American Journal of Environment and Climate (AJEC)

ISSN: 2832-403X (ONLINE)

VOLUME 5 ISSUE 1 (2026)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Environment and Climate (AJEC)

Volume 5 Issue 1, Year 2026
ISSN: 2832-403X (Online)
DOI: https://doi.org/10.54536/ajec.v5i1.6301
https://journals.e-palli.com/home/index.php/ajec

Zero-Discharge Strategies for Sustainable Wastewater Management: A Case Review of a 300 MW Oil-Fired Power Plant in Bangladesh

Md. Ariful Islam[1*], Md. Abu Sayeed[2], Shahidullah[3], Md. A. Quium Sarkar[4]

Article Information

Received: July 25, 2025

Accepted: December 01, 2025

Published: March 30, 2026

Keywords

Effluent Treatment Plant, Environmental Sustainability, Pollution Control, Power Plant, Water Treatment Plant, Zero Discharge Plan

ABSTRACT

Crude oil-fired power plants generate significant volumes of wastewater containing oily residues, chemical contaminants, and domestic effluents, posing serious environmental risks if discharged untreated. This study explores the implementation of a Zero Discharge Plan (ZDP) at the Summit Gazipur II Power Plant in Bangladesh aiming to eliminate liquid waste discharge through comprehensive treatment and reuse strategies. The research outlines a multi-stage Effluent Treatment Plant (ETP) process incorporating physicochemical separation, activated sludge treatment, and advanced filtration systems including multi-grade filters, carbon filters, and reverse osmosis (RO) units. Wastewater sources such as engine lubrication systems, cleaning operations, and other facilities were analyzed for key pollutants including Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Oil and Grease etc. The treated water was successfully used for different purposes of cleaning, gardening other non-potable applications, aligning with 3R/4R principles and Department of Environment (DoE) regulations. To run this power plant, engine (Generator) and boiler require demineralized (DM) water for cooling and generating stream consecutively. Water treatment plant produces DM (demineralized) water and rejects 40% mineralized water which generally contains no pollutants. This study shows the proper strategy plant for reusing this rejected water as part of resource efficiency and no discharge to water bodies. The findings demonstrate that ZDP not only ensures regulatory compliance but also contributes to environmental sustainability and resource efficiency in power generation. This model offers a replicable framework for other industrial facilities seeking to minimize ecological footprints through integrated wastewater management.

INTRODUCTION

It's one of the most discussed topics around the world, environmental conservation. Climate change caused by persistent environmental destruction poses a danger to, among other things, the existence of life on earth (Sadulaeva, 2023). Environmentalists around the globe have long sought to draw the attention of world leaders to these and other time-sensitive environmental crises (Damoah et al., 2023). The Stockholm Conference on the Human Environment in 1972 was one of the very first collective efforts at the international level (Oral, 2024). The Earth Summit in Rio de Janeiro, Brazil in 1992 provided a renewed impetus for these efforts. Besides the global environmental problems, Bangladesh is a victim of local and regional problems (R. Ahmed, 2025). Bangladesh is affected by environmental problems both naturally and by man-made. In Bangladesh, the first environmental activities were initiated shortly following the Stockholm Conference on Human Environment during 1972 (Bint-E-Basar & Tasnim, 2024). Based on the outcome of the Stockholm Conference and after the promulgation of the Water Pollution Control Ordinance in 1973, a water pollution control-oriented project was undertaken with funding from the Government of Bangladesh (Bashar & Fung, 2020). Power generation, particularly from fossil fuel sources, has a substantial environmental impact that has become a significant concern with the pressing challenge of climate change and need for sustainable energy solutions (Runtuwene et al., 2025). One promising approach is the development of zero-discharge effluent treatment plants for HFO-based power plants, which can significantly mitigate the environmental footprint of these facilities (Kaur & Sharma, 2025). The concept of zero-discharge effluent treatment is centered on the comprehensive management and reuse of all liquid waste streams generated by the power plant, eliminating the need for any discharge of effluents into the surrounding environment (Ahirrao, 2014). One of the key aspects of a zero-discharge effluent treatment plan is the meticulous segregation and categorization of the various wastewater streams generated within the power plant, each with its unique characteristics and treatment requirements. By adopting a holistic approach to water management, the plant can optimize the treatment processes and maximize the potential for water reuse and recycling, minimizing the need for freshwater intake and reducing the environmental impact of the facility (Jivani et al., 2025). This research paper examined the technical considerations

[1] Department of Environment, Health and Safety, Summit Gazipur II Power Limited, Gazipur, Bangladesh
[2] Department of Civil Engineering, Dhaka University of Engineering and Technology (DUET), Gazipur, Bangladesh
[3] Department of Environment, Health and Safety, Ace Alliance Power Limited, Gazipur, Bangladesh
[4] Department of Chemistry, (Testing Laboratory for Water, Chemicals and Oil), Summit Gazipur II Power Limited, Gazipur, Bangladesh
[*] Corresponding author's e-mail: arifulislam14121@gmail.com

and implementation strategy plan for a zero-discharge effluent treatment plan in an HFO-based power plant named Summit Gazipur II Power Plant, Dhaka, Bangladesh, drawing valuable insights from the said industry case studies and best practices that have proven effective in achieving the ambitious goal that has been approved by the body of Department of Environment (DoE) which is a government responsible for the protection of environment in Bangladesh.

As Bangladesh's economy has rapidly expanded in recent years, driven by a growing population and rapid industrialization, the country has experienced a concomitant surge in energy demands (Amin & Rahman, 2019). Summit Gazipur II Power Limited (SGIIPL) is one of them to serve the nation energy since 2018. It is located near Dhaka at Kodda Bazar, Gazipur, Bangladesh (Map-1). The plant's contracted capacity is 300 Mega Watt, while the gross capacity is 307 MW. Engine: Wartsila (18X18V46) Generator: ABB. Fuel type is Heavy Furnace Oil (HFO). The total premise is of 22 acres land and is located at own land of company. Project appeasement started on 10th August 2017 and went for operation on 10' May 2018. The Project cost is the amount of USD 194 million (Figure 1).

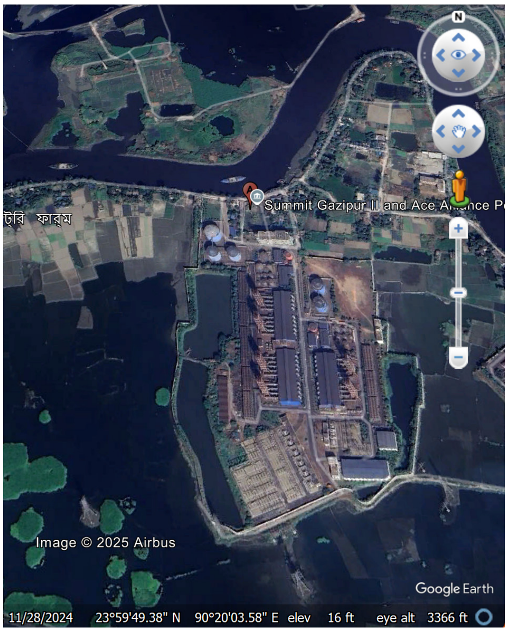

Figure 1: Map1- Google Earth View of the Location SGIIPL, 300 MW Power Plant

The research is conducted in the Summit Gazipur II 300 MW Power Plant, which recently introduces a novel zero-discharge scheme aimed at reducing environmental damage and stimulating sustainable waste water treatment and storage. The study starts with a complete site survey and data collection to gather all the detail information of the plant operations, wastewater sources, and treatment units. A complete knowledge of plant layout and operations can be used to determine what are the most critical sources of wastewater, and where is it possible (in the plant) to reuse that water. Wastewater generation and flow variations are determined for the purpose of estimating effluent system volume, and characteristic pollutant concentrations in each stream are used to evaluate chemical content and contaminant levels. The existing ETP performance is assessed for identification of operational constraints and improvement potential. The appropriate treatment technology is chosen based on the characterization of wastewater to achieve zero discharge with efficiency, cost-effectiveness and environmental friendly procedure that meets the regulatory requirements. Secondly, a system design of concept level is provided including process flow diagrams, equipment specifications, and arrangement sketches for the zero-discharge facility. Then, a cost-benefit analysis is carried out to evaluate the economic viability including capex, opex and maintenance cost. A complete feasibility study then takes place, to examine technical, economic and regulatory feasibility of the project. Finally, the research concludes with documentation and recommendations for the proposed zero discharge system indicating its advantages and how realistic it can be when implemented practically.

The concept of zero discharge for power plants has gained significant attention in recent years to mitigate environmental concerns and reduce the carbon footprint of energy generation (Prado de Nicolás et al., 2023). Zero discharge is a wastewater management strategy for a power plant that eliminates the discharge of any liquid effluent from the process by combining advanced treatment, concentration, and final crystallization, so that no liquid stream exits the plant (Maiti et al., 2021). Given the growing availability of ZD in water-stressed and pollution-prone areas, it is rapidly becoming a reality due to the advantages of its operation in terms of providing the maximum amount of usable water and the minimal pollution of surface waters (Modi et al., 2022). In the context of heavy fuel oil-based power plants, the implementation of a zero-discharge plan holds immense potential (Y. Wang, 2016). A crude oil-fired thermal plant generates several wastewater streams, namely, boiler blowdown, cooling tower blowdown, fuel-oil washing and slop, desulfurization, and utility/domestic wastewater (Obodovych et al., 2023). Wastewaters from a crude oil-fired thermal plant are high in total dissolved solids, with variable pH, hydrocarbons-oils & grease, suspended solids, chemical oxygen demand, and sometimes contain heavy metals or treatment chemicals such as anti-scalants, biocides (Meneceur et al., 2023). Fuel-related streams (fuel-washing and slops) contain high hydrocarbons and organic load and need pretreatment before biological or physico-chemical polishing (Beni et al., 2023). Bangladesh is increasingly dealing with growing industrial wastewater volumes and critical freshwater stress in several areas (Gulfam-E-Jannat et al., 2023). National environmental regulators and sector-specific authorities insist on stricter effluent standards, ETP performance, and environmental management plans by the industries (M. T. Ahmed et al., 2025). Numerous studies and government publications define the necessity to heighten effluent control and identify pilot or sectoral efforts in the sense of ZD or mostly ZD solutions in textiles and chemical processing, given growing regulatory pressure and freshwater shortage. The solution in power formation is almost non-existent, but discussions started in terms of LCPD requirements as part of efficient modern plant design and environmental clearance conditions.

The existing literature on this topic provides valuable insights into the various approaches and considerations for achieving zero discharge. For instance, a study on the process design of zero discharge of wastewater in a power plant located in Northwest China highlights the importance of rational water resource utilization and wastewater recycling in promoting sustainable development (Sohel et al., 2022). Similarly, a feature article on "Health, Safety, and Environment" discusses the technical and operational challenges associated with implementing zero-discharge goals, emphasizing the need for site-specific evaluation and the minimization of long-term environmental risks (H. Halimuzzaman et al., 2024). Based on the existing literature, the hypothesis for this research paper is that the implementation of a comprehensive zero-discharge plan at an HFO-based power plant can significantly reduce the environmental impact and improve the overall sustainability of the facility.

To test this hypothesis, the research paper will: build upon the current understanding of zero-discharge approaches by conducting an in-depth literature review to identify the existing strategies, technical considerations, and best practices for implementing such plans in the context of HFO-based power plants. Secondly, the paper will develop a conceptual framework for a zero-discharge plan that is tailored to the specific characteristics and operational requirements of an HFO-based power plant. Finally, the paper will analyze the potential benefits, challenges, and implementation strategies associated with the proposed zero-discharge plan, providing valuable insights for power plant operators and policymakers. Although this study effectively models the efficient wastewater management system using a well-designed zero-discharge strategy with its focus on water resources efficiency, it also has several limitations related to scope and application. "The research is site-specific with regards to the 300 MW Summit Gazipur II Power Plant, a specific site power plant such as, operational procedures, data types and regulatory scenarios may not be directly comparable or transferable from the studied facility to other generation plants that have different operations process, data structure or technology. Second, data availability and quality presented a limitation resulting from limited human resources and time, as well as lacking of advanced measuring devices for properties such as chemical composition, water loss in gasification processes (percentage of tar decomposition), total effluent in volumes. Therefore, the study was based on sample-based information, which probably is not a true reflection of the entire system. Moreover, technical issues originated from economic constraints to adopt advanced technologies including membrane filtration, reverse osmosis (RO), and automatic data recording devices. The restrictions of the company's privacy policy are finally reflected in the bottom level of access to detailed information on operations as they relate to the zero discharge plan, with limitations placed only on analyzing basic and utility activities of wastewater disposal (this time - even without possibility for cross-examination of specific industrial activity) but not those concerning total organizational tasks. A Zero Discharge Plan (ZDP) for a HFO power plant's effluent treatment is aimed at eliminating the release of liquid waste into the environment, and to save water resources through the technological implementation of radiator close lube system for cooling engine water, thus ensuring sustainable and environmentally safe operations. Below are potential research objectives for such a plan:

1. To save water, energy and resources by using a closed-loop cooling system for radiators and encouraging optimal plant functioning.
2. For the reuse and recycling of treated wastewater in homes, cleaning and garden water use to achieve upmost degree of water recovery.
3. To prevent heat and chemical contamination, in order to protect water habitats and adjacent environments.
4. To demonstrate, optimize and evaluate advanced treatment technologies (e.g., RO, ultrafiltration, MEE) for full scale commercial deployment to achieve zero discharge.
5. To increase both cost and energy efficiency with respect to domestic and international environmental legislation.
6. To achieve sustainable water resources and health protection by eco-friendly methods of wastewater treatment.

METHODS AND MATERIALS

A robust and systematic approach is necessary in order to ensure that wastewater streams are being adequately managed to reduce liabilities as well as the possibility of environmental harm, within a ZERO-DISCHARGE plan for an ETP such as in an HFO power plant. As pointed out by previous research (Y. Wang, 2016), zero discharge promotes the use of new and low-impact technologies in an attempt to address ecological problems. In order to do that, the current study used both primary and secondary data collection methods. Field data were collected in site surveys, continuous sampling, and direct observations followed by interviews with plant managers, engineers and environmental officers for learning the operational practices. Furthermore, water quality testing included total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD), pH, and oil and grease content analysis that characterized the effluent. Secondary data were obtained from different departments of the power plant such as energy generation (generation data) was obtained from the operation department (control room), waste water treatment records were achieved using effluent treatment plan (ETP) operational logbook and details on demineralized water production is available in water treatment plant (WTP). In addition, plant layout and processes information was analyzed to determine the source of wastewater and potential reuse opportunities; flow rates and pollutant concentrations in the wastewater streams were quantified to evaluate system performance. The operation manual of the ETP and WTP was studied to know what type of treatment is carried out by these plants, and the Environmental Impact Assessment (EIA) report analyzed for possible environmental impacts from wastewater discharge. Taken together, these sources of data created a comprehensive basis for an evaluation of the zero-discharge implementation at the HFO power plant. Statistical data were shown using tables, charts, and calculation procedures. Engineering models, maps, layout plants, and design were used for analyzing justifying and interpretating the relevant information.

RESULTS AND DISCUSSION

Effluent Treatment Plant (ETP) is established for the treatment of wastewater. Wastewater contains oil and different solid, chemical, and biological elements that must be separated to make environmentally friendly safe water. The freshwater discharge capacity of ETP is 1000 liters per hour. There are many sources of wastewater of this power plant while the main source is crude oil. When crude oil is treated in fuel treatment plant the wastewater is generated and finally it is treated in ETP through different stages and mechanisms. It is a legal requirement of the department of Environment, Govt. of Bangladesh to install ETP for ensuring safe water release to environment and making no water pollution. The presence of oily water poses a significant challenge for achieving zero discharge. Effective treatment strategies are essential to remove oil and other contaminants before the water can be reused or discharged. (M. Halimuzzaman et al., 2024) discussed various mitigation strategies for membrane fouling in oily wastewater treatment, a common issue in zero-discharge systems. (Damoah et al., 2023) focused on organics removal from oily bilgewater using electrocoagulation, a potential treatment method for engine wastewater as well. (Maiti et al., 2021) explored advanced membrane technologies for oil or water separation, which could be relevant for achieving high-quality water reuse in a zero-discharge system.

Sources of Wastewater

The main source of oily water is furnace or crude oil. In a crude oil-fired power plant, oily water from the fuel treatment plant typically originates from several operational and maintenance activities. Here's a breakdown of the main sources. The major sources of oily water in the fuel system of a heavy fuel oil (HFO) power generation plant usually originate from fuel filtration and separation equipment where any wash than may be applied to flush out filters or separators usually contains some remnants of oil, and coalescers or centrifuges may even produce an oily demulsed hydrocarbon containing water during washing cycles. Aside from stormwater and sanitary sewage, the bulk of the wastewater produced as a result of plant operation is oily. A significant culprit is the engine procedure, where oil water leaks out and spills around the alternators. For the Summit Gazipur II Power Plant (SGIIPL), which utilizes 18 engines or generators, each unit connects to a separated pit through small drainpipe. These pits are connected to a central pit, where wastewater is pumped into a 200MT capacity oily water tank and then processed at the Effluent Treatment Plant (ETP) (Bashar & Fung, 2020). The oily water usually comes from the engines, which come from several different points like engine lubrication system, where human spillage or oil leakage allow direct discharge of the oils to mix with the washdown waters (Engine Lubrication System & How Oil Circulates in IC Engines, 2024). Furthermore, leaks from the fuel system and cleaning/maintenance of the engine is (sic) also a source of contamination as are spills, both accidental and operational, while in operation. All of these sources collectively generate oily wastewater which should be collected, separated, and treated properly to prevent environmental pollution and ensure the continuous operation of the power plant. The engine and washing effluent of HFO engines in a power plant is complex, involving a variety source and load of contaminates. The wastewater resulting from the engine's functioning usually includes emulsified oil in it, making usual separation processes not suitable for this (Oily Water Treatment, 2023). The concentration of oil in these effluents is extensively variable, depending on working conditions and origin, besides heavy metals, detergents and suspended solids may also be presents contributing to an additional difficulty to eliminate this pollution. Apart from the engine related discharges, significant waste water is also produced due to cleaning operations of equipment and machinery, which vary both in terms of magnitude and composition according to the type of equipment under consideration, cleaning frequency and chemcial agents used. For example, cleaning of boilers leads to the generation of effluent consisting soot and ash, scale and chemicals used for the cleaning; cleaning up turbine systems results in the release of oily water with grease and fine metal particles present; while cleaning cooling towers and heat exchangers results in generating effluents that contain deposits of scale, biocides, as well as corrosion inhibitors. Also, cleaning of floors and surfaces in the plant generates wastewater containing oils, soaps and solids; as well as washing vehicles and equipment produces wastewater with oil, grease, grime etc. All these dissimilar sources combined result in a complex wastewater stream that needs sophisticated physical technologies to remove oils, solids and chemicals prior to ZLD (zero liquid discharge) without breekabout of environmental standards.The engine and washing discharges created when HFO is used as fuel for engine operation in a power plant are very complex generated by various sources and carrying diversified number of pollutants. The wastewater produced while operating the engine generally includes emulsified oil, or small oil droplets suspended throughout the water, which is not effectively removed by traditional separation methods (Oily Water Treatment, 2023). The oil content of these effluents depends on operating conditions and the origin and widely vary among them, and obtaining additional pollutants such as heavy metals, detergents or suspended solids which make it more difficult to handle. In addition to the engine-related discharges, significant wash-off is generated from cleaning activities of different facilities and equipment, which depends on the type, frequency and use of cleaning chemicals as well. For example, boiler cleaning creates wastewater of soot and ash, scale and chemical residues; turbine cleaning produces greasy water of grease and fine metal particles; while cooling tower and heat exchanger cleaning yields effluents with scale deposits, biocides, corrosion inhibitors. Moreover,* floor and surface cleaning* in the facility adds wastewater with oils, soaps and solids along with vehicle and equipment washing which brings suspended oil, grease, gunk into the waste stream. As a result, this mixture of raw water has become heterogeneous and heavily contaminated effluent thus necessitating the use of advanced physical and chemical treatment processes in order to efficiently remove oils & greases, solids and chemicals (grease-like molecules), in the discharged processed water before common ground discharge - for which Aquatech's client combined into an ambitious goal that was implementing ZLD: Zero Liquid Discharge.

Oily Water Generated from the HFO Sludge

During the power generation of HFO-based power plant, it is used a heavy fuel oil (HFO) as a main energy source and then oil-containing sludge is generated with combustion and treatment process on fuel. This sludge is collected in a sludge tank, oil-water mixture separated; sludge of more possibility treated /send for disposal and oil containing water from separation + sludge tank sent to Effluent Treatment Plant (ETP). The oily water produced by HFO sludge is one of the major sources of waste and a great barrier to accomplish zero liquid discharge (ZLD). As noted by Obodovych et al. (2023). HFO sludge is a non-homogeneous mixture of oil, water and sediments and contaminants having a high percentage of oil content, which requires efficient separation and treatment techniques? It may also have heavy metals, suspended solids becomes an indispensable waste due to the consideration regarding prevention and control of environmental pollution. Several tactics are crucial to overcome these challenges to implement ZLD. First, **sludge handling should be optimized by which oily wastewater generation can be minimized as described in Jivani et al. (2025). Second, sludge through oil recovery can reduce the volume of waste and make the waste oil a useful resource (Sadulaeva, 2023). Third, remaining foul water after extraction of oil needs to be further treated at an advanced stage in order to remove any trace contaminants that remain before re-using or recycling it. Last, thermochemical treatment techniques such as those based on oxidative and non-oxidative processes (Obodovych et al., 2023) can be used to treat the sludge efficiently with potential energy recovery. In this context, to design an efficient zero-discharge system in HFO power plant, it is important for the environmental engineers to know what are the individual constituents of the sludge and oily water (composition, behaviour and treatment potential)?

Waste Water from Domestic Use and Sanitation Facilities

The domestics waste water produced in the power plant is generated mainly from kitchens, toilets, bathrooms dormitories and offices, which accounts for lower volume compared with industrial effluents, but it is extremely critical to a successful implementation of an efficient zero liquid discharge (ZLD) system. It is called blackwater, for coming out of the hanging toilet, while derives from sinks, washing basins, bathroom activities and is generally referred to as greywater and normally includes organic matter, nitrogen, phosphorus, pathogens and traces of cleaning chemicals (Scholz 2024; Jannah 2023). The quantity of domestic wastewater in total is highly dependent on the number of people on board and their use of water. Domestic wastewater especially in most places with soak well or septic system having percolation and partial treatment but it is the proper 16 designed which avoid contaminate ground water or surface water. For ZLD Activated Sludge or Membrane Bioreactor (MBR) processes can be employed to reach a high quality effluent for reuse using Wastewater Treatment, 2023. MBR systems in particular have advantages of small footprint, high efficiency treatment and are commonly selected for industries. The treated wastewater can be utilised for non-potable applications, such as, toilet flushing, floor wash and landscape irrigation, which in turn reduce the usage of freshwater (Abd‐Elaty et al., 2022; Shakir et al., 2016). In addition, so somewhere like power plant side it can combine with the Industrial effluent treatment unit and industrial effluent treatment areas too thus saving space , cost & operation. Consequently, an established programme of home wastewater management--comprising treatment, reuse and environmental protection measures - is beneficial in promoting resource efficiency and sustainability objectives as well as underpinning the zero descharge policy.

Effluent Treatment Plant Design Consideration

The design flow capacity for the wastewater treatment plant is 8000 Liter/day according to operate 8 hours per day, so design capacity of the plant is 1000Liter/hr. In average, the amount of wastewater from cleaning of engines and equipment is 5,000 liters per month and wastewater generated from consumption of fuel for production purpose is 101,000 liters per month. It will be also several times higher if the plant produces power at its maximum level.

