CHAPTER 1

INTRODUCTION

1.1. The Backdrop

In many parts of the world, economic, social and political problems have arisen following rapid industrial development and urbanization, resulting in adverse effects on the quality of life. Urbanization in general initially places pressure on and overstrains public amenities. However, long-term and wider issues would eventually also be encountered as industrialization and urbanization exert pressure on the larger resource base that supports the community. This larger resource base includes forestry, freshwater and marine resources, as well as space suitable for further development. The difficulties associated with environmental degradation often originate from industrial development. They are amplified by rapid urbanization that is responsible for the growth of many major cities. In Asia, urbanization is exacerbated by large rural–urban migrations. These migrations emerge in response to perceived opportunities for a better livelihood in industrialized, economically booming urban areas. Rapid industrialization and its concentration in or near urban centers have placed very high pressures on the carrying capacity of the environment at specific locations. At these locations waterbodies such as rivers, lakes, and coastal waters have typically been severely affected.

Freshwater is a vital natural resource that will continue to be renewable as long as it is well managed. Preventing pollution from domestic, industrial, and agro-industrial activities is important to ensure the sustainability of the locale's development. Undoubtedly the water pollution control efforts which have been underway in many countries have already achieved some success. Nevertheless the problems that are confronted grow in complexity and intensity. It is estimated that 785 million people in Asian developing countries have no access to sustainable safe water (Sawhney, 2003). The pollution of freshwater bodies with the consequent deterioration in water quality can only worsen the situation. Such pollution has been brought about by the discharge of inadequately treated sewage and industrial wastewaters. This book focuses on the latter. Perhaps not unexpectedly, as the demand for more water is met, the volumes of wastewater can also be expected to increase. Coastal waters are also under pressure as they receive effluents discharged directly into them or indirectly from rivers. While most communities in Asia do not use coastal waters as a source of potable water (via desalination), there is already a movement towards this direction, as in the case of Singapore. Even though coastal waters are not yet a major source of potable water, they are, nevertheless, very important since they support fisheries and tourism industries. The ecosystems in many of Asia's coastal waters are fragile; damage to these ecosystems as a result of pollution can adversely affect fishery industries. The latter, in many instances, depend on mangrove forests as spawning grounds for marine life which are subsequently harvested.

Industrial wastewaters (including agro-industrial wastewaters) are effluents that result from human activities which are associated with raw-material processing and manufacturing. These wastewater streams arise from washing, cooking, cooling, heating, extraction, reaction by-products, separation, conveyance, and quality control resulting in product rejection. Water pollution occurs when potential pollutants in these streams reach certain amounts causing undesired alterations to a receiving waterbody. While industrial wastewaters from such processing or manufacturing sites may include some domestic sewage, the latter is not the major component. Domestic sewage may be present because of washrooms and hostels provided for workers at the processing or manufacturing facility. Examples of industrial wastewaters include those arising from chemical, pharmaceutical, electrochemical, electronics, petrochemical, and food processing industries. Examples of agro-industrial wastewaters include those arising from industrial-scale animal husbandry, slaughterhouses, fisheries, and seed oil processing. Agro-industrial wastewaters can be very strong in terms of pollutant concentrations and hence can contribute significantly to the overall pollution load imposed on the environment. It is perhaps ironic that the very resources which promoted industrial development and urbanization in the first place can subsequently come under threat from such development and urbanization because of over and inappropriate exploitation. Appropriate management of such development and resources is a matter of priority. The South Johore coast was such a case (ASEAN/US CRMP, 1991). This was then, economically, one of the fastest growing areas in Malaysia and potential damage to the environment of such development, if not properly managed, was recognized.

