Development of a Pilot-Scale Treatment Plant for Market Wastewater of Khulna City

by

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A thesis submitted in partial fulfillment of the requirements for the degree of
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in Department of Civil Engineering

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Declaration

This is to certify that the thesis work entitled 'Development of a Pilot-Scale Treatment Plant for Market Wastewater of Khulna City' has been carried out by Azrina Karima in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Abstract

In developing countries like Bangladesh, urbanization mostly takes place in unplanned and informal way. With high population density and inappropriate construction approach of commercial areas, market wastewater has become a severe problem and threat to environmental sustainability. Market wastewater is mainly produced at butcher houses, during chicken slaughtering and processing, at fish markets, etc. Market wastewater contaminated with animal body fluid, blood, worms, bacteria and viruses are causing environmental pollution and posing a threat to public health. Therefore, market wastewater should be treated prior to disposal into the environment. In this context, this study aims at: (a) determining the physical, chemical/biochemical and microbial characteristics of market wastewater, (b) developing a pilot-scale treatment unit for the market wastewater and finally (c) monitoring its performance and address any modification if necessary.

A comprehensive field survey had been conducted in three markets situated near Moyur River. The market wastewater was collected in jerry can and brought to laboratory for various wastewater quality analyses such as Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Iron (Fe), Nitrate (NO_3), Phosphate (PO_4), Total Solids, Total Suspended Solids (TSS), Total Volatile Solids (TVS), Volatile Suspended Solids (VSS), Electrical Conductivity (EC), Temperature, pH, Alkalinity, Total Coliform (TC) and *Escherichia coli (E. coli*). In market wastewater: TSS, BOD_5 and TC were found to be 1,840-3,300 mg/L, 62-619 mg/L and 3,400-6,00,000 N/100 mL, respectively. In order to minimize the pollutants in market wastewater, a pilot-scale treatment unit, adopting the activated sludge process, has been developed in the laboratory. In treated water: TSS, BOD_5 and TC were found to be in the range of 760-2,800 mg/L, 17-124 mg/L and 2,740-7,00,000 N/100 mL, respectively. These laboratory test results suggest that the performance of the treatment unit was not adequate to meet the acceptable limit for disposal into inland watercourses (ECR’97). Installing a duel-media granular filtration system as an additional treatment unit to developed activated sludge process treatment system improved the effluent quality within the acceptable limit. The TSS, BOD_5 and TC in treated effluent was found to be 95 mg/L, 4 mg/L and 750 N/100 mL, respectively. This study finally recommended an implementation plan of installing treatment plants in various markets of Khulna city.

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CHAPTER 1
INTRODUCTION

1.1 Background

Urbanization is one of the most important demographic trends now and growth is particularly rapid in developing countries. The majority of urban growth is associated with the rapid expansion of smaller urban centers and peri-urban developments, which mostly is unplanned and informal. The developed part of the developing country like Bangladesh is even built in a piecemeal fashion. Rapid industrial development is a crucial part of advancement as improper planning may lead to environmental damage. For high population density and careless construction of commercial areas, Bangladesh is now suffering from various problems. Market wastewater is one of these problems, which mainly is produced from the commercial areas referring butcher houses, chicken and fish slaughtering and processing unit, etc. (Parkinson & Tayler, 2003).

Due to huge population, unemployment problem, lack of public awareness and mostly ignorance of the administration of well-planned market places, the wastewater generated from that part is polluting the main watercourses of Bangladesh. In developed countries, the slaughterhouses consist of separate treatment plants but in our country, there are no separate slaughterhouses rather there are some extra spaces for slaughtering animals in the markets. Wastewater produced from those slaughterhouses and processing units combined with wastewater from other units is dumped together in the main watercourses through canals and open channels. This kind of markets wastewater contains highly contaminated body fluid, blood, worms, bacteria and viruses.

Children and others in communities may come into contact with polluted water, especially as they often play in open areas where wastewater and refuses collect. Exposure to this, health risks are increased due to increased microbial pathogens and deteriorating physico-chemical parameters. The surface water drainage systems are invariably combined with literally every kinds of commercial disposal system along with market wastewater. However, depending on the type of waterborne disease and on the physical health of the individual concerned, the person may either recover completely or suffer permanently from the resultant disease. In addition, a variety of skin and ear infections may arise as a result of contaminated water coming into contact with broken skin or penetration of the ear. Furthermore, discharge of improperly treated effluent often results in an increased number of bacterial, viral and protozoan pathogens which may result in a range of waterborne related diseases such as giardiasis and gastroenteritis Often the discharge of extremely turbid effluent from the slaughterhouse in conjunction with dense algal blooms results in poor visibility within these water bodies thus creating dangerous situations for recreational users. In addition, water bodies used for full contact recreational activities may serve as a source of various infectious diseases which may be contracted either by ingestion of contaminated water or through full body contact. A number of indirect health hazards such as chemical contaminants, disease-transmitting organisms such as mosquitos and fresh water snails implicated in malaria and bilharzia, may also arise depending on the state of the surface water source, leading to additional human health hazards (Naidoo & Olaniran, 2013).

The lack of infrastructure and services and effective systems for managing market wastewater has led to widespread pollution of surface water and groundwater and deterioration in environmental health conditions. Hence, market wastewater should be treated prior to disposal with a view to reducing the negative impacts on human health and environment. The introduction of small-scale treatment unit for the market wastewater could be an admirable solution as the effluent quality will be within the water quality standard that can be discharged back to the environment safely. There are numerous processes for the treatment of market wastewater depending on the type and extent of contamination. A physical treatment process followed by chemical and biological purification methods can effectively remove suspended solids along with the organic substances and toxic pathogens from market wastewater (World Health Organization, 2006).

According to Khulna City Corporation, Khulna is the third largest city of Bangladesh which is situated in coastal belt with 1.5 million people. In Khulna city, in spite of having huge population, there is no designated disposal site or any treatment facility for the market wastewater and in most cases it is directly disposed to the nearby water bodies. Among various markets, The Gollamari bazar, Nirala bazar, Boyra bazar, Banaragti bazar and New market are worth mentioning. Among those, the Gollamari bazar is situated near the river Moyur. The market wastewater produced from the Gollamari bazar is directly; and the wastewater from other markets via local canals is disposed to the Moyur River without any treatment, causing serious health hazard and pollution of the river water by aggravating the quality of the river water.

1.2 Objectives of the study

The specific objectives of this study are outlined below:

a) To determine the physical, chemical/biochemical and microbial characteristics of market wastewater from Khulna city;

b) To develop a pilot-scale treatment unit for the market wastewater; and

c) To monitor the performance of the pilot-scale treatment unit.

1.3 Structure of the dissertation

The study has been offered in six distinct chapters comprising different aspects of this study (Figure 1.1). The chapters reveal the physical, chemical and biological characteristics of market wastewater, construction methodology of a pilot-scale treatment unit for the market wastewater and its performance study, modification of the treatment unit and finally proposed a guideline for the implementation of the treatment unit in various markets of Sonadanga Thana of Khulna City for long term environmental sustainability.

Chapter-1 gives a general concept of market wastewater situation in Bangladesh and the environmental concerns related to its effect on water sources along with and impact on human health with an increase of various disease outbreaks.

Chapter-2 comprises of a comprehensive literature review encompassing the detail of market wastewater. It also provides information on the rapid urban growth which has led to unplanned market development along with its negative environmental impacts, involvement of ecological imbalance, environmental pollution and disease outbreaks and finally an overview solution for the disaster in Bangladesh perspective.

Chapter-3 contains elaborate description of field survey strategy, analytical methods and experimental procedures employed in this study along with the fundamental principles underlying those.

Chapter-4 draws information on the impact and change of various physical, chemical and biological properties of market wastewater in treatment process. It also includes the performance study of the treatment unit and compares results among difference samples of market wastewater.

Chapter-5 provides an overview on modification system of the developed treatment unit for an improved treatment level. It also depicts how the modified unit operates and contributes to the betterment of the properties of the market wastewater. Finally, this chapter describes the method for an ultimate implementation of the market wastewater treatment system into different markets of Khulna city.

Chapter-6 draws final conclusions based on logical reasoning of the market wastewater quality parameter analysis and performance study of the developed treatment unit. It also provides a conceptual idea on practical implementation on different markets and few recommendations for future related studies.

An annotated reference list of the literatures cited in the dissertation follows the last chapter.

CHAPTER 2
LITERATURE REVIEW

2.1 General

This chapter reviews the relevant literature with regard to the theme of the dissertation. The global trends of urbanization as well as the development of commercial area in Bangladesh in a piecemeal fashion are focused. It provides the rapid growth of commercial places cum market places has led to both short and long term negative environmental impacts, involving ecological imbalance, environmental pollution and disease outbreaks. The physical, chemical and biological characteristics of market wastewater influence aquatic imbalance and leave impacts on human health. It manifests the construction and execution efficiency of a treatment unit to alleviate the pollution level of the market wastewater. Finally, advises a guideline for improvement of the treatment process.

2.1.1 Scenario of global urbanization and market wastewater

The dynamic of population is usually assumed to be exogenous, while in fact it is affected (and affects) economic performance and other key variables. Because of huge population growth in the 20th century, the world's population is expected to be ten times larger by 2050 (roughly 10 billion) than it was for most of the 19th century (around 1 billion). Virtually all the population increase is expected to take place in developing countries (Stephenson et al., 2013).

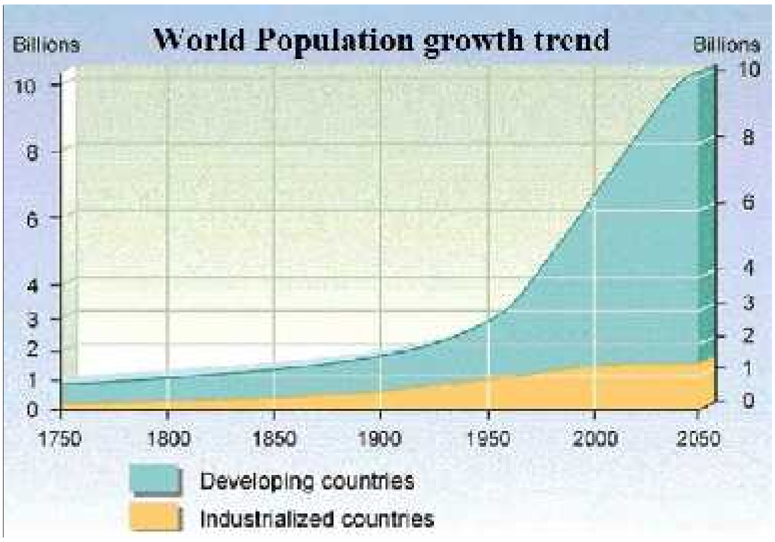


Figure 2.1 Population growth trend throughout the world (Source: World Bank, 2012)

Most of the population increase which is expected to take place over the next decade will be concentrated in urban areas, especially in developing countries. About 67 percent of world's population is expected to be concentrated in urban areas by year 2050. Urban dwellers tend to change consumption habits and consume more manufactured goods and service (FAO, 2012).

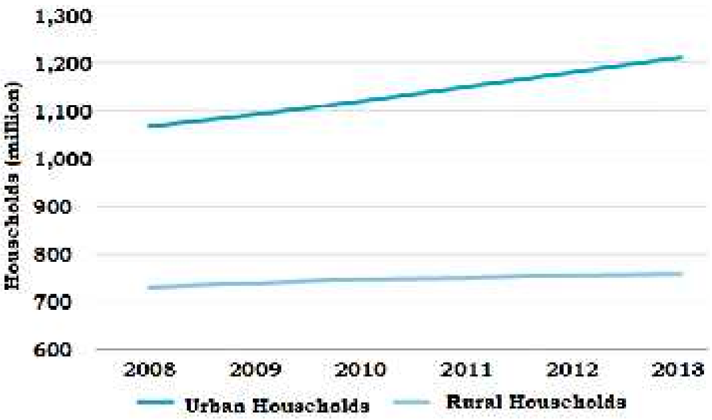


Figure 2.2 Trend of urbanization throughout the world (Source: Euromonitor International, 2014)

Global food demand is increasing driven by of population, economic growth and urbanization, particularly in developing countries. Since the 1960s global food consumption is increasing. This is the consequence of the increase of the population and of per capita food consumption in kcal/person/day (as estimated by the national average apparent food consumption) rising worldwide (FAO, 2012).

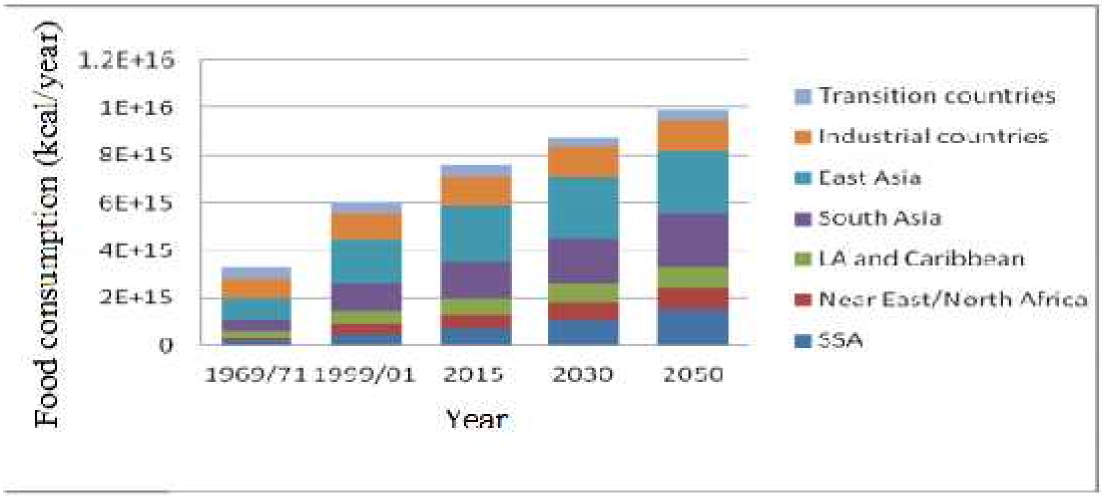


Figure 2.3 World total apparent food availability (Source: FAO, 2009)

As per capita food consumption has increased there has been a parallel change in dietary patterns, at least in the countries that experienced such growth (FAO, 2012). Most countries are shifting from plant-based diets to highly refined foods, meats and dairy products along with the fish and fishery products, with the exception of a few poor countries that cannot afford the leap (Fanzo, 2015). Demand for fish and fishery products is driven by two main factors, income and population growth as well as increasing urbanization, improved distribution and logistics (FAO, 2012). On average, the US consumes 124 kg/capita/y compared to the global average of 38 kg/capita/y. The countries that consume the least meat are in Africa and South Asia, where the highest burden of under-nutrition lies, with consumption in some countries as low as 8.5 kg/person/year in Ethiopia and around 3 kg/person/year in Bangladesh (Fanzo, 2015).

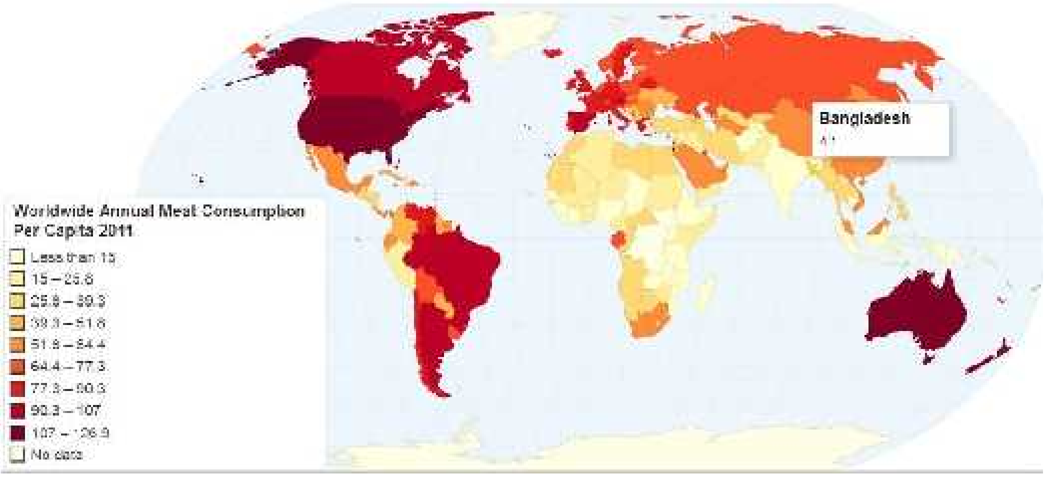


Figure 2.4 Worldwide meat consumption (Source: FAO, 2014)

Worldwide increasing human population, coupled with expanding urbanization and higher average income is putting increasing pressure on the meat supply. The increasing demands on meat in the developed countries led to expansion of abattoir industries in number and capacity (FAO, 2012). In developed countries there are also separate processing unit for fisheries and seafood which process fish concurrently or seasonally (Colic et al., 2007). But in developing countries there is no such industry for slaughtering animals, meat and fish processing rather these facilities stay within the local market places. As, increased population and urbanization following the worldwide transition towards a free market economy, especially in developing countries, many small and medium-size slaughterhouses appeared drastically (Borda et al., 2005). Although slaughter-houses are an important economic activity to the operators as well as livestock producers they however represent a major environmental challenge particularly water, soil and land pollution. The major waste associated with slaughter-house operations are blood, dung and slurry which are washed into waterways or disposed off on land leading to pollution of the respective components of the environment (Hailu & Ayenew, 2015). In developed countries, most slaughterhouses have adjacent treatment units but due to lack of the restrictive sanitary-veterinary legislation the slaughtering units of developing countries often dispose wastewater generated within its periphery into water courses without slightest treatment which eventually leads to disease outbreaks.

2.1.2 Existing state of market wastewater in Bangladesh

Being the eighth most populous country, Bangladesh faces great challenge to cope up with the trend of urbanization. Although still predominantly rural, the country has urbanized dramatically and since 1970 the urban population has risen from less than 8% to an estimated 28.4% in 2011. Though the level of urbanization is still rather low, it however already had a very large population 42.7 million, living in the countries nearly 570 urban centers. Projections, keeping in mind the growth rates of population observed during 2001-2011 and based on the UN population projection model, indicate that Bangladesh would achieve 'the tipping point' of 50 per cent urban by 2047. Thus, Bangladesh is expected to be majority 'urban' within the next 35 years which eventually with the extreme population density would place enormous pressures on land and urban services (Islam, 2015).