Effluent Treatment Process

In this proposal, the effluent treatment plant will be Preliminary, primary or physico-chemical and secondary or biological, activated sludge type treatment according to the nature of the contaminated effluents and the discharge standards.

Preliminary Treatment

This is the removal of insoluble material, ie suspended solid, from the effluent prior to any downstream process. In preliminary treatment portion different size screener to added for removal of plastic or other floating inert materials.

Primary or Physico- Chemical Treatment

There still will be a large quantity of suspended and soluble pollutants after screening, so primary or physico-cnemical treatment is required to eliminate suspended oil and soluble solids to protect and improve the biological treatment unit, this can be done by floatation or filtration. In this primary treatment section usually involves one or more processes our options are as follows.

(a) Oil Trap and Equalization: for removing suspended oil and balancing the variation of effluents.

(b) Reaction/Flash mixer tank: for proper mixing of coagulant and effluents

(c) Primary clarifier: for maximize removal of suspended solids and reduction of organic load (BOD/COD) entering the downstream biological treatment plant

Secondary/Biological Treatment

This achieves a reduction in the biological loading of the final effluent discharged into the inland or river. This stage is particularly important for optimizing the plant's operation and thus achieving cost savings.

There are numerous biological treatment systems available, the most common being the activated sludge process. We choice activated sludge process, which is found to be efficient in the removal of soluble biodegradable organic pollutants.

In this Secondary treatment section usually involves more process, our options are as follows.

(a) Aeration tank: for removing organics by microbiological growth

(b) Secondary clarifier: for settlement and remove of biological sludge

Tertiary Treatment

In the tertiary treatment portion the output water from secondary treatment process shall be collected to the clarified water tank & clarified water shall be pumped under medium pressure through Multi grade Filter & Carbon Filter for the adjustment of color, odor, & other parameters.

Process Description

The wastewater from OTP (Drier) and other wastewater from utility will be collected through screener to oil trap cum equalization tank. It is a rectangle RCC tank that will be used as a primary source from where raw effluent is transferred to the primary clarifier by pump through flash mixture/reaction tank. When the effluent is transferred to the primary clarifier then the optimum number of coagulants (Lime, alum and poly electrolyte) shall be added through flash mixture/reaction tank. PH Correction Unit has been introduced here to make the required pH of the effluent for proper chemical reaction. Effluent from the primary clarifier shall be transferred to the activated sludge plant or aeration tank by gravitationally for biological treatment purposes. In an activated sludge plant adequate air will be supplied by air blower. After biological treatment the effluent is transferred to the secondary clarifier for settlement of biological sludge at the bottom of the clarifier. The overflow water from secondary clarifier will be collected in clarified water tank. Biological sludge from secondary clarifier to be returned (10-15%) at aeration tank as an activated sludge process for rapid growing the bacteria. Sludge from the bottom portion of the primary and secondary clarifier shall be drained periodically into sludge holding tank then to be dehydrated by screw filter press. In the Activated sludge plant, we have to supply sufficient air with the help of a disc type air diffuser taking air from blowers for bacterial growth. The clarified water overflow from secondary clarifier shall be collected to the clarified water tank & clarified water shall be pumped under medium pressure through Multi grade Filter & Carbon Filter for the adjustment of color, odor, pH & other parameters. Sludge collected from primary & secondary clarifier allows to transferring through screw filter press by pump. A small portion of the sludge containing as all portion of water from the screw press will return to the oil trap cum equalization tank. After a suitable duration sludge with sand will be disposed of at selected sludge damping area (Figure 2).

Process Unit Description and Design

All the effluent will be collected from different floors and OTP (Dryer) to the equalization tank through screener at screen chamber. Oil Trap cum Equalization tank is made of RCC & is constructed by the clients according to the drawing & design supplied by ALTERNATOR

Construction : RCC (Reinforcement Cement Concrete)

Location : Underground

PH Correction Unit

One set of automatic pH correction units will be used for pH correction of the effluent water. Chemical flow control will be done by dosing pump for caustic. We have

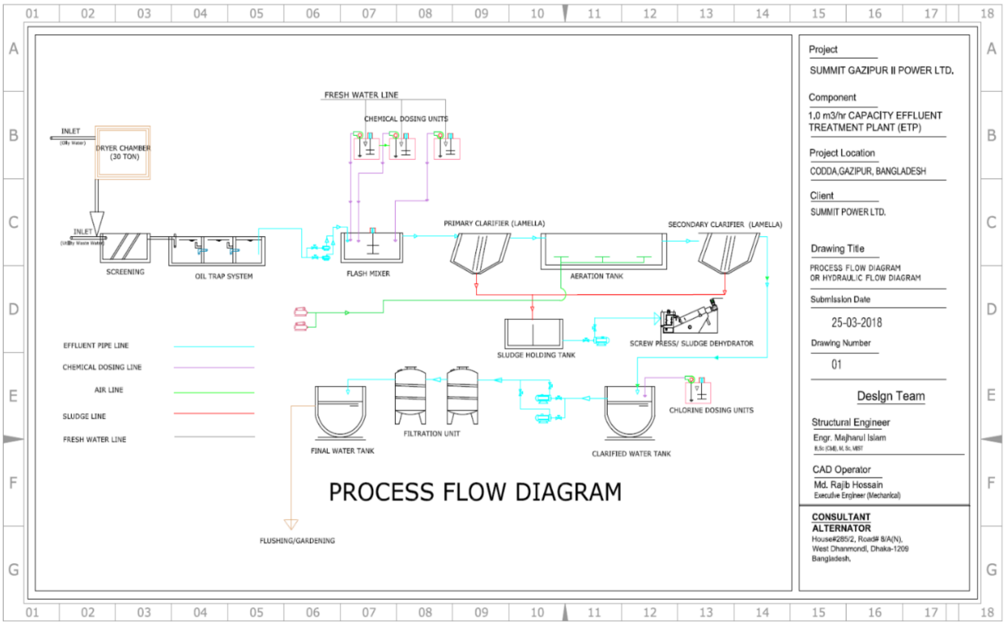

Figure 2: ETP's Process Flow Diagram

to prepare the solution for the acid dosing Unit before starting the plant. In this regard 40-50 ml of hydrochloric acid will be added with 100-liter fresh water taking in a supplied PVC Tank of capacity 100 liter. Hydrochloric acid will be mixed well with water for proper reaction.

Preparation of PC solution

Poly aluminum Chloride (PAC), a water treatment chemical used as a coagulant, is prepared before starting the plant. In this regard 2 kgs of PAC will be added with 200-liter fresh water taking in a supplied PVC Tank of capacity 200 liter. PAC will be mixed well by agitator driven by gear motor for proper mixing.

Preparation of Lime Solution

Lime solution is prepared before starting the plant. In this regard 2 kgs of Lime (Calcium Hydroxide) will be added with 200-liter fresh water taking in a supplied PVC Tank of capacity 200 liter. Lime will be mixed well with water taking air from air blower through fine bubble air strainer for proper mixing.

Preparation of the Poly Electrolyte (PE) Solution

Poly Electrolyte (PE) solution is prepared before starting the plant. In this regard 12 gr of Poly Electrolyte (PE) will be added with 100-liter fresh water taking in a supplied PVC Tank of capacity 100 liter. Poly Electrolyte will be mixed well by agitator driven by gear motor for proper mixing.

Preparation for the Solution of Chlorination Unit

Another solution is prepared for Chlorination Unit before starting the plant. In this regard 50 gr. of Bleaching Power will be added with 100-liter fresh water taking in a supplied PVC Tank of capacity 100 liter. Bleaching Power will be mixed well with water for better performance.

Chemical Dosing

Lime = 200 gm. per 1000 ltr. Per hour (As Dosing Chemical)
PAC = 200 gm. per 1000 ltr. Per hour (As Dosing Chemical)
PE = 12 gm. per 1000 ltr. Per hour (As Dosing Chemical)
Total = 462 gm. per 1000 ltr. per hour.
= 3,696 gm. per 1000 ltr. Per day at 8 working hours.

Effluent Transfer Pump

Effluent transfer pump will be used for lifting effluent from equalization tank to reaction and flocculation tank.

Reaction Tank

In this process, coagulants are used in the reaction tank before suspended solid settling. Coagulants are added to the wastewater to make the solids settle. It is a rectangular MS tank.

Dosing Unit

Three PVC tanks will be used to prepare the chemical solution. The agitator and gear box will be fitted with each tank for proper mixing of coagulant. Flow as well as mixing of the chemical will be controlled by dosing pump. Lime and alum will be used as coagulant agents and Poly electrolyte will be used as bonding elements. Three individual dosing pumps will be used for lime, Alum and Poly electrolyte solution.

Primary Clarifier

It is a MS made Lamellar conical bottom tank of capacity 1000Liter and it is constructed by us according to drawing & design. Waste water from oil trap cum equalization tank. To eliminate the suspended solids to protect the biological reactors, this can be done sedimentation flotation or filtration. The function of the primary clarifier is to settle particles from flash mixture/reaction tank.

Aeration Tank

In the aeration tank aerobic treatment for the removal of biodegradable organic matter from liquid waste is an odorless process and consists of two phases operating simultaneously. One phase is biological oxidation that has by-products such as carbon dioxide, and it yields energy. The second phase utilizes the energy from the oxidation phase for synthesis of new cells, as shown by the following simplified equation: microbial cells + organic matter + O_2-CO_2+H_2O+NH_3+ more cells Organics in wastewater are removed by microbiological grm, vth and stabilized by biochemical synthesis and oxidation reaction. It is a RCC made rectangular tank and is constructed by the client according to the drawing & design supplied by ALTERNATOR. Air will be supplied from blower through diffuser.

Secondary Clarifier

It is a Lamella type chamber's MS tank with conical bottom. Inner chambers have a pocket around its circumference. Internal chamber and the conical bottom part will be made by MS also.

Clarifier Water Tank

It is a circular PVC tank of capacity 3000 Liter and is supplied by us.

Sludge Holding Tank

It is a rectangular RCC tank of capacity 6.0 cum and is constructed by the client according to the drawing & design supplied by ALTERNATOR.

Final Water Tank

It is a circular PVC tank of capacity 3000 Liter and is supplied by us and used after final treatment.

Chlorive Dosing Unit

One set of chlorine dosing unit will be used for disinfection of treated water for gardening purposes. Chemical flow control will be done by dosing pump for chlorine.

Filtration Unit

Pressure feed pump will be used to transfer the clarified water through Multimedia Filter and Carbon Filter.

Multigrade and Carbon Filter

Multi-grade filter & activated carbon filter

The filtration section mainly comprises of following equipment

1.Multi-Grade Filter (MGF)

2.Activated Carbon Filter (ACF)

Water from Clear Water Tank which will be pass through Multi-grade Filter (MGF) and then Activated Carbon Filter (ACF) with the help of Pressure Feed Pump.

Operation of multi-grade filter & activated carbon filter

The filter mentioned has been designed to provide trouble-free service. Each of the above filter units needs to be backwashed once in 24 hours.

Quantity : 01
Capacity : 500 Liter
Vessel Dimension : D16 inch *H 65 inch
Vessel Materials : FRP
Operation : Continuous service with backwash device
Pipes & Fittings : PVC
In/Out Connection : 25 mm
Media : Graded sand and gravel and activated Carbon

Screw Press Filter

It is Sludge dehydrator to dehydrate sludge collected from primary and secondary clarifier to sludge holding tank by screw press.

Specification

Type : MYDL101
Dimension : L1850xW740xH1040 (mm)
Capacity : 5/7 kg/Hour
Power : 0.36 KW
Protection Level : IP55 F
Power supply : 380V/3/50 Hz
Output sludge moisture content : 75-85%
Polymer feeding rate : DS 0.2 1%
Flush water : 24L/h
Water supply pressure : 0.2 MPa
Country of origin : China

Chemical reaction involved in the physiochemical wastewater treatment

Physicochemical wastewater treatment involves a variety of chemical reactions depending on the specific contaminants being targeted and the treatment methods employed. Here's a breakdown of some common reaction types:

Specific Reactions in Your ETP

The specific chemical reactions involved in the physicochemical treatment of wastewater at your HFO power plant will depend on the chosen treatment methods and the characteristics of the wastewater. You can find more details about these reactions in the design documents for your ETP or by consulting with water treatment experts. (Kumar et al., 2024) provides a general overview of chemical processes in water and wastewater treatment. (Morinaga et al., 2023) discusses heterogeneous Fenton-like processes, which involve oxidation reactions. (Jain et al., 2018) describes electrocoagulation, which involves electrochemical reactions. (Hussain et al., 2022) discusses effluent management in a metal finishing industry, which may involve some similar chemical reactions. (Alam et al., 2024) focuses on wastewater minimization, which can indirectly influence the chemical reactions involved in treatment. (C. Wang et al., 2023) discusses the treatment and disposal of industrial wastes, which may involve some of the reaction types mentioned above. (Collivignarelli et al., 2025) discusses thermophilic aerobic membrane reactors, which involve biological reactions in addition to any physicochemical pre-treatment. (Modi et al., 2022) focuses on membrane fouling mitigation, which can influence the choice of chemical treatment methods. (Jivani et al., 2025) describes activated sludge processes, which primarily involve biological reactions. (Obodovych et al., 2023) discusses microalgae and wastewater treatment, which involves biological processes.

Chemical coagulation and flocculation are used as a means of improving the performance of primary settling facilities and as a basic step in the independent physical – chemical treatment of wastewater. ETP inlet and outlet test results show its parameters are below the limit of DoE's standards.

Reactions associated with Ferrous Sulfate and Lime

In most cases, ferrous sulfate cannot be used alone as a precipitant because lime must be added at the same time to form a precipitate. When ferrous sulfate is added to wastewater, the following reaction occurs:

$FeSO_4.H_2O$ + $Ca\ (HCO_3)^2$ $Fe\ (HCO_3)^2$ + $CaSO_4$ + $7H_2O$

Ferrous Sulfate Calcium Carbonate Ferrous Bicarbonate Calcium Sulfate

(Soluble) (Soluble) (Soluble) (Soluble)

$Fe\ (HCO_3)^2$ $Fe\ (OH)_2$ + CO_2

Ferrous Bicarbonate Ferrous Hydroxide Carbon dioxide

(Soluble) (Very slightly soluble) (Soluble)

If sufficient alkalinity is not available, lime is added in excess in conjunction with ferrous sulfate. The resulting reaction is:

$Fe\ (HCO_3)^2$ + $2Ca\ (OH)_2$ $Fe\ (OH)_2$ + $2CaCO_3$ + $2H_2O$

Ferrous Bicarbonate Calcium Hydroxide Ferrous Hydroxide Calcium Carbonate

(Soluble) (Slightly Soluble) (Very slightly Soluble) (Somewhat Soluble)

Ferrous hydroxide can be oxidized to ferric hydroxide, the final form desired, by oxygen dissolved in the wastewater. The reaction is:

$Fe\ (OH)_2$ + $1/4O_2$ + $1/2H_2O$ $Fe\ (OH)_3$

Ferrous Hydroxide Oxygen Ferric Hydroxide

(Very slightly soluble) (soluble) (insoluble)

The insoluble ferric hydroxide is formed as a bulky, gelatinous flock.

Test Report (Inlet and Outlet water of ETP)

ETP's inlet and outlet water quality test was carried out and different parameters were used and comparing with Bangladesh Standard (Bint-E-Basar & Tasnim, 2024) wastewater standards. Result was found satisfactory. Bureau Veritas Bangladesh Private Limited (https://www.bureauveritas.com.bd), 2018 (Figure 3).

Industry & Facilities Division
Third Party Inspection Report

BUREAU VERITAS 1828

Page 16 of 17

□ Interim
√ Final

INSPECTION REPORT N° BV/ SGIIPL/01/SE-FEB-2025

BV Job nr: BAN.D.3084A5.024.748

Water Quality Parameters comparing with Bangladesh Standards (ETP Inlet and outlet)

Sl. No.	Water Quality Parameters	Result Inlet	Result Outlet	ECR'23 Wastewater Standards	Methods/ Equipment's
1	Arsenic	<1.0	<1.0	200 ppb	HGAAS
2	BOD 5 Day, 20^0C	14.3	3.9	30 mg/L	5 days BOD Test
3	Cadmium (Cd)	< 0.001	<0.001	2 mg/L	APHA 3111.B
4	Chlorine (Residual)	<0.03	<0.02	1 mg/L	DPD Photometric
5	Chromium (Cr)	< 0.005	0.005	0.5 mg/L	APHA 3111.B
6	COD	92.0	14.0	200 mg/L	Photometric
7	Copper (Cu)	<0.1	<0.1	3.0 mg/L	APHA 3111.B
8	Iron	<0.1	<0.1	3 mg/L	FAAS
9	Lead (Pb)	<0.01	<0.01	0.1 mg/L	APHA 3111.B
10	Mercury (Hg)	<0.001	<0.001	0.01 mg/L	APHA 3111.B
11	Oil and Grease	< 2.0	<2.0	10 mg/L	APHA 5520.B
12	pH	7.42	7.62	6-9	pH Meter
13	Suspended Solids (SS)	10.2	3.3	100 mg/L	APHA 2540.D
14	Temperature	25	25	≤ 5^0C of surface water	Thermometer
15	Zinc (Zn)	<0.04	< 0.04	5 mg/L	APHA 3111.B

Note: All parameters within the standard limits.

Figure 3: Water Quality Parameter

Generation of Treated Water

The amount of treated water depends on the use of fuel and generation of electricity. Total five years data from 2019 to 2025 (up to Oct) have been shown (Table 1).

Table 1: Fuel Consumption and Generation

Year	Electricity Generation Gross (Mega Watt Hour)	Engine Fuel Consumption (Kilo Gram)	Amount of Generation of oily water (Metric Ton)	Amount of Treated water (Metric Ton)
2019	299000	61164230	125.57	75
2020	950859.602	193835083	527.75	443.5
2021	1130881.99	230731052.72	131.5	100
2022	299000280	61164230	148	105
2023	607998	124411722.00	114	67
2024	628750.34	127940268	606.76	386

Use of ETP's Outlet Water

Gardening

This power plant owns 22 acres of total land and among them more than 33% of the area is vegetated by various fruit trees, flowers, herbs and grassland. It needs a huge amount of water for irrigation. The final treated water from ETP's outlet is used for garden watering.

Cleaning

Vehicle, air filter, and other machinery of equipment are cleaned by using ETP's outlet water.

Storage of Fire Water Tank

This plant has 1000 metric ton capacity of fire water tank to mitigate the fire hazard. This tank is always full of water and due to natural loss of water the empty tank is refilled by ETP's outlet water.

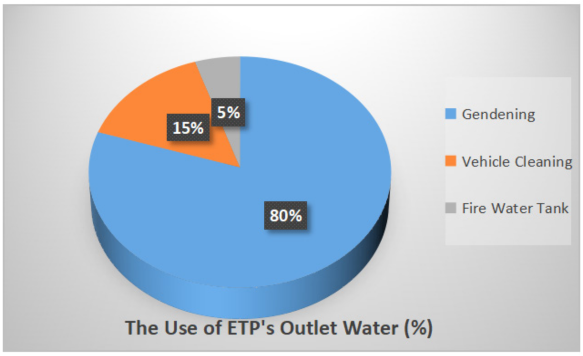

Figure 4: Usage of ETP's Outlet Water (Treated Water)

This pie chart represents the use of outlet or treated water from Effluent Treatment Plant in four different sectors. It is highly clear that 80% treated water is used in gardening section where 15% and only 5% are used in vehicle cleaning and fire water reserve tank respectively. Total amount of treated water is used as part of zero discharge plan. The amount of treated water can contribute to the requirement of use of three different sectors. This can save water from extraction of ground water as much as possible (Figure 4).

Water Treatment Plant

For a HFO fired engine, the cooling system works as an independent circuit mostly controlled by the radiator and expansion tank to recover and reuse. In operation of the engine, the heat generated by the combustion is absorbed by a passing coolant that is pumped through the engine block, cylinder head and other heat producing sections. The warmed coolant diametrically flows into the radiator, and is cooled due to airflow across the radiator fins with either moving air (particularly often when the vehicle is in motion) or stationary. As the coolant heats, it expands and its volume increases so the excess is forced into the expansion tank, and as it cools a vacuum form in the cooling system which daws lost coolant back from the expansion tank to fill radiator & engine block. Pressure control is ensured: by a cap on the expansion tank and another pressure release device located on the radiator overpressure is avoided in the system. This closed system provides an efficient heat transfer and engine cooling while recycling the coolant to be used again- No water waste - It recovers and reuse the coolant. * Environmental aspect: the system saves water by repeatedly using it, with loses being natural like evaporation and systematic as for HFO power plant stable support to sustainable water management in fact.

Benefit of Closed -Loop System and Relevancy with Zero Discharge Plan

The closed-loop cooling system of the heavy fuel oil power plant is designed, on the one hand to be able to recover energy and allow a water saving (so that water constantly passes through the engine plus radiator and is not lost notably (at most being subject to minor evaporation or due to losses inside the system during its use for cooling). Re-utilizing demineralized (DM) water - chemically treated to satisfy engines' requirements- the system avoids the emission of water polluted by chemicals into the environment, thus decreasing water pollution. Besides, additionally the close-loop system leads to pertinent economic advantages: only minimal new chemicals are necessary for treatment, the electrical energy required for the water production is less than 6, and expenses concerning labour force and machine hours/maintenance are minimized. In general, the process allows maintaining sustainable operation while saving water and chemicals, blocking unproductive investments in a safe and environmentally sound way.

Water Treatment Plant for Producing DM (Demineralized Water)

Heavy fuel oil (HFO) power plants need demineralized (DM) water for cooling, as it complies with strict engine requirements and prevent from corrosion, abrasion and detrimental metal reaction, but also guarantees efficient use of cooling. DM water is obtained through multiple stage treatment by which minerals, salts and other impurities are removed to make it suitable for industrial use. Primary production technologies are ion exchange or **conventional (cation-anion and mixed bed resins), membrane filtration such as reverse osmosis (RO)+electrodeionization(EDI), or conventional techniques such as distillation and multiple-effect evaporation (MEE) which is now less favorable due to high energy consumption. Efficient **pre-treatment of raw water using pressure sand filters(PSF) and activated carbon filters (ACF) is essential for the removal of suspended solids, color, odour, and organic matter as well protecting the life of resins and membranes. Basically, the work principles of producing DM water are ion-exchanging adsorptions that, for example, cations and anions are exchanged by active resins acid and alkali regenerated, and membrane separations where dissolvable solid was strip so the water conductivity achieved an extremely low level. The improvement of the fully automated and membrane-based systems, as scale inhibitors with reverse osmosis being followed by electrode ionization (RO+EDI), has resulted in savings on man power, higher availability of the high-quality DM water at plant site at affordable cost and above all reliability making this system into an indispensable sustainable solution for HFO power plant cooling towers (Figure 4).

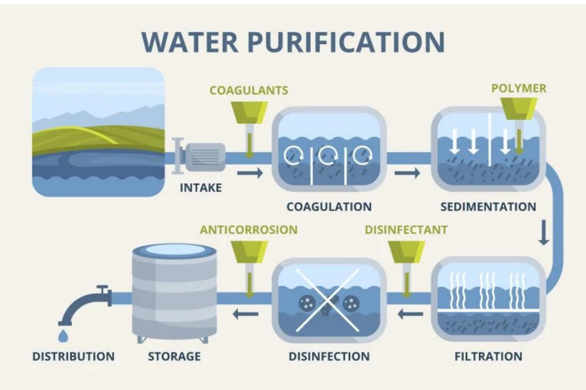

Figure 5: Process Flow Diagram of Water Treatment Plant (Source: https://sarvowater.com/demineralization-dm-water-filtration-plant)

Utilization of Rejected Water from Water Treatment Plant

The reject water from a Demineralization (DM) water treatment plant, also known as deionized water, is essentially water with most of its mineral ions removed. This rejected water typically contains concentrated levels of dissolved salts and other impurities that were present in the source water. While it's not suitable for applications requiring high purity water, it can be managed and potentially reused for various purposes, reducing overall water consumption and waste (Figure 5). Here's a more detailed breakdown:

What is DM Water Reject?

