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Design of Zero Liquid Discharge Plant

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Abstract

The Zero Liquid Discharge (ZLD) process involves several stages, including pretreatment, evaporation, crystallization, and solid waste management. Pretreatment removes solids, oils, and contaminants from the wastewater. Evaporation applies heat to evaporate water, leaving behind concentrated brine or salts. Crystallization or membrane filtration further separates dissolved salts and minerals, ensuring the treated water meets required quality standards. Solid waste generated during the process is appropriately managed or repurposed.

Keywords: *Zero liquid discharge, Wastewater.*

1. Introduction

Zero Liquid Discharge (ZLD) is an advanced wastewater management approach that aims to eliminate the discharge of liquid waste from industrial or municipal facilities. It is a water treatment process designed to recover and reuse all the wastewater generated, leaving behind zero liquid waste for disposal [1]. ZLD systems employ a combination of various treatment technologies to achieve this goal. The ZLD process typically involves several stages, including pretreatment, evaporation, crystallization, and solid waste management. During pretreatment, the wastewater undergoes screening, filtration, and chemical treatment to remove solids, oils, and other contaminants. The pretreated water then enters an evaporation unit where heat is applied to evaporate the water, leaving behind concentrated brine or salts.

1.1. Objective

The goal of a Zero Liquid Discharge system is to reduce the volume of wastewater that requires further treatment, economically process wastewater, and produce a clean stream suitable for reuse. The ZLD system removes dissolved solids from the wastewater and returns pure water to the process [2-3].

1.2. Overview

A zero liquid discharge (ZLD) plant is a wastewater treatment system designed to eliminate all liquid waste discharge from an industrial process. ZLD plants use a combination of different treatment technologies to recover water for reuse and to treat and dispose of any remaining solid waste [4]. The main objective of a ZLD plant is to minimize the amount of liquid waste that needs to be discharged into the environment, which helps to protect natural water resources and reduce the environmental impact of industrial operations. ZLD plants are typically used in industries such as power generation, petrochemicals, and textiles, where large volumes of wastewater are generated and regulatory compliance is a concern. The ZLD process involves multiple stages of treatment, such as pre-treatment, filtration, evaporation, crystallization, and drying. The final product of a ZLD plant is usually a solid waste that can be disposed of safely or used as a raw material for other processes. ZLD plants can be expensive to build and operate, but they offer significant environmental benefits and can help companies meet regulatory requirements for wastewater management. Why Zero liquid discharge is important (ZLD)? Environmental Protection: ZLD plants help to protect natural water resources by eliminating the discharge of liquid waste into rivers, lakes, or oceans. This helps to prevent contamination of surface and groundwaters, which can have significant impacts on ecosystems and public health. Compliance with Regulations: In many countries, there are strict regulations regarding the discharge of wastewater from industrial processes. ZLD plants can help companies to comply with these regulations and avoid fines and legal actions. Resource Conservation: By recovering and reusing water from industrial processes, ZLD plants help to conserve water resources. This is particularly important in water-scarce regions where water is a valuable and limited resource [5]. Cost Savings: ZLD plants can be expensive to build and operate, but they can also lead to cost savings in the long run. By recovering and reusing water, companies can reduce their reliance on freshwater sources, which can be costly to obtain and transport. ZLD plants can also recover valuable materials from wastewater, such as minerals, which can be sold for additional revenue in Figure 1.

1.3. Different Methods Can be Used to Achieve ZLD

- Evaporation (Thermal process)
- Reverse osmosis (Membrane Technology)
- Ultra filtration (Membrane Technology)
- Electrolysis
- Membrane distillation

1.4. ZLD is Made Up of the Following Components

- Pre-treatment - ETP (physicochemical and Biological)
- RO/UF (membrane processes)
- Evaporator (thermal processes)