The impact of industrial wastewater discharges on the environment and human population can be tragic at times. Some 50 years ago, the Minamata disease which spread among residents in the Yatsushiro Sea and the Agano River basin areas in Japan was attributed to methyl mercury in industrial wastewater (Matsuo, 1999). However, tragedies as dramatic as the Minamata episode have not occurred frequently. Nevertheless, instances of pollution with potentially adverse impacts in the longer term have continued to occur. In the interim before the realization of these longer term impacts, a decline in the quality of life arising from the deterioration in water quality which various populations must access may become increasingly discernable. Examples of these, their recognition, and the efforts made to remedy the situations in the 1980s include the protection of Malaysian coastal waters from refinery wastewater (Yassin, 1987), the Tansui River in Taiwan where pesticides and heavy metals were discovered in the sludge (Liu & Kuo, 1988), the Nam Pong River in Thailand which was polluted by the pulp and paper industry (Jindarojana, 1988), and the Buriganga River in Bangladesh which had been polluted by, among other industries, tanneries (Ahmed & Mohammed, 1988). Similar reports in the 1990s include the Kelani River in Sri Lanka (Bhuvendralingam *et al.*, 1998), the Laguna de Bay in the Philippines (Barril *et al.*, 1999), and the Koayu River which had occurrences of *Cryptosporidum* oocysts and *Giardia* cysts after receiving inadequately treated piggery wastewater (Hashimoto & Hirata, 1999). Such reports are still frequent in the 2000s and caused concerns in Vietnam (Nguyen, 2003) and Korea (Kim *et al.*, 2003). The fact that water pollution due to discharges of inadequately treated industrial wastewater has occurred over decades in Asia obviously means solutions have not been found for all such occurrences. Towards the end of 2004, the Huai River in China was reported to have been so seriously polluted by paper-making, tanning and chemical fertilizer factories, farmers in Shenqiu County had fallen very ill after using the river water (The Strait Times, 2004). There has, however, been progress and an example is the successful ten year river pollution clean-up program in Singapore (Chiang, 1988).

Agro-industrial wastewaters, as a sub-class of industrial wastewaters, can have considerable impact on the environment because they can be very strong in terms of pollutant strength and often the scale of the industry generating the wastewater in a country is large. Citing ASEAN countries in Asia as examples, agro-industrial wastewaters had and in some instances still contribute very significantly to pollution loads. For example in 1981 the Malaysian palm oi and rubber industries contributed 63% ($1460\,td^{-1}$) and 7% ($208\,td^{-1}$) of the BOD (Biochemical Oxygen Demand) load generated per day respectively. This is compared with $715\,td^{-1}$ of BOD from domestic sewage (Ong *et al.*, 1987). In the Philippines, pulp and paper mills generated $90\,td^{-1}$ of BOD load (Villavicencio, 1987). Agro-industrial sites are therefore often the largest easily identifiable point sources of pollutant loads. While there are exceptions, individual industrial wastewater sources associated with manufacturing in Asia are, in contrast, more often small to medium sized compared to the former. The classifications of a small and medium-sized manufacturing facility have been defined in terms of the numbers of employees employed at such sites — $10 \sim 49$ persons and $50 \sim 199$ persons respectively.

Notwithstanding their small to medium sizes, the collective contribution from such enterprises to pollution is not necessarily negligible.

It should also be noted that while industrial wastewater sources may be small to medium-size, they are generally located in urban centers where building congestion is already a problem. To aggravate the situation, such factory operations may have no long-range project planning and are also unable to exploit advantages associated with economies of scale. A number of such operations may also try to maximize profits by reducing overheads and "unnecessary" expenditure associated with pollution control requirements — the result of an absence of an appropriate corporate culture and hence a weaker social conscience in terms of care for the environment. On a positive note, however, economic development over the last few decades has enabled necessary managerial, financial, and technological capabilities to address problems of pollution and environmental degradation over the broad spectrum of factory sizes. There is also a growing realization that the cost (in terms of the human and economic costs) of cleaning up after the act is frequently more than preventing the pollution in the first place.

1.2. What is Industrial Wastewater?

To begin the discussion on industrial wastewater, it may be useful to compare industrial wastewater with domestic sewage since designers of wastewater treatment facilities often begin their careers and almost certainly their education in environmental engineering by looking at sewage and sewage treatment plants. The latter can then provide a familiar framework which the reader can use to compare industrial wastewater and its treatment.

Domestic sewage is wastewater discharged from sanitary conveniences in residential, office, commercial, factories and various institutional properties. It is a complex mixture containing primarily water (approximately 99%) together with organic and inorganic constituents. These constituents or contaminants comprised suspended, colloidal and dissolved materials. Domestic sewage, since it contains human wastes, also contains large numbers of micro-organisms and some of these can be pathogenic. Waterborne bacterial diseases that can be present in sewage include cholera, typhoid and tuberculosis. Viral diseases can include infectious hepatitis. Inorganic constituents include chlorides and sulphates, various forms of nitrogen and phosphorous, as well as carbonates and bicarbonates. Proteins and carbohydrates constitute about 90% of the organic matter in domestic sewage. These arise from the excreta, urine, food wastes, and wastewater from bathing, washing, and laundering, and because of the latter, soaps, detergents, and other cleaning products can be found as well. Domestic sewage has a flow pattern which typically shows two peaks — in the morning before the start of working hours and in the evening after the population has returned from work. Typically these hydraulic peaks would also become more distinct as the sewage flows considered come from smaller populations and consequently smaller sewer networks. Variations in sewage characteristics across a given community tend to be relatively small although variation across communities can be more readily detected. Notwithstanding these variations, the composition of domestic sewage is such that it lends itself well to biological treatment in terms of the availability of and balance between carbonaceous components and nutrients. The biodegradability of sewage can be estimated by considering its Chemical Oxygen Demand (COD) and the corresponding BOD_5 (5 day BOD), and is indicated by its COD:BOD_5 and BOD_5:N:P ratios. This would typically be about 1.5:1 and 25:4:1 respectively. The nitrogen, N, would typically be in the form of organic nitrogen and ammonia-nitrogen (Amm-N). Nitrates (NO_3-N) would not be expected to be present as conditions in the sewers would be such that nitrate formation is unlikely while nitrate degradation because of anoxic reactions is likely. The phosphorous (P) would be a combination of organic and phosphate (PO_4) forms. The pH of sewage would be within the range of 6–9 and this is generally considered suitable for biological processes. Examples of values of BOD_5, TSS (Total Suspended Solids), and TKN (Total Kjeldhal Nitrogen) which have been used for purposes of plant design are 250, 300 and 40 mg L^{-1} respectively. As indicated earlier in this paragraph, sewage characteristics can vary across communities and a raw sewage BOD_5 of 500 mg L^{-1} has been encountered.

Industrial (including agro-industrial) wastewaters have very varied compositions depending on the type of industry and materials processed. Some of these wastewaters can be organically very strong, easily biodegradable, largely inorganic, or potentially inhibitory. This means TSS, BOD_5 and COD values may be in the tens of thousands mg L^{-1}.

Because of these very high organic concentrations, industrial wastewaters may also be severely nutrients deficient. Unlike sewage, pH values well beyond the range of 6–9 are also frequently encountered. Such wastewaters may also be associated with high concentrations of dissolved metal salts. The flow pattern of industrial wastewater streams can be very different from that of domestic sewage since the former would be influenced by the nature of the operations within a factory rather than the usual activities encountered in the domestic setting. A significant factor influencing the flow pattern would be the shift nature of work at factories. These shifts may be 8 h or 12 h shifts and there can be up to three shifts per day. These shifts may mean that there can be more than the two peaks in flow seen in sewage and there may be no flow for parts of the day. Factories may operate five to seven days per week. A consequence of this can be the possibility of zero flow on days when a factory is not operating. In contrast to the narrower band of variation in the characteristics of domestic sewage within a community, industrial wastewaters can have very different characteristics even for wastewaters from a single type of industry but from different locations. The cause of these differences has much to do with the operating procedures adopted at each site and the raw materials used therein. To further complicate matters, wastewater characteristics within a factory can also vary with time because it may practice campaign manufacturing, or it may practice slug discharges on top of its usual discharges. Apart from these events which occur on a regular basis, there would be spillages and dumping which may occur within the factory infrequently but can have very adverse impacts on the performance of the wastewater treatment plant. Consequently it would be prudent to assess an industrial wastewater, as well as its pretreatment and treatment requirements very carefully and not immediately assume that its wastewater characteristics and treatment requirements are similar to a previously encountered example. It would also be prudent to acquire some understanding of the nature of the factory's operations. A more detailed discussion of the characteristics of industrial wastewaters is made in Chapter 2.