DM water treatment plants remove mineral ions like sodium, calcium, iron, and others, as well as anions like chloride, sulfate, and nitrate. The rejected water from this process contains these removed ions, along with other dissolved solids and potential contaminants.

Usage of DM water and production of rejected water in SGIIPL

Demineralized water is required for engine cooling purposes as well as used in fire tube boilers for generating stream that is required to heat up the fuel. The main source of DM water is ground deep tubewell which is 16 in boring. The DM water tank capacity is 30 Metric tons. DM water is generated following the engine running time. It depends on demand for electricity generation. Generation of raw water, DM water and 40% rejected water yearly data are demonstrated in Table 2 below:

Management and Reuse Options

Wastewater treatment plants

In some cases, DM plant reject water is directed to wastewater treatment plants. However, this can negatively impact the wastewater treatment process, especially the biological treatment stages.

Reverse Osmosis (RO) reject recovery

RO technology can be used to further treat the DM reject water, recovering some of the water and concentrating the remaining waste.

Industrial applications

Rejected water can be reused in some industrial processes, such as cooling towers, provided the water quality meets the specific requirements.

Agricultural uses

In some cases, the rejected water can be used for irrigation, especially for salt-tolerant crops.

Microalgae cultivation

Research has shown that DM reject water can be used as a growth medium for microalgae, which can then be harvested for various purposes, including biofuel production.

Table 2: Usage of DM water and production

Year	Amount of Raw Water (Metric Ton)	Total DM water production (Metric Ton)	Total Amount of 40% rejected water (Metric Ton)
2019	13679	8207.8	5471.6
2020	30030	18018	12012
2021	32842	19705	13137
2022	56168.3	33701	22467.3
2023	26250	15750	10500
2024	26628	15977	10651

Construction materials

Alkali activation techniques can be used to solidify the salts in the rejected water, creating materials that can be used in construction.

Groundwater recharging

Soak pits can be used to manage the rejected water and allow it to slowly infiltrate the ground, potentially recharging groundwater supplies.

Other uses

Depending on the specific composition of the rejected water and the local regulations, other potential uses include toilet flushing, washing machines, and industrial cleaning.

Rejected water use in 300 MW Power Pant

According to the operational manual of water treatment plant 40% of water is rejected. This rejected water contains high concentrations of minerals salt and other non-detrimental particles that are generally non harmful for the environment. In this power plant there is a proper plan and specification area where rejected water is reused in the following areas.

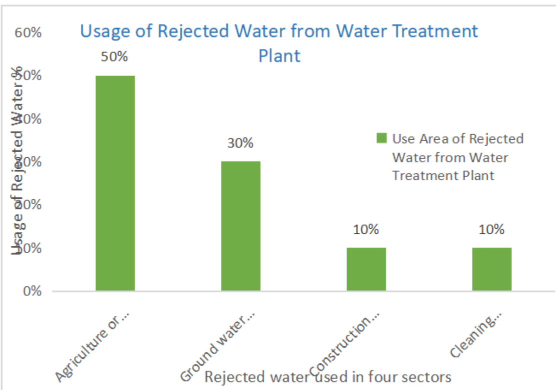

Figure 6: Usage of Rejected Water from Water Treatment Plant

Usage of rejected water from Water Treatment Plant is shown in bar diagram section wise in four distinct applications. This data clearly shows how the rejected water is being reused for multiple purposes. This power plant has large vegetation and garden area, so 50% of water used in agriculture sector where groundwater discharge is 30% and rest of the water is used in construction and cleaning purposes with the same ratio (Figure 6).

Recommendations

SGIIPL has already been practicing many of the options of Zero Discharge Plan. Most importantly, the wastewater being produced from the production and operation process is well managed considering the Zero Discharge. However, there are few rooms to adopt some of the options to foster the Zero Discharge considering the 3R/4R. The recommendations for the said options are as follows:

1.It is utmost responsibility of the plant's authority to ensure the standards of the ETP treated water as mentioned in this Plan.

2.The functionality and overall efficiency of ETP should be audited externally every year.

3.The wastewater to be generated from the kitchen and other domestic uses should be monitored to ensure that those are not dumped directly into any open water body.

4.The septic tank to be included with the sanitary facilities will need to be monitored so that it is constructed considering the environmental parameters as well as the efficiency of the soak wells to be constructed for wastewater treatment will be needed to verify.

5.Rainwater harvesting may be adopted by SGIIPL. The rainwater can be stored on the lake and withdrawal through piped lines which may be used for toilet flashing and other domestic cleaning purposes (e.g. bathing, cleaning of utensils). But minimal filtration arrangement should be included with the pipeline so that clean water can be withdrawal.

6.Authority will need to engage external consultants to audit the implementation of this Zero Discharge Plan and SGIIPL will need to fulfill the recommendations of that audit.

CONCLUSION

This study demonstrates that a well-designed and systematically implemented zero-discharge effluent treatment plan is both technically feasible and environmentally effective for an HFO-based power plant in Bangladesh. Using the Summit Gazipur II 300 MW Power Plant as a case study, the research shows that integrated wastewater segregation, physicochemical and biological treatment, closed-loop cooling, and extensive reuse of treated and reject water can successfully eliminate liquid effluent discharge. The existing ETP performance complies with Department of Environment standards, while treated and rejected water reuse significantly reduces groundwater abstraction and environmental pollution. Although challenges remain regarding site-specific limitations, data availability, and adoption of advanced technologies, the findings confirm that zero-discharge strategies can enhance water efficiency, regulatory compliance, and sustainability in fossil-fuel-based power generation. This study provides practical insights and a replicable framework for policymakers and power plant operators seeking environmentally responsible and resource-efficient wastewater management solutions.

REFERENCES

Ahirrao, S. (2014). Chapter 13—Zero Liquid Discharge Solutions. In V. V. Ranade & V. M. Bhandari (Eds.), Industrial Wastewater Treatment, Recycling and Reuse (pp. 489–520). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-08-099968-5.00013-1

Ahmed, M. T., Mustakim, K. N. E., Parvin, R., & Babar, S. A. (2025). Surface water quality of Balu River, Dhaka, Bangladesh. Research Square. https://doi.org/10.21203/rs.3.rs-5723330/v1

Ahmed, R. (2025). Major Current Environmental Problems in Bangladesh: Causes, Implications, and Citizen Solutions. AMPLITUDO : *Journal of Science and Technology Innovation, 4*(2), 118–124. https://doi.org/10.56566/amplitudo.v4i2.329

Alam, P., Islam, S. U., Naaz, D., Raina, Y., Mazhar, M. A., & Khan, A. H. (2024). Overview of Wastewater Treatment, Recycling, and Reuse. In Innovative and Hybrid Technologies for Wastewater Treatment and Recycling. CRC Press.

Amin, S. B., & Rahman, S. (2019). Urbanisation and Energy Linkages in Bangladesh. In S. B. Amin & S. Rahman (Eds.), Energy Resources in Bangladesh: Trends and Contemporary Issues (pp. 85–88). Springer International Publishing. https://doi.org/10.1007/978-3-030-02919-7_17

Bashar, T., & Fung, I. W. H. (2020). Water Pollution in a Densely Populated Megapolis, Dhaka. *Water, 12*(8), 2124. https://doi.org/10.3390/w12082124

Beni, A. A., Adel, M. S. S., Zaeimdar, M., Ghadi, A., Hassani, V., Jalalvandi, K., Abdollahi, S. A., Beni, A. A., Adel, M. S. S., Zaeimdar, M., Ghadi, A., Hassani, V., Jalalvandi, K., & Abdollahi, S. A. (2023). Petroleum Wastewater Treatment. In Sewage Management. IntechOpen. https://doi.org/10.5772/intechopen.109853

Bint-E-Basar, K. T., & Tasnim, K. S. (2024). ENVIRONMENTAL MANAGEMENT AND JUSTICE SYSTEM IN BANGLADESH: ISSUES AND LEGAL FRAMEWORK. *Journal of Asian and African Social Science and Humanities, 10*(1), 46–57. https://doi.org/10.55327/jaash.v10i1.322

Collivignarelli, M. C., Bellazzi, S., & Abbà, A. (2025). Circular Economy Applied to Sludge Minimization: The STAR Project. *Membranes, 15*(1), 15. https://doi.org/10.3390/membranes15010015

Damoah, B., Keengwe, S., Owusu, S., Yeboah, C., & Kekessie, F. (2023). The Global Climate and Environmental Protest: Student Environmental Activism a Transformative Defiance. *International Journal of Environmental, Sustainability, and Social Science, 4*(4), 1180–1198. https://doi.org/10.38142/ijesss.v4i4.734

Gulfam-E-Jannat, S., Golui, D., Islam, S., Saha, B., Rahman, S. M., Bezbaruah, A. N., & Iskander, S. Md. (2023). Industrial Water Demand and Wastewater Generation: Challenges for Bangladesh's Water Industry. *ACS ES&T Water, 3*(6), 1515–1526. https://doi.org/10.1021/acsestwater.3c00023

Halimuzzaman, H., Jaideep, Imam, M., Fahmida, Nahidul, M., Masrur, M., & Neherin, N. (2024). Healthcare Service Quality Digitization with Enterprise Resource Planning. *Journal of Angiotherapy, 8*(5), 1–11. https://doi.org/10.25163/angiotherapy.859716

Halimuzzaman, M., Sharma, J., Karim, M. R., Hossain, M. R., Azad, M. A. K., & Alam, M. M. (2024). Enhancement of Organizational Accounting Information Systems and Financial Control through Enterprise Resource Planning. In Synergy of AI and Fintech in the Digital Gig Economy. CRC Press.

Hussain, S., Aneggi, E., Trovarelli, A., & Goi, D. (2022). Removal of Organics from Landfill Leachate by Heterogeneous Fenton-like Oxidation over Copper-Based Catalyst. *Catalysts, 12*(3), 338. https://doi.org/10.3390/catal12030338

Jain, B., Singh, A. K., Kim, H., Lichtfouse, E., & Sharma, V. K. (2018). Treatment of organic pollutants by homogeneous and heterogeneous Fenton reaction processes. *Environmental Chemistry Letters, 16*(3), 947–967. https://doi.org/10.1007/s10311-018-0738-3

Jannah, N. (2023). HUBUNGAN ANTARA AIR LIMBAH RUMAH TANGGA DENGAN LINGKUNGAN HIDUP | ALADALAH: Jurnal Politik, Sosial, Hukum dan Humaniora. https://ejurnalqarnain.stisnq.ac.id/index.php/ALADALAH/article/view/552

Jivani, J., Srinivasarao, M., & Dhanwani, A. (2025). Modified sustainable water management strategy in batch process plants: A case study on reducing freshwater consumption. *Water Supply, 25*(2), 212–227. https://doi.org/10.2166/ws.2025.016

Kaur, R., & Sharma, M. (2025). Integrating Renewable Energy Solutions for Environmental Sustainability: Challenges, Opportunities, And Policy Implications. *International Journal of Latest Technology in Engineering Management & Applied Science, 14*(7), 483–486. https://doi.org/10.51583/IJLTEMAS.2025.1407000057

Kumar, A., Yadav, J., Vohra, R., Sebastian, A., Kumar, A., Yadav, J., Vohra, R., & Sebastian, A. (2024). Water and Wastewater Engineering (water-and-wastewater-engineering) [Chapter]. Https://

Services.Igi-Global.Com/Resolvedoi/Resolve.Aspx?Doi=10.4018/979-8-3693-1396-1.Ch002; IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-1396-1.ch002

Maiti, S., Kane, P., Pandit, P., Singha, K., & Maity, S. (2021). Chapter Nine—Zero liquid discharge wastewater treatment technologies. In S. S. Muthu (Ed.), Sustainable Technologies for Textile Wastewater Treatments (pp. 209–234). Woodhead Publishing. https://doi.org/10.1016/B978-0-323-85829-8.00006-7

Meneceur, S., Bouafia, A., Laouini, S. E., Mohammed, H. A., Daoudi, H., Chami, S., Hasan, G. G., Abdullah, J. A. A., & Salmi, C. (2023). Removal efficiency of heavy metals, oily in water, total suspended solids, and chemical oxygen demand from industrial petroleum wastewater by modern green nanocomposite methods. *Journal of Environmental Chemical Engineering, 11*(6), 111209. https://doi.org/10.1016/j.jece.2023.111209

Modi, R., Kavaiya, A. R., Vanzara, P. B., & Raval, H. D. (2022). Membranes in Zero-Liquid-Discharge Systems for Efficient Processes toward Sustainable Environment: A Review. *Journal of Environmental Engineering, 148*(11), 03122004. https://doi.org/10.1061/(ASCE)EE.1943-7870.0002040

Morinaga, A., Kijima, M., Katayama, Y., & Tsutsumi, H. (2023). Electrospun CuO–Fe3O4 Tube Catalyst for the Decomposition of Organic Matter via an Accelerated Heterogeneous Fenton-like Process. *The Journal of Physical Chemistry C, 127*(44), 21552–21560. https://doi.org/10.1021/acs.jpcc.3c05481

Obodovych, O. M., Sydorenko, V. V., Bulii, Y. V., & Stepanova, O. E. (2023). WASTEWATER TREATMENT OF THERMAL POWER PLANTS (TPP). *Thermophysics and Thermal Power Engineering, 45*(2), 69–76. https://doi.org/10.31472/ttpe.2.2023.8

Oral, N. (2024). A Stocktake of Ocean Governance Fifty Years after Stockholm: New Challenges for International Law. https://doi.org/10.1163/15718085-bja10192

Prado de Nicolás, A., Molina-García, Á., García-Bermejo, J. T., & Vera-García, F. (2023). Desalination, minimal and zero liquid discharge powered by renewable energy sources: Current status and future perspectives. *Renewable and Sustainable Energy Reviews, 187,* 113733. https://doi.org/10.1016/j.rser.2023.113733

Runtuwene, S. J., Pandelaki, V. M., Mandagi, J. J. J., Kembuan, R. J., & Kaeng, V. P. (2025). Power Generation Using Energy Friendly Renewables Milieu (Wind Energy). Cerdika: *Jurnal Ilmiah Indonesia, 5*(8), 2493–2500. https://doi.org/10.59141/cerdika.v5i8.2792

Sadulaeva, A. (2023). Evolution of the Global Environmental Agenda: Climate Change, Biodiversity Loss. *BIO Web of Conferences, 63,* 03015. https://doi.org/10.1051/bioconf/20236303015

Scholz, M. (2024). Chapter 3—Sewage treatment. In M. Scholz (Ed.), Wetlands for Water Pollution Control (Third Edition) (pp. 15–17). Elsevier. https://doi.org/10.1016/B978-0-443-13838-6.00003-3

Sohel, M. S., Shi, G., Zaman, N. T., Hossain, B., Halimuzzaman, M., Akintunde, T. Y., & Liu, H. (2022). Understanding the Food Insecurity and Coping Strategies of Indigenous Households during COVID-19 Crisis in Chittagong Hill Tracts, Bangladesh: A Qualitative Study. *Foods, 11*(19), 3103. https://doi.org/10.3390/foods11193103

Wang, C., Deng, S.-H., You, N., Bai, Y., Jin, P., & Han, J. (2023). Pathways of wastewater treatment for resource recovery and energy minimization towards carbon neutrality and circular economy: Technological opinions. *Frontiers in Environmental Chemistry, 4.* https://doi.org/10.3389/fenvc.2023.1255092

Wang, Y. (2016). Zero Discharge of wastewater Treatment Technology of Wet Desulfurization in Coal-fired Power Plants. 294–297. https://doi.org/10.2991/emcpe-16.2016.62