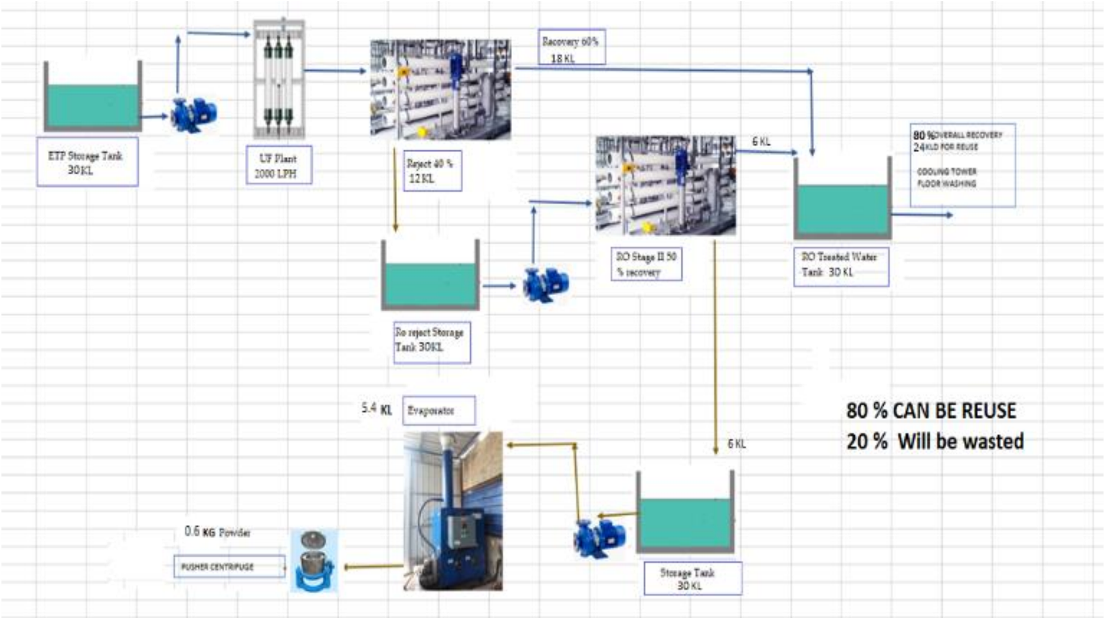

Figure 1 Process Flow Diagram for Zero Liquid Discharge

1.5. Points to be Considered for Design

- Wastewater Characteristics: The characteristics of the wastewater being treated, such as pH, temperature, flow rate, and contaminants, must be carefully analysed to select the appropriate treatment technologies and processes [6].
- The proposed design shall provide zero liquid discharge plant of 30 KLD capacity which will be consisting of ETP (bar screen chamber, equalization tank, Reaction tank (physic-chemical process), tertiary treatment filters and sludge dewatering unit), Ultrafiltration plant, Double stage RO Plant & Evaporator unit.
- The wastewater which is shall be utilized for

Flushing, gardening purpose, floor washing & cooling towers & industrial manufacturing process.

- The design must consider the overall cost of the system, including capital and operational costs, as well as the potential benefits of resource recovery, energy savings, and regulatory compliance.

2. Design of Zero Liquid Discharge System

Table1 Salient features of proposed project

Source of water	Trade Effluent
Total discharge	30,000, Litres
ETP designed	30 KLD capacity
Working hours	20 hrs./Day

Pre-treatment - ETP (physicochemical Process). As show in Table 1&2.

Table2 The Raw Effluent & Treated Effluent Quality as Per Norms

Parameters	ETP Inlet	ETP outlet
pH	11-12	5.5-9.0
Total Suspended solid	500-600	≤100
Total Dissolved solid	4000-5000	≤2100
Chemical Oxygen Demand	500-600	≤ 250
BOD	250-300	≤ 30
Oil and Grease	100-200	≤ 10
Chloride as Cl2	1000-1200	≤ 600
Sulphate as SO4	1500-2000	≤ 1000

2.1. Design of Bar Screen Chamber

The raw untreated effluent from various sources from plant will be collected in bar screen tank. The bar screen tank has an MS/SS Screen for trapping floating & large sized solids. This enables to remove the solids of more than 5 to10mm size ensuring that the downstream piping, equipment's are not clogged and choked.

Design flow = 3.0 m3/hr.
Assume the detention time = 0.25 hrs.
Volume of chamber = Flow x Retention Time
Volume = 3.0 m3/hr. X 0.25 hrs. = 0.750 M3
Size of Chamber:

2.2. Design of Oil & Grease Chamber

Design flow = 3.0 m3/hr.
Assume the detention time = 0.50 hrs.
Volume of chamber = Flow x Retention Time
Volume = 3.0 m3/hr. X 0.50 hrs. = 1.5 M3

2.3. Design of Collection Tank

The raw untreated effluent from the process will have varying flow and intermittent frequency, they always carry an unsteady load. To stabilize the flow and to maintain a constant pollutant load to the process, an equalization tank is proposed. The effluent free from floating solids and floating oil gets homogenized, providing a uniform load to the treatment system.