On some occasions industrial wastewaters are discharged into a sewerage system serving commercial and residential premises. Such a combination of wastewater streams is known as municipal wastewater and the quality of such a mixture of wastewaters can vary depending on the proportion of industrial wastewaters in it and the type of industries contributing the industrial wastewater streams. Usually the domestic and commercial components in municipal wastewater can be expected to provide some buffering in terms of the characteristics of the combined flow. This is then expected to enable the combined wastewater to be treated easily compared to the treatment of the industrial wastewater on its own. However, even where the option of discharging into a sewerage system is available, some degree of pretreatment is frequently required at the factory before such discharge is permitted. Such pretreatment may include pH adjustment to 6–9 and BOD_5 reduction to 400 mg L^{-1} as being currently practiced in Singapore (Pakiam *et al.*, 1980). This is to protect the receiving sewers from corrosion and also protect the performance of the receiving treatment plant from an organic substrate overload.

1.3. Why is it Necessary to Treat Industrial Wastewater?

All major terrestrial biota, ecosystems, and humans depend on freshwater (i.e. water with less than 100 mg L^{-1} salts) for their survival. The earth's water is primarily saline in nature (about 97%). Of the remaining (3%) water, 87% of it is locked in the polar caps and glaciers. This would mean only 0.4% of all water on earth is accessible freshwater. The latter is, however, a continually renewable resource although natural supplies are limited by the amounts that move through the natural water cycle. Unfortunately precipitation patterns, and hence distribution of freshwater resources, around the globe is far from even. Where precipitation does fall heavily, there are often difficulties with storage because of space constraints. Furthermore the available freshwater has to be shared between natural biota and human demands. The latter, aside from direct human consumption, includes water for agricultural, urban, and industrial needs. Freshwater shortages increase the risk of conflict, public health problems, reduction in food production, inhibition of industrial production expansion, and these problems threaten the environment.

Freshwater shortages are, however, not only due to uneven distribution of freshwater resources and demand for freshwater but also, increasingly, due to the declining water quality in freshwater sources already in use. This declining water quality is primarily due to pollution. It should not be forgotten that in the wider context of resources associated with water, the marine environment is also included in the picture. While the latter was, in the past, primarily associated with the fisheries resource, it can also include tourism and the feed for desalination in the current context. Untreated industrial wastewaters would add pollutants into waterbodies — freshwater and saline. These receiving waterbodies, freshwater and marine, can include ponds, lakes, rivers, coastal waters, and the sea. It would be useful to bear in mind that pollutants introduced into a river or some other freshwater waterbody do eventually end up in the sea, the ultimate receptacle for waterborne pollutants if these are permitted to find their way through the environment unimpeded. An example of riverine pollution are the rivers flowing through urban and industrial areas such as Hanoi and Ho Chi Minh City in Vietnam picking up pollutants such as heavy metals and organochlorine pesticides and herbicides. These pollutants reach the sea eventually and therein threaten the fisheries (Nguyen *et al.*, 1995). On Hainan Island (Southern China), for example, industries such as sugar refineries, paper mills, shipyards, and fertilizer plants accounted for about half the total wastewater generated and reaching the sea. This had resulted in incidences of the red tide in Houshui Bay and an area northwest of the island (Du, 1995). Obviously then, inadequately treated industrial wastewaters discharged into rivers would not only affect the freshwater in these areas but also the receiving coastal and sea waters. Eventually coastal resources such as the mangrove and reef ecosystems, and thereafter fisheries would be affected. The discharge of inadequately treated industrial wastewaters can therefore have far-reaching consequences. In the last decade, the emergence of industrial pollution has been identified as a trend in the coastal areas of Southern China, Vietnam, Kampuchea, and Thailand.

The effects pollutants have on the water environment can be summarized in the following broad categories:

(a) Physical effects — These include impact on clarity of the water and interference to oxygen dissolution in it. Water clarity is affected by turbidity which may be caused by inorganic (Fixed Suspended Solids or FSS) and/or organic particulates suspended in the water (Volatile Suspended Solids or VSS). The latter may undergo biodegradation and thereby also have oxidation effects. Turbidity reduces light penetration and this reduces photosynthesis while the attendant loss in clarity, among other things, would adversely affect the food gathering capacity of aquatic animals because these may not be able to see their prey. Very fine particulates may also clog the gill surfaces of fishes and thereby affecting respiration and eventually killing them. Settleable particulates may accumulate on plant foliage and bed of the waterbody forming sludge layers which would eventually smother benthic organisms. As the sludge layers accumulate, they may eventually become sludge banks and if the material in these is organic then its decomposition would give rise to malodours. In contrast to the settleable material, particulates lighter than water eventually float to the surface and form a scum layer. The latter also interferes with the passage of light and oxygen dissolution. Because of the former, these scum layers affect photosynthesis. Discharge limits on wastewater or treated wastewater discharges typically have a value for TSS such as $30\,mg\,L^{-1}$ or $50\,mg\,L^{-1}$. Many industrial wastewaters contain oil and grease (O&G). While some of the latter may be organic in nature, there are many which are mineral oils. Notwithstanding their organic or mineral nature, both types cause interference at the air-water interface and inhibit the transfer of oxygen. Apart from their interference to the transfer of oxygen from atmosphere to water, the O&G (particularly the mineral oils) may also be inhibitory. Unlike domestic sewage, industrial discharges can have temperatures substantially above ambient temperatures. These raise the temperatures of the receiving water and reduce the solubility of oxygen. Apart from this, rapid changes in temperature may result in thermal shock and this may be lethal to the more sensitive species. Heat, however, does not always have a negative impact on organisms as it may positively affect growth rates although there are limits here too since the condition may favor certain species within the population more than others and over time biodiversity may be negatively affected;

(b) Oxidation and residual dissolved oxygen — As suggested in the preceding paragraph, waterbodies have the capacity to oxygenate themselves through dissolution of oxygen from the atmosphere and photosynthetic activity by aquatic plants. Of the latter, algae often plays an important role. However, there is a finite capacity to this re-oxygenation and if oxygen depletion, as a result of biological or chemical processes induced by the presence of organic or inorganic substances which exert an oxygen demand (i.e. as indicated by the BOD or COD), exceeded this capacity then the dissolved oxygen (DO) levels would decline. The latter may eventually decline to such an extent that septic conditions occur. A manifestation of such conditions would be the presence of malodours released by facultative and anaerobic organisms. An example of this is the reduction of substances with combined oxygen such as sulphates by facultative bacteria and resulting in the release of hydrogen sulphide. The depletion of free oxygen would affect the survival of aerobic organisms. DO levels do not, however, need to drop to zero before adverse impacts are felt. A decline to 3–4 mg L^{-1}, which still means the water contains substantial quantities of oxygen, may already adversely affect higher organisms like some species of fish. If inhibitory substances are also present, then the DO level at which adverse effects may be felt can be even higher than before. The case of elevated water temperatures due to warm discharges is somewhat different. The elevated temperatures can affect metabolic rates positively (possibly twofold for each 10°C rise in temperature) but elevated temperatures also reduce the solubility of oxygen in water. This would mean increasing demand for oxygen while its availability declines. Because of the impact of DO levels on aquatic life, much importance has been placed on determining the BOD value of a discharge. Typical BOD_5 limits set are values such as 20 and 50 mg L^{-1};

(c) Inhibition or toxicity and persistence — These effects may be caused by organic or inorganic substances and can be acute or chronic. Examples of these include the pesticides and heavy metals mentioned in the preceding section. Many industrial wastewaters do contain such potentially inhibitory or toxic substances. The presence of such substances in an ecosystem may bias a population towards members of the community which are more tolerant to the substances while eliminating those which are less tolerant and resulting in a loss of biodiversity. For similar reasons, an awareness of the impact such substances have on biological systems is not only relevant in terms of protection of the environment but is of no less importance in terms of their impact on the biological systems used to treat industrial wastewaters. Even successful treatment of such a wastewater may not necessarily mean that the potability of water in a receiving waterbody would not be affected. For example small quantities of residual phenol in water can react with chlorine during the potable water treatment process giving rise to chlorophenols which can cause objectionable tastes and odors in the treated water. Apart from the organic pollutants which are potentially inhibitory or toxic, there are those which are resistant to biological degradation. Such persistent compounds can be bioaccumulated in organisms resulting in concentrations in tissues being significantly higher than concentrations in the environment and thereby making these organisms unsuitable as prey/food for organisms (including Man) higher up the food chain. While some organic compounds may be persistent, metals are practically non-degradable in the environment;

(d) Eutrophication — The discharge of nitrogenous and phosphorous compounds into receiving waterbodies may alter their fertility. Enhanced fertility can lead to excessive plant growth. The latter may include algal growth. The subsequent impact of such growth on a waterbody can include increased turbidity, oxygen depletion, and toxicity issues. Algal growth in unpolluted waterbodies is usually limited because the water is nutrient limiting. While nutrients would include marco-nutrients like nitrogen, phosphorous, and carbon, and micro-nutrients like cobalt, manganese, calcium, potassium, magnesium, copper, and iron which are required only in very small quantities, the focus in concerns over eutrophication would be on phosphorous and nitrogen as quantities of the other nutrients in the natural environment are often inherently adequate. In freshwaters the limiting nutrient is usually phosphorous while in estuarine and marine waters it would be nitrogen. Treatment of industrial wastewater (or domestic sewage for that matter) can then target the removal of either phosphorous or nitrogen, depending on the receiving waterbody, to ensure that the nutrient limiting condition is maintained. Given the litoral nature of many nations in Asia, removal of nitrogen would likely be necessary if the wastewater contained excessive quantities. When the nutrient limiting condition is no longer present in the waterbody, and when other conditions such as ambient temperature are appropriate, excessive algal growth or algal blooms (e.g. the red tide) may occur. Apart from aesthetic issues, such algal blooms may affect the productivity of the fisheries in the locale. It should be noted that not all industrial wastewaters contain excessive quantities of nutrients, macro and micro. This deficiency, if there is, results in process instability and/or the proliferation of inappropriate microbial species during biological treatment of the wastewaters. Bulking sludge is a manifestation of such an occurrence. To address this deficiency, nutrients supplementation is required. The quantities used should be carefully regulated so that an excessive nutrients condition is not inadvertently created and these excess nutrients subsequently discharged with the treated effluent. In terms of BOD:N:P, the optimal ratio for biotreatment is often taken as 100:5:1 while the minimum acceptable condition can be 150:5:1;

(e) Pathogenic effects — Pathogens are disease-causing organisms and an infection occurs when these organisms gain entry into a host (e.g. man or an animal) and multiply therein. These pathogens include bacteria, viruses, protozoa, and helminthes. While domestic and medical related wastewaters may typically be linked to such micro-organisms (and especially the bacteria and viruses), industrial wastewaters are not typically associated with this category of effects. The exception to this is wastewaters associated with the sectors in the agro-industry dealing with animals. The concern here would be the presence of such organisms in the wastewater which is discharged into a receiving waterbody and diseases, if any, are then transmitted through the water. While many of these organisms can be satisfactorily addressed with adequate disinfection of the treated effluent and raw potable water supplies during the water treatment process, there are those which cannot be dealt with so easily. Two examples of such organisms, *Cryptosporidum* and *Giardia*, were identified in Sec. 1.1. These belong to the protozoa family. The difficulty is that the infected host does not necessarily shed the organism but is likely also to shed its eggs or oocysts. The latter can unfortunately be resistant to the usual disinfection processes. An outbreak of cryptosporidiosis, a gastrointestinal disease, would result in the hosts suffering from diarrhea, abdominal pain, nausea, and vomiting.

With the above effects in view, industrial wastewater treatment would typically be required to address at least the following parameters:

(a) Suspended solids (SS);
(b) Temperature;
(c) Oil and grease (O&G);
(d) Organic content in terms of biochemical oxygen demand (BOD) or chemical oxygen demand (COD);
(e) pH;
(f) Specific metals and/or specific organic compounds;
(g) Nitrogen and/or phosphorus;
(h) Indicator micro-organisms (e.g. *E. Coli*) or specific micro-organisms.