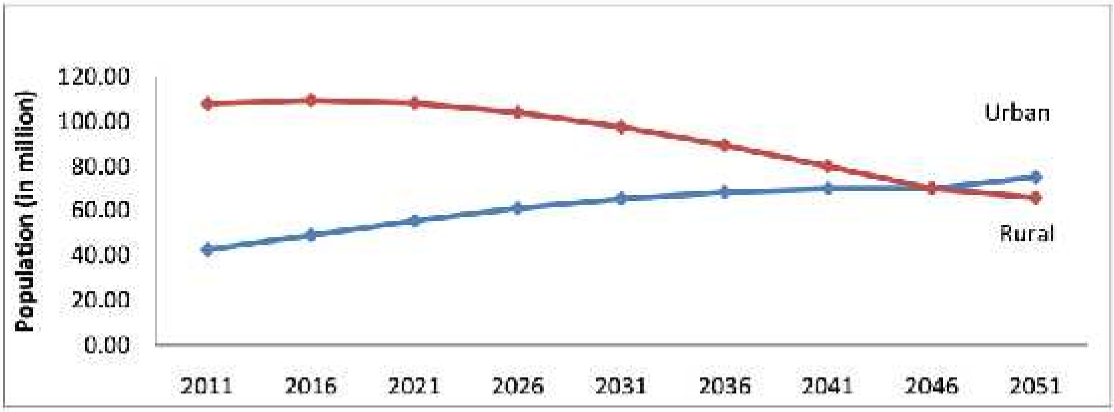


Figure 2.5 Projected Rural and Urban Population of Bangladesh: 2011-2051 (Source: Bangladesh Census and estimations, 2011)

At the beginning of the 21st century, Bangladesh is facing a water quality crisis resulting from continuous population growth, urbanization, land use change, industrialization, food production practices, increased living standards and poor water use practices and wastewater management strategies. In Bangladesh, as in many other parts of Asia, the quality and coverage of service provision is generally poor and systems for wastewater management are ineffective. Centralized agencies struggle to keep pace with the rate of urban development and hence many communities suffer from environmental health related problems due to the poor collection and treatment of wastewater.

In Bangladesh there are fewest treatment plants for treatment of domestic wastewater and industrial wastewater but there is no treatment facility for market wastewater. There is little concern about market wastewater due to unconsciousness and lack of knowledge of the devastating impact of it on the environment. Disposal of such market wastewater into open water sources through local storm sewerage is very common in Bangladesh. Contamination of surface water bodies and groundwater aquifers by pollutants from market wastewater along with those from domestic pollution exacerbate water quality problems and endanger both natural ecosystem integrity and public health. Poor water quality affects the availability of fresh water for different uses and has negative impacts on the livelihoods of the poorer communities. Wastewater management has a direct impact on the biological diversity of aquatic ecosystems, disrupting the fundamental integrity of our life support systems, on which a wide range of sectors, from urban development to food production and industry, depend. It is essential that wastewater management be considered as part of an integrated, full life cycle, ecosystem-based management system that operates across all three dimensions of sustainable development (social, economic and environmental), geographical borders, and includes both freshwater and marine waters (United Nations Water, 2015).

2.2 Characteristics of market wastewater

Market wastewater is a kind of commercial wastewater which at a first glance seems to be enriched with biodegradable elements along with physical pollutant and some chemical constituents as usage of pesticides and fertilizers to the crops. For this, characterization of market wastewater is very important to develop strategies for its treatment (Savin & Butnaru, 2008). To get a complete and clear conception about its characteristics detail laboratory test should be done. Generally, wastewater composition is as the figure below:

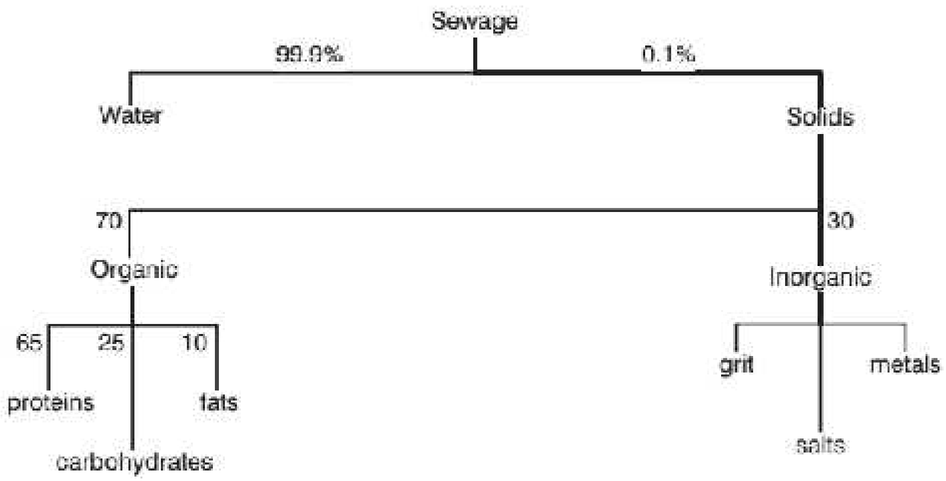


Figure 2.6 Composition of wastewater (Mara, 2004)

Though the composition of the market wastewater varies widely both in quality and characteristics from day to day and seasonally, still the wastewater can be dissected generally as shown in Table 2.1 (Kushwah et al., 2011).

Table 2.1 Characteristics of market wastewater

Type	**Physical**	**Chemical/ biochemical**			**Microbial**
		ORGANIC	INORGANIC	GASES	
Characteristic	Color	Carbohydrates	Alkalinity	Hydrogen sulfide	Animals
	Odor	Fats, oils, and grease	Chlorides	Methane	Plants
	Solids	Pesticides	Heavy metals	Oxygen	Eubacteria
	Temperature	Phenols	Nitrogen		Archaebacteria
		Proteins	pH		Viruses
		Surfactants	Phosphorus		
		Volatile organic compounds	Priority polluter Sulfur		

2.2.1 Physical characteristics of market wastewater

The physical market wastewater characteristics refer to the physical property of water or to the composition of the physical constituents of it. The principal physical characteristics of wastewater are its solids content, color, odor and temperature.

Solids: The total solids in a wastewater consist of the insoluble or suspended solids and the soluble compounds dissolved in water. The suspended solids content is found by drying and weighing the residue removed by the filtering of the sample. Between 40 and 65% of the solids in an average wastewater are suspended. Usually about 60% of the suspended solids in wastewater are Settleable. Solids may be classified in another way as well: those that are volatilized at a high temperature (500 ± 50 °C) and those that are not. The former is known as volatile solids, the latter as fixed solids. Usually, volatile solids are presumed to be organic matter, although some organic matter will not burn and some inorganic salts break down at high temperatures (Munter, 2011).

Color: Color is a qualitative characteristic that can be used to assess the general condition of wastewater. Wastewater that is light brown in color is less than 6 hours old, while a light-to medium grey color is characteristic of wastewaters that have undergone some degree of decomposition or that have been in the collection system for some time. Lastly, if the color is dark grey or black, the wastewater is typically septic, having undergone extensive bacterial decomposition under anaerobic conditions (Munter, 2011).

Odor: Odor is undoubtedly the most complex of all the air pollution problems. Odor is produced by gas production due to the decomposition of organic matter or by substances added to the wastewater. Whether pleasant or unpleasant, odor is induced by inhaling air-borne volatile organics or inorganics. Though foul odor may not cause direct damage to health, undesirable odor contributes to air quality concerns and affect human lifestyles. Toxic stimulants of odor may cause ill health or respiratory symptoms and secondary effects may cause nausea, insomnia and discomfort. Very strong odor can result in nasal irritation; trigger symptoms in individuals with breathing problems or asthma. Chemical composition of some common odor forming reagents is given below (GoI, 2008):

Table 2.2 Chemical composition of odor forming reagents

Compound	Chemical Formula	Odor quality
Amines	CH_3NH_2, $(CH_3)_3H$	Putrid, Fishy
Ammonia	NH_3	Pungent, Irritating
Diamines	$NH_2(CH_2)_4NH_2$, $(CH_2)_5NH_2H_{25}$	Rotten eggs
Mercaptans (methy1 and ethy1)	CH_3SH, $CH_3(CH_2)SH$	Decayed cabbage
Inorganic sulfides	$(CH_3)_2S$	Decayed Cabbage
Skatole	C_9H_9N	Faucal, nauseating

Temperature: Temperature has a great influence on wastewater and it receiving water body. Wastewater with high temperature can raise the temperature of receiving streams locally and disrupt the natural balance of aquatic life. It also affects bacterial growth, chemical reactions and reaction rates during treatment process. Temperature has also a direct impact on the physical chemical characteristics of the solids and solution, including the ability to form a scum layer. It also affects the solubility of gases (Mahmoud, 2011). Bacteria generally flourish in an environment, which meets certain prerequisites for growth. Mesophilic bacteria grow best in temperate environments between 20^{o}C and 50^{o}C, as compared to psycrophiles and thermophiles, which prefer colder (<20^{o}C) or hotter (>50^{o}C) conditions, respectively. The overall optimum temperature reported for growth of nitrifying bacteria appears to be in the range of 28^{o}C - 36^{o}C whereas little nitrifier growth was found below 5^{o}C and more than

54°C. So, temperature is reliable for low methanogenic activity and low hydrolysis rate (Carley, 2003).

2.2.2 Chemical/biochemical characteristics of market wastewater

The chemical or biochemical characteristics of wastewater range in a huge scale. Prominently the chemical/ biochemical characteristics are of two categories like organic and inorganic matter which are discussed below:

Organic matter ($C_aH_bO_c$): Mainly organic matter is derived from animals and plants along with manmade activities. Approximately 75% suspended solids and 40% filtered solids are organic in wastewater. The organic part mainly is of proteins (40-60%), carbohydrates (25-50%) and fats, oils, and grease (FOG) (10%). Primary and secondary sewage treatment processes remove some of these pollutants, particularly oxygen-demanding substances, oil, grease and solids. Others, such as refractory (degradation-resistant) organics (organochlorides, nitro compounds etc.) are not efficiently removed. Figure 2.7 is indicating the organic constituents of wastewater.

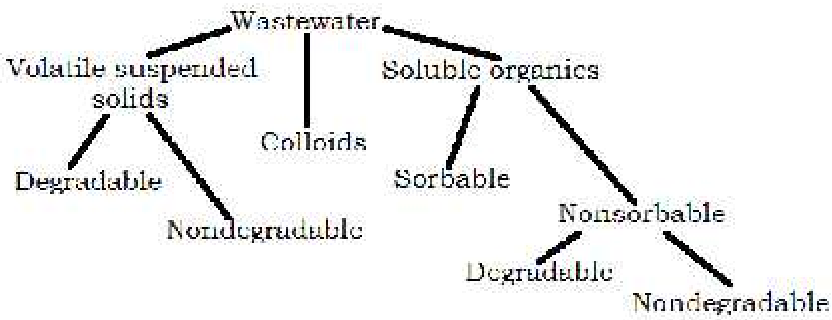


Figure 2.7 Partition of organic constituents of wastewater (Munter, 2011)

Measurements of organic matter: Wastewater is usually treated by supplying them with oxygen so that bacteria can utilize the wastewater contents as food. The general equation is:

$$\text{Wastewater + Oxygen} \xrightarrow{\textit{bacteria}} \text{Treated wastewater + New bacteria}$$

The nature of domestic wastewater is so complex that it precludes its complete analysis. However, since it is comparatively easy to measure the amount of oxygen used by the bacteria as they oxidize the wastewater, the concentration of organic matter in the wastewater can easily be expressed in terms of the amount of oxygen required for its oxidation. Many parameters have been used to measure the concentration of organic matter in wastewater. The following are the most common used methods:

Theoretical Oxygen Demand (ThOD): This is the theoretical amount of oxygen required to oxidize the organic fraction of the wastewater completely to carbon dioxide and water. Because wastewater is so complex in nature its ThOD cannot be calculated, but in practice it is approximated by the chemical oxygen demand.

Chemical Oxygen Demand (COD): This is obtained by oxidizing the wastewater with a boiling acid dichromate solution. This process oxidizes almost all organic compounds to carbon dioxide and water, the reaction usually proceeding to more than 95 per cent completion. The advantage of COD measurements is that they are obtained very quickly (within 3 hours), but they have the disadvantages that they do not give any information on the proportion of the wastewater that can be oxidized by bacteria, nor on the rate at which bio-oxidation occurs.

Biochemical Oxygen Demand (BOD): This is the amount of oxygen required for the oxidation of a wastewater by bacteria. It is therefore a measure of the concentration of organic matter in a waste that can be oxidized by bacteria ('bio-oxidized' or 'biodegraded'). BOD is usually expressed on a 5-day, 20°C basis – that is as the amount of oxygen consumed during oxidation of the wastewater for 5 days at 20°C. This is because the 5-day BOD (usually written 'BOD_5') is more easily measured than is the ultimate BOD (BOD_u), which is the oxygen required for the complete bio-oxidation of the waste.
From the foregoing it is apparent that: ThOD > COD > BOD_u> BOD_5 (Mara, 2004)

Inorganic matter: The principal chemical inorganic parameters include free ammonia, inorganic phosphorus, chloride, sulphates, pH, alkalinity, trace elements, such as iron, copper, zinc and cobalt which living organisms need for proper growth. Heavy metals can also produce toxic effects though many of the metals are also classified as priority pollutants. Measurements of gases, such as hydrogen sulphide, oxygen, methane and carbon dioxide are made to help the treatment system to operate and some of these gases are corrosive. A brief discussion on the inorganic matters concerned in wastewater treatment is given below:

Chlorides: Chlorides affects the biological process in high concentrations which indicates that the water body has been used for waste disposal. It may have an impact on the final use of treated wastewater (Mahmoud, 2011).

Nitrogen: nitrogen is important in wastewater management. It can have adverse effects on the environment, since its discharge above the required limit of 10 mg/L can be undesirable due to its ecological and health impacts. Nitrogen is required by all organisms for the basic processes of life to make proteins, grow and reproduce. It is recycled continually by plants and animals. Most organisms cannot use nitrogen in the gaseous form (N_2) for their nutrition, so they are dependent on other organisms to convert it into other forms. The principal forms of nitrogen are organic nitrogen, ammonia, nitrate and nitrite. Ammonia, nitrate and nitrite make up the inorganic forms. Organic and inorganic forms of nitrogen may cause eutrophication problems in nitrogen-limited freshwater lakes and in estuarine and coastal waters. In the environment, ammonia is oxidized to nitrate, creating an oxygen demand and low dissolved oxygen in surface waters (Akpor & Muchie, 2011).

Phosphorus: An excess content of phosphorus in receiving waters usually leads to extensive algal growth (eutrophication). Controlling phosphorus discharge from wastewater treatment plants is a key factor in preventing eutrophication of surface waters. The following groups of phosphorus compounds are of great importance in wastewater: organic phosphates, condensed phosphates and inorganic phosphates. Although phosphate itself does not have notable adverse health effects, phosphate levels greater than 1.0 mg/L may interfere with coagulation in water treatment plants (Akpor & Muchie, 2011).

Gases: Certain gases in wastewater can cause odors, affect treatment, or are potentially dangerous. Methane (CH_4) gas, for example, is a byproduct of anaerobic biological treatment and is highly combustible. The gases hydrogen sulfide (H_2S) and ammonia (NH_3) can be toxic and pose asphyxiation hazards. Ammonia as a dissolved gas in wastewater also is dangerous to fish. Beside that there are few other important gases of concern in wastewater treatment: N_2, O_2, CO_2 etc.

pH: The hydrogen-ion concentration is an important quality parameter of both natural and waste waters. It is a very important factor in the biological and chemical wastewater treatment. It is used to describe the acid or base properties of wastewater. Water and wastewater can be classified as neutral, alkaline or acidic according to the following ranges: pH= 7 neutral; pH> 7 Alkaline and pH< 7 Acidic. A pH less than 7 in wastewater influent is an indication of septic conditions while values less than 5 and greater than 10 indicate the presence of industrial wastes and incompatibility with biological operations. The pH concentration range for the existence of biological life is quite narrow (typically 6-9) (Akpor & Muchie, 2011).

2.2.3 Microbial characteristics of market wastewater

Biological communities of water bodies include primary producers, consumers, and decomposers that interact and form food webs. The decomposers include various microbial groups, such as fungi and bacteria. Most of the nutrient regeneration and nutrient cycling in water bodies and sediment are mediated by bacteria and other microorganisms which might be added by the improper disposal of wastewater (Mcpherson et al., 1996). The major microorganisms found in wastewater influents are viruses, bacteria, fungi, protozoa and helminthes. Although various microorganisms in water are considered to be critical factors in contributing to numerous waterborne outbreaks, they play many beneficial roles in wastewater influents. Traditionally, microorganisms are used in the secondary treatment of wastewater to remove dissolved organic matter. Their presence during the different treatment phases can enhance the degradation of solids, resulting in less sludge production. Apart from solid reduction, wastewater microbes are also involved in nutrient recycling, such as phosphate, nitrogen and heavy metals. Microorganisms are also responsible for the detoxification of acid mine drainage and other toxins in wastewater. Microbial pollutants can also serve as indicators of water quality (Akpor & Muchie, 2011). A brief narration on the main microorganisms of concern in wastewater treatment is given below:

Bacteria: The most important organisms in biological, wastewater treatment plants are the bacteria—eubacteria and archaebacteria. Bacteria enter wastewater treatment plants through fecal waste and as soil and water organisms. The archaebacteria consist of the halophiles, thermacidophiles, and methanogens. Only the methanogens or methane-forming bacteria are of importance in wastewater treatment plants by stabilizing wastes through their conversion to methane (CH_4). Halophilic bacteria along with cyanobacteria and photosynthetic bacteria produce gas vacuoles to regulate cell buoyancy. Thermacidophiles (high-temperature-loving and low pH-loving) or thermacidophilic bacteria perform no role in wastewater treatment plants (Gerardi, 2006).

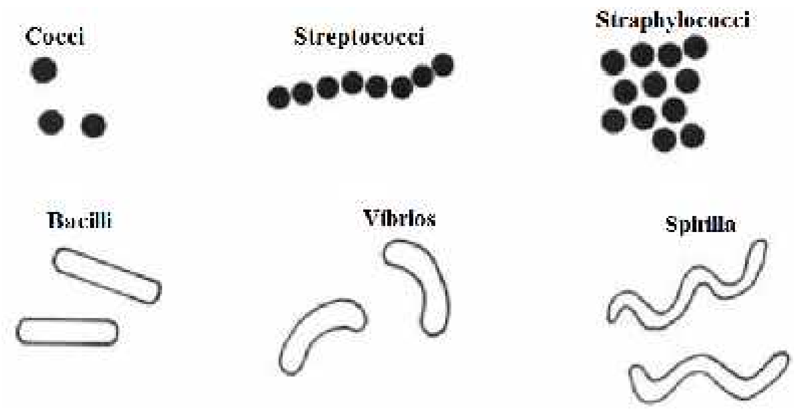


Figure 2.8 Common bacterial shapes (Mara, 2004)

Temperature and pH are very important environmental parameters for bacteria. Most bacteria grow well in the temperature range 15–40^{o}C and prefer near neutral or slightly alkaline conditions, around pH 6.5–8.5 (Mara, 2004).

Fungi: Fungi usually are saprophytic organisms which obtain their nourishment from the degradation of dead organic matter and are classified by their mode of reproduction. Most fungi are free-living and include yeast, molds and mushrooms. The optimum pH for most species of fungi is 5.6 and their nitrogen nutrient requirement for growth is approximately one-half as much as that for bacteria. In the activated sludge process filamentous fungi may proliferate and contribute to settleability problems in secondary clarifiers. The proliferation of filamentous fungi is associated with low pH (<6.5) and low nutrients. Although filamentous fungi (Figure 2.9) contribute to settleability problems in the activated sludge process, the presence of a large and diverse population of fungi is desired for the treatment of some industrial wastewaters and composting of organic wastes (Gerardi, 2006).

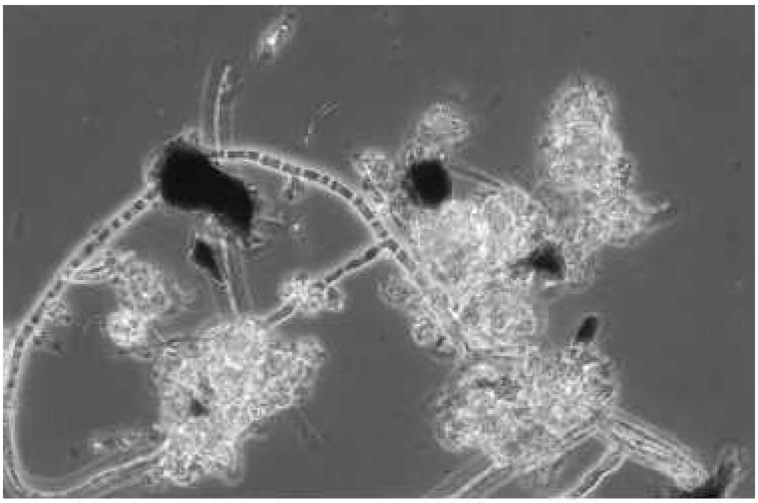


Figure 2.9 Filamentous fungi (Gerardi, 2006)

Algae: The micro-algae are single-celled Eukaryotes which contain large amounts of chlorophyll, the pigment that captures light energy in photosynthesis. The algae use this energy to fix carbon dioxide which is their main source of carbon, although they can grow photoheterotrophically on simple organic compounds (such as acetate). During photosynthesis oxygen is produced from water and in facultative and maturation ponds this is the main source of oxygen used by the bacterial heterotrophs in the ponds for the removal of BOD. The algae, when they are photosynthesizing rapidly, induce a high pH in the ponds (especially in maturation ponds); the pH can rise to >9.4, which is critical for fecal bacterial die-off in ponds (Mara, 2004).

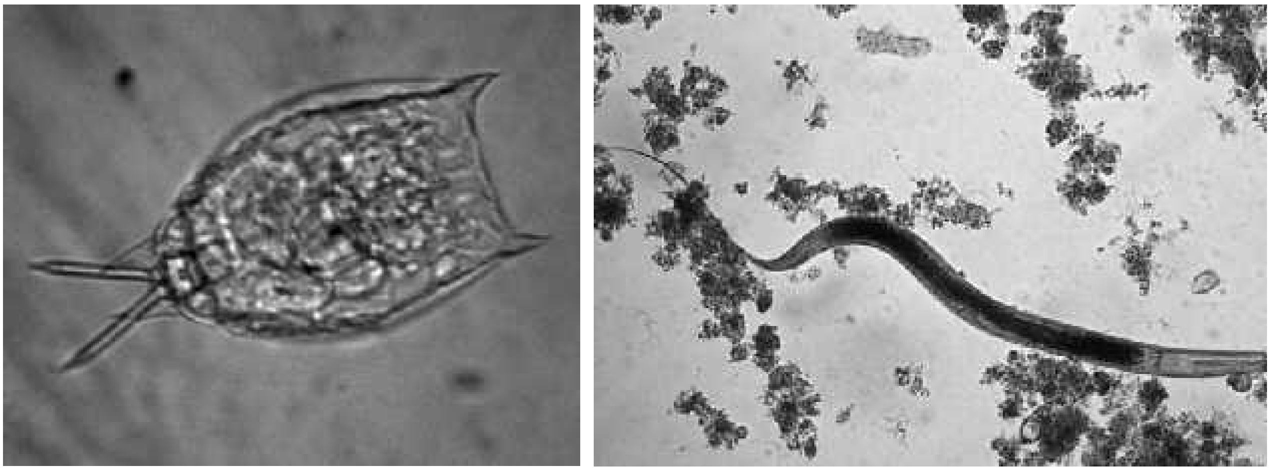
Protozoa: Protozoa are single-celled eukaryotes, very widely distributed in nature most of which are non-pathogenic along with some other important human pathogenic species (Mara, 2004). Most protozoa are free-living and solitary, but some do form colonies (Gerardi, 2006). The protozoa can be conveniently classified into three groups: amoebae, ciliates and flagellates (Figure 2.10). The last two groups are important in wastewater treatment. Protozoa have been extensively studied in conventional wastewater treatment processes such as activated sludge and biofilters (Mara, 2004). Ciliated protozoa are the most important groups of protozoa in the activated sludge process. They add weight to floc particles and improve their settleability, consume dispersed cells and cleanse the waste stream, produce and release secretions that coat and removes fine solids (colloids, dispersed cells, and particulate material) from the bulk solution to the surface of floc particles and recycles nutrients (nitrogen and phosphorus) through their excretions. A healthy protozoan population in activated sludge aeration tanks significantly improves the treatment efficiency – effluent suspended solids concentrations are ~70% less with ciliated protozoa (Gerardi, 2006).

The amoeba Ciliate Flagellate

Figure 2.10 Various kinds of protozoa (Gerardi, 2006)

Viruses: Viruses are extremely small (~20–200 nm) parasitic microbes which can reproduce only by invading a host cell whose reproductive processes they redirect to manufacture more viruses. Domestic wastewater contains many human viruses, including the rotaviruses and noroviruses that are the major viral causes of diarrhea. Bacterial viruses are called 'bacteriophages' and these can be used to model viral die-off in waste stabilization ponds. They may possibly be prokaryotes that have evolved from intracellular parasitic forms to become the 'simple' packets of RNA or DNA that they are today (Mara, 2004).

Rotifers and Nematodes: Rotifers and nematodes are multicellular microscopic animals. Nematodes are one of the type of helminthes (worms) group which are important because a few of them cause disease and because a group of them are highly tolerant of pollution and oxygen depletion in freshwaters (Mara, 2004). Rotifers and nematodes provide numerous benefits to the activated sludge process. In addition to these benefits provided by the ciliated protozoa, the metazoan burrows into floc particles. The burrowing action promotes acceptable bacterial activity for the degradation of substrates (carbon and energy sources used by bacteria for cellular growth and activity) in the core of the floc particle by permitting the penetration of dissolved oxygen, nitrate, substrates and nutrients (Gerardi, 2006).



Rotifer in free-swimming mode — Free-living nematode

Figure 2.11 Microscopic views of rotifer and nematode (Gerardi, 2006)

2.3 Strength of market wastewater

The higher the concentration of organic matter in a wastewater, the 'stronger' it is said to be. Wastewater strength is often judged by its BOD_5 or COD (Table 2.3). The strength of the wastewater from a community is governed to a very large degree by its water consumption.

The other factor determining the strength of market wastewater is the BOD (= amount of organic waste) produced per person per day (Mara, 2004).

Table 2.3 Wastewater Strength in Terms of BOD_5 and COD

Strength	BOD_5 (mg/l)	COD (mg/l)
Weak	<200	<400
Medium	350	700
Strong	500	1000
Very strong	>750	>1500

2.4 Overview on environmental impact of market wastewater

Market wastewater is generated from the commercial areas which containing huge amount of water along with heavy biodegradable waste such as: animal blood and body fluid, urine, soil from hides and hooves, solubilized fat, and cleaning compounds along with washed wastewater of the equipment and facilities washing; sometimes feces and soft tissue removed during trimming and cutting. Untreated market wastewater comprises a mixture of fats, proteins and fibers, resulting in a high content of organic matter and causes a contaminating effect to the rivers and sewage systems (Hailu & Ayenew, 2015). The impacts are discussed briefly below:

2.4.1 Aggravation of aquatic ecosystem

According to the fourth World Water Development Report, presently only 20% of globally produced wastewater receives proper treatment (United Nations Water, 2015). The existing wastewater treatment is failing worldwide as service coverage increases in terms of access to improved toilet facilities, but with far less attention paid towards ensuring that waste streams are adequately collected and treated prior to discharge into the environment. As a result, the majority of wastewater is discharged without any form of treatment into the environment; spreading diseases to humans and damaging key ecosystems such as coral reefs and fisheries. Inadequately treated wastewater discharged into a stream or river develops a eutrophic condition within the aquatic environment due to the exposure of biodegradable, oxygen consuming compounds. If this condition were sustained for a sufficient amount of time, the ecological balance of the receiving stream, river or lake (i.e., aquatic micro-flora, plants and animals) would be upset. Continual depletion of the oxygen in these water systems would also result in the development of obnoxious odors and unsightly scenes. Processing wastes and wastewater are primarily organic in nature and therefore subject to bacterial decay. As a result, the oxygen concentration in the water is reduced with an increase in BOD. Nutrients resulting from decaying organic matter enhance plant growth and excessive plant growth together with oxygen depletion can lead to alterations in ecosystem structure (Islam et al., 2004). It is important to note that other constituents of wastewater effluents also play an important role in the depletion of DO. The bacterial breakdown of organic solids presents in wastewater and the oxidation of chemicals in it can consume much of the dissolved oxygen in the receiving water bodies (Akpor & Muchie, 2011)

2.4.2 Pollution in surface water

Haphazard disposal of untreated wastewater from households as well as institutions and commercial places is causing severe deterioration of water bodies in Bangladesh. Environmental conditions arising from inadequate or non-existing wastewater management pose significant threats to human health, well-being and economic. Surface waters contain levels of phosphorus in various compounds, which are essential constituents of living organisms. An excess content of phosphorus along with nitrogen in receiving waters usually leads to extensive algal growth (Akpor & Muchie, 2011). Nitrogen in the form of ammonia is toxic to fish and exerts an oxygen demand on receiving water by nitrifiers. Partially decomposed market wastewater effluents entering waters sources contain a variety of harmful substances and pathogens and a variety of other organic and inorganic wastes. Around the point of discharge, there is a short-term increase in nutrients and, hence, prey items for the fish and, on occasions an increase in habitat complexity, which may cause an initial population rise in fish species. Yet, as nutrient levels increase so does the chance of algal bloom development, toxin production and a corresponding decrease in dissolved oxygen. Fish species feeding in water contaminated by algal toxins will absorb these toxins and are subject to mass mortality (Islam & Tanaka, 2004). Other potential problems caused by the mass release of processing wastes and associated debris are the loss of amenities affecting the recreational use of water (Islam et al., 2004). Due to excessive nitrogen and phosphorus in market wastewater receiving water bodies may suffer like detrimental consequences like extensive growth of rooted aquatic life interferes with navigation, aeration and channel capacity along with odors and discoloration of the water, thus interfering with recreational and aesthetic water use. Long-term reductions in dissolved oxygen concentrations can result in changes in species composition. Poorly treated market wastewater effluent can also lead to physical changes to receiving water bodies. The release of suspended solids into receiving waters can have a number of direct and indirect environmental effects, including reduced sunlight penetration (reduced photosynthesis), physical harm to fish, and toxic effects from contaminants attached to suspended particles. Another environmental impact of untreated wastewater effluent, which at times can be linked to health, is the phenomenon of bioaccumulation and biomagnification of contaminants. The release of toxic substances from wastewater into receiving water bodies has direct toxic impacts on terrestrial plants and animals. The toxic impacts may be acute or cumulative due to high levels of ammonia and chlorine, high loads of oxygen-demanding materials, or toxic concentrations of heavy metals and organic contaminants (Akpor & Muchie, 2011).

2.4.3 Diseases outbreak

Approximately two-thirds of the population in the developing world has lack adequate means of disposing of wastewater. Untreated market wastewater disposal to main water courses can cause a major public health risk as it can lead to outbreaks of diseases such as diarrhea, cholera, and typhoid. The market wastewater may contain huge amount of nitrogenous compounds originated from animal body fluid which is along with phosphorus liable for eutrophication. The cyanobacterial toxins are produced by microscopic algae can reach undesirable concentrations during eutrophication. These toxins are concentrated further in the food chain when shellfish and other aquatic life consume the algae. Paralytic shellfish poisoning, diarrheal shellfish poisoning and amnesic shellfish poisoning are examples of infections caused by toxic algae. In some cases, liver cancer in humans is thought to be associated with exposure to cyanobacterial toxins through contaminated drinking water or recreational water contact. Nitrates and nitrites are also of concern because nitrites react with amino acids in the stomach to form nitrosamines, which have been found to be powerful carcinogens in animals and humans. Methemoglobinemia is the most significant health problem associated with nitrate in water. The most dangerous among other consequences of exposure to ammonia is pulmonary edema, followed by severe irritation to moist tissue surfaces. Market wastewater contains a wide variety of viruses, bacteria, and protozoa from animal body fluid which is directly disposed to open water bodies, rivers through canal leads to most common health hazards. Microbial pathogens are considered to be critical factors contributing to numerous waterborne outbreaks such as chronic diseases with costly long-term effects like degenerative heart disease and stomach ulcer. Viruses are the most important and potentially most hazardous pollutants which are generally more resistant to treatment, more infectious, more difficult to detect and require smaller doses to cause infections (Akpor

& Muchie, 2011). Different health hazard originated from untreated directly disposed wastewater into watercourses are listed in Table 2.4.

Table 2.4 Acute and chronic health effects associated with microbial pathogens in wastewater

Pathogen	Agent	Acute Effects	Chronic Or Ultimate Effects
Bacteria	*Escherichia coli*	Diarrhea	Adults: death (thrombocytopenia)
	(E. coli)		Children: death (kidney failure)
	Legionella pneumonia	Pneumonia	Elderly, death
	Helicobacter pylori	Gastritis	Ulcers and stomach cancer
	Vibrio cholerae	Diarrhea	Death
	Campylobacter	Diarrhea	Death: Guillain-Barre syndrome
	Yersinia	Diarrhea	Reactive fever
	Salmonella	Diarrhea	Reactive fever
	Cyanobacter	Diarrhea	Potential fever
	Leptosporosis	Fever, Chills	Well's Disease
Parasites	*Giardia lamblia*	Diarrhea	Lactose intolerance, Failure to thrive, severe hypothyroidism
	Cryptosporidium	Diarrhea	Death in immunocompromised host
	Acanthamoeba	Eye infections	
Viruses	*Hepatitis viruses*	Liver infection	Liver failure
	Adenoviruses	Eye infections	
	Enchoviruses	Meningitis	

2.4.4 Economic instability

Humanity's overall demand for natural resources already exceeds Earth's bio-capacity. Contributions to this excessive environmental footprint are extremely uneven, however: the global inequalities in incomes and wealth described above translate directly into starkly differing environmental impacts. Consumption patterns and technological progress are sometimes called sustainability levers, as they can mitigate the environmental impact of income growth (United Nations, 2013). Income, consumption patterns and wastewater production are seamlessly related to each other and they contribute to environmental and economic fluctuation. Wastewater is a complex resource, with both advantages and inconveniences for its use. Wastewater and its nutrient contents can be used for crop production, thus providing significant benefits to the farming communities and society in general. However, wastewater use can also impose negative impacts on communities and on ecosystems creating economic losses and instability. The quantity of processing wastewater that is generated and its general quality (i.e., pollutant strength, nature of constituents) has both economic and environmental consequences with respect to its treatability and disposal. The economics of the wastewater lie in the amount of product loss from the processing operations and the cost of treating this waste material. The cost for product loss is self-evident; however, the cost for treating the wastewater lies in its specific characteristics. Two significant characteristics which dictate the cost for treatment are the daily volume of discharge and the relative strength of the wastewater. Other characteristics become important as system operations are affected and specific discharge limits or restrictions are identified (i.e., exoskeleton material, scales, entrails) (Carawan et al., 1979). In case of treatment process of market wastewater, algal-rich wastewater may clog water treatment plant filters and result in reduced backwashing thus wastewater treatment cost increases. The decay of this material can consume most or all of the dissolved oxygen in the surrounding water, thus threatening the survival of many species of fish and other aquatic life which can be considered as economic loss (Akpor & Muchie, 2011).

2.4.5 Impact on climate change

Primary Greenhouse Gases (GHGs) of concern from Wastewater are: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Wastewater as well as its sludge components can produce CH_4 if it degrades anaerobically. It can also be a source of nitrous oxide (N_2O) and carbon dioxide (CO_2). N_2O is mainly associated with the degradation of nitrogen components in the wastewater, e.g., urea, nitrate and protein. In the aerobic process, CO_2 is produced through the breakdown of organic matter (Gupta & Singh, 2012). Methane and nitrous oxide are 21 times and 310 times more powerful than CO_2, respectfully. These two greenhouse gases will rise 25% and 50%, respectively, in just a decade if not controlled properly (Lamizana, 2013).

2.5 Treatment objectives of Market wastewater

Even though it appears to be in plentiful supply on the earth's surface, water is a rare and precious commodity, and only an infinitesimal part of the earth's water reserves (approximately 0.03%) constitutes the water resource which is available for human activities. The growth of the world's population and industry has given rise to a constantly growing demand for water in proportion to the supply available, which remains constant. Thus, it is necessary to minimize its consumption and it is also necessary to return it back to the environment with the minimum contamination load because of the limited capacity of self-purification, hence the importance of wastewater treatment (Awaleh & Soubaneh, 2014). The prevention of pollution of water sources and protection of public health by safeguarding water supplies against the spread of diseases, are the two fundamental reasons for treating wastewater. This is accomplished by removing substances that have a high demand for oxygen from the system through the metabolic reactions of microorganisms, the separation and settling of solids to create an acceptable quality of wastewater effluents, and the collection and recycling of microorganisms back into the system, or removal of excess microorganisms from the system (Akpor & Muchie, 2011). Wastewater treatment is needed on a truly enormous scale in developing countries and it must be done for the specified purpose to produce an effluent that can be safely discharged into inland or coastal waters or the treated wastewater can be profitably and safely used in agriculture and aquaculture – for wastewaters are simply too valuable to waste. If a treated wastewater is discharged into a river it exerts a demand on the oxygen resources of the river. This removal of dissolved oxygen (DO) for wastewater oxidation must be balanced by an addition of oxygen. The most important source of oxygen for re-oxygenation of the river is the atmosphere: there is a mass transfer of oxygen from the atmosphere across the water surface to the river water below. The rate of this transfer is proportional to the oxygen deficit in the water. This competition between de-oxygenation and re-oxygenation results in a DO profile which typically shows a distinct 'sag' some distance below the point of discharge (Figure 2.12). In order to prevent the river becoming anaerobic, there must be an adequate DO reserve at all points along the river. Analysis of the oxygen sag curve provides a convenient method of determining the degree of treatment that should be given to the effluent before it is discharged (Mara, 2004). For balancing the oxygen supply and maintaining the aerobic condition the effluent BOD_5 should remain within 50 mg/L according to the Environment Conservation Rules, GoB (1997). As the market wastewater is a strong wastewater, it should be treated prior to disposal undoubtedly.

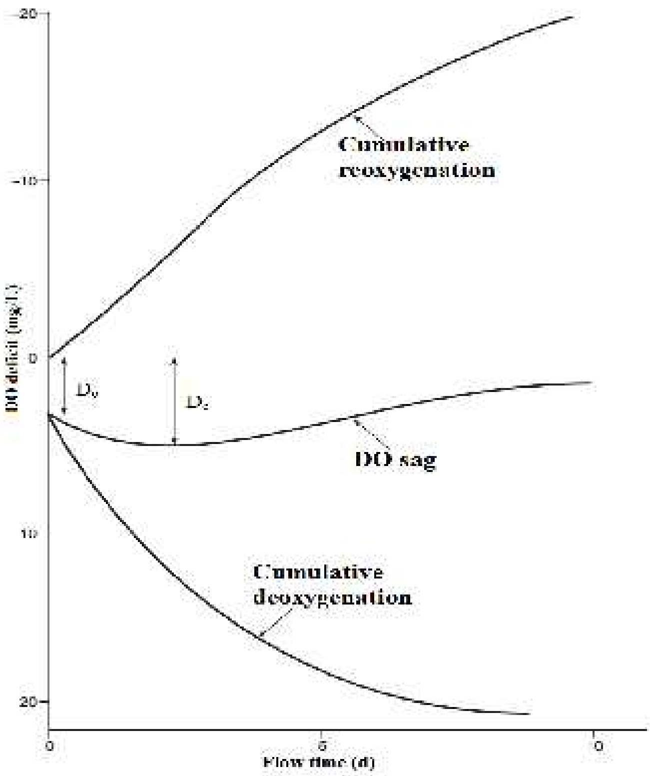


Figure 2.12 Formation of sag curve due to de-oxygenation and re-oxygenation (Mara, 2004)

2.6 Treatment methods of Market wastewater

Market wastewaters usually contain huge organic and biodegradable matter including an inorganic part in varying concentrations. This enables the necessity of treatment plant targeting treatment of high strength wastewater with cleaner technologies which are more effective (Awaleh & Soubaneh, 2014). There are numbers of treatment processes exist in different treatment plants of the world which mainly follow four classifications of treatment mechanism. Preliminary treatment involves the removal of large particles as well as solids found in the wastewater. The second classification is primary treatment, which involves the removal of organic and inorganic solids by means of a physical process. The third treatment is called secondary treatment; this involves biological (bacterial) degradation of undesired products where suspended and residual organics and compounds are broken down. The fourth is tertiary treatment, normally a chemical process and very often including a residual disinfection (Awaleh & Soubaneh, 2014). Beside these, the treatment system can be classified as follows:

Preliminary and primary wastewater treatment processes

a. Preliminary treatment
    i. Screening and comminution

ii. Grit removal

iii. Pre-aeration

iv. Equalization

v. pH control

vi. Flotation

vii. Coagulation and chlorination, etc.

b. Primary treatment

c. Sedimentation with chemical coagulation

d. Suspended growth processes and/ or Fixed growth processes

Biological wastewater treatment processes

a. Suspended growth processes

i. Ponds: Aerobic ponds, Aerobic-anaerobic (facultative) ponds, Anaerobic ponds

ii. Activated sludge: Conventional (plug-flow), Completely mixed, Step aeration, Contact stabilization, Extended aeration, Pure oxygen system, Continuous loop reactors, Nitrification, Biological denitrification

b. Fixed film processes

i. Trickling filters: Low Rate (Standard), Intermediate rate, High Rate, Super Rate (Synthetic Media)

ii. Rotating biological contractors

iii. Activated biological filter

iv. Anaerobic denitrification filter

c. Miscellaneous Biological Systems

i. Package plants

ii. Batch activated sludge

iii. Sequencing batch reactors

iv. Septic system

v. Overland flow

Physical and Chemical Wastewater Treatment Processes

a. Activated carbon adsorption

b. Chemical oxidation

i. Chlorination

ii. Alkaline chlorination

iii. Ozonation

iv. Hydrogen peroxide oxidation

v. Ultraviolet radiation

vi. Ionizing radiation

c. Solids removal

i. Chemical precipitation phosphorus removal

ii. Sedimentation

iii. Micro-screening

iv. Filtration: Multi-media, Diatomaceous earth

d. Membrane processes

Industrial process wastewater treatment

a. pH control

b. Heavy metal removal and recovery

c. Cyanide destruction

d. Oil removal

e. Deep well injection etc. (Technical manual, 1987)

In the treatment of wastewater, biological treatment appears to be a promising technology. Both aerobic and anaerobic processes can be used; the former involves the use of free or dissolved oxygen by microorganisms (aerobes) in the conversion of organic wastes to biomass and CO_2 while in the latter complex organic wastes are degraded into methane (CH_4), CO_2 and H_2O through three basic steps (hydrolysis, acidogenesis including acetogenesis and methanogenesis) in the absence of oxygen. A mixed aerobic-anaerobic treatment system could also be introduced which is drawn in Figure 2.13.

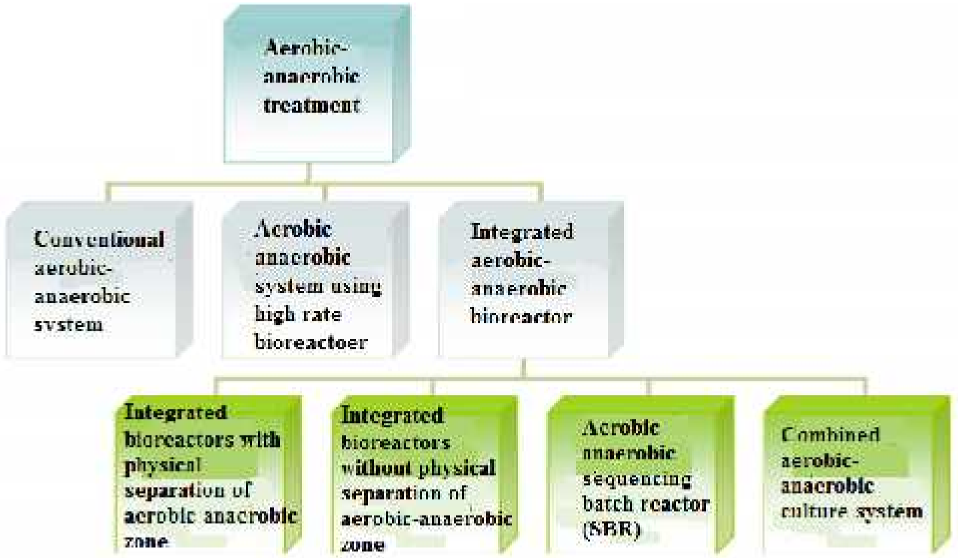


Figure 2.13 Types of combined anaerobic–aerobic system (Chan et al., 2009)

Aerobic biological processes are commonly used in the treatment of organic wastewaters for achieving high degree of treatment efficiency by higher removal of soluble biodegradable organic matter and producing biomass is generally well flocculated, resulting in lower effluent suspended solids concentration (Chan et al., 2009). By following the above mentioned concept it can be concluded that, activated sludge process might be the best suited treatment system for treating the market wastewater as it is an aerobic biological treatment system which is cost effective and requires minimum of space to conduct the operation.

2.7 Treatment of Market Wastewater by Activated Sludge

Biological treatment of waste is a very important aspect of public health. There are varying types of treatment processes that are found today in wastewater treatment (Wintle, 2008). Activated sludge process is the most commonly used biological wastewater treatment system (Rustum, 2009). In the early years of the twentieth century the method of biological treatment was devised, and now forms the basis of wastewater treatment worldwide.

2.7.1 Bacterial activity in Activated Sludge

It simply involves confining naturally occurring bacteria at very much higher concentrations in tanks. These bacteria, together with some protozoa and other microbes, are collectively referred to as activated. The bacteria remove small organic carbon molecules by ‘eating’ them. As a result, the bacteria grow, and the wastewater is cleansed and ready for disposal to natural streams. Whilst the concept is very simple, the control of the treatment process is very complex, because of the large number of variables that can affect including the changes in the composition of the bacterial flora of the treatment tanks, quality of market wastewater passing into the plant, influent in flow rate, chemical composition, pH and temperature. For control of the biological processes in a treatment plant, it is necessary to have some knowledge of the organic strength, or organic load, of the influent wastewater. The Total Organic Carbon (TOC) is analytically straightforward to measure to get a concept of the organic strength. Organic carbon can also be measured by chemical oxidation which is commonly known as COD test. The current method used to determine the biodegradable carbon, is the BOD test (Davies, 2005) (Figure 2.14). The organic carbon is removed by the ingestion by the bacteria which is the basic principal in the treatment of market in activated sludge system. In this system, the dominant organisms are the bacteria, of which there may be 300 species present.

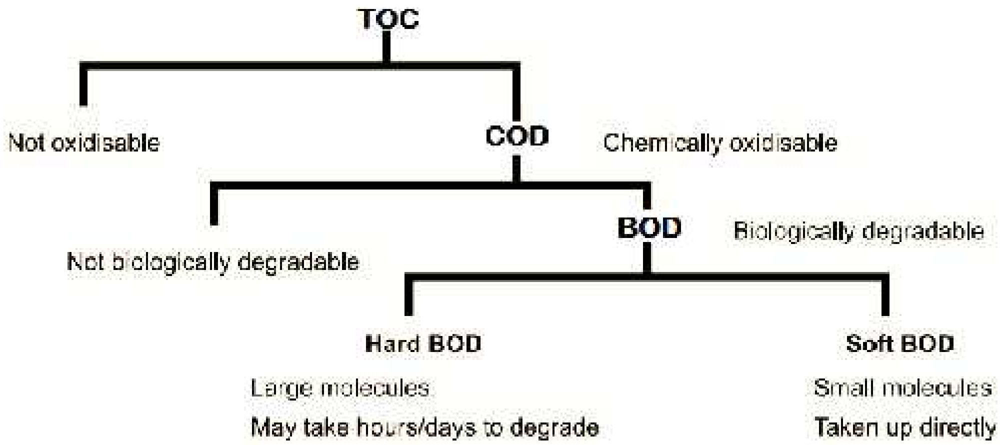


Figure 2.14 The relationship between the organic carbon fractions in sewage (Davies, 2005).

Once the bacteria are inside, the carbon compounds are metabolized by them. Metabolism comprises the thousands of simultaneous chemical reactions that are going on at any one time inside the bacterium. In each of these reactions, a substrate, in the presence of an enzyme (which acts as a catalyst), is converted into a product.

$$\text{Substrate} \xrightarrow{\textit{Enzyme}} \text{Product}$$

Although there are many thousands of chemical reactions involved in the metabolism of a bacterium; the three major processes: ingestion, respiration and growth and division, are identified that are relevant to the biological treatment of market wastewater which are shown in the figure below:

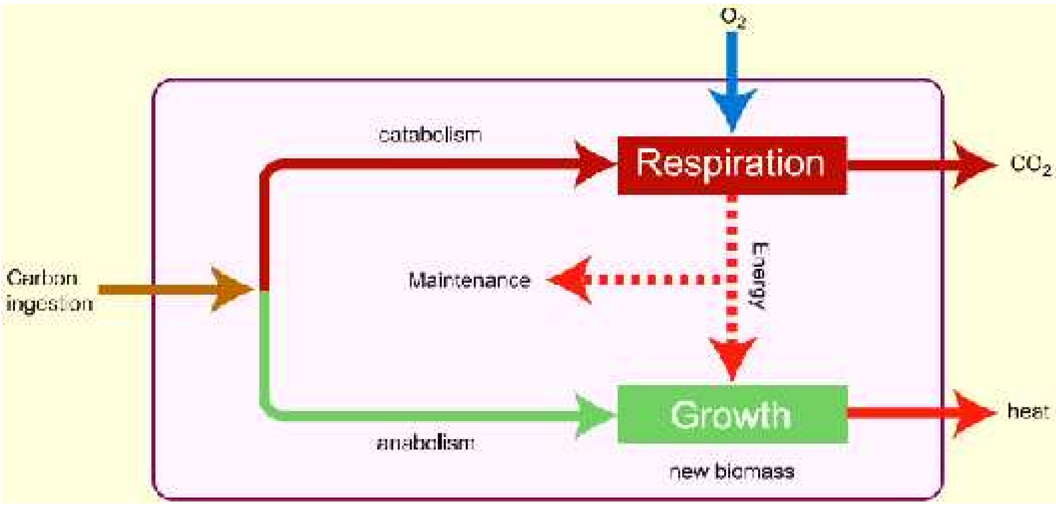


Figure 2.15 Representation of a single bacterium showing the relationship between the 3 processes (Davies, 2005)

It will be noted that the three processes correspond to the major processes that we shall see when we examine the operation of the treatment works aeration basin. They can be summarized as:

Bacterial process	**Treatment plant process**
Ingestion	Biodegradation
Respiration	Aeration requirement
Growth and division	Biomass production

2.7.2 Basic activated sludge treatment plant layout

A typical treatment plant comprises three phases of treatment – primary, secondary and tertiary. Primary treatment involves settlement of solids in a clarifier tank. The wastewater then passes to the secondary treatment or aeration tanks. This is the major biological phase of treatment by the activated sludge bacteria. A tertiary phase may be used to further improve the quality of the secondary effluent, by removing nitrogen, phosphates, suspended solids or pathogens, as required. There are many designs of aeration tank, including plug-flow, completely mixed, percolating filter, sequencing batch reactor and so on (Figure 2.16) (Davies, 2005).

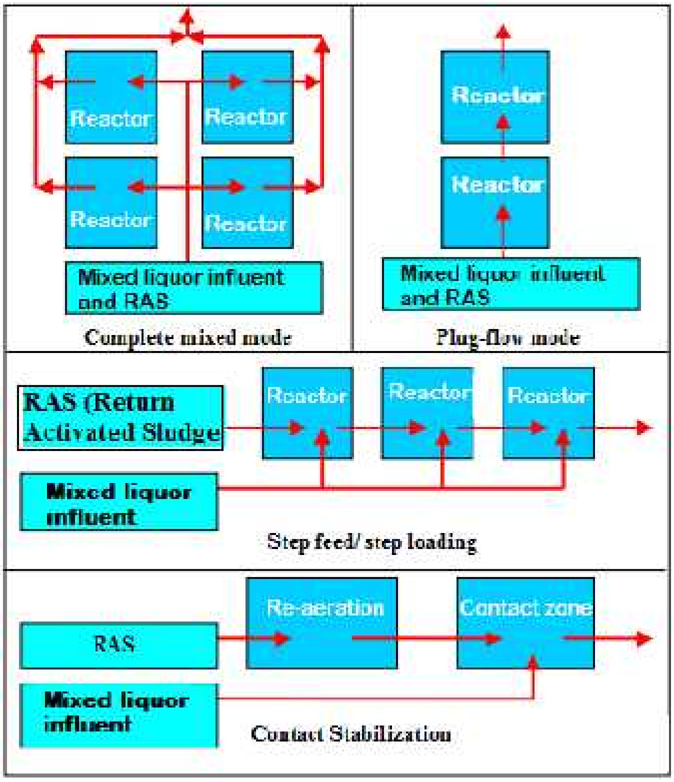


Figure 2.16 Representation of a single bacterium showing the relationship between the 3 processes (Rustum, 2009)

The simplified form of these is conventional activated sludge process which basically consists of several biological reactors (aerated tanks) and solid-liquid separators (secondary clarifiers or settlers). In this biological process microorganisms oxidize and mineralize organic matter. Hence, the main requirement of the activated sludge process is to keep a high concentration of a mixed culture of microorganisms, known as the mixed liquor suspended solids (MLSS), in an artificially aerated reactor. The composition of the species of microorganisms depends not only on the influent wastewater but also on the operation of the wastewater treatment plant. The microorganisms grow slowly in the aerated tank and are kept suspended either by blowing air into the tank or by using agitators. Oxygen is used by the microorganisms to oxidize organic matter. On leaving the aeration tank, the MLSS enters the secondary settling tank where it is clarified and thickened. To maintain the microbiological population in the aeration tank, part of the thickened sludge from the secondary clarifier is re-circulated back to the aeration tank; the surplus thickened sludge is then wasted. The volume of sludge returned to the aeration basin is normally 40 to 60% of the wastewater flow (Rustum, 2009). A basic schematic of the biological process in an activated sludge process is illustrated in Figure 2.17.

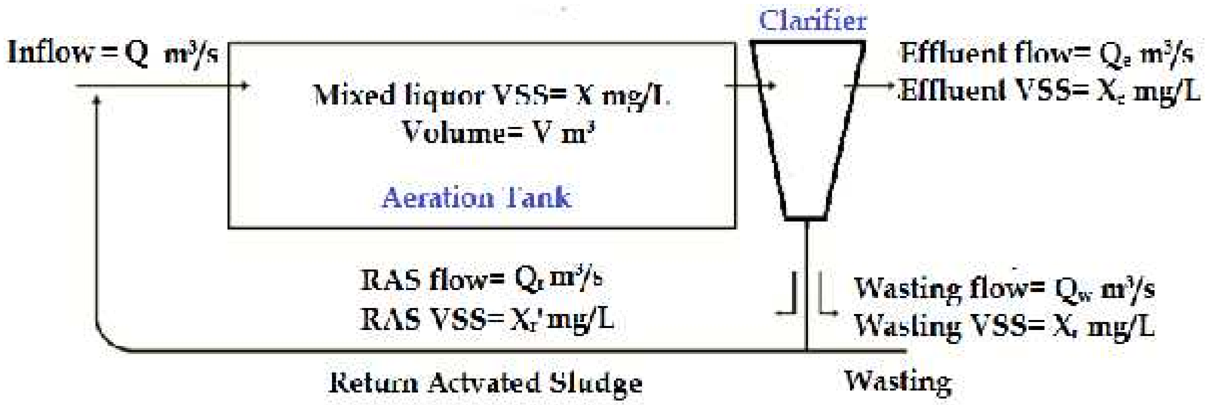


Figure 2.17 Basic schematic of the biological process in an activated sludge process (Davies, 2005)

The biomass growth rate depends on many variables such as the amount of biomass, the substrate, temperature, pH, and the presence of toxins. The growth in number and diversity of bacteria occurs over time or increasing mean cell resident time or sludge age. During this time, the BOD is transformed into new less polluting wastes and more new bacterial cells or sludge. The bacteria along with ciliated protozoa and metazoan, remove fine solids and heavy metals from the bulk solution. An additional and critical role performed by the ciliated protozoan and metazoan is the consumption of the dispersed cells. The consumption of dispersed bacteria by these organisms is known as cropping action. By cropping bacteria, the bacteria are removed from the waste stream. During bio-reduction (decay of microorganisms), biologically inert (non-biodegradable) matters are produced. Incoming wastewater will contain some inert matter as well. This matter flows unaffected through the process and is collected and removed in the settler.

The secondary clarifier (SC) is an integral part of the activated sludge system. It has two main functions: it separates the biomass from the water in order to produce a good quality effluent free from settleable solids and it also thickens the biomass. Part of the thickened biomass is then wasted as sludge and part of it is returned to the biological reactor to maintain an appropriate biomass concentration. The SC also removes floating foam and scum produced in the aeration tank. To obtain the desired level of performance in an activated sludge system, a proper balance must be maintained between the amount of food (Organic matter), organisms (activated sludge), and dissolved oxygen (DO). The majority of problems with the activated sludge process results from an imbalance between these three parameters. The actual operation of an activated sludge systems is thus regulated by three factors: aeration and dissolved oxygen, the rate of activated sludge recirculation (RAS) (pumped from the secondary clarifier back to the aeration tank), and the amount of excess sludge withdrawn from the system (WAS) (usually pumped from the secondary clarifier towards sludge treatment) (Rustum, 2009).

2.7.3 Process variables used in control of activated sludge

The commonly used process variables that may be used in control of the treatment: measurements of sludge biomass, treatment duration and retention times in the system, and the ratio of the concentration of influent BOD to the activated sludge biomass.

Mixed Liquor Suspended Solids (MLSS): In a well-operated plant, most of the bacterial biomass is associated with the activated sludge floc. By filtering and drying a sample of the suspended solids, and then weighing the dried residue, a measure of the biomass may be obtained. It is referred to as the Mixed Liquor Suspended Solids, or MLSS, and is expressed in mg/L. However, under some circumstances a significant proportion of the MLSS may be inorganic material. For this reason, some process engineers prefer to derive a weight for the organic matter in the sludge. This is done by combusting the dried residue in a furnace at 500°C, reweighing, and obtaining the volatilized organic matter, by subtraction. This is referred to as the Mixed Liquor Volatile Suspended Solids or MLVSS which is universally used in process control as a measure of biomass. It may be intuitive to think that higher efficiency of treatment would be achieved by increasing the MLVSS, since the more organisms that are present in the mixed liquor; the faster the BOD should be ingested. However, high MLVSS concentrations create problems in aeration and also in settlement of sludge in the clarifier. Under steady-state conditions, the mass balance for biomass may be written as:

Biomass in influent+ Biomass accumulated= Biomass in effluent+ Biomass wasted

Hydraulic retention time (HRT) or volumetric loading: This is the average time spent by the influent sewage in the aeration tank. It is calculated as the tank volume (m^3) divided by the flow rate. Since flow rate Q is normally expressed in m^3/d and hydraulic retention time for the system is normally expressed in hours, the formula used is:

$$\text{HRT, } \theta_s = V/Q \times 24 \text{ hours}$$

Where, V= volume of reactor+ volume of settling tank

The hydraulic retention time for the reactor is: $\theta = V_r/Q \times 24$ hours

Where, V_r = volume of reactor

Clearly the higher the inflow rate Q, the sooner the sewage influent will reach the outlet and therefore the lower will be the residence time or hydraulic retention. The hydraulic retention time must be sufficiently long for removal of the requisite proportion of BOD from the mixed liquor.

Sludge residence time or sludge age (SRT) or mean cell residence time: Sludge age is the mean residence time of the microorganisms in the system. It is calculated as the total amount of MLSS in the system divided by the MLSS that is lost in wasting and in the effluent, each day i.e.

$$\theta_c = \frac{VX}{Q_w X_r + (Q - Q_w) X_e}$$

where, V= volume of aeration tank (m^3)

Q_w=wasting flow rate (m^3/s)

X_r = micro-organism concentration of the return sludge line (mg/L) = X_w

X_e= micro-organism concentration of secondary settling tank (mg/L) or using the usual notation:

$$\text{SRT or } t_S = \frac{V.X}{Q_w.X_w + Q_e.X_e} \text{ days}$$

The MLVSS in the RAS is not included in the calculation. It will be noticed that under steady state conditions, the denominator equals the net sludge production each day. If it is large, as a result of rapid growth of the activated sludge, the sludge age will be low. Conversely if very little growth of sludge is produced, the 'average age' of the sludge in the system increases, since it is recycled in the RAS many times. Values of sludge age may vary from < 0.5days, in a very high-rate system, to 75 days in low growth-rate systems, such as extended aeration systems. In a conventional plant, SRT would normally be between 3-4 days. Low SRT values are associated with non- or poorly flocculating sludge and poor settling characteristics.

The flowrate of sludge to be wasted is:

$$Q_w = \frac{VX}{_c X_r}$$

Where: V= micro-organism concentration in aeration tank, MLVSS in mg/L

Return sludge flow rate is:

$$Q_r = \frac{QX' - Q_w X_r' - (Q - Q_w) X_e}{X_r' - X'}$$

Where: X'= mixed liquor suspended solids, mg/L

X_r'= micro-organism concentration in return sludge line, mg/L

The net activated sludge produced each day is determined by:

$$Y_{obs} = \frac{Y}{1 + k_d \, _c} \quad \text{and}$$

$$P_x = Y_{obs} Q(S_o S)(10^{-3} kg/g)$$

Where: P_x = net waste activated sludge produced each day in terms of VSS, kg/d

Y_{obs} =observed yield, kg MLVSS/kg BOD_5 removed.

(Davis & Cornwell, 1998)

Sludge loading or f/m ratio: The rate of biomass growth, and rate of respiration (and hence rate of BOD removal by bacterial ingestion) increases with increase in BOD loading. However, the rate of BOD removal in the aeration tank is also related to sludge biomass. The higher biomass results in higher rate of BOD removal. In order to measure the amount of feed available to a unit of biomass, the BOD is divided by the MLSS. The value obtained is the so called sludge loading, more commonly referred to as the f/m ratio or the food/microorganism ratio. As the ratio of food (BOD) to microorganism increases, so will the rate of BOD removal, growth rate, and respiration rate. The f/m ratio is a useful value for the treatment plant manager since there are predictable consequences of running the plant at different f/m ratio values. It is calculated as the daily flow of BOD divided by the total MLSS in the aeration tank (derived from the product of the MLSS and the volume of the aeration tank). Thus:

$$\text{f/m} = \frac{\text{BOD (mg/L) x flow (m}^3\text{/d)}}{\text{MLVSS (mg/L) x tank volume (m}^3\text{)}} \text{ mg/(mg.d)}$$

Or, using the previous notation:

$$\text{f/m} = \frac{S_o \text{ x } Q}{X \text{ x} V}$$

The values for f/m range from about 0.5 to 1.0. For conventional plants an f/m of between 0.2 and 0.5 is usually aimed for. At higher values, the rate of treatment increases, but at the cost of poor settleability of the sludge. The f/m values below 0.2 are associated with slow BOD removal rates, but with very good sludge settlement. (Davies, 2005)

Mass of oxygen: oxygen is used in the system to degrade the substrate to produce the high-energy compounds for cell-synthesis and for respiration. The amount of oxygen required may be estimated as:

$$Mo_2 = \frac{Q(S_o - S)(10^{-3} kg/g)}{f} - 1.42(P_x)$$

Where: Q= wastewater flowrate into the aeration tank, m^3/d

S_o= influent soluble BOD_5, mg/L

S= effluent soluble BOD_5, mg/L

f= conversion factor for converting BOD_5 to ultimate BOD_L

P_x= net waste activated sludge produced each day in terms of VSS, kg/d.

(Davis & Cornwell, 1998)

CHAPTER 3
METHODOLOGY

3.1 Research strategy

This chapter includes the thorough research process. Sequential steps of works for this study are outlined below:

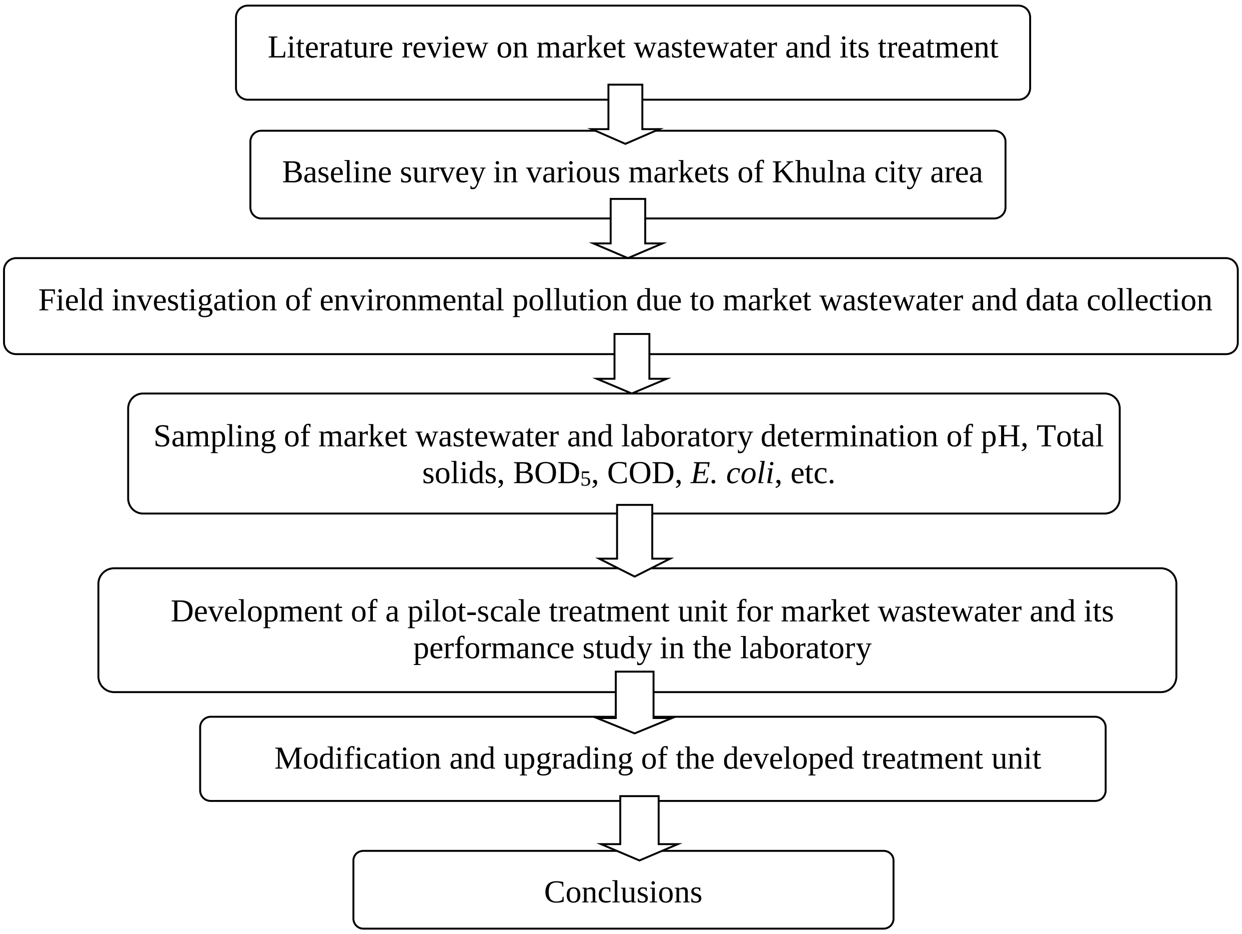


Figure 3.1 Flowchart showing the sequential steps in the research work

A field inspection was made in Khulna city to assess the negative impact of market wastewater. Firstly, detailed field survey was carried out in various markets of Sonadanga thana. Secondly, design criteria considering the characteristics obtained by laboratory analysis of the market wastewater was made and a pilot-scale wastewater treatment unit was developed in the laboratory. Finally, detailed performance study was carried out and treatment efficiency of different unit processes was monitored.

3.2 The Baseline survey

Detailed field survey was carried out in various markets of Khulna metropolitan area covering around 8.42 sq. km (located in between $22^{0}48'$ and $22^{0}51'$ north latitudes and in between $89^{0}31'$ and $89^{0}34'$ east longitudes). The baseline survey was carried out mainly in Gollamari bazar, Nirala bazar and Banaragti bazar which are the main markets situated around Moyur River. The market wastewater is disposed directly to the River and other surrounding water bodies. Along with wastewater from other sources, the market wastewater is aggravating the ecosystem of Moyur River.

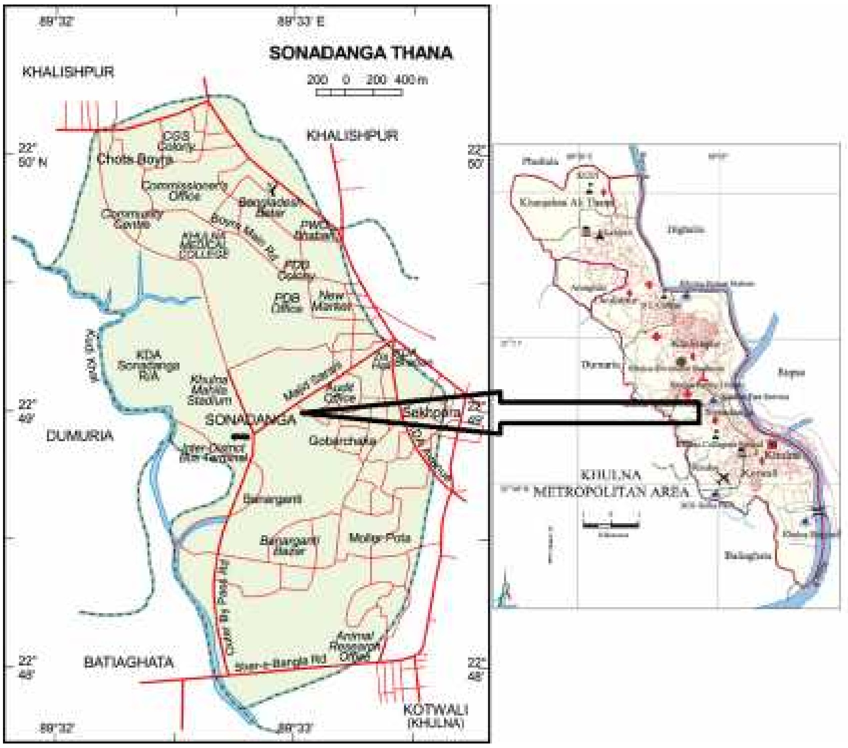


Figure 3.2 Location of the study area

3.3 Market wastewater sample collection

When untreated, market wastewater can have serious impacts on the quality of the environment and on the health of people. The Moyur River gets the whole untreated part of the market wastewater from the main markets of Sonadanga thana by open canals and local drains. The market wastewater was collected before it gets disposed to local drains.

The collected wastewater samples were analyzed individually. Few samples were taken from the slaughterhouse. The samples contained mostly animal blood and body fluid, which was directly dumped into open channels after generation. Few samples were taken from the fish market. The samples contained mostly body fluid of fishes but not blood.

Figure 3.3 Few samples of market wastewater

This water is also directly dumped into open channels after generation. Other samples were taken from the vegetables market, but combined wastewater from fish market and vegetable market flow through open channels of the vegetables market. The samples contained mostly debris of vegetables and body fluid of fish. The wastewater samples were collected in a well cleaned, properly dried 'jerry can' following standard protocol for sampling (Figure 3.3) and transported to the laboratory for analysis. The physical, chemical and biological characteristics were determined in the laboratory to identify the extent of pollution. All the parameters were measured in a day so no further preservation was done. The following table identifies the samples of market wastewater used for laboratory tests:

Table 3.1: Different samples market wastewater

Samples	**Sources of the samples**
Sample 1	Gollamari slaughterhouse: blood, liquid gut content
Sample 2	Banargati Market (fish section): body fluid and slime
Sample 3	Nirala Market (fish + vegetable section): debris of vegetables and body fluid of fish

Figure 3.4 Collection of market wastewater in jerry can

3.4 Development of pilot-scale market wastewater treatment unit

To characterize market wastewater, the physical, chemical and biological characteristics were determined in the laboratory to identify the extent of pollution. After the primary test to measure wastewater quality of three raw samples design criteria considering those characteristics were made for the treatment unit. Based on the developed criteria, a pilot-scale wastewater treatment unit was constructed in the laboratory. The activated sludge process was adopted for this treatment method, as this method is comparatively cheap and easy to operate (Davis & Cornwell, 1998). The pilot-scale wastewater treatment unit are made of high quality plastic container and consisted of a primary clarifier, the aeration tank with an aeration pump, the secondary clarifier with a pump for returning sludge and a final chamber for storing treated water (Figure 3.5). All the containers are of same dimension.

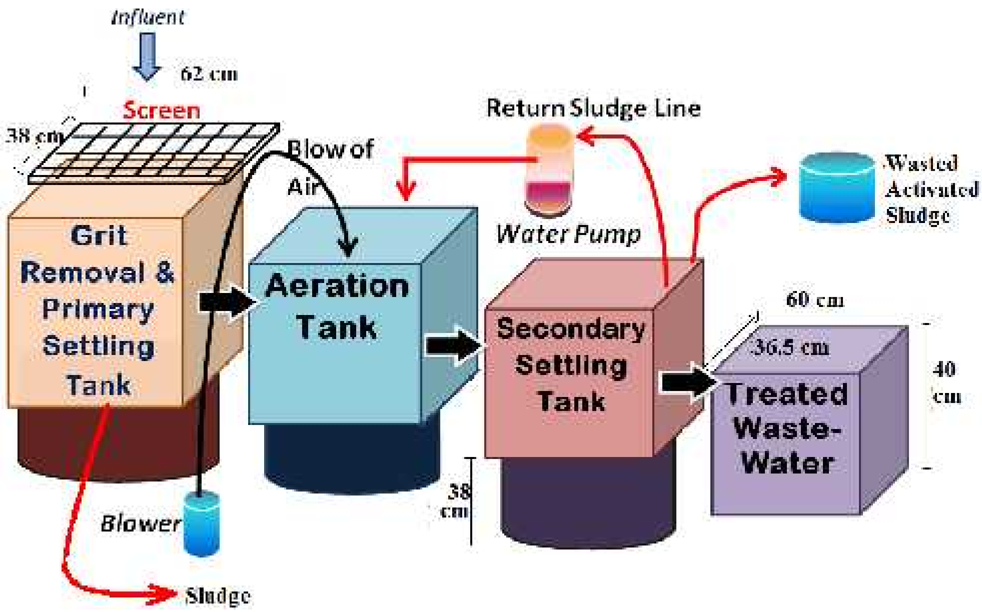


Figure 3.5 Line diagram of treatment unit for market wastewater

The following line diagram (Figure 3.6) is showing numerical values of different process variables for developed pilot-scale treatment unit.

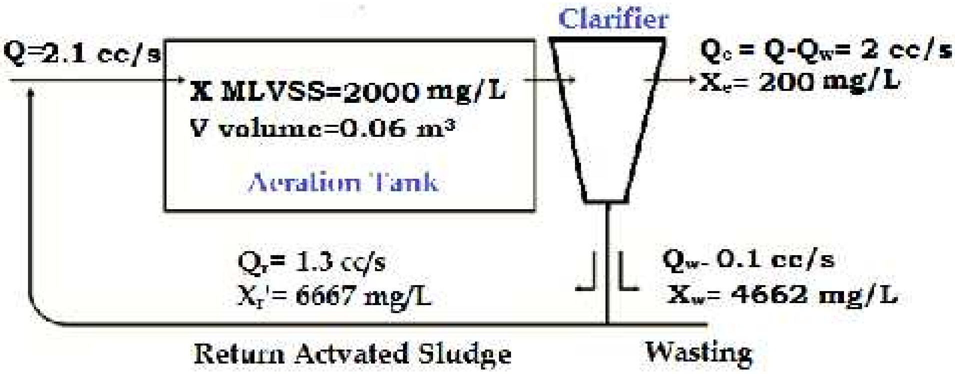


Figure 3.6 Process variables for developed pilot-scale treatment unit for market wastewater

The influent was passed through the screen (0.25 cm x 0.25 cm) to strain off any solid waste into the primary clarifier, which was also worked as a grit chamber. Then it was transferred to the next compartment, the aeration tank with a flow rate of 2.1 mL/s. The hydraulic retention time for this developed treatment unit was calculated as 4 hours in the aeration tank. The market wastewater was then carried to the next chamber, the secondary clarifier, for bacterial floc formation and settlement of the active sludge. From the secondary clarifier, a return sludge line was maintained through a pump which returned 1.3 mL/s of activated sludge to the aeration chamber. A balance was made in the wastewater flow rate between the aeration chamber and secondary clarifier. Another sludge line was also formed in secondary clarifier to discard fixed amount of wastewater with a flowrate of 0.1 mL/s to maintain the activated sludge process properly. After the continuation of all these steps, finally the treated water was collected in treated wastewater chamber. In this whole process, the wastewater had a total run time or mean cell residence time of approximately 3 days and the f/m ratio was maintained as 0.93 mg/mg*d. The detail calculation for this pilot-scale treatment unit is attached in ‘Appendix A’ at the end of the dissertation. Figure below is showing the laboratory setup of treatment unit.

Figure 3.7 Laboratory setup of treatment unit for market wastewater

3.5 Monitoring the developed treatment process

The performance of the developed treatment unit has been closely monitored to determine the treatment efficiency of this system. At first, the wastewater flow rate was set manually and maintained as per calculation according to established formula for activated sludge process. The mixed liquor volatile suspended solids of the market wastewater was determined. In order to maintain uninterrupted oxygen supply and return sludge pumping, the devices used for these purposes had been checked every day for their functional conditions.

3.6 Laboratory analysis

To characterize the market wastewater laboratory analysis was made for physical, chemical and microbial properties of following the Standard Methods (SM) of Analysis (APHA, 1999). To determine the temperature of the market wastewater a thermometer was used as an experimental instrument. The pH was measured with a pH meter (HACH, sension2). For determining total solids, total suspended solid, total volatile solid and volatile suspended solid evaporating dish, digital balance (OHAUS, adventure, readability 0.000), thermostatic water bath, oven (HERAEUS), desiccator, filter paper, filtration apparatus or suction apparatus (SARTORIUS), ignition instrument and gloves were used. Electrical conductivity of the market wastewater was measured with the conductivity meter (HACH, sension156). The nitrate (NO_3-N), phosphate (PO_4) and iron (Fe) were determined using Spectrophotometer (HACH, DR 2700). The BOD_5 of the market wastewater was determined with the help of

BOD bottle, dissolved oxygen meter or BOD meter (HACH, HQ 40d) and incubator (VELP SCEINTIFICA, FTC 90E) as well as the COD of the market wastewater was tested with COD vial and COD reactor. Diluted wastewater sample was taken in a volumetric flask to determine the alkalinity using. To determine the number of coliforms and *Escherichia coli,* diluted sample of market wastewater was filtered through cellulose nitrate filter using filtration apparatus and incubator (GENLAB, mini/30/DD). All the processes of determining the physical, chemical/biochemical and microbial properties of the treated market wastewater remained same except for the sample as treated market wastewater. The illustration below is showing some instruments used during the treatment process of market wastewater:

COD reactor used in COD test

Measurement of dissolved oxygen for BOD test

Petri dish used in coliform test

Filtration apparatus

Water bath

Spectrophotometer

Figure 3.7 Some laboratory instruments used in treatment of market wastewater

CHAPTER 4
PERFORMANCE STUDY OF DEVELOPED PILOT-SCALE TREATMENT UNIT

4.1 Background

Evaluation of wastewater treatment was done from the characteristics of wastewater flowing in and out of the developed market wastewater treatment unit i.e., its removal efficiency was obtained by calculating the difference in each parameter concentrations of the influent and effluent quality and comparing them with the standard for disposal of market wastewater into water courses according to The Environment Conservation Rules (1997).

4.2 Results and discussion

Wastewater characteristics based on the analysis of different samples from raw and treated wastewater is discussed in a broad spectrum according to physical, biochemical/chemical and microbial properties. The characteristics of raw market wastewater samples from the laboratory test are presented in Table 4.1. This summary table reveals the present condition of the market wastewater and its level of pollution.

Table 4.1: Water quality test results of raw market wastewater samples

Water Quality Parameters	Unit	Raw market wastewater			*ECR'97 discharge standard
		Sample 1 (Gollamari bazar)	Sample 2 (Banaragti bazar)	Sample 3 (Nirala bazar)	
Biochemical Oxygen Demand (BOD_5)	mg/L	619	141	62	50
Chemical Oxygen Demand (COD)	mg/L	960	380	160	200
Total Solids	mg/L	5080	3560	3280	-
Total Suspended Solids	mg/L	3300	3040	1840	150
Total Volatile Solids	mg/L	3100	1640	1400	-
Volatile Suspended Solids	mg/L	1960	1580	1280	-
Electrical Conductivity	mS/cm	66.69	1.63	3.95	1.2
Temperature	^oC	30.9	28.1	27.7	40
pH	--	8.6	7.9	7.5	6.0- 9.0
Iron (Fe)	mg/L	35	4.5	21	2
Nitrate (NO_3-N)	mg/L	1020	9	24	10
Phosphate (PO_4)	mg/L	4510	178	40	-
Alkalinity (as $CaCO_3$)	mg/L	2500	1000	2000	-
Total Coliform	N/100 mL	600000	6000	3840	-
Escherichia coli (*E. coli*)	N/100 mL	280000	2000	1800	-

*ECR'97: The Environmental Conservation Rules (1997)

There is no set standard for disposal of market wastewater in inland water bodies in Bangladesh. So, the standards for waste from industrial unit is considered for market wastewater for disposal into inland water courses. The results of different raw market wastewater samples manifested that huge amount of polluting agents that are dumped every day in the water bodies without any treatment which was alarming for the ecology of inland surface water. In the pilot-scale treatment unit these three samples were treated to reduce the level of pollution. The findings are described following sections.

4.2.1 Treatment efficiency of the water quality parameters

The chemical and biochemical characteristics of market wastewater changed a lot after treatment in the developed pilot-scale treatment unit. Results from the three samples before and after treatment are illustrated in graphical representations in under mentioned paragraphs.

4.2.1.1 Biochemical Oxygen Demand (BOD_5)

The most important water quality parameter is the Biochemical Oxygen Demand (BOD_5). From figure 4.1, it is clear that, after treatment of market wastewater the BOD_5 of all the samples has been reduced significantly. The standard value of BOD_5 for disposal to inland water bodies is 50 mg/L (ECR, 1997). In case of sample-1 and sample-2, the BOD_5 after treatment higher than the standard but in case of sample-3, the treated value of BOD_5 lied within the limit (Figure 4.1). Though the value of BOD_5 after treatment was higher than standard limit but the removal efficiencies were 80%, 58% and 73% for sample-1, sample-2 and sample-3, respectively. Despite this positive trend of BOD_5 removal, to get a standard value of BOD_5 after treatment, the treated market wastewater might again run through the system as raw wastewater or some modification in process variables might be done or some additional treatment process might be adopted before disposal to inland water bodies.

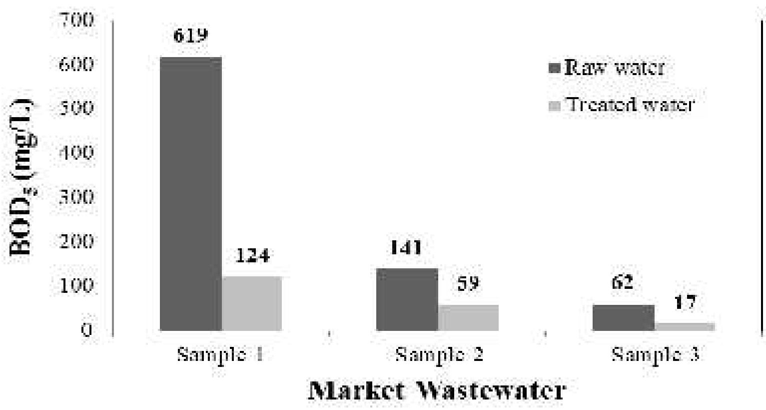


Figure 4.1: The difference in BOD_5 before and after treatment

4.2.1.2 Chemical Oxygen Demand (COD)

The Value of Chemical Oxygen Demand (COD) showed a positive result after treatment. For sample-1, sample-2 and sample-3, COD removal efficiencies were 67%, 58% and 31%, respectively. Usually, the higher degree of COD removal at higher MLVSS is due to higher number of microorganisms present in the aeration tank. In market wastewater, the higher amount of VSS influenced COD removal efficiency. The standard value of COD for industrial wastewater for disposal into inland water bodies is 200 mg/L (ECR, 1997) which was not fulfilled by sample-1. So, before disposal of sample-1 market wastewater, it is needed further treatment. The change in COD has shown in figure 4.2.

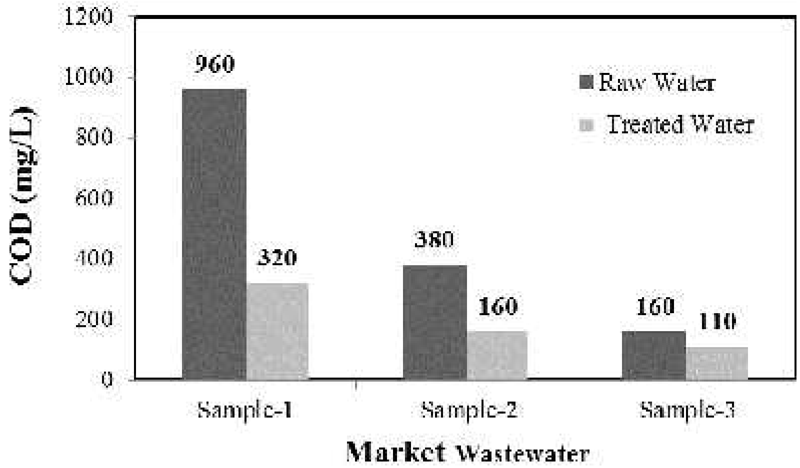


Figure 4.2: The variation in COD before and after treatment

The BOD_5 and COD removal efficiencies of the developed treatment unit are the main focus of the activated sludge process. Due to consumption of biodgradable element from the wastewater and floc formation followed by settlement of sludge by the micro-orgnisms, other water quality parameters also displayed changes after treatment. The effects are also discussed below:

4.2.1.3 Iron (Fe)

Excessive iron might injure carbon cycle and health of living creatures though it is essential for nitrogen binding and nitrate reduction in wastewater. Analyzing the market wastewater samples, it was obvious that, the first and third samples contained huge amount of iron as the samples might have fraction of animal blood. After treatment all samples reduced in iron content, proving the success of the treatment unit. According to ECR (1997), the iron content in wastewater effluent for disposal into open water bodies should not exceed 2 mg/L. For sample-1 and 2, the requirement did not fulfill which means, modification of the treatment unit was need (Figure 4.3).

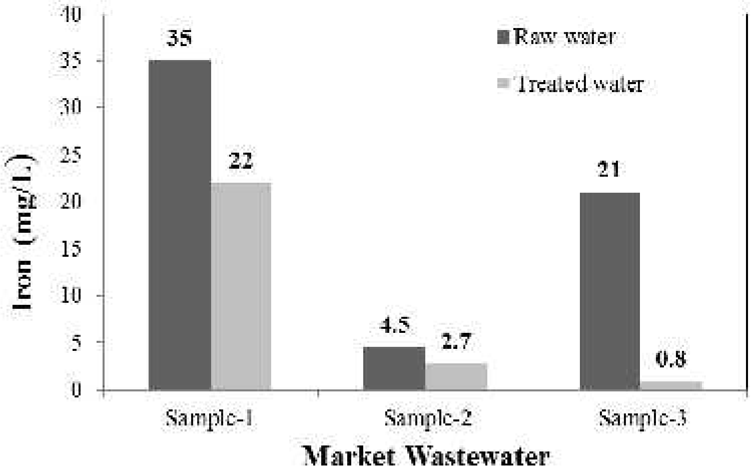


Figure 4.3: The changes in iron content of market wastewater before and after treatment

4.2.1.4 Nitrate (NO_3)

The nitrate content (NO_3-N) of the first sample was too high compared to other samples, but after treatment it reduced almost 90%. The standard limit for nitrate for disposal in surface water is 10 mg/L (ECR, 1997). In spite of reducing 90% nitrate from the market wastewater sample-1, the treated wastewater could not meet the requirement due to high nitrate loading. So, this sample might require further treatment. The reduction in nitrate content is shown in Figure 4.4.

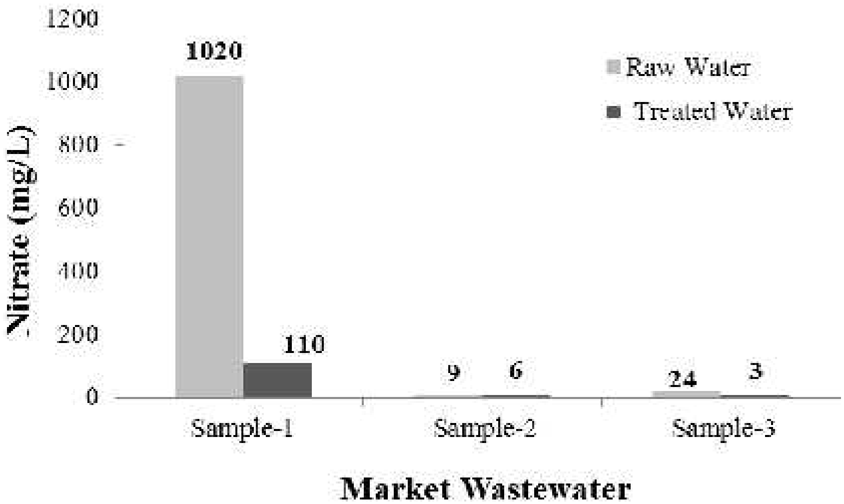


Figure 4.4: The difference in nitrate in market wastewater before and after treatment

4.2.1.5 Phosphate (PO_4)

The standard limiting value for phosphate for safe disposal as sewage into inland surface water bodies is 35 mg/L (ECR, 1997). There is no set standard for industrial wastewater disposal in this case. The treatment of sample-3 was satisfactory in this case but in sample-1 and sample-2 the treated wastewater contained phosphate beyond acceptable limit which could not be allowed for safe disposal to natural streams. As phosphates increase along with the increment of nitrates in open water bodies, the growth of aquatic plants is encouraged and algal blooms can occur which eventually will decrease dissolved oxygen levels. But as the value of nitrate of market wastewater after treatment is considerably under the standard level, only increased value of phosphate alone cannot be liable for algal bloom. From this discussion, it is obvious that, the developed treatment method alone is not capable to meet the standard requirements for safe disposal of effluents into inland surface water bodies. Thus, a proposal for modification on the developed pilot-scale treatment unit could be a solution of this problem. The variation of phosphate was shown in figure 4.5.

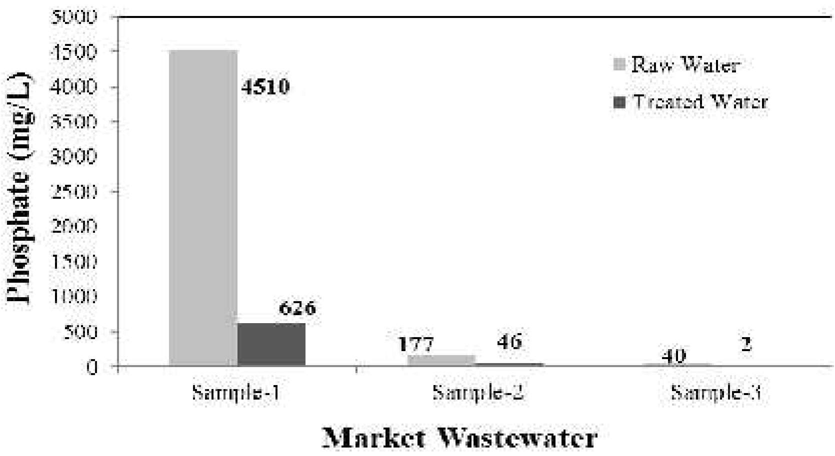


Figure 4.5: The variation in phosphate in market wastewater before and after treatment

4.2.1.6 Alkalinity

Alkalinity is the key to steady-state operations in activated sludge process. Nitrification of the wastewater is the single largest factor which leads to the consumption of alkalinity as for nitrification, the pH of the system gets reduced. But, in market wastewater, the pH did not reduce rather in all cases it increased a little and remained steady at an alkaline level and the alkalinity reduction pattern was not similar for three samples. So, even after huge nitrate drop for the first sample, the alkalinity reduction was a lot less. The changes are drawn in figure 4.6.

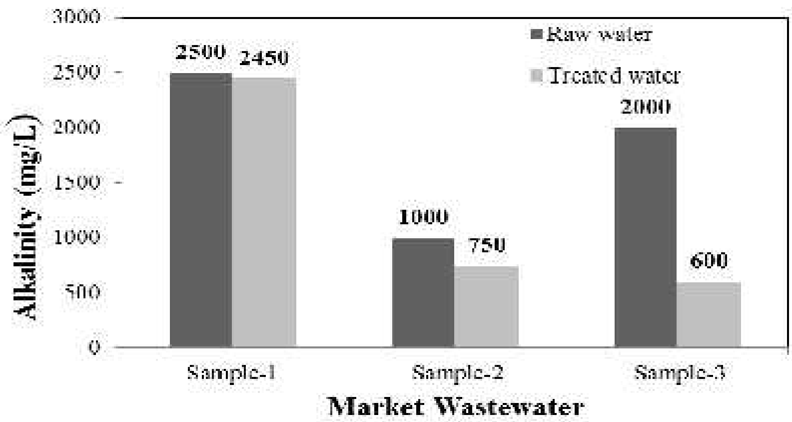


Figure 4.6: The difference in alkalinity in market wastewater before and after treatment

4.2.1.7 Temperature

Temperature had a significant effect on the growth rate of microorganisms. The rate of biological activity was influenced by temperature because of the depth of penetration of oxygen into the floc or film. For economic and geographical reasons, most aerobic biological treatment processes operated in the mesophilic range which is around 15−40°C (Henze, et al., 2011). Results of the three samples of market wastewater before and after treatment in the developed treatment unit were indicating a mesophilic range which is the most suitable condition for activated sludge process. The activated sludge process has no direct effect on temperature of the wastewater. The irregular pattern in changes of temperature in market wastewater might be due to weather effect. The graphical representation of comparative plot of different temperature between raw and treated market wastewaters is shown below in Figure 4.7.

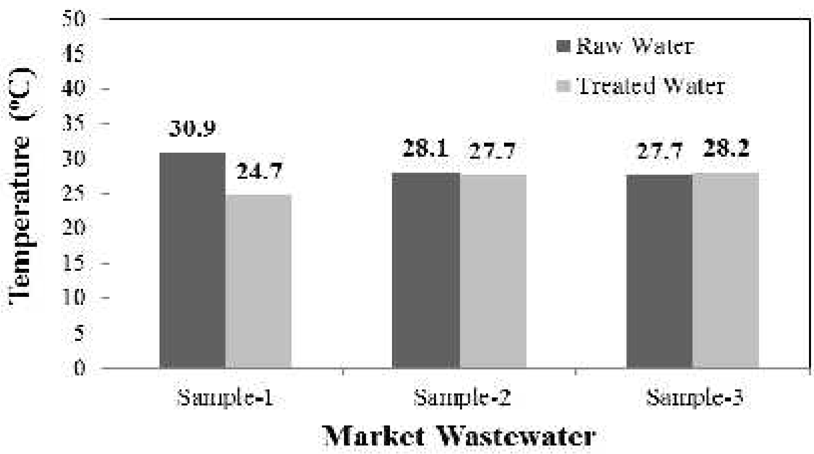


Figure 4.7: The changes in temperature before and after treatment

4.2.1.8 pH

The standard value of pH for good ecological balance was within 6.0 to 9.0. All three types of the wastewater treatment bacteria, psycrophiles, mesophile and thermophile, operate most efficiently at a pH of 6.8-7.2. When the pH drops below 6.0 or rises above 8.5, activity drops off dramatically. Bioactivity in wastewater treatment processes tends to lower the pH. This happens because carbon dioxide that is released in the decomposition process reacts with water to create carbonic acid. But, in all cases of market wastewater, the values of pH increased after treatment although the treated values remain within standard limit. The trend of increasing pH in treated wastewater might be a result of CO_2-freed air (as due to continuous air flow, the CO_2 strips out of the system) which has the potential to increase the pH of wastewater to high levels (Cohen & Kirchmann, 2004). From the figure below, the trend in change of pH in market wastewater is illustrated clearly. The first sample was enriched with animal body fluid which made it higher in pH content.

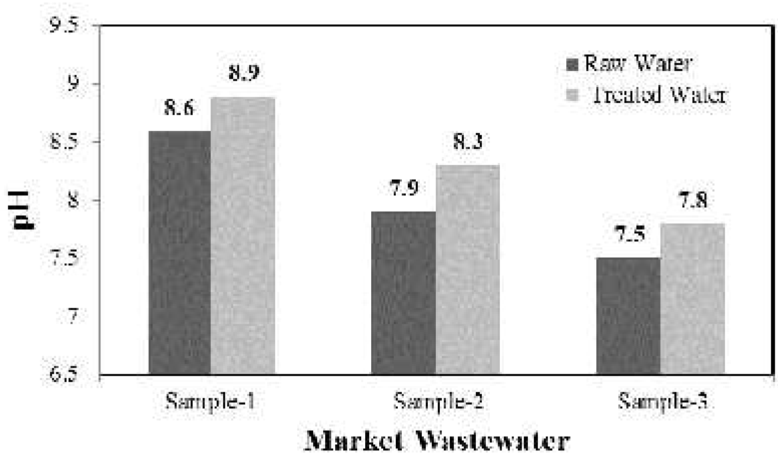


Figure 4.8: The variation of pH before and after treatment

4.2.1.9 Total Solids

The amount of total solids in both raw and treated market wastewater was high. After treatment, the solids content did not decrease much except for sample-2. This could happen as a result of unsuccessful sludge settlement or considerably higher (0.93 mg/mg*d) f/m ration. This is a clear indication for a modification of existing treatment unit. The results are shown in the figure below:

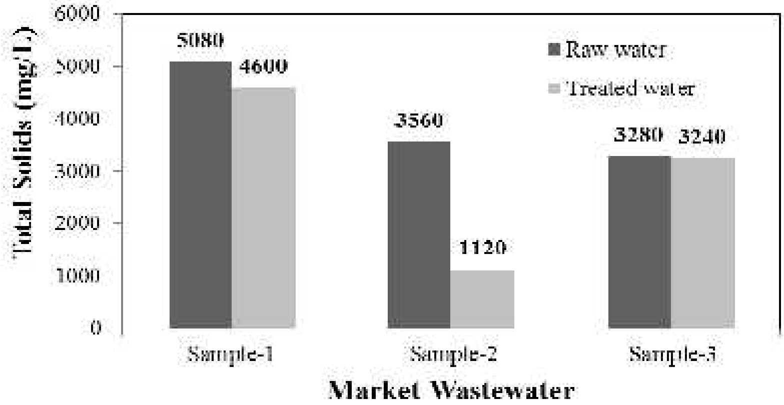


Figure 4.9: The difference in total solids before and after treatment

4.2.1.10 Total Suspended Solids

The total suspended solids (TSS) in treated water had the same pattern like total solids. The TSS decreased remarkably in case of sample-2 and sample-3 after treatment showing a good sludge settleability. According to ECR (1997), the suspended solids should not exceed 150 mg/L. Figure 4.10 is showing the trend.

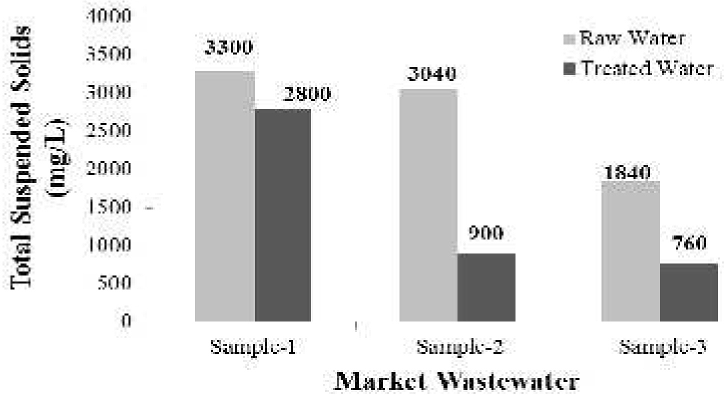


Figure 4.10: The variation in total suspended solids before and after treatment

4.2.1.11 Total Volatile Solids (TVS)

It normally represents the approximate amount of organic matter present in the solid fraction of wastewater. The greater the concentration of organic or volatile solids in wastewater, the stronger it is. Theoretically, total solid content of wastewater is about 50 percent organic. Comparing Figure 4.9 with the figure below, it can be seen that, TVS is almost 50% of TS of market wastewater. Due to biological activity and floc formation of the micro-organisms, the TVS recued around 16% for sample-1 and 50% for sample-2 and 3. Even after treatment, this huge amount of TVS could possibly cause damage to the treatment facility. The comparative plot is drawn below in Figure 4.11.

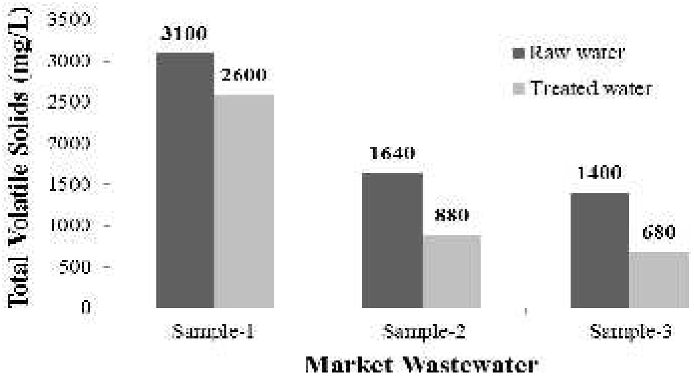


Figure 4.11: The changes in total volatile solids before and after treatment

4.2.1.12 Volatile Suspended Solids (VSS)

The volatile suspended solids reduced almost in a same way for the three samples. The VSS of the treated samples was almost 50% of the raw VSS. The VSS was the active biomass concentration which was mostly used up during treatment. Still, after treatment the treated wastewater contained high VSS for all cases. Figure 4.12 represents the comparative plot of VSS.

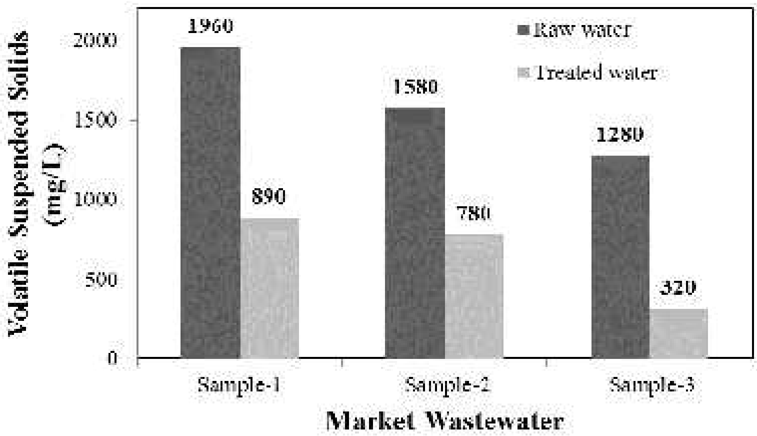


Figure 4.12: The variation in volatile suspended solids before and after treatment

4.2.1.13 Electrical Conductivity (EC)

Electrical conductivity is directly related to the total salt concentration. So, the main process that reduces conductivity in wastewater treatment is biological nutrient removal. In these three samples, only sample-1 showed a huge drop in EC after treatment whereas, sample-2 and 3 remained close to the raw value. The different pattern of treatment could be explained with biological nutrient removal tendency. Biological nitrogen removal technique includes consuming alkalinity or hydroxide ions. If the amount of available alkalinity is high enough, biological nitrogen removal through nitrification followed by denitrification gives a decrease in EC (Levlin, 2010). Sample-1 contained heavy nitrate content as a raw market wastewater but after treatment it reduced dramatically. On the other hand, sample-2 and 3 did not change much after treatment (Figure 4.4). This explains the EC changing pattern which is drawn in Figure 4.13.

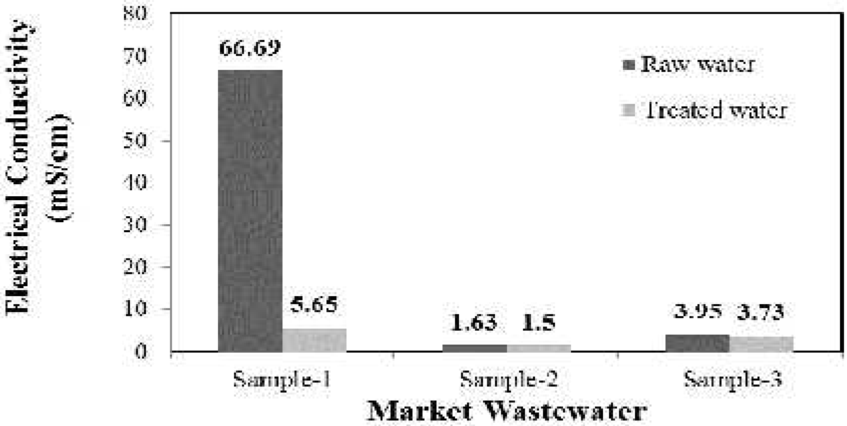


Figure 4.13: The difference in Electrical Conductivity before and after treatment

4.2.1.14 Total Coliform and *Escherichia coli (E. coli)*

One of the most important factors for wastewater is the number of coliform. Market wastewater was also contaminated with faeces. After biological treatment using activated sludge process, the bacteriological contamination was not found to be reduced possibly for not using any disinfectant in the experimental procedure (Figure 4.14). There may be another reason for increament of coliform as the pH of wastewater increased after treatment. Low pH usually kills off micro-organisms in wastewater. Most organic matter and bacteria we are familiar with and contact daily are best suited to a neutral or slightly basic environment.

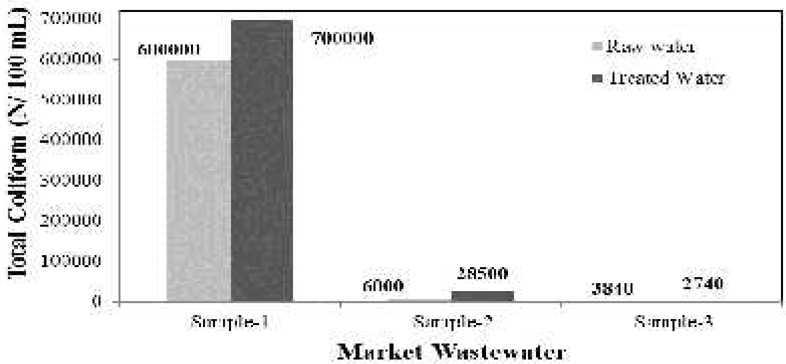


Figure 4.14: The difference in number of total coliforms before and after treatment

Alwan (2008) suggested that, at an acidic pH, the excess hydrogen ions begin to form bonds with and break down the cell, slowing their growth or killing them outright, for what after a wastewater treatment cycle the pH must be raised back to neutral. But, in this pilot-scale treatmenmt unit the pH level was above neutral for all samples which lead to coliform existance. Thus, the treated wastewater must be disinfected before disposal to natural stream.

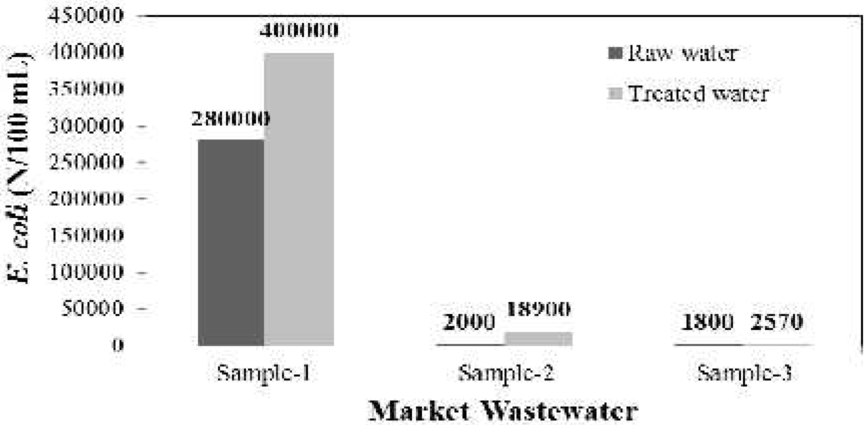


Figure 4.15: Variation of number of *E. coli* in market wastewater before and after treatment

After the treatment process, the water quality parameters were measured again to check the performance of the developed treatment unit. The outcome of this test is listed below in Table 4.2.

Table 4.2: Water quality test results of treated market wastewater samples

Water Quality Parameters	Unit	Treated market wastewater Sample 1 (Gollamari bazar)	Sample 2 (Banaragti bazar)	Sample 3 (Nirala bazar)	*ECR'97 discharge standard
Biochemical Oxygen Demand (BOD_5)	mg/L	124	59	17	50
Chemical Oxygen Demand (COD)	mg/L	320	160	110	200
Total Solids	mg/L	4600	1120	3240	-
Total Suspended Solids	mg/L	2800	900	760	150
Total Volatile Solids	mg/L	2600	880	680	-
Volatile Suspended Solids	mg/L	890	780	320	-
Electrical Conductivity	mS/cm	5.65	1.50	3.73	1.2
Temperature	^oC	24.7	27.7	28.2	40
pH	--	8.9	8.3	7.8	6.0- 9.0
Iron (Fe)	mg/L	22	2.7	0.8	2
Nitrate (NO_3-N)	mg/L	110	6	3	10
Phosphate (PO_4)	mg/L	626	46.8	2.4	-
Alkalinity (as $CaCO_3$)	mg/L	2450	750	600	-
Total Coliform	N/100 mL	700000	28500	2740	-
Escherichia coli (*E. coli*)	N/100 mL	400000	18900	2570	-

The water quality parameters have improved using activated sludge process as treatment method in developed pilot-scale unit. But, as this is strong wastewater, the effluent could not meet the standard. So, it needs to be treated again in this pilot-scale unit or in another modified unit before disposal into any open water sources.

In case of wastewater effluent taken back as new influent and run through the whole system again with activated sludge process, few water quality parameters might show improvement after treatment. But, the number of coliforms might increase after treatment with activated sludge process. Considering this, introduction of another form of treatment process with the existing activated sludge process possibly be the suitable solution to the treatment process.

4.3 Conclusions

Performance of the developed pilot-scale treatment unit varied depending on the parameters. Few water quality parameters improved and fulfilled the standard value whereas the others did not. Removal efficiency of BOD_5 and COD was quite good but due to huge pollutant loading the effluent was unable to meet required standard. Along with BOD_5 and COD removal, the pilot-scale treatment unit also removed solids, nitrates, phosphates and other parameters. Not using any disinfectant led the number of coliform increased. Overall, review of the performance of the pilot-scale treatment unit necessitates an additional treatment option or a modification. Introducing a new modification unit may be the best accomplishment to elevate the quality of market wastewater.

CHAPTER 5

PROPOSAL FOR MODIFICATION OF THE TREATMENT UNIT

5.1 Background

The pilot-scale treatment unit developed in the laboratory could not remove all the harmful contaminants from market wastewater as per standard limit (ECR, 1997). Thus, an improved treatment method was required prior to disposal of the effluent. There are many different treatment processes available and their suitability is a function of source water quality, level of operation skills and maintenance. It is imperative that the selection of technology for treatment process is done taking the above into consideration to ensure that they remain sustainable. Analyzing the results of treatment stated in previous chapter, addition of a biological removal treatment process would be the desired solution here which will lead to multiple barrier treatment system.

5.2 Introduction of modified treatment unit

Market wastewater treatment process included firstly the physical removal of contaminants through screening and settling followed by biological removal of microorganisms through activated sludge process. Introducing another method of biological removal of microorganisms into the system after the activated sludge process would amplify treatment accuracy. This different number of stages of treatment processes is called the multiple barrier principle. This is an important concept as it provides the basis of comprehensive treatment of wastewater and provides a system to prevent complete treatment failure due to a breakdown of a single process.

The improved method of biological removal of microorganisms would be a granular duel-media filtration method adopted for up-flow sludge blanket reactor (SBR), as it is extremely good at removing microbial contamination, traditionally known worldwide and economic method of wastewater treatment (Huisman & Wood, 1974). Instead of conventional sand filter the duel-media up-flow filtration technique increases the time of filtration cycle and reduces substantially the necessary time for backwashing. (Zouboulisa et al., 2007)

5.2.1 Treatment mechanism through modified system

In slow sand filter, the operating filtration rate is considered to be varies in the range of 0.1-0.3 $m^3/m^2/hr$. The top layers of the sand become biologically active by the establishment of a microbial community on the top layer of the sand substrate. These microbes usually come from the source water and establish a community within a matter of a few days. The sand filtration rate facilitates the establishment of this microbial community. The majority of the community is predatory bacteria who feed on water-borne microbes passing through the filter. The microbial community forms a layer called the schumtzdecke and can develop up to 2cm thick before the filter requires cleaning. Once the schumtzdecke becomes too thick and the rate of filtration declines further it is scraped off, a process done every couple of months or so depending on the source water.

In the granular duel-media filtration technique this principle of sand filter remains the same except for the duel filter media and up-ward flow path of wastewater. After treatment with the developed treatment unit, the effluent is needed to pass slowly through the brick-chips media and sand filter to improve the water quality. Instead of following the traditional down-flow method, the flow path could be up-ward through brick-chips layer first and then sand bed and finally the supernatant could be disposed off through an outlet arrangement. This approach is recommended for longer duration of filter run with less operation and maintenance requirements. (Zouboulisa et al., 2007)

5.2.2 Fabrication and installation of the modified unit

The extended modified duel-media filtration unit was constructed with locally available brick-chips bed at the bottom of the container along with sand bed on its top. Both granular media were well cleaned before use and formed a uniform thick layer of 5 cm height each. The effluent treated wastewater first traveled through the brick-chips bed followed by sand bed forming an up-flow of wastewater. Another market wastewater sample was used in this modified unit after treatment in the previously developed pilot-scale treatment unit, taken from the fish market of Banrgati market which was a mixture of fish and vegetable wastewater, was passed slowly through the media to allow the formation of the microbial community or the schumtzdecke for biological treatment which took roughly 4 to 5 days. The treated wastewater was collected from the top of the modified treatment unit after 6 days and tested for the water quality parameter. Figure 5.1 and 5.2 is showing the modified treatment unit of market wastewater.

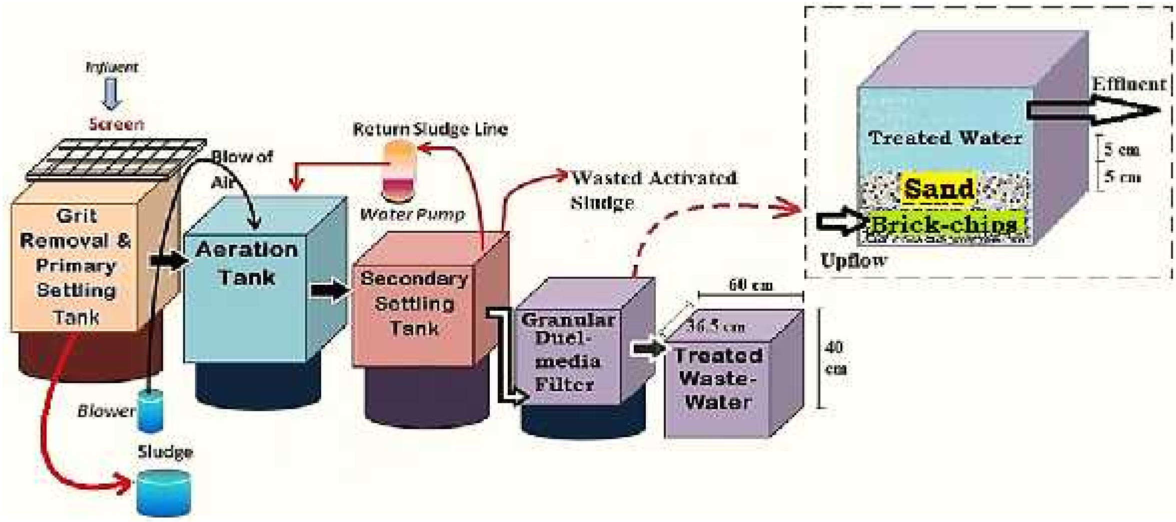


Figure 5.1 Line diagram of modified treatment unit of market wastewater

Figure 5.2 The modified duel-media treatment unit of market wastewater

5.2.3 Performance study of the modified treatment unit

Before studying the treatment efficiency in modified unit, a table below is given to indicate the samples clearly. The market wastewater is considered as three different samples and further observations are described accordingly.

Table 5.1: Compared samples of market wastewater

Samples	Sample description
Raw wastewater	Wastewater from Banrgati market (fish and vegetable wastewater)
Treated wastewater (developed unit)	Treated effluent wastewater from the developed treatment unit just before the treatment operation started in the modified part
Treated wastewater (modified unit)	Treated effluent wastewater after treatment in the modified part were collected

With these three samples the water quality parameters were tested individually. The BOD_5 and COD removal efficiencies for modified unit were 90% and 77%, respectively. of the treated market wastewater reduced to standard limit as the pollution level was quite less. After treatment in the modified unit, the amount of iron and phosphate has slightly increased. This is probably due to their natural presence in soil that had been used in brick making and thus appeared in brick-chips.

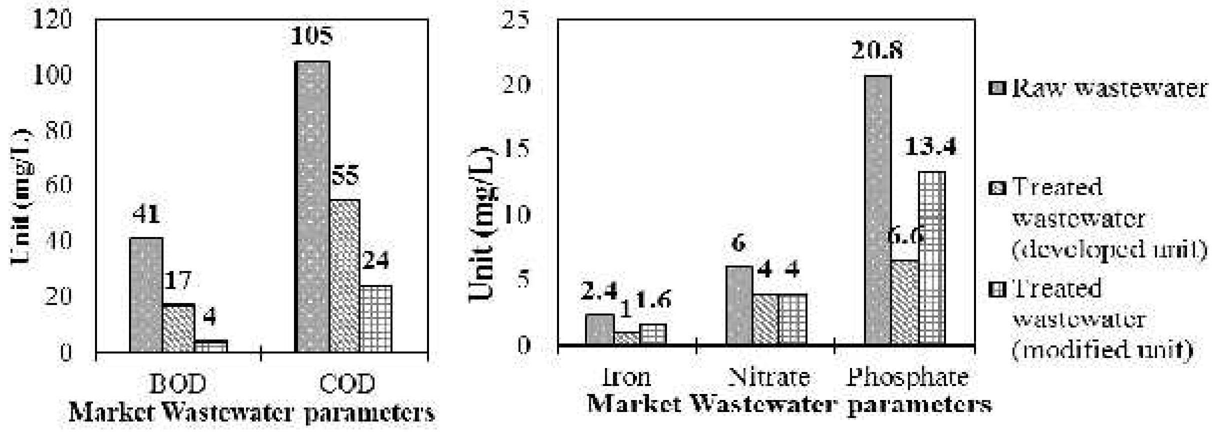


Figure 5.3 Changes among various water quality parameters after treatment in developed and modified treatment unit

The value of pH remained steady after treatment in modified. The value of electrical conductivity declined after treatment in both developed and modified treatment units. According to ECR (1997), the standard value of electrical conductivity should be within 1.2 mS/cm, which was not fulfilled even after treatment in modified unit.

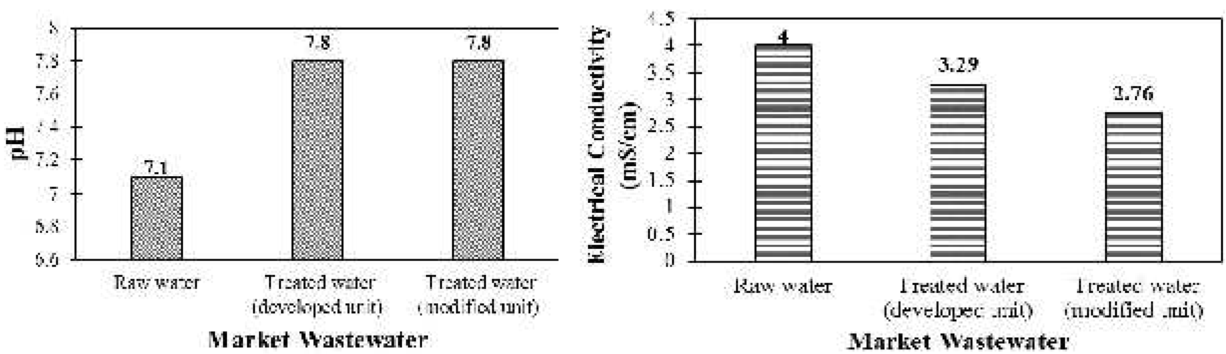


Figure 5.4 The comparison among values of pH and electrical conductivity after treatment

A huge change was observed in case of amount of solids after treatment in modified treatment unit. The amount of Total Solids (TS), Total Suspended Solids (TSS), Total Volatile Solids (TVS) and Volatile Suspended Solids (VSS) reduced drastically after being passed through the duel-media filtration unit. The amount of alkalinity also exhibited the same movement. Though, the value of SS reduced drastically but electrical conductivity did not reduce relevantly. This might happen as a result of sand filtration where suspended particles got strained unlike dissolved solids.

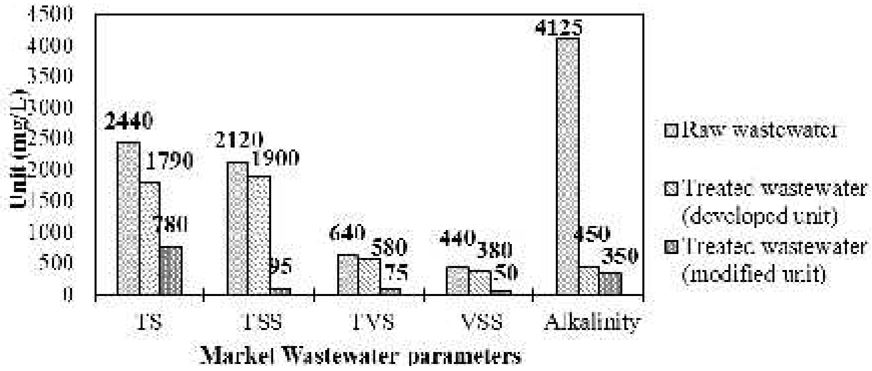


Figure 5.5 The differentiation among various water quality parameters after treatment

The microbial characteristics of market wastewater had visibly improved after treatment in modified treatment unit. The number of total coliform reduced significantly whereas the number of *E. coli* became nil. Most of the biomass and biological treatment occurred in the upper portion of the sand bed where the microbial community or the schumtzdecke has formed and ruled the surface charge attraction and coagulation mechanism for treatment. The graphical representation is shown in figure 5.6.

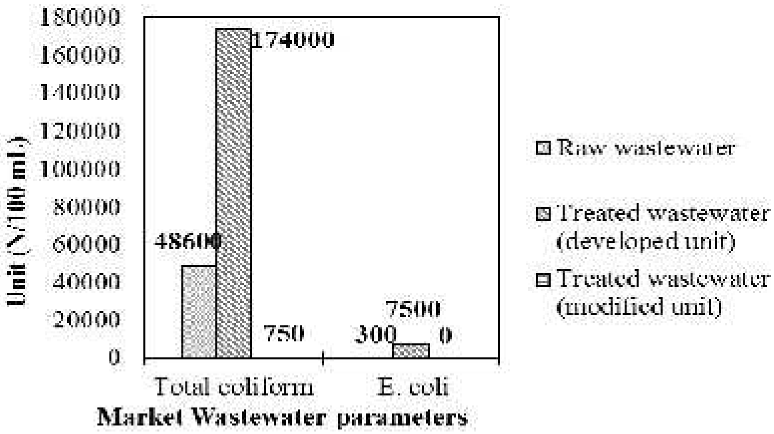


Figure 5.6 Changes among microbial water quality parameters after treatment

The overall changes are represented in Table 5.2 to summarize the performance of the modified treatment unit. Moreover, the standard limit for wastewater disposal into inland water bodies according to ECR (1997) are listed for a comparison among all the parameters.

Table 5.2: Water quality test results of market wastewater samples

Water Quality Parameters	Unit	Raw Market Wastewater	Treated Market Wastewater (Developed Treatment Unit)	Treated Market Wastewater (Modified Treatment Unit)	*ECR'97 discharge standard
Biochemical Oxygen Demand (BOD_5)	mg/L	41	17	4	50
Chemical Oxygen Demand (COD)	mg/L	105	55	24	200
Total Solids	mg/L	2440	1790	780	-
Total Suspended Solids	mg/L	2120	1900	95	150
Total Volatile Solids	mg/L	640	580	75	-
Volatile Suspended Solids	mg/L	440	380	50	-
Electrical Conductivity	mS/cm	4.0	3.29	2.76	1.2
Temperature	^{o}C	19.4	20.2	21.1	40
pH	--	7.1	7.8	7.8	6.0- 9.0
Iron (Fe)	mg/L	2.4	1.0	1.6	2
Nitrate (NO_3-N)	mg/L	6	4	4	10
Phosphate (PO_4)	mg/L	20.8	6.6	13.4	-
Alkalinity (as $CaCO_3$)	mg/L	4125	450	350	-
Total Coliform	N/100 mL	48600	174000	750	-
Escherichia coli (*E. coli*)	N/100 mL	300	7500	0	-

From the table the result of using the modified treatment unit is indicating a positive trend. All the parameters are within standard limit after treatment in duel-media filter. The number of coliforms is also satisfactory along with the amount of solids. The solid part has been reduced visibly which is shown in figure below:

Raw market wastewater | Treated market wastewater with activated sludge process | Treated market wastewater with modified treatment unit

Figure 5.7 Treatment efficiency of modified duel-media treatment unit

From the experimental data analysis, it is found that the accuracy of the duel-media filtration system is quite good. Due to using the activated sludge process the amount of solids were reduced which served positively for the duel-media filtration system for longer run of operation and maintenance. Though the system needed large area for sand filtering and relatively intensive labor still it was easy to operate and economic method without any use of chemical disinfectant and hence ensures environmental sustainability.

5.3 Conclusions

Market wastewater is becoming a huge burden to the environment as mass negligence to this issue pushing our open water sources to death every second. Treating the wastewater with the proposed modified treatment unit before its direct disposal into open water courses could save them. But, only this theoretical knowledge would not be helpful if it is not taken into action and actually constructed and operated. For a sustainable market wastewater solution, a large scale wastewater treatment plant should be adopted in different markets of Khulna city idealizing above mentioned theories.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Background

This work investigated the characteristics of the market wastewater and how to improve the condition. The study had three major objectives: (1) To determine the physical, chemical/biochemical and microbial characteristics of market wastewater from Khulna city; (2) To develop a pilot-scale treatment unit for the market wastewater; and (3) To monitor the performance of the pilot-scale treatment unit. Conclusions with regard to each objective are stated in section 6.2 and recommendations are listed in section 6.3.

6.2 Conclusions

Regarding the first objective of determining the characteristics of MW:

Market wastewater was a strong wastewater which was found to be highly polluted with biodegradable organic matter with BOD_5 ranged from 60-619 mg/L, TSS 1800-3300 mg/L, TC 3800-600000 per 100 mL, Nitrate 10-1020 mg/L and Phosphate 40-4510 mg/L; none satisfied the standards for disposal into inland water bodies according ECR’97. It was also a source of huge electrical conductivity and alkalinity (measured as $CaCO_3$) ranged from 1.63-66.69 mS/cm and 1000-2500 mg/L, respectively with a pH value around 7.5-8.6. Considering all these factors it became obvious to treat the wastewater before disposal.

Regarding the second objective of developing a pilot-scale treatment unit:

A pilot-scale treatment system has been developed in the laboratory using Activated Sludge Process with some empirical formula and assumed arbitrary coefficients. Process variables for the developed treatment unit were: mean cell residence time= 3 days; hydraulic retention time= 4 hours and The F/M ratio= 0.93 mg/mg*d with influent inflow rate of 2.1 mL/s, wasting flow rate of 0.1 mL/s and return sludge flow rate of 1.3 mL/s.

Regarding the third objective concerning the performance study of the developed treatment unit:

The BOD_5 and COD removal efficiencies of the developed market wastewater treatment unit were found to be ranged from 58%-80% and 31%-67%, respectively. In treated market wastewater BOD_5 was found to be ranged from 20-120 mg/L, TSS 700-2800 mg/L, TC 2700-700000 per 100 ml, Nitrate 5-110 mg/L and Phosphate 2-626 mg/L. Though, the treatment efficiency for removal of BOD_5 and COD of the developed pilot-scale treatment unit was quite good, still the treated effluent could not meet standards for safe disposal into inland water bodies. Addition of a modified duel-media sand filter to the developed unit enhanced the efficiency of the treatment process and satisfied all criteria for safe disposal according to ECR'97.

6.3 Recommendations

Market wastewater should be treated before drainage into canals, rivers as chemical contaminants tend to have longer-term effects on health, and suspended solids affect microbial survival and the acceptability of water along with high potential for polluting river water ecosystem and environment. General impacts of processing wastes are believed to be the same as other sources of pollution that cause eutrophication of the environment. However, application of the modified treatment options with the developed treatment unit can substantially reduce the waste loads. For greater interest and sustainability of the river biology, treatment units should establish effective effluent treatment and monitoring facilities to reduce waste loads and pressure on the ecosystem. Implementation guidelines could be adopted for different markets of Khulna city to reduce the pollution occurring due to market wastewater and the Government must come forward to facilitate wastewater treatment plant installation with technical guidance and also with financing. In the long run, a good result from the concept of wastewater treatment plant installation can only be ensured by proper monitoring and environmental audit to solve the problem which aims at burning issue like environmental conservation. Also, further research is essential to carry out the sustainability of market condition.

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APPENDIX A

Expected Effluent BOD=100 mg/L

Expected Effluent SS= 200 mg/L

Flow of WW, Q= 0.0000021 m^3/s = 2.1 ml/s = 2.1 cc/s

Influent BOD, S_o= 619 mg/L

Here, K_s= 100 mg/L

k_d= 0.05 per d

μ_m= 2.5 per d

We know, soluble BOD, S= BOD allowed- BOD in suspended solids

= 100- (factor of biodegradable constituent * ultimate BOD) *200

= 100-(1.42*0.55*0.53)*200= 20 mg/l

Mean cell residence time

$\rightarrow S= \{K_s (1+ k_d *\theta_c)\}/ \{\theta_c (\mu_m - k_d) -1\}$

$\rightarrow \theta_c= 2.72 \approx 3$

$\rightarrow \theta_c$= 3 days

The microbial concentration, X= 2000 mg/L

$X= \{\theta_c * Y (S_o-S)\}/ \{\theta (1+ k_d* \theta_c)\}$

$\rightarrow \theta = \{\theta_c * Y (S_o-S)\}/ \{X (1+ k_d * \theta_c)\}$

$\rightarrow \theta$ = 0.13 days ≈ 4 hours

$\rightarrow \theta$ = 4 hours

We know, θ= V/Q

$\rightarrow$ 4 = V/ (0.0000021* 3600)

$\rightarrow$ V= 0.06 m^3

The F/M ratio = $QS_o/(VX)$ = 0.0000021m^3/s*619 mg/L/ (0.06 m^3*2000 mg/L)

= 0.93 mg/mg*d.

Here,

SVI= 150 taken from a chart (Design of Municipal Wastewater Treatment Plant, 1992)

X_r'= Return sludge VSS= 1000*1000/SVI (mg/g*mL/L)= 6666.67 mg/L

X_r= Wasting VSS= X_r'/ 1.43= 6666.67/1.43= X_w= 4662 mg/L

X'=Mixed Liquor Suspend Solid, MLSS= 1.43*MLVSS= 2860 mg/L

The wasting flow rate for sludge, Q_w= VX/ (θ_c* X_r) = (0.06* 2000)/ (3* 4662)

= 0.009 m^3/d = 0.1 cc/s

The return sludge flow rate, Q_r= [QX'-Q_w X_r'- (Q-Q_w) X_e]/ (X_r'-X')= 1.3 cc/s

The sludge production:

Y_{obs}= Observed yeild, kg VSS/kg BOD removed

= Y/ (1+k_d*θ_c) Y= 0.5

= 0.434 kg VSS/kg BOD removed

P_x = Net waste activated sludge produced each day in terms of VSS, kg/d

=Y_{obs} Q(S_o-S) (10^{-3} kg/g)

= 0.047 kg/d of VSS

Increase in MLSS= 1.43* P_x = 1.43* 0.047 = 0.07 kg/d

The mass of solids lost in effluent= (Q-Q_w) X_e= (2.1-0.1) *200

= 0.03 kg/d

The mass to be wasted= 0.07-0.03= 0.04 kg/d

The required amount of oxygen, M_{oxy}= [Q(S_o-S)/f] kg/g -1.42* P_x

= [0.0000021 (619-20)/ 0.68]- (1.42* 0.047)

= 0.0927 kg/d of oxygen

Air density= 1.185 kg/m^{-3}

Oxygen content in air=23.2% = 0.232

Efficiency= 10%= 0.1

The amount of air supplied at a 10% efficiency rate= M_{oxy}/ (Air density*0.232*0.1)

= 0.0927/ (1.185*0.232*0.1)

= 3.37 m^3/d