industrial facilities were located within 200 km of Oula. Hazardous waste generated from the chemical industry totaled 111,000 tonnes. To determine the efficiency, questionnaires were sent to several chemical plants in Northern Ostrobothnia in 2004 and 2005. Questions asked respondents about actions that were taken to prevent waste, benefits of said actions, future actions that could be implemented, and key parameters that were used to reduce waste. The questionnaire had a total of 14 questions.

Results show that companies mainly implement waste reduction during the manufacturing process. Ninety-two percent of respondents identified improved machine maintenance as the favored management techniques opposed to others. Eighty-five percent of respondents identified the importance of training for waste management procedures. Furthermore, 85% of respondents reported waste reduction by using a smaller amount of raw materials and 77% of respondents reported waste reduction by using more efficient processes. Water and energy considerations are typically important considerations in industrial processes. From the survey, 77% of respondents indicated the importance of energy reduction while only 44% of companies indicated the importance of water reduction. Other actions that were taken indicated that 23% use cheaper electricity, 31% adjust temperature, 31% use reusable packages, and 31% use less water for flushing. Additionally, 54% of respondents bought raw materials in bulk, 61% used recycled solvents and plastics, 31% used energy recovery methods, and 23% used off site recycling [14].

10 Summary

There is need for better and more frequent monitoring waste practices from the chemical industry. Furthermore, water reduction practices were rarely used from chemical industries. Company culture largely affected the way in which company

addressed waste management. In order to implement the most efficient and optimized process, employees should be knowledgeable about the processes utilized at their chemical company as well as any restrictive regulations and resources available. With proper education and training, chemical industries can properly reduce the amount of waste produced [14, 15].

Glossary

Aerobic treatment A biological process that uses oxygen to break down organic contaminants and other pollutants like nitrogen and phosphorous.

Anaerobic treatment A biological process where microorganisms degrade organic contaminants in the absence of oxygen.

Biological treatment *Biological treatment* (or biotreatment) processes are those which remove dissolved and suspended organic chemical constituents through biodegradation, as well as suspended matter through physical separation.

Chemical industry The *chemical industry* comprises the companies that produce *industrial chemicals*.

Oxidation Any chemical reaction that involves the moving of electrons.

Pharmaceutical products Fundamental component of both modern and traditional medicine.

Pretreatment Any [treatment](#) received before some other process.

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