Maximum design flow 30 M3/day
Design flow = 3.0 m3/hr.
Assume the detention time = 10 hrs.
Volume of Tank = Flow x Retention Time
Volume = 3.0 m3/hr. X 10 hrs. = 30 M3
Size of tank

2.4. Design of Reaction Tank

The homogenized untreated effluent is then pumped into Reaction cum settling tank. The raw untreated effluent is flash mixed in an inbuilt chamber with a suitable coagulant and flocculants. Coagulation & Flocculation is a process by stirring to bring the suspended particles together so they will form larger more settles able clumps called flocs. At the end of the mixing/flocculation process, most of the turbidity and particulate matter in the water should be formed into a material called flocs. Flocs consists of relatively large clumps of impurities and bacteria bound together in clusters of about 0.1 to 3 mm in size. After Flocculation effluent from the flocculation chamber flows to settling tank. The flocs thus formed will aid easy settling and to be removed in the settling tank from the bottom as Sludge. The sludge is to be routed through gravity to the sludge drying beds. As we have a total effluent of 30,000 Lit/Day, time required for each batch for Physicochemical treatment (Neutralization, flocculation, & settling) will be 8-

10 Hrs. Total influent -30 M3 /Day for 20 Hrs.
1st Batch =15 M3/day for 10 Hrs
2 nd Batch = 15 M3/day for 10 Hrs
Design Flow = (Flow m3)/ (Time required for 1 batch hr.)
Design flow = 1.5 m3/hr.
Volume of Reaction Tank = Flow x Retention Time
Volume = 1.5 m3/hr. X 10 hrs. = 15 M3

3. Tertiary Treatment

3.1. Filtration System

The treated effluent is collected in a supernatant tank for further polishing though filtration process.

3.2. Pressure Sand Filter

The Clarified Water from supernatant tank is passed through a PSF which contains Sand & Pebbles as Media. The sand media enables to trap the particles more than 50-micron size, and treat the effluent to reduce the TSS load < 10 ppm to meet the discharge norms.

Pressure Sand Filter

Assuming 20 Hours of operation in a day average flow rate = 3.5 Cu.m / H
Considering one PSF with the period of filtration of 8-8.5 hrs/day
Filter type = Vertical type sand filter

Q = VA
Q= Flow
V= Velocity
A= Area
Area = flow/Velocity
Area = (3.5)/ (15)
Area = 0.233 m2
Area = π/(4) d2
0.233 = 0.784 d2
D = 0.545 m ≈ 0.600 m
Filter dia. = 0.6 m

Provide Filter size= 0.6 m dia. x 1.8 m ht – 1 nos

3.3. Activated Carbon Filter

The activated Carbon filter uses a bed of activated carbon to remove contaminants and impurities, using chemical adsorption. Each particle/granule of carbon provides a large surface area/pore structure, allowing contaminants the maximum possible exposure to the active sites within the filter media. Typical particle sizes that can be removed by carbon filters range from 0.5 to 50 micrometers. The carbon filter also helps in reducing the color & odor causing biological contaminants.

Assuming 20 Hours of operation in a day average flow rate = 3.5 Cu.m / H Considering one ACF with the period of filtration of 8-8.5 hrs./ day
Filter type = Vertical type carbon filter

Q = VA
Q= Flow
V= Velocity
A= Area
Area = flow/Velocity
Area = (3.5)/ (15)
Area = 0.233 m2
Area = π/ (4) d2
0.233 = 0.784 d2
D = 0.545 m ≈ 0.600 m
Filter dia. = 0.6 m

Provide Filter size= 0.6 m dia. x 1.8 m ht – 1 nos

3.4. Sludge Dewatering System

Design throughput flow 30 KLD Quantity of sewage to be
Design BOD removal 30 kg/day = 30 KLD x 450 mg/L
= 30000 L/day x 0.000450 kg/L
= 13.5 kg/day
Excess Sludge produced = 13.5x 0.25= 3.375 kg/day
Dry weight basis, 0.25 kg of excess sludge per kg of BOD)
Proportion of solids in the cake = 25% = 0.25
Sludge cake volume = 3.375/0.25 = 13.5 L.

4. Ultrafiltration Unit

Ultrafiltration (UF) is a key component of Zero Liquid Discharge (ZLD) systems, which are designed to eliminate liquid waste streams and recover clean water for reuse. When selecting an ultrafiltration unit for a ZLD system, here are some criteria to consider:

Membrane Material: Select an ultrafiltration membrane material that is suitable for the feed water quality and operating conditions. Common UF membrane materials for ZLD systems include polyether sulfone (PES), polyvinylidene fluoride (PVDF), and polysulfide (PS).

Pore Size: UF membranes are available with different pore sizes. For ZLD systems, select a UF membrane with a pore size that can effectively remove suspended solids, colloids, and other impurities from the feed water.

Flux Rate: The UF membrane flux rate is the amount of water that can be treated per unit area of membrane per unit of time. Select an ultrafiltration unit with a high flux rate to minimize the footprint of the ZLD system.

Cleaning System: UF membranes require regular cleaning to maintain their performance. Select an ultrafiltration unit with an effective cleaning system that can remove fouling and prevent membrane damage.

Operating Conditions: The operating conditions of the UF unit, including temperature, pressure, and pH, must be compatible with the feed water quality and the ZLD system design.

Energy Efficiency: Select an ultrafiltration unit with high energy efficiency to minimize operating costs and reduce the environmental impact of the ZLD system in Figure 2.

Figure 2 Ultrafiltration

4.1. Design Basis for Ultrafiltration Unit

Design Basis

Input: 30, OOO Lit

Working Hours: 15 Hrs

Flow Rate: 2 m3/hr

Reverse osmosis (RO) is a critical component of many Zero Liquid Discharge (ZLD) systems, which are designed to eliminate liquid waste streams and recover clean water for reuse. When selecting an RO plant for a ZLD system, here are some criteria to consider:

Feed Water Quality: The quality of the feed water is one of the most important criteria to consider when selecting an RO plant for a ZLD system. The feed water should be analyzed to determine the presence of contaminants such as salts, minerals, and dissolved solids, and the RO plant should be designed to remove these impurities.

Recovery Rate: The recovery rate of the RO plant is the percentage of feed water that is converted into treated water. The recovery rate of the RO plant should be optimized to reduce the volume of wastewater generated by the ZLD system.

RO Membrane Material: Select an RO membrane material that is compatible with the feed water quality and operating conditions. Common RO membrane materials for ZLD systems include cellulose acetate, thin film composite (TFC), and aromatic polyamide.

RO Membrane Configuration: The configuration of the RO membrane elements can have a significant impact on the performance and energy efficiency of the RO plant. Consider the design of the RO membrane elements, including the number of stages, the diameter and length of the elements, and the type of element connections.

Energy Efficiency: The energy consumption of the RO plant is a significant operating cost of the ZLD system. Select an RO plant with high energy efficiency to minimize operating costs and reduce the environmental impact of the ZLD system.

Pretreatment System: RO membranes require pretreatment to remove suspended solids, bacteria, and other impurities that can foul the membranes. Select an RO plant with an effective pretreatment system that can reduce fouling and extend the life of the RO membranes.

Maintenance and Monitoring: The RO plant should be designed for ease of maintenance and monitoring, with features such as automated cleaning cycles, remote monitoring, and diagnostic tools to identify and resolve performance issues.

The working of an RO plant involves several stages, including pre-treatment, RO filtration, and post-treatment. Here is a brief overview of each stage:

Pre-Treatment: The pre-treatment stage involves the removal of suspended solids, organic matter, and other impurities from the feed water to prevent fouling and damage to the RO membrane. Pre-treatment may involve processes such as filtration, sedimentation, and chemical treatment.

RO Filtration: The RO filtration stage involves the use of a semi-permeable membrane to remove dissolved solids, bacteria, and other contaminants from the water. The membrane acts as a physical barrier that allows only water molecules to pass through while blocking the passage of dissolved salts and other impurities.

Post-Treatment: The post-treatment stage involves the final polishing of the water to remove any remaining impurities and adjust its pH and mineral content to meet the desired specifications. Post-treatment may involve processes such as demineralization, pH adjustment, and disinfection.

4.2. Design Basis for RO Plant

In a Reverse Osