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Project Name:- Analysis of Textile ETP Technology and Environmental Policies for a Sustainable Future

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1.0 Abstract:

The work focuses on the implementation of textile industry effluent management, the current pollution scenario in Bangladesh caused by these effluents, and the proposed solution of installing an effluent treatment plant. Despite the presence of ETP equipment in almost all textile industries in Bangladesh, many factories do not operate them regularly because of high maintenance and operational costs (Haque et al., 2018; Rahman & Islam, 2020) [1]. Rapid industrialization has intensified environmental pollution through the discharge of untreated toxic waste (Islam et al., 2021) [2]. On the other hand, the increasing industrialization is contributing severe pollution to the environment by the toxic waste discharge. The liquid effluents from industries are causing major havoc to the environment, ecology, agriculture, aquaculture, and public health since the development of textile industries in the country. It had become a prerequisite to set up ETP in each industrial establishment, particularly at dyeing industries that were discharging immense amounts of liquid waste to the rivers every day. But, for the successful implementation of ETPs, industry owners will have to be socially responsible, and at the same time, the government should provide the factory owners with logistic support and a relaxed timeframe to set up ETPs.

2.0 Introduction:

Industrialization is a natural outcome of economic growth in a developing country. In the context of employment-focused industrialization, the textile industry holds a crucial position, providing significant opportunities for the economic development of Bangladesh. With the industrial development in Bangladesh, the waste management systems did not develop accordingly. Despite having ETP equipment, almost all industries are seen discharging their waste into water and on land without any treatment or after partial treatment. Of the environmental elements, water is the most affected, as the big industries are usually situated on the riverbanks, and due to the continuous receiving of the effluents, the toxicity of these river waters increases day by day. Environmental pollution caused by industries has now become a major concern for the country (Bhuiyan, M.A.H. et al., 2011). (Islam and Jolly, 2007) (Jolly and Islam, 2006) [3-5]. Major polluting industries such as textile and dyeing units, paint manufacturing, tanneries, oil refineries, chemical complexes, fish processing units, fertilizer factories, cement plants, soap and detergent units, and other light industries in Bangladesh directly release untreated toxic effluents into rivers (Jolly, Ph.D. thesis, 2011) [6]. Textile dyeing wastes contain unused or partially used organic compounds and high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD). It is a positive development that many industries are advancing in setting up and operating their own ETPs to meet national and international standards. This effort is also driven by increasing awareness among individuals about the harmful effects of industrial effluents.

2.1 Objectives:

- To find the implementation process of effluent treatment plants of textile industries.
- To find the chemicals used in ETP data.
- To find the capacity for effluent treatment.
- To find the effect of untreated water on the environment.

2.2 Pollution Scenario Due To Textile Effluent:

In Bangladesh, industrial establishments are customarily located in the vicinity of sources of water. A mixture of toxic elements-both organic and inorganic-flows into the water bodies from these industries mostly without any treatment. Therefore, industrial units discharge their untreated wastewater directly into rivers without considering the harm it is causing to the environment. Textile and dyeing industries generate wastewater as a byproduct of their manufacturing processes. This wastewater contains various pollutants from stages such as sizing, bleaching, mercerizing, fancy dyeing, screen printing, yarn dyeing, and finishing. The chemicals used in these industries include acrylonitrile, chlorinated phenols, salicylamides, organic mercury compounds, and copper ammonium carbonate. Organic matter in the wastewater lowers water quality because it uses up dissolved oxygen as it breaks down. Non-biodegradable organic substances stay in the water system for a long time and may find their way into the food chain. Inorganic pollutants mainly include metallic salts, basic or acidic compounds. These salts can create chemical changes and biochemical changes in river systems, hence deteriorating the quality of water. Per the knit dyeing process, in local textile industries, it is between 150 to 330 liters of wastewater per kilogram of fabric, while recommended as only up to 100 liters per kilogram by the Environmental Conservation Rules, 1997.[7]

The disposal of such large volumes of wastewater containing toxic substances poses a severe threat to ecosystems and aquatic life, as well as to irrigable land. These pollutants enter the food chain, resulting in declining fisheries and agricultural productivity. The pollution also leads to lower- quality fish yields. Textile industries also produce a great quantity of sulfates in their wastewater. In nature, these sulfates can transform into hydrogen sulfide, which is extremely poisonous as a gas. There is more than enough proof to show that the leftover textile dyes in wastewater can serve as respiratory irritants, and they do cause coughing and create irritation in the throat, besides giving symptoms akin to asthma. It should be noted that the wastewater from textiles contains much salt and other dissolved solids. Standard means of treating wastewater do not remove the salinity effectively. Therefore, whether

treated or untreated, its disposal into water systems significantly increases the salinity of the water. This free flow of untreated wastewater into the rivers greatly degrades water quality to an unacceptable level. It puts a larger menace on water supplies, human health, fisheries, and agriculture. The Government of Bangladesh working recently with United Nations Environment Programme (UNEP) has recently undertaken a comprehensive study of industrial pollution in greater Dhaka concerning six major industrial areas: Savar, Konabari, Tejgaon, Tongi, Hazaribagh, and Narayanganj (GOB & UNEP, 2021) [8].

3.0 Wastewater:

Water is no longer considered usable for a given operational purpose that is directly or indirectly discharged from the industry.



Fig. 1 Wastewater

3.1 High Pollutant Printing Sources Concentrations:

- Contains an assortment of various processing chemicals: pastes, urea, starches, gums, binders, acids, thickeners, alkalis, reducing agents, film-forming polymers, polyacrylates, mineral oils, APEO surfactants, isopropanol, melamine derivatives, among others
- Typically highly colored, with high BOD, oily appearance, and may contain heavy metals.
- It has high suspended solids, is slightly alkaline, and is generated in small volumes.

3.2 Wastewater Treatment Plant:

Effluent treatment systems are important in industries to clean up wastewater for recycling, thereby reducing reliance on freshwater or potable water. This not only saves the cost of acquiring water but also preserves the natural environment from contamination. By reusing wastewater, industries can comply with the set regulations concerning pollutant discharge and contribute toward a greater cause of environmental protection.

3.2.1 The Objectives of Wastewater Treatment Are:

- Such systems of effluent treatment should aim at the realization of high-quality water discharge into natural environments, with efficient removal of impurities at the lowest cost.
- Avoid and/or minimize other environmental impacts-odor creation, gas emission, and solid disposal.
- Produce treated water for reuse and recycling.

4.0 What is ETP?

ETPs are the mechanisms and procedures through which contaminated wastewater from various industrial or commercial activities is treated before being discharged into the environment or put to other beneficial uses. It is a fact that most of the effluents from industries contain all types of pollutants, which can be removed effectively through proper treatment.

4.1 Need for ETP:

- Effluent treatment systems are important in industries to clean up wastewater for recycling, thereby reducing reliance on freshwater or potable water.
- This not only saves the cost of acquiring water but also preserves the natural environment from contamination. By reusing wastewater, industries can comply with the set regulations concerning pollutant discharge and contribute to a greater cause of environmental protection.



4.2 Flow Chart For ETP:




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4.2.1 Screens:

- The first Screening is the initial step in the process at wastewater treatment plants. Its main purpose is to remove large items like rags, paper, plastic, and metal from wastewater. These objects can cause damage or blockage in the equipment, pipes, and other related structures that come after the screening stage. Many newer wastewater treatment facilities use two types of screens—coarse and fine screens. [9]
- Based on methods of cleaning, such as mechanical or manual.



Fig. 2 Screens

4.2.2 Effluent Inlet:

The effluent inlet in an Effluent Treatment Plant (ETP) is the point of entry for wastewater into the treatment system. It is typically designed to allow for a controlled and even distribution of effluent throughout the treatment process.



Fig. 3 Effluent inlet

4.2.3 Primary Screen:

The primary screen is the first stage of solid removal in the treatment process. It prevents particles and dirt from the collection sump tank whose size is above 10 mm.



Fig. 4 Primary screen

4.2.4 Automatic Rotary Bar Screen:

The machine in ETPs removes solid waste (2–10 mm) from wastewater using a rotating screen. It lets water pass, catches solids, and cleans itself to keep the water flowing smoothly.



Fig. 5 Automatic rotary bar

4.2.5 Equalization Tank:

An ETP has a tank that stores incoming wastewater to balance flow and pollution levels. It helps keep the treatment process steady and consistent. [10]

4.2.5.1 Capacity:

- Maintain retention hours of about 15.6 hours. (tank volume/flow rate). A coarse (dies/tube) type diffuser is used by this tank.

4.2.5.2 Testing Parameters:

- PH, TDS, DO, TSS, BOD, COD, Temperature, IN, TP.

4.2.5.3 Working Principle:

1. Flow Balancing: Equalizes variable inflow rates to provide consistent flow to downstream treatment units.



Fig. 6 Equalization tank

2. Load Equalization: Reduces fluctuations in pollutant concentrations (e.g., BOD, COD, pH).
3. Mixing: Mechanical or air mixing keeps solids suspended and prevents settling.
4. Storage: Temporarily store excess wastewater during peak flow times.
5. Aeration (optional): May include aeration to prevent odors and maintain aerobic conditions.
6. PH Adjustment: Allows time for chemical dosing for pH neutralization if needed.

4.2.6 Neutralization Tank:

- A neutralization tank is a dedicated unit designed to adjust the pH level of acidic or alkaline wastewater. A neutralization tank is used to provide treatment to highly acidic or highly alkaline effluent through neutralizing pH by the addition of chemicals. The raw effluent from the storage tank will have an alkaline pH & be neutralized by auto-dosing 98% H_2SO_4 . Industry requires neutralization of discharged effluent when it has highly acidic and/or highly alkaline effluent. A pH of 7 indicates a neutral state, neither acid nor alkaline; above 7 is considered alkaline, and below 7 is acidic. A good range for the stream is a pH within a range of 6-9, & the operator must see that.
- These standards are met. Alkaline effluent is neutralized by sulfuric acid or CO_2 or waste boiler flue gas. This tank is also used for lifting units. [11]



Fig. 7 Neutralization tank

4.2.7 Anaerobic Digestion:

Anaerobic digestion is a biological process to break down organic matter in wastewater in the absence of oxygen. It involves the use of anaerobic bacteria that decompose organic compounds, such as sewage sludge or organic industrial waste, to produce biogas and nutrient-rich digestate. The process occurs in an oxygen-free environment, typically in an anaerobic digester, where the bacteria convert organic material into methane and carbon dioxide gases. [12]



Fig. 8 Anaerobic digestion

4.2.7.1 Working Principle:

1. **Influent entry (bottom):**
 - Wastewater enters from the floor of the reactor and flows upward.
2. **Sludge blanket formation:**
 - Inside the reactor, a dense blanket of anaerobic sludge (biomass) forms and stays suspended.
3. **Biological degradation:**
 - Anaerobic microorganisms digest organic matter, producing biogas (mainly methane + CO_2).
4. **Three-phase separation:**
 - A gas-solid-liquid separator at the top divides:
 - Gas (collected for energy).
 - Solids (returned to the sludge blanket).
 - Treated effluent (discharged or further treated).
5. **Settling zone:**
 - The upper zone allows solids to settle back to the sludge blanket, maintaining system stability.

4.2.8 Anoxic Tank:

Anoxic tanks play a role in the biological upgrade of surface-removing nitrogen compounds from the wastewater in an atmosphere that would be free of oxygen to support denitrification bacteria. This bacteria transforms nitrate and nitrite to nitrogen gas which eventually reduces the overall nitrogen content in the effluent. Reduced nitrogenous content means less pollution when treated water is disposed of into the environment. [13]



Fig. 9 Anoxic tank

4.2.8.1 Working Principle:

1. **Nitrogen Removal (via nitrification-denitrification):**
 - Nitrification: (NH_4^+) Ammonia $\rightarrow (\text{NO}_2^-)$ Nitrite $\rightarrow (\text{NO}_3^-)$ Nitrate by aerobic bacteria.
 - Denitrification: (NO_3^-) Nitrate $\rightarrow (\text{N}_2)$ Nitrogen gas by Anaerobic Bacteria $\rightarrow$ released to the atmosphere.
2. **Phosphorus Removal:**
 - Biological: Phosphate-Accumulating Organisms (PAOs) absorb Phosphorus in alternating anaerobic and aerobic zones.
 - Chemical: Adding chemicals like alum or ferric chloride to Precipitate Phosphorus.

4.2.9 Spray Pond:

A spray pond sprays wastewater into the air. This helps it mix with oxygen, some water evaporates, and the water becomes cleaner and cooler.



Fig. 10 Spray Pond

4.2.10 Disinfection Drain:

Disinfection drain cleans the treated water before it goes into the environment. It uses chemicals or UV light to kill harmful microorganisms.

4.2.11 Distribution Tank:

A distribution tank as a responsible for collecting wastewater from the neutralization tank and return sludge tanks and distributing treated water for various purposes. It acts as a reservoir for the treated effluent before it is supplied to different usage points.



Fig. 11 Distribution tank

4.2.12 Biological Oxidation/aeration Tank:

An oxidation tank facilitates the removal of organic pollutants from wastewater. It creates an oxygen-rich environment where aerobic bacteria break down the color of water and control COD, BOD, TSS, and TDS present in the effluent. This process promotes the oxidation and decomposition of pollutants, resulting in cleaner water that is environmentally safer before further treatment or discharge.[14]



Fig. 12 Biological oxidation

4.2.12.1 Function of This Tank Is Given Below:

- Raw influent + Activated Sludge + Oxygen + Nutrient Micro-organism + SO_2 + CO_2 + NO_3

4.2.12.2 Purpose of Aeration:

- Increasing dissolved oxygen.
- Removing unwanted gases and volatile organic compounds.
- Enhancing biological treatment.

4.2.12.3 Key Monitoring Points:

- pH value in different locations.
- The activated sludge is a bacterial mass formed by several types of microorganisms that grow attached to organic and inorganic particles.
- To survive with bacteria, we must maintain an environment like temperature (29 to 32°C). pH (7.5 to 8.0), DO (1.5-2.5 ppm), & adequate retention hours.
- Flocculation of the bacterial cells (flock-forming bacteria) leads to the formation of small aggregates, which also include inorganic particles.
- Flocculation is made possible by the production of the bacteria of a viscous extracellular matter that works as a binding agent (this is called micro-structure). The microstructure tends to be round-shaped.
- Fine type (9" disc) of diffuser used by this tank to survive bacteria by attraction.
- Urea/DAP dosing will be done for the growth of bacteria; this growth of bacteria will help to increase the biomass in the aeration tank.
- The aeration tank is for a food to microorganisms (F/M) ratio of 0.15 and mixed liquor suspended solids (MLSS) concentration of 4000 mg/l.

4.2.13 Secondary Clarifier/ Sedimentation:

- A secondary clarifier assists in the separation of suspended solids from the treated wastewater. It receives effluent from the biological treatment process and allows the settled solids, known as sludge, to settle at the bottom of the clarifier. The clarified water is then discharged or further processed for advanced treatment, while the sludge is collected and sent for sludge management or dewatering processes. [15]
- The purpose thereof being to clarify the water at the end of said oxidation tank, in such a way that allows



Fig. 13 Secondary clarifier/ Sedimentation

for sedimentation of the activated sludge on the bottom of said tank and its subsequent recycle. The water and sludge admixture from the oxidation tank are introduced into the middle part of sedimentation tank through a dedicated pipe. As the accessional speed is low in the sedimentation tank, biological sludge flocs will be separated from water and controlled to gather at its bottom. Clear water that is free of suspended solids exits from the top of the sedimentation tank through overflow weirs.

- Activated sludge is separated by a laminar plate & taken in the centered bottom hole by scraping blades. Laminar plate used by lamella clarifier (LC) at 60 angles.
- Treated water is going to be in the post-aeration tank, cross the V-notch weir, & then be discharged. The solid portion goes to the distribution tank submersible pump with gravitational force.

4.2.13.1 Key Monitoring Points:

- Sludge blanket depth level (2-3) ft for thickening, 3ft for buffer zone & 8ft for clarification typically. To monitor the thickness of the sludge blanket to avoid washing out of solids from the clarifier.
- The return sludge: flow rate should be adjusted to maintain the sludge blanket as low as possible.
- Floating solids on the clarifier surface are an indication of a problem called "rising sludge," which occurs when the DO (Dissolved Oxygen) concentration in the secondary clarifier drops, resulting in an anoxic condition.
- V-notch weir: A weir is a level-maintained structure (often v-notched) in a final clarifier used to provide a uniform effluent flow. Clarifier weirs should be inspected daily for:
 - Level weirs even flow uniformly across the weirs.
 - Algae plugging v-notches.
 - Condition of the weirs.
 - Effluent quality and quantity.

4.2.13.2 Coagulation:

- Coagulation is the process of conversion of finely dispersed colloids into a small flock with the addition of coagulants.
- Coagulation can either be followed by the process of settling or flotation.

4.2.13.3 Flocculation:

- Flocculation serves to join coagulated particles together by mechanically creating a velocity gradient within a liquid.
- Organic polyelectrolyte flocculation aids are good for enhancing soluble solids removal.
- Flocculation enhances the removal of finely divided solids by gravity settling.

4.2.13.4 Detractors/Scrapers:

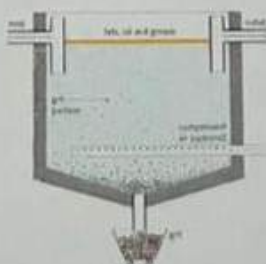
- Detractors are shallow circular ponds used in pre-treatment plants for grit removal.
- Chain- or blade-type detractors/scrapers are used in an adjacent channel into which the collected grit is transferred.
- Used when the soft and sticky substance sticks to fixed bars and cannot get through the screen. Grits with a 6 mm diameter are removed in the detractor.

4.2.13.5 Grit Chamber:

A grit chamber is principally designed for the removal of inert inorganic material, mainly sand, gravel, and other heavy solid particles that are denser than the organic solids in wastewater. It protects against damage to pumps, pipes, and other equipment by preventing settling in pipe bends and channels. The removed material is collected from the chamber and utilized for landfilling, road making, and on the sludge drying beds.

4.2.13.5.1 Major Objectives:

- Protection of pumps, valves, piping, etc.
- Minimizing the chances of pipe choking with inorganic inert material.
- Pre-prevention of grit occupies space in primary and biological treatment units.




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4.2.13.5.2 Working Principle of Grit Chamber:

A grit chamber works by the process of sedimentation. Wastewater slows down when it enters the chamber, hence heavier particles (grit) have time to settle at the bottom by gravity. The settled grit is then collected and removed from the chamber while the rest of the wastewater, now free from grit, continues to flow to the next steps of treatment. The efficiency of a grit chamber in removing grit largely depends on several factors, such as the size and density of the grit particles, the velocity at which wastewater passes through the chamber, and most importantly the structure and design of the chamber. [16]



Fig. 14 Grit chamber

4.2.14 Return Sludge Tank:

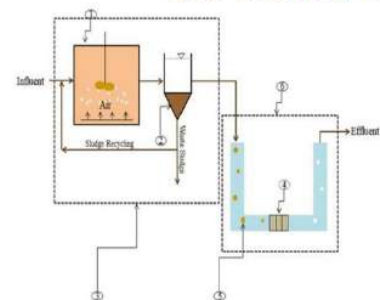
A return sludge tank collects a portion of the treated sludge from the secondary clarifier and returns it to the aeration tank or activated sludge process for reseeded. The return sludge reintroduces active microorganisms, aiding in the breakdown of organic matter and ensuring efficiency and stability of the treatment process.



Fig. 15 Return sludge tank

4.2.15 Sludge Recycle Tank:

- Sludge recirculation is very important for plant operation. It works 24 hours a day and is needed to extract sludge settled on the decanter floor to put it back in the aeration tank.
- Usually, this operation is made by means of submersible pumps at low speed (to avoid breaking the sludge floc) with a specific dosing of impeller that avoids the obstruction.
- It is very important to monitor the levels of solids in these recycled streams to avoid the buildup of excessive levels of inert solids in the secondary treatment system.

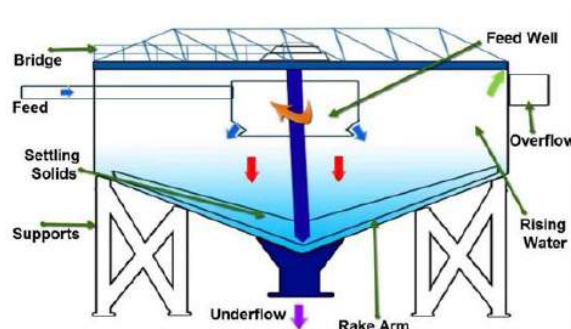


4.2.16 Sludge Thickener Tank:

A sludge thickener tank is a specialized tank used in wastewater treatment to increase the solids concentration in sludge, essentially removing excess water and reducing its volume. This process prepares the sludge for subsequent treatment steps like digestion or dewatering. It permits the dry substance to increase from 1% to a max. of 3%. The decanted water returns inside the biological plant. The thickened sludge is extracted by means of a screw press to improve the dry content to 25%.



Fig. 16 Sludge Thickener



4.2.16.1 Objectives:

- Reducing volume.
- Gain 5-10% solid content.

- Improved Digestion.
- Easier Dewatering.
- Environmental Benefits.

4.2.17 Screw Press Sludge Dehydrator:

Herein dewatering of the wet sludge is carried out & excess water is carried to the collection sump tank.

4.2.17.1 Objectives:

- Reducing sludge volume
- Reducing operational costs.
- Gain 35% solid content
- Environmental Benefits
- Methods: Screw press.
- Capacity: 10kgs/hour.
- Achieve 20-30% solid content.

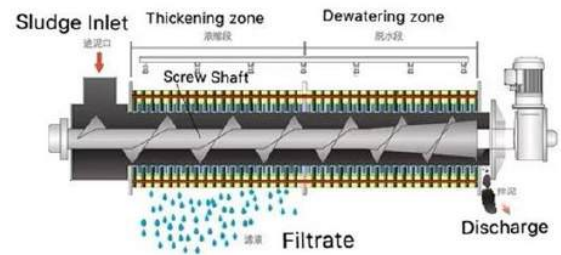


Fig. 17 Screw press Sludge

4.2.18 Sludge Drying Bed:

A sludge drying bed is a simple and cost-effective method for dewatering sludge by using natural evaporation and gravity drainage. It involves spreading a thin layer of digested sludge on a porous bed, typically made of layers of sand and gravel, and allowing it to dry naturally over time.

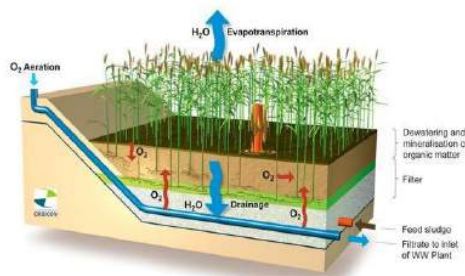


Fig. 18 Sludge Treatment Reed

4.2.18.1 Objectives:

- Reduction of volume.
- Easy to transport and operate.
- Healthy product.
- Achieving dry content up to 60-90% is possible.

4.2.18.2 Working Principle:

- **Sedimentation tank**
 - Sludge from sedimentation tanks (e.g., primary or secondary clarifiers) is pumped onto the drying bed.
 - The bed is typically a shallow, sand-filled basin over a layer of gravel and a drainage system.
- **Drainage:**
 - Free water drains downward by gravity through the sand and gravel layers.
 - Perforated underdrains collect and carry away this filtrate, which can be returned to the treatment plant.
- **Evaporation:**
 - Evaporation. Surface water will evaporate due to the effect of sunshine and winds. A great proportion of the water can be taken off, especially under hot, dry climatic conditions.
- **Drying:**
 - Over a period of several days (typically between 7 to 15 days), sludge becomes drier and more solid. Sludge, when dried, attains a solids content of between 20 to 40 percent depending on the conditions.

- **Sludge Removal:**

- After drying, the sludge is taken off the bed either by hand or machine. It can be thrown away, burned, turned into compost, or used as a fertilizer based on what it contains and the rules that apply.

4.2.19 Sludge Storeroom:

A sludge storeroom is a word often used for the place, usually a tank or room, in a wastewater treatment plant or similar facility where sludge-which is actually a mixture of solids and liquids-is kept temporarily before further processing or disposal.



Fig. 19 Sludge storeroom

4.2.19.1 Benefits Of This Process:

- Some wastewater treatment facilities use a slightly varied process known as flotation thickening. This process utilizes gravitational forces in a different set of mechanics.
- Flotation thickeners utilize pressurized air pumps that aerate the sludge mixture. Once the air mixes into the solution of sludge, air bubbles attach themselves to the biosolids. Then, they carry the sludge upward where a scraper removes the waste.

4.2.19.2 Sludge Storing Criteria:

1. Here, the dry sludge is stored for 3-6 months.
2. Storage location best practices.
 - In shade/under cover.
 - Without contact with water or agricultural land.
 - Protected from rain and flooding.
 - Without access for non-authorized people and animals.
 - Proper labeling of the storage container.

4.2.20 Sludge Dumping Area:

A sludge dumping area, also known as a sludge landfill or surface disposal site, is a designated area where sludge, a semi-fluid mass of sediment resulting from wastewater treatment, is disposed of. These areas are often found at wastewater treatment plants or designated sites for final sludge disposal. After six months of storage, the dry sludge is dumped here with proper documentation.



Fig. 20 Sludge dumping

4.2.21 Holding Tank:

A holding tank serves as a temporary storage reservoir for incoming wastewater from the secondary clarifier before it undergoes treatment. It helps regulate the flow rate and volume of wastewater entering the treatment plant.



4.2.22 Multigrade Filter:

A multigrade filter is used for the filtration of suspended particles from wastewater. It consists of multiple layers of different sizes. media, such as stone, to remove TSS. As the wastewater flows through the filter, the media layers trap and remove suspended solids, ensuring the effluent meets the required quality standards before further treatment or discharge.



Fig. 21 Multigrade filter

4.2.22.1 Trickling Filter Treatment:

Wastewater is sprayed through a rotating sprinkling arm on circular beds made of coarse media (of crushed stones, gravels, or synthetic material) that are 3–10 feet deep in the trickling filter treatment process. A layer of microorganisms known as zoogloal film is created when they adhere to and proliferate on the media. Millions of microorganisms in this zoogloal film convert the organic material in the effluent into simple, soluble matter. After being drained at the bottom, treated wastewater is collected and goes through sedimentation (SST).

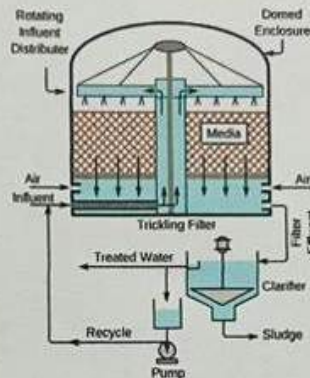


Fig. 22 Trickling filter

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4.2.22.1.2 Working Principle:

Primary treated wastewater is sprinkled over a bed of media (like rocks or plastic).

- **Media Support:** The bed supports aerobic microbial biofilm that grows on the surface of the media.
- **Biological Treatment:** As the wastewater trickles down, microorganisms break down organic matter.
- **Aeration:** Air flows naturally (or by forced ventilation) to provide oxygen for aerobic activity.
- **Effluent Collection:** Treated water is collected at the bottom and usually sent to a secondary clarifier.
- **Sloughing:** Excess biofilm sloughs off and is removed in the clarifier.

4.2.22.2 Activated Carbon Filters:[17]

The filtered water from the Multigrade sand filter flows through the activated carbon filter, which is also a vertical pressure vessel. It includes a perforated plate with polystyrene strainers at the bottom and top, as well as perforated brass strainers. Between these strainers is the filter media, consisting of 900 to 1000 mm activated carbon granules placed over a layer of graded gravel.

In the activated carbon filter, any odor and to some degree color in the wastewater is absorbed by the carbon, resulting in filter water that is exceptionally clear.

- The backwashing for both the activated carbon filter and the sand filter will be performed twice daily, and the water generated during this process will be recycled back into the collection tank.
- The filter media from the activated carbon filter and the sand filter will be tightly packed and then sold to another party.

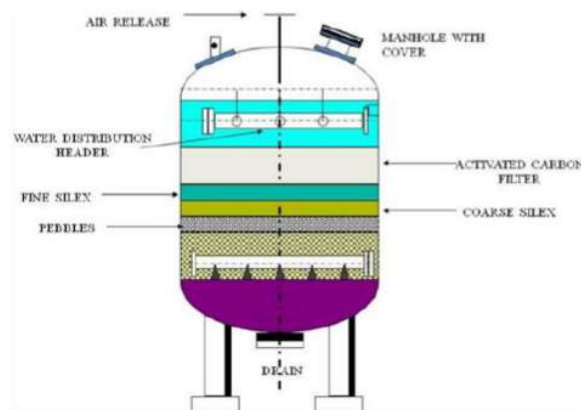


Fig. 23 activated carbon filters

4.2.22.3 UP-flow Anaerobic Sludge Blanket Reactor (UASP):

- Raw effluent is introduced from the bottom of the reactor and flows upward through a sludge blanket composed of biologically formed particles.
- Treated effluent rises to the top along with generated biogas in the form of small bubbles. Treated effluent is collected through overflow weirs, and biogas is collected through gas collection domes from the top.
- The separated solids fall back through the baffle system on top, which allows them to settle down in the sludge blanket.

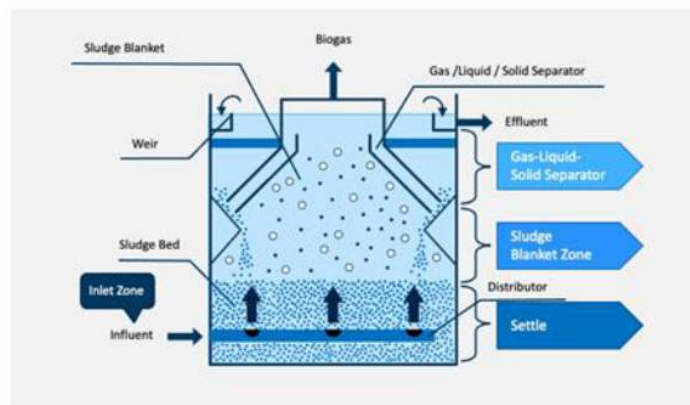


Fig. 24 UP-flow Anaerobic Sludge Blanket Reactor (UASP)

4.2.22.3 Sand Filter:

A sand filter is a water treatment system that uses a bed of sand to remove suspended solids and other impurities from water. It works by passing water through the sand, where particles are trapped due to the sand's porous structure. Sand filters are mostly used for various applications, including swimming pools, industrial methods, and drinking water treatment.

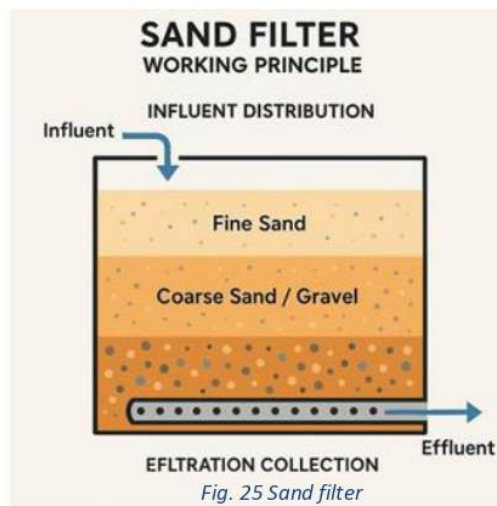
4.2.22.3.1 Working Principle:

1. Influent distribution:

- Wastewater (proportioned to take out the larger solids) is distributed equally at the top of the sand bed.

2. Filtration layers:

- Water moves down vertically through the sand. Typical layers include:-
 - ✓ Top fine sand: This layer helps in trapping small particles.
 - ✓ Coarse sand/gravel layer: It supports the filtration bed and also helps in easy drainage.
- Physical Filtration:- Suspended solids get trapped mechanically in the pores between the sand grains. Big pieces get stuck at the top, while small pieces go further in.
- Biological Action (mostly in slow sand filters): - A living layer builds up on top of the sand. It has tiny life forms that break down organic stuff and germs, helping to clean the water.



2. Effluent collection:

- Clean water exits through a drainage system at the bottom, often through collecting pipes.

4.2.23 Outlet Flow Meter:

4.2.23.1 Purpose: Measures the flow rate of treated effluent leaving the plant so that environmental compliance can be achieved, and process control maintained.

4.2.23.2 Common Types:

1. Electromagnetic.
 2. Ultrasonic flow meters.
- **Electromagnetic Flow Meter:**
 - It depended on Faraday's Law of Electromagnetic Induction.
 - As conductive water passes through a magnetic field imposed by the meter, it will induce a voltage proportional to velocity.
 - **Ultrasonic Flow Meter:**
 - Waves of sound above human hearing bouncing through moving water.
 - Measures the difference in transit time or Doppler shift to derive the velocity of flow.
 - ✓ **Output:** Provides a continuous digital/analog signal to SCADA or monitoring systems for recording flow in such units as m³/h or L/s.



Fig. 26 Outlet Flow Meter

4.2.24 Post Aeration Tank:

A post-aeration tank provides additional oxygen to the treated wastewater to maintain dissolved oxygen (DO) before it is discharged. The post-aeration tank helps to minimize the biological oxygen demand (BOD) and ensure the effluent meets regulatory requirements for oxygen content, thereby safeguarding the receiving water body. Lastly, water goes to the Water.



Fig. 27 Post aeration tank

4.2.25 Water Reclamation Plant (WRP):

Wastewater treatment is define to the process of restoring water that has been used by human activity or natural sources to a level of quality that is acceptable. This can be achieved through various processes, including chemical, biological, or physical processes. Water can be treated to meet different standards of purity depending on its intended purpose, such as supporting aquatic eco-systems, providing safe drinking water.[18]

4.2.25 Main Stages of WRP Process:

1. Pre-treatment (Screening & Grit Removal):

- Removes large solids, plastics, grit, and oils.

2. Primary treatment:

- Settling tanks remove suspended solids and some organic matter.

3. Secondary treatment (biological process):

- Microorganisms (aerobic/anaerobic) degrade organic pollutants.
- Removes BOD, COD, and nutrients.

4. Tertiary treatment (advanced treatment):

- Filtration (sand, membrane, activated carbon).
- Removes TDS, color, phosphate, ammonium, nitrates.

5. Disinfection:

- Chlorination, UV, or ozone to kill pathogens.

6. Reuse / Discharge:

- Treated water reused for agriculture, cooling, industrial process, or released safely to rivers.

4.2.25.1 Key Benefits:

- Reduces pollution load in rivers.
- Provides alternative water sources.
- Protect environment and public health.
- Meets regulatory discharge standards.

5.00 Effluent Parameter:

Parameter	Full Form / Meaning	Key Point	Effect on Water Quality
BOD	Biochemical Oxygen Demand	Oxygen is needed by microbes to decompose organic matter	High BOD = high pollution, low oxygen for fish
COD	Chemical Oxygen Demand	Oxygen is needed to chemically oxidize pollutants	High COD = polluted water
TDS	Total Dissolved Solids	Dissolved salts, minerals, metals	Affects taste, hardness, and conductivity



TSS	Total Suspended Solids	Undissolved particles (silt, clay, organic matter)	High TSS = turbidity, blocks sunlight
DO	Dissolved Oxygen	Oxygen present in water	Low DO = aquatic life stressed or dead
Phosphate	Nutrient (PO_4^{3-})	Needed for growth of plants & algae	Excess = eutrophication (algal bloom)
Ammonium Nitrate	(NH_4NO_3) Nitrogen compound	Comes from fertilizer, sewage	Excess = pollution, algal growth
Color	Appearance of water	Caused by organics, metals, waste	Indicates contamination
Temperature	Heat level of water	Affects DO solubility & aquatic metabolism	High temp = low DO, stress to organisms

6.0 Recommended Standard Level of Discharge Water:

Parameter	Value
PH	6-9
BOD	< 30 mg/l
COD	< 150 mg/l
TDS	< 2100 mg/l
TSS	< 50 mg/l
DO	4.5-8 mg/l
Phosphate	-
Ammonium nitrate	< 10 mg/l
Color	< 150 (according to Pt.Co)
Temperature	(Ambient temperature $\pm$ 15) °C


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**7.0 Characteristics of Discharge Water (Inlet & Outlet):**

SQUARE FASHIONS LIMITED
Industrial Environment Management (IEM) Laboratory

F-IEM-LAB01
Revision No: 10

Effluent Analysis Report

Sample Location : ETP, SFL, Bhaluka, Mymensingh
Sample : ETP Raw & Treated Water
Sample Received Date : 06.07.2025
Type of plant : Anoxic and Aerobic Treatment Process
Lab Sample ID : Review Paper-1

Date of Testing: 06.07.2025 to 11.07.2025

Sample Name: Raw Effluent (Homogenized Tank)

Parameter	Unit	Result	Test Method
Raw Effluent Flow Rate	m ³ /hr	-	-
Colour	APHA	200	APHA 8025 (Platinum-Cobalt)
PH at 35 °C	-	11.00	4500-H+B, Electrometric (pH meter)
Temperature	°C	-	2550B, Thermometric
Phosphate, PO ₄ ³⁻	mg/l	-	Spectrophotometer (Molybdovanadate)
Ammonia, NH ₃ -N	mg/l	-	8038 USEPA Nessler Method
Nitrate, NO ₃ -N	mg/l	-	8039 USEPA Cadmium Reduction Method
Nitrite, NO ₂ -N	mg/l	-	8507 USEPA Diazotization Method
Total Suspended Solid (TSS)	mg/l	60.0	2540D Standard Method
Total Dissolved Solid (TDS)	mg/l	2500.0	2540D, Electric Conductivity
Dissolved Oxygen (DO)	mg/l	8.64	4500-C C. Azide Modification Method
BOD ₅	mg/l	371.0	10099 Respirometric Method

Sample Name: Oxidation Tank

Parameter	Unit	Result	Operational Standard	Test Method
Effluent, pH at 30±2 °C	-	10	6.5 to 8.5	4500-H+B, Electrometric (pH meter)
Sludge Quantity (Wet)	mg/l	-	-	2540 F, Settleable solids
DO	mg/l	8	2.0 to 4.0	4500-C C. Azide Modification Method
MLSS	mg/l	-	3000 to 3500	2540 D TSS (Inside Oxidation Tank)
SVI	mg/l	-	100 to 150	2710 D. Sludge Volume Index



Sample Name: Treated Effluent (Clarifier Tank Outlet)

Parameter	Unit	Result	Standard		ZDHC Standard			Meet with ZDHC Value	Test Method
			BSR	DoE of GoB	Foundational	Progressive	Aspirational		
Temperature	°C	32	37	≤37	Max 35	Max 30	Max 25		2550B, Thermometric
PH at 31.2 °C	-	7.66	6 to 9	6 to 9	6 to 9	6 to 9	6 to 9	Aspirational	4500-H+B, Electrometric (pH meter)
Colour	APH A/Pt Co	145	-	-	-	-	-		APHA 8025 (Platinum-Cobalt)
Colour (456nm,525nm,620nm)	m ⁻¹	-	-	-	7;5;3	5;3;2	1;1;1		Spectrophotometer (Molybdovanadate)
Phosphate, PO ₄ ³⁻	mg/l	-	-	-					8038 USEPA Nessler Method
Ammonia, NH ₃ -N	mg/l	-	-	≤ 5	10	1	0.5		8039 USEPA Cadmium Reduction Method
Nitrate, NO ₃ -N	mg/l	-	-	≤ 10	-	-	-		8507 USEPA Diazotization Method
Nitrite, NO ₂ -N	mg/l	-	-	-	-	-	-		10248 SulfaVer 4 Method
Sulphate, SO ₄ ²⁻	mg/l	-	-	-	-	-	-		8021 USEPA DPD
Chlorine, Cl ₂	mg/l	-	-	-	-	-	-		4500-B Mercuric Thiocyanate Method
Chloride, Cl ⁻	mg/l	-	-	≤ 600	-	-	-		2540D Standard method
Total Suspended Solid (TSS)	mg/l	13.0	30	≤ 100	50	15	5	Progressive	2540D, Electric Conductivity
Total Dissolved Solid (TDS)	mg/l	1520.0	-	-	-	-	-		4500-C C. Azide Modification Method
Dissolved Oxygen (DO)	mg/l	11.52	-	-	-	-	-		8000 USEPA Reactor Digestion Method
COD	mg/l	119.0	200	≤ 200	150	80	40	Foundational	10099 Respirometric Method
BOD ₅	mg/l	19.0	30	≤ 30	30	10	5	Foundational	2550B, Thermometric

Note: Water temperature of canal is 32

Ref. for Standard:

BIS – Bureau of Indian Standards
DoE – Department of Environment
GoB – Govt. of Bangladesh

Shrining
10-07-2015

Sr. Executive, IEM, SFL

8.0 Methodology:

8.1 Colour APHA 8025 (Platinum-Cobalt) Methods:

The APHA 8025 method, also known as the Platinum-Cobalt (Pt-Co) method, is a standardized procedure for measuring the true and apparent color of water, wastewater, and seawater. This method is mostly used in environmental and industrial laboratories to assess the quality of clear to yellowish liquids. [19]

8.1.1 Method:

- **True color:** Decided by filtering the sample to remove suspended particles.
- **Apparent color:** Measured using unfiltered samples, including both dissolved and suspended materials.

The color is measured in Platinum-Cobalt Units from 0 to 500 (distinctly yellow) based upon dilutions of a 500-ppm platinum-cobalt solution, as defined by ASTM D1209.

8.1.2 Procedure:

1. Sample preparation:

- For true color: Filter to remove suspended solids.
- For apparent color: Use the unfiltered sample.

2. Blank calibration:

- A sample cell should be filled with 25 mL of filtered deionized water-for true color-or unfiltered deionized water-for apparent color-and then used to calibrate the colorimeter as a blank.

3. Sample measurement:

- Fill a second sample cell with 25 ml of the prepared sample.
- Insert the sample cell into the colorimeter and record the Pt-Co value.

4. Accuracy check:

- Use a standard solution (e.g., 250 Pt-Co units) to verify the instrument's accuracy. [19]

8.2 Total Suspended Solids (TSS) – Standard Method 2540 D:

8.2.1 Total Suspended Solids (TSS) – SM 2540d: [20]

8.2.1.1 Principle:

TSS is determined by filtering a known volume of water or wastewater through a pre-weighed glass-fiber filter, drying the filter with residue at 103–105°C, and re-weighing. The increase in weight represents the suspended solids retained.

8.2.1.2 Procedure:

1. Pre-weigh a clean, dried filter (W_1).
2. Filter the measured volume of the sample.
3. Dry the filter and residue at 103–105°C until constant weight.
4. Cool it in a desiccator and weigh again (W_2).
5. Calculate TSS:

$$\text{TSS (mg/L)} = \frac{(W_2 - W_1) \times 1000}{\text{Sample volume (mL)}}$$



Fig. 28 spectrophotometer
(Color, TSS, TDS)



8.2.2 Electrical Conductivity (EC) – SM 2510B:

8.2.2.1 Principle:

Conductivity is defined as the capacity of water to carry an electric current. Therefore, higher ion focuses in water will support better conductivity. It is measured using a conductivity meter and its probe.

8.2.2.2 Procedure:

- ✓ Standardize the conductivity meter with a KCl solution of known concentration.
- ✓ Wash the electrode with deionized water.
- ✓ Place the probe in the water sample.
- ✓ Read and record the conductivity values as $\mu\text{S}/\text{cm}$ (temperature compensated).

8.3 Total Dissolved Solid (TDS) 4500-C Azide Modification Method: [21]

The 4500-O C Azide modification is a standard method used for the determination of DO in water, wastewater, and effluent samples. It becomes important to use the azide modification when interfering materials, such as nitrite or ferrous iron, are present in the sample that would normally interfere with the regular iodometric titration method.

8.3.1 Azide Modification Method:

8.3.1.1 TDS (Total Dissolved Solids) 4500-C Azide Modification Method:

- Glass-fiber filter paper ($0.45 \mu\text{m}$).
- Filtration apparatus (vacuum or pressure).
- Evaporating dishes (pre-weighed).
- Drying oven ($103\text{--}105^\circ\text{C}$).
- Desiccator with desiccant.
- Analytical balance (sensitivity $\pm 0.001 \text{ g}$)
- Graduated cylinders / pipettes.
- Beakers and sample containers.
- Tongs / forceps (for handling hot dishes).

The azide modification is an improvement of the original Winkler method by way of adding sodium azide to the sample; hence, interference due to nitrite ions is substantially curtailed. Under normal conditions, these would have reacted with iodide and free iodine, thus causing much interference in the determination. The steps are detailed as follows:

1. **With manganous sulfate:** Manganous sulfate is added. Manganous ions will react with the dissolved combined oxygen in the alkaline medium to form a precipitate of manganese oxide hydroxide.
2. **With Addition of sodium azide and potassium iodide:** Sodium azide, and potassium iodide are added as reagents to it. Azide will suppress interference by nitrite and iodide will react with manganese precipitate, thereby freeing iodine.
3. **Acidification:** The sample is acidified with sulfuric acid, so that the iodine is reduced to iodide
4. **Titration:** The liberated iodine is titrated with standard sodium thiosulfate solution using starch indicator to determine the endpoint.

This method is applicable for samples containing nitrite concentrations greater than $50 \mu\text{g}/\text{L}$ and ferrous iron concentrations up to $1 \text{ mg}/\text{L}$. It is widely used in environmental monitoring and water quality assessments.

8.4 COD (Chemical Oxygen Demand) 10099 Respiro Metric Method:

8.4.1 The Equipment List In Points For COD 10099 Respiro Metric Method:

- Respiro metric COD analyzer (e.g., OxiTop® system).
- Sealed Respiro metric bottles/vials.
- Incubator ($20 \pm 1^\circ\text{C}$).
- Pressure or gas sensors (integrated in analyzer).
- Magnetic stirrer (for mixing samples)
- Pipettes and graduated cylinders.
- Calibration standards (e.g., potassium hydrogen phthalate).
- Cleaning supplies (distilled water, brushes, detergent).

8.4.2 Working Principle:

1. Wash culture tube and caps with 20% H_2SO_4 before first use to prevent contamination.
2. Refer to table 5220:1 for proper sample and reagent volume.



3. Place the sample in a culture tube and digestion solution.
4. Carefully run the sulfuric acid reagent down inside of the vessel.
5. Tightly cap tubes and invert each several times to mix completely.
6. Place tubes in block digester. Preheated to 150°C and relaxed for 2 hours behind a protective shield.
7. Cool the vessel to room temperature and place it in the test tube rack.
8. Remove culture tube caps and add small TEF-covered magnetic stirring bars.
9. If culture tubes and ampules are used, transfer contents to a large container for titrating.
10. Add 0.05 to 0.10 ml (1 to 2 drops) of Ferrion Indicators in Stir rapidly on magnetic stirrers while titrating with standardized 0.10M FAS.
11. The endpoint is a sharp color change from blue-green to reddish brown.
12. Calculation:

$$\text{COD as Mg O}_2/\text{L} = \frac{(A-B) \times M \times 8000}{\text{ML Sample}}$$

Where,

A = M_L FAS used for blank-DM

B = M_L FAS used for the Sample

M = Molarity of FAS and,

8000 = (Milliequivalent weight of Oxygen) × 1000 ml divided by L

FAS means- (Ferrous Ammonium Sulfate) [(NH₄)₂Fe(SO₄)₂·6H₂O]

8.4.2.1 Table: 5220: I Sample and Reagent Quantities for Various Digestion Vessels.

Digestion vessel (mm)	Sample (ml)	Digestion solution (ml)	Sulfuric acid reagent (ml)	Total volume (ml)
16x100	2.5	1.5	3.5	7.5
20x150	5.0	3.0	7.0	15.0
25x150	10.0	6.0	14.0	30.0
Standard 10 mm ampule	2.5	1.5	3.5	7.5

8.5 Overview of USEPA Method 8000 (Reactor Digestion Method): [22]

The USEPA Method 8000 is a colorimetric procedure for determining Chemical Oxygen Demand (COD) in water, wastewater, and seawater using a closed reflux digestion method. This method is widely used for regulatory reporting and environmental monitoring.

8.5.1 Equipment:

- Block heater set to 150°C.
- Commercially supplied digestion vials with pre-mixed reagents.
- Hach Spectrophotometer (e.g., DR 3900, DR 3800, DR 2800, DR 2700).
- Class A volumetric pipette.

8.5.2 Reagent Ranges:

- Low Range (LR): 3–150 mg/l
- High Range (HR): 20–1500 mg/l
- High Range Plus (HR+): 200–15,000 mg/l

8.5.3 Principle:

Samples are digested at 150°C for 2 hours with a strong oxidizing agent, potassium dichromate (K₂Cr₂O₇), in sulfuric acid. In this manner, oxidizable organic compounds reduce the dichromate ion (Cr₂O₇²⁻) to green chromic ion (Cr³⁺), and the remaining Cr₆⁺ is measured calorimetrically.

**8.5.3.1 Procedure:**

- Prepare the sample by homogenizing if necessary.
- Add 2 mL of the sample to the appropriate digestion flask.
- Place the flask in the preheated block heater at 150°C for 2 hours.
- Allow the flask to cool to approximately 120°C.
- Invert the flask several times to mix.
- Measure the absorbance using the Hach Spectrophotometer at the specified wavelength (e.g., 420 nm for LR or 620 nm for HR).

8.6 BOD₅ 2550B, Thermometric Method:**8.6.1 Equipment list in points only for BOD₅ Thermometric Method (APHA 2550B):**

- Thermometric BOD analyzer.
- Incubator (20 ± 1 °C).
- Sealed sample bottles/vials.
- Thermometric probes/sensors
- Pipettes and graduated cylinders.
- Nutrient solutions & seed culture (if required).
- Calibration standards (Glucose-Glutamic Acid solution).
- Magnetic stirrer/shaker (optional).
- Thermometers.
- Cleaning supplies (bottle brushes, distilled water, detergent).

8.6.2 Working principle:

- The sample's pH must be adjusted to be between 6.5 and 8.0.
- Note on the right: To reduce pH, Sulfuric Acid (H₂SO₄) must be used, and to increase pH, Caustic Soda (NaOH) must be used.
- The sample volume must be taken (30 units).
- If taking readings from the incubator daily, an attempt must be made to add the chemical.
- If the sample's pH is correct, take 300 ml of the sample in a BOD bottle.
- Add the BOD kit (Nutrient).
- Add a certain amount of Hydroxide (5-6 drops) to the seal/neck of the BOD bottle.
- Seal it onto the BOD tracker and turn it on.
- Select the sample by pressing... (The sentence is incomplete on the chart).
- Press the "Off" button to start it.
- After that, press all the buttons and then exit. When it reaches three, press OK.
- The analyzer measures the temperature change over a 5-day period.
- Calculate the BOD₅ based on the observed temperature change.

$$\text{BOD}_5 (\text{mg/L O}_2) = K \times \Delta T$$

Where:

- ΔT / ΔT = Temperature rise in the sealed bottle (°C) after 5 days
- KKK = Calibration constant (mg O₂/L per °C), determined experimentally using a standard solution of known BOD₅ (often **glucose-glutamic acid standard = 198 mg/L**)

9.0 Biological Treatment in Textile ETP – Process Description: [23-24]**1. Screening:**

- Removes large solids (rags, fibers, plastics) to protect pumps and downstream equipment.

2. Grit chamber:

Allows sand, grit, and heavy inorganic particles to settle, preventing abrasion and blockages in pumps and pipes.

3. Equalization tank:

- Balances flow, load, and pH variations to ensure steady conditions for subsequent treatment. Mixing prevents solids settling and odors.

4. Coagulation–Flocculation: Chemicals (e.g., alum, ferric salts, PAC) are added to destabilize colloids and



color; flocs form and settle easily.

5. **Primary clarifier:**

- Settling tank where suspended solids and chemical flocs are removed. Reduces TSS and some BOD.

6. **Aeration tank (biological reactor):** ASP / MBBR / SBR / MBR) [25]

- ✓ Microorganisms degrade organic matter.
- ✓ ASP (Activated Sludge Process): Suspended microbes oxidize BOD.
- ✓ MBBR (Moving Bed Biofilm Reactor): Biofilm carriers improve efficiency.
- ✓ SBR (Sequencing Batch Reactor): Fill-and-draw system for flexible operation.
- ✓ MBR (Membrane Bioreactor): Put together biological treatment with membrane filtration for high quality effluent.

7. **Secondary clarifier:**

- Separates biomass (activated sludge or detached biofilm) from treated water. A portion of sludge is recycled; excess goes to sludge handling.

8. **Treated effluent:**

- Effluent leaving the biological stage is significantly reduced in BOD, COD, and nutrients.

9. **Tertiary Treatment (if needed):** [26]

- Polishing stage to meet strict standards: sand/activated carbon filtration, UV/chlorination, or Advanced Oxidation (Ozone, Fenton).

10. **Discharge / reuse:**

- Treated water is discharged to the environment and reused in processes (washing, dyeing, cooling).

11. **Sludge Handling** → Thickening → Dewatering → Disposal

- Thickening: Concentrates sludge.
- Dewatering: Reduces water content (filter press, centrifuge).
- Disposal: Landfill, compost, or incineration depending on regulations.

10.0 Advanced Oxidation Textile ETP Process:

The Advanced oxidation has proven to be one of the most efficient processes in the treatment of textile effluent regarding degradation of refractory organic pollutants. It basically consists of the generation of hydroxyl radicals (OH) by different methods such as ozonation, UV irradiation, and Fenton's reagent among others, which very aggressively break down contaminants into simple, less hazardous substances.

10.1 AOP-Based Textile ETP Process Flow: [27-28]

AOP-Based Textile ETP Process Flow:

Pre-treatment:

Screening → Equalization → Neutralization → Coagulation/Flocculation

- **Primary treatment:**
Sedimentation → Removal of large solids
- **Secondary treatment:**
Biological Treatment (e.g., Activated Sludge Process) → Reduction of BOD and COD
- **Tertiary treatment (aop stage):**
AOP (e.g., Ozone, UV/H₂O₂, Fenton's Reagent) → Degradation of residual organic pollutants
- **Post-treatment:**
Filtration → Reverse Osmosis (optional) → Final Discharge or Reuse

11.0 Difference Between Biological, Chemical and Advanced Oxidation:

Parameter	Biological	Chemical	Advanced Oxidation
Target pollutants	Biodegradable organics (BOD, some COD)	Color, TSS, heavy metals	Recalcitrant dyes, toxic organics, micropollutants
Efficiency	BOD > 90%, COD 60–80%	Color > 80%, COD ~50–70%	COD > 80–90%, Color > 90%
Sludge	Biological sludge (can be stabilized/used)	High chemical sludge	Minimal
Cost	Low–moderate	Moderate	High
Operational complexity	Medium (biological expertise)	Low–medium (chemical dosing)	High (UV, ozone, catalysts)
Best used for	Large volumes with biodegradable load	Quick TSS & color removal	Toxic & non-biodegradable compounds

12.0 Choosing The Best Method:

12.1 Biological Treatment:

- Best for: **High BOD/COD, biodegradable organics** (starch, sizing agents, natural fibers).
- Advantages: Low cost, eco-friendly, proven technology.
- Limitation: **Not effective alone** for synthetic dyes, toxic chemicals, or high-salt wastewater.
- **Best when** → textile effluent has **high organic load but moderate dye/chemical pollution**.

12.2 Chemical Treatment:

- Best for: Color, turbidity, suspended solids, heavy metals.
- Advantages: Fast, easy operation.
- Limitation: Produces large sludge volume, higher recurring cost.
- Best when → effluent needs quick color removal and TSS reduction before discharge or biological treatment.

12.3 Advanced Oxidation (AOPs):

- Best for: Recalcitrant dyes, toxic organics, non-biodegradable pollutants.
- Advantages: Very high COD/color removal produces biodegradable intermediates.
- Limitation: Expensive (energy + chemicals), not ideal for full-scale primary treatment.
- Best when → effluent contains synthetic dyes, persistent organic pollutants, or needs tertiary polishing to meet strict standards.

13.0 Best Overall Method: Hybrid/Integrated Approach: [29]

The hybrid (integrated) approach you described is widely considered among the best “practical optimum” strategies for textile effluent treatment (ETP). The literature generally supports a multi-stage / hybrid scheme combining physical-chemical, biological, and advanced (oxidation / membranes / adsorption) units. Below is a refined, referenced version of your text plus some caveats and design tips.

13.1 Best Overall Method: Hybrid / Integrated Approach:

No single method is perfect. The globally accepted best practice in textile effluent treatment is a combined (hybrid) treatment system:

- **Primary (physical–chemical) stage:**
 - Coagulation / flocculation, neutralization, sedimentation / clarification.
 - Purpose: remove suspended solids, colloids, color carriers, and adjust pH.
 - Typical removal: much of total suspended solids (TSS), some color and metals.
- **Secondary (biological) stage:**
 - Options: ASP (Activated Sludge Process), MBBR (Moving Bed Biofilm Reactor Membrane), Bioreactor (MBR), or other biological reactors.
 - Purpose: degrade biodegradable organics (BOD / COD), remove nutrients.
 - Achievable reduction: large fraction (often 60–90 %) of biodegradable load.
- **Tertiary / polishing stage:**
 - Advanced Oxidation Processes (AOPs: Ozonation, Fenton, UV/H₂O₂, etc.), membranes (nanofiltration, reverse osmosis), adsorption (activated carbon, resins), or combinations.
 - Purpose: degrade recalcitrant dyes / organics, remove residual color / micropollutants, ensure regulatory compliance.
 - Helps push final effluent quality to high standards.

It can achieve very high removal efficiencies (e.g., COD > 90%, color > 90–95%) at a lower overall cost than if full-scale AOPs were used alone. It balances energy and reagent consumption with operational complexity and reliability. The combination of physical, chemical, biological, and advanced processes is the only flexible strategy that can be used effectively in treating complex textile wastewater streams. [29]

13.2 Why the Hybrid Approach Works Better:

- **Synergy & Complementarity:** Each stage targets different fractions of the load. Physical-chemical handles coarse solids and colloids, biological degrades the bulk biodegradable organics, and tertiary treats what’s left (e.g., non-biodegradable dyes, trace organics).
- **Cost Optimization:** A series-connection of AOPs or membranes on the complete untreated effluent would be infeasibly costly (in reagents, energy and membrane fouling), the load of these advanced units becomes less if they are placed after primary/secondary stages.
- **Flexibility & Robustness:** Adjustable to different wastewater characteristics (dye loads, salt concentration, pH fluctuations) common in textile plants. An energy-efficient, hybrid-system design permits bypass, modular add-ons, redundancy or switch-modes based on any load influent strength.
- **Regulatory compliance & water reuse:** Most standards require very low residuals (color, COD, toxicity)



in the effluent. High purity is required for reuse (within the plant itself)-hybrid gives more margin.

- **Resource Recovery / ZLD (Zero Liquid Discharge):** The stages that hybrids help facilitate include membrane concentration, salt recovery, and chemical recycling, which therefore make closed-loop ("zero discharge") schemes more feasible.[30]

13.3 Design Optimization — Hybrid/Integrated Textile ETP: [31]

✓ Pretreatment and source segregation:

- Proper pretreatment, and source segregation remove large solids, oil, and grit before main treatment ensure less wear and tear on the equipment and reduces the load in subsequent units.
- High pollutant streams such as dyeing rinse, wash waters, etc., if segregated, only these need to be given full treatment.

✓ Apply organic & low-chemical processes:

- E.g., UASB (anaerobic) + bio-filtration rather than heavy chemical treatment.
- Save chemical cost and sludge handling cost.
- An experiment done at Dalas Fashion Ltd & Liz Fashion Ltd, Gazipur, Bangladesh, infers that the installation of UASB + bio-filtration removes about 94-98% COD/BOD with much lower yearly costs compared to chemical ETP.

✓ Chemical Dosing Optimization:

- Carry out frequent jar-tests to make sure of the minimum chemical dose that is required.
- Avoid overdoses, which is costly and increase the sludge.

✓ Measures of energy efficiency:

- Use efficient blowers, pumps, diffusers.
- Variable frequency drives (VFD), or automatic control to use less energy when loads are low.
- Shared/central ETPs for multiple factories.
- Small & medium factories sharing one good quality plant.
- Shared cost, better economies of scale.

Install monitoring & regular maintenance:

- Flow, pH, COD/BOD sensors at critical locations so that problems can be identified in better time.
- Cleaning, maintenance carried out regularly to prevent inefficiencies (such as blocked pipes, fouled membranes, etc.) [31]

13.4 Caveats, Challenges & Design Considerations:

- **Inter-stage matching:** The design must ensure that primary and secondary stages reduce load sufficiently, so the tertiary unit is not overloaded. Poor matching may lead to AOPs or membranes failing or being uneconomical.
- **Sludge handling:** The sludge is usually created during the primary and biological steps, and you've got to think about in.
- **Fouling / scaling in membranes:** Pre-treatment is critical to reduce fouling (suspended solids, colloids, organics).
- **Operational complexity:** More stages → more controls, instrumentation, maintenance.
- **Cost vs benefit tradeoff:** Sometimes, for lower-strength effluents, simpler systems (just primary + biological) may suffice. The extra cost of tertiary needs justification (e.g. strict discharge limits, reuse needs).
- **Chemical dosing, pH control, reaction kinetics:** These need optimization especially in the primary and AOP stages.
- **Salt / salinity issues:** Many textile effluents are saline; biological processes can be sensitive to salinity, and membranes must be chosen accordingly.
- **Energy & carbon footprint:** AOPs and membranes are energy-intensive; balance sustainability.

14.0 What is ZLD?

ZLD (Zero Liquid Discharge) is a wastewater treatment strategy in which no liquid effluent is discharged from the facility. All wastewater is treated so that water is recovered (for reuse), and only solid waste (salts, concentrated brine, other residues) is disposed of or further processed. The goal is maximal water reuse, minimal waste, and minimal environmental discharge. [32]


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14.1 Zero Liquid Discharge (ZLD) process:

Stage	Purpose / What is Removed / What Happens	Common technologies
Pre-treatment Equalization	Balance flow, pH, temperature; remove large suspended solids; reduce shock loads; protect downstream units	Screening, sedimentation, primary clarifiers, equalization tanks, coarse filters
Primary biological treatment	Remove biodegradable organics (BOD, COD), nutrients; reduce microbial load; reduce overall pollutant load so the advanced steps are less stressed	Activated Sludge, MBBR, Sequencing Batch Reactors (SBR), anaerobic treatment in some cases
Tertiary treatment polishing	Remove dissolved solids, salts, color, recalcitrant organics; prepare water to reuse / potable or process water quality	Ultrafiltration (UF), Reverse Osmosis (RO), Nanofiltration, advanced oxidation (AOPs), adsorption, etc.
Concentration evaporation	Concentrate the RO reject / brine; reduce volume of liquid waste; recover water by thermal methods; convert dissolved solids to solid form	Multiple-Effect Evaporators (MEE), Mechanical Vapor Recompression (MVR), thermal crystallizers, evaporators, etc.
Solid waste / salt recovery	Solidify, treat, dispose of or reuse salts / crystallized solids; possible recovery of chemicals, salts (e.g., bleaching salts, alkali, etc.)	Crystallization units, solid drying, incineration (if necessary), sales of by-products, etc.

14.2 Challenges:

- High energy consumption, especially in evaporators/thermal concentration units.
- High CAPEX (capital cost) and maintenance costs.
- Solid waste disposal/management becomes more significant (salts, brine sludge).
- Fouling, scaling, and corrosion issues in membranes and concentration units.
- Need for reliable power, skilled operation & maintenance.

14.3 ZLD in Bangladesh:

- **Status & feasibility:**
 - Here is what current sources say about Bangladesh's ability to adopt ZLD and what the challenges/opportunities are.
- **Evidence/pilot projects in Bangladesh:**
 - The SMEP program (Sustainable Manufacturing and Environmental Pollution) is funding a pilot ZLD program in Bangladesh's textile sector, in partnership with Kingsley Engineering, Stone Capital, Lenn Tech, etc. The pilot aims to purify and reuse up to 95% of textile wastewater.
 - The pilot includes innovations such as efficient pretreatment using electrocoagulation, multiple RO stages, and advanced evaporation/crystallization for RO reject waters.
 - It discusses reuse of ETP effluent after treated by UF+RO. It presents technical performance and economic costs for reuse. Advanced membrane reuse is technically possible here but with cost implications.
- **Regulatory & environmental drivers:**
 - ETPs is a requirement of the Department of Environment (DoE) in Bangladesh. The standards are being set for effluent discharge. Increasing pressure on reducing environmental pollution, groundwater, surface water, health risk, etc.
 - Water scarcity /groundwater depletion problem many factories consume huge amounts of groundwater. Reuse/recycling (enabled by ZLD) reduces freshwater dependence.

14.3.1 Challenges In Bangladesh:

- **Power Supply & Energy Costs:** Zero liquid (ZLD) discharge normally involves adopting several energy-consuming processes (for instance, evaporation and crystallization). The major challenges in Bangladesh are energy cost, availability, and reliability. A study revealed that if sufficient energy (gas or grid power) is not made available, ZLD fully across most of the textile facilities would not be attainable.
- **Technical Capacity & Infrastructure:** Present facilities in most existing industries have say they have conventional ETP but do not possess full ZLD systems. Upgrading to install advanced ZLD systems and their operation and maintenance does require technical know-how investment and skilled operators.
- **Cost & economics:** High capital cost, operating costs (especially for energy), and uncertain returns (e.g.,

market for recovered salts, cost savings) slow down adoption. Also, incentive structures are still evolving.

- **Regulation enforcement & monitoring:** Even with new regulations, consistent enforcement and monitoring are sometimes weak. Also, while legal frameworks exist or are being updated, translating them into on-the-ground compliance (especially for smaller factories) is a challenge.

14.3.2 ZLD Possible & Effective in Bangladesh? [33]

Putting together the above, ZLD is possible in Bangladesh, but with caveats. It will not be trivial and likely will be more feasible initially for larger factories or industrial clusters under certain conditions.

Conditions for feasible, effective ZLD in Bangladesh,

1. **Adequate pretreatment:** High removal of suspended solids, color, oils, etc., before RO/evaporation to reduce load and protect expensive equipment.
2. Stable supply & pricing of energy, or access to cheaper/renewable energy to reduce operating cost. It is possible to integrate the use of waste heat or cogeneration.
3. **Financial incentives / support:** Subsidies, low-interest financing, shared community costs, or regulatory incentives to offset high CAPEX.
4. **Economies of scale / shared infrastructure:** Clustering factories to share central ZLD plants or shared services could reduce per-unit cost.
5. **Strong regulatory frameworks & enforcement:** To ensure discharge limits push for ZLD or high reuse, to provide certainty and drive investment.
6. **Market/brand demand:** Foreign buyers demanding more sustainable practices may provide a premium or willingness to pay for products made under ZLD compliance.
7. **Technology innovation/cost declines:** Advances in membrane technology, energy efficiency, evaporation methods, etc., can reduce costs over time.

15.0 Effects of Untreated Wastewater on Rivers and Agricultural Land: [34-35]

Untreated or inadequately treated wastewater contains a mix of organic matter, nutrients (Nitrogen and Phosphorus), pathogens, heavy metals, salts, micro-pollutants (like antibiotics and industrial chemicals), and suspended solids. When it is discharged into rivers or used (directly or indirectly) for irrigation of agricultural land, there are multiple harmful effects.

1. River impacts:

- Eutrophication and algal blooms:
 - High levels of nitrogen and phosphorus from wastewater stimulate excessive growth of algae. When algae die, their decomposition consumes dissolved oxygen (DO), causing hypoxia (low oxygen) or even anoxia (zero oxygen) in the water.
 - Algal blooms may also produce cyanotoxins harmful to aquatic life, animals, and humans.
- Depletion of Dissolved Oxygen (DO); Increased BOD and COD:
 - Organic matter in untreated wastewater is decomposed by bacteria, which consume oxygen (raise Biological Oxygen Demand, BOD). High BOD lowers DO, harming fish and other aerobic aquatic organisms.
 - Chemical Oxygen Demand (COD) also rises, affecting water quality.
- Loss of biodiversity:
 - Fish, macroinvertebrates, aquatic plants, and other species are sensitive to low oxygen, toxic substances, or altered habitat conditions. Species that cannot tolerate pollution die off; ecosystem structure is disturbed.
- Toxicity and bioaccumulation:
 - Heavy metals such as cadmium, lead, chromium, and mercury, among others, do not easily break down. They stay in sediments and the flesh of aquatic organisms. After ingestion by fish accumulation occurs within their bodies then up the food chain onto predators and ultimately humans who consume the fish.
- Pathogens and human health risks:
 - Raw sewage bears bacteria, viruses, and parasites. If it does not enter the drinking water stream but enters any river used for bathing or fishing as well, then diseases such as cholera and dysentery including hepatitis can be contracted.
- Physical & chemical water quality alteration:
 - Solid matter makes more turbidity adds reduced penetration of light. Quality water gets lower by salinity, pH changes, and heavy metals.
- Economic and social impacts:
 - Fishery goes down. Recreation potential (swimming, boating) goes down. Toxic fish mean ruined livelihoods. The upstream/downstream community gets hit with a loss of clean water plus treatment costs, plus medical expenses.

2. Agricultural / crop land impacts: [36]

- **Soil contamination and degradation:**
 - Soil structure contains heavy metals (Pb, Cd, Cr, Ni, etc.) from un-treated wastewater which slowly builds up in the soil. It can change soil structure and makes it less fertile killing the organisms within the soil. Salts build up in soils irrigated with salty wastewater; unproductive soils result from osmotic stress conditions; reduced water availability.
- **Pathogen transfer & health risks:**
 - Pathogens, bacterial, viral and parasitic may be in crops if irrigated with untreated wastewater. If these are consumed in the raw or undercooked state, they transmit diseases to humans.
- **Food safety & crop quality:**
 - Uptake of heavy metals by plants, which may accumulate in edible parts, affecting food safety.
 - Yield reduction due to phytotoxicity (toxins, salts, excess chemical load). Some crops sensitive to heavy metal or salt stress will show stunted growth or lower productivity.
- **Groundwater & soil water contamination:**
 - Percolation of contaminated water (with nitrates, heavy metals, and salts) into groundwater aquifers, affecting drinking water quality.
- **Long-term soil health & productivity loss:**
 - Over time, soil microbiota (beneficial bacteria and fungi) may be harmed, reducing nutrient cycling. Soil physical properties (structure, porosity) may be altered by salts or heavy metals. This leads to longer-term loss of fertility and potential desertification or land abandonment.

16.0 How Properly Treated Effluent Improves Fish Reproduction & Agricultural Productivity:

When ETP is used correctly and wastewater is treated to a good standard, there are several beneficial effects for aquatic life (including fish reproduction) and for agriculture. These positive effects depend on treatment quality, monitoring, dilution, and matching the treated water quality to the needs of the ecosystem or crop.

1. Benefits for fish & aquatic life (including reproduction): [37]

- **Reduction of toxicity:** Effluent treated carries a very much reduced amount of chemicals, dyes, heavy metals, and pathogens as compared to untreated wastewater. Lower stress means less damage to organs (gills, liver, and gonads) and better general health. Studies indicate fish exposed to textile effluent treated microbially have significantly reduced histological damages, compounds.
- **Better levels of oxygen:** With a reduced organic load and good biodegradation of waste, less oxygen will never be used up in decomposition. Conditions of higher dissolved oxygen (DO) will support normal metabolic activity therefore requiring DO for gamete formation and spawning behavior as well as eggs and larvae.
- **Better offspring:** With reduced stressors (heavy metals, endocrine-disrupting substances) fish are able to manifest normal reproductive cycles, fertility, proper sex differentiation, and embryo survival. While some studies have indicated that certain pollutants even after the effluent has been treated continue to disrupt reproduction, the damage is less compared to untreated effluent.
- **Habitat recovery:** Cleaner water makes for better habitat substrate. Healthy ecosystems help with breeding by providing places for fish to spawn, offering cover for young fish, and ensuring there is food available.

2. Benefits for agriculture: [38]

- **Nutrient supply:** Treated effluent contains residual N, P, K, micronutrients, & organic matter. This work in the manner of a fertilizer reducing the amount of synthetic fertilizer input needed. Wastewater crop yields were substantially above yields from crops irrigated with treated waste. Barley yield increased by about 54% under treated wastewater irrigation relative to freshwater in an arid/semi-arid region.
- **Improved soil fertility & structure:** Organic matter in treated effluent improves soil texture by making the earth more friable and able to hold more moisture at the same time increasing the



microbial activity of the soil. Better root development, drought resistance and consistent crop growth are the results.

- **Water savings:** Treated effluent used for irrigation saves freshwater supplies. In areas where water is not abundant or there is a rainfall deficit, this makes more freshwater available for drinking, maintaining the environment, & many other uses.
- **Cost savings:** There will be less expenditure on chemical fertilizer; lower freshwater procurement costs; possibly reduced cost of wastewater discharge or regulatory penalties.

3. Conditions/requirements for these benefits to be realized: [38]

- To ensure treated effluent actually brings these benefits (rather than risks), certain conditions must be met:
 - Sufficient treatment: Treatment sufficiency Secondary treatment, removal of all harmful chemicals, pathogens, heavy metals, color, etc. If treatment is low, residual pollutants can affect both fish reproduction as well as crops.
 - Monitoring & Control: Correlative surveillance of water quality (BOD, COD, heavy metals, salts, pathogens, endocrine disruptors) to guarantee it is at a safe level. Regulatory standards should be used to define the levels..
 - Dilution / mixing: In some conditions, treated effluent is mixed with freshwater. This helps in reducing any remaining toxicity as well as the salinity of the water making it compatible for aquatic life or certain crops.
 - Appropriate use: Matching treated water to the use (e.g., which crops are tolerant of certain salinity or chemical levels, which fish species are sensitive). Also avoid using edible parts of crops when Chemical residues are present unless proven safe.
 - Soil & habitat management: Proper soil drainage to avoid salt build-up; maintaining habitat structure for aquatic life; controlling other stressors (e.g., overfishing, habitat loss).

17.0 ETP Cost vs Environmental Damage Cost:

- **Installation & operational costs:**
 - According to a World Bank report, installing individual ETPs for medium to large textile factories in Dhaka typically costs US\$1-3 million (capital cost), and the operating cost is about Tk 9-10 per cubic meter (for treating wastewater).
 - For Centralized ETPs (CETPs) shared among ~40 factories, capital cost can be around US\$40 million, but operating cost drops (economies of scale) to $\approx$ Tk 5-6 per m³.
- **Environmental damage costs:**
 - Factories discharging untreated or poorly treated effluent incur fines, health damage, and ecosystem degradation. The operating cost of an ETP ($\approx$ Tk 13,350,000 BDT annually for a dyeing factory) is much higher than average fines ($\approx$ Tk 1,965,000) for non-compliance, making paying fines often cheaper than operating an ETP well.
 - Also, loss of ecosystem services (clean water, fisheries, crop yields) and public health costs (waterborne diseases) are not always quantified in factory accounts but impose large costs on communities and governments.
- **Comparison & implications:**
 - When comparing, the true cost of not having proper ETP often exceeds the cost of installing & operating an ETP—especially when considering long-term environmental, health, agricultural, and social losses.
 - However, in many small or medium factories, immediate cash flow, technical capacity, and regulatory enforcement are weak, so decision-makers often underestimate environmental damage or assume it's not their responsibility.

18.0 Low-Cost ETP Models for Small & Medium Textile Factories:

1. Anaerobic treatment first:

- Use of UASB (upflow anaerobic sludge blanket) or hybrid anaerobic reactors (e.g., HUASB) to reduce BOD/COD before downstream aerobic or physical/chemical treatment. Bangladesh researchers have tested hybrid UASB with textile wastewater.

2. Co-digestion & sludge recycling:

- Using local substrates (cow dung, sawdust, sewage sludge) to co-digest textile sludge to produce biogas and reduce pollutant load. This helps offset energy/operational costs.

3. Simplified physical/chemical processes:

- Use of coarse screening, oil & grease traps, sedimentation, and low-dose coagulation/flocculation can reduce solids and color with lower CAPEX.

4. Shared/centralized etps (cetps):

- A group of small factories share one facility; economies of scale lower CAPEX/OPEX per unit volume. The World Bank report cited earlier mentions savings when ~40 factories share a CETP.

5. Operational efficiency & optimization:

- Train local operators, use simple automation or monitoring, schedule maintenance, optimize chemical dosing, and reduce energy usage. These reduce OPEX noticeably.

19.0 Waste to Energy: Sludge / Biogas Potential: [39]

There is growing evidence that textile sludge and wastewater organic content can be used to generate useful energy, which helps offset costs of ETPs.

- Anaerobic co-digestion of ETP sludge: A study found that co-digesting textile sludge with sewage sludge or other organic sources under mesophilic conditions ($\approx 37^{\circ}\text{C}$) can achieve high biogas yields, with COD or BOD reductions in the range of ~ 33 - 88.5% and ~ 48 - 67.1% , depending on the substrate mix.
- Energy potential in Dhaka area: An aggregation analysis of 100 textile factories in Greater Dhaka estimates that anaerobic stabilization of their wastewater could generate $\approx 185,538$ kWh/day, or ~ 7.7 MW of power, which corresponds to lost revenue of $\sim$ Taka 512 million ($\sim$ US\$6.6 million) per year if not used.
- Pilot low-scale biogas from sludge: Lab-scale work (e.g., Southeast University) showed that textile sludge mixed with cow dung, etc., under anaerobic digestion, can generate biogas even with relatively small sludge amounts.

20.0 Conclusion:

One of the greatest environmental challenges in Bangladesh has been the issue of treating textile effluents since the textile sector is the lifeline of the industrial economy of the country. The findings from this study show that random release of untreated or inadequately treated textile effluents seriously contaminates river and soil, disrupts aquatic biodiversity, lowers agricultural productivity, and poses high health risks to populations. The very high values of BOD, COD, TSS, TDS color, and toxic dyes existing in industrial wastewater necessitated the installation of proper treatment technologies in each textile industry.

The project is proof that the ETP plays a very significant role in pollution minimization by removing hazardous wastes through an organized sequence of physical, chemical, and biological treatments. Major steps in treatment—including screening, equalization, neutralization, anaerobic and aerobic digestion, oxidation, clarification, sludge management, and tertiary filtration—are described to explain how each unit operation contributes toward purification of wastewater. The laboratory has proved that after treatment, the pH value as well as BODs, COD, TSS, and color are within permissible limits set by DoE and ZDHC standards. If the ETPs operate successfully, this water can be reused inside the factory or can be safely disposed of; hence, dependency on fresh water sources reduces and promotes sustainability.

Also brought out is the fact that in any combination of physical-chemical, biological, and advanced oxidation processes (AOP), hybridization or integration proves to be the best method for the treatment of textile wastewater. In this way, high efficiency in pollutant removal (color and COD up to 90-95%) with low sludge generation and operational cost optimization can be realized. If applied as a tertiary treatment stage, AOP efficiently decomposes persistent dyes and toxic organics that cannot be removed by biological treatment. This hybrid system can realize the long-term fulfillment of environmental quality discharge standards for effluent.

It also found major problems with ETP implementation all over Bangladesh. Many large sectors do not feel eager to set up or run ETPs because of high capital investment, and some do so due to operational complexity, energy consumption, or the unavailability of trained personnel. The government should make an incentive policy and provide low-interest loans and technical training, besides increasing the monitoring service by enforcing the penalty system for non-compliance. Shared or centralized ETPs are also a feasible solution for small industries in groups since they cut costs and ensure proper management.

Over time, joining ETPs with ZLD can turn the textile industry into a circular water economy. ZLD does not only recycle up to 95% of wastewater for reuse but also helps in getting salts and some by-products, which add value, hence supporting the concept of waste-to-resource conversion. However, it requires high energy to attain full ZLD as well as advanced technology and strong industrial commitment.

The treatment of textile effluents through scientifically designed ETP is not just a regulatory obligation but an integral part of sustainable industrial development and environmental protection, because only then can there be true sustainability in hybrid ETP systems that effectively reduce the ecological footprint of the textile industry in Bangladesh. Hybrid ETP systems supported by strong government policies, corporate social responsibility, and public awareness—cleaner rivers for safe agricultural production and improved aquatic life in a healthier ecosystem—are what such support means. The investment turns into that which leads toward a green, sustainable,



globally competitive textile industry in Bangladesh because this type of investment becomes a pathway to such an industry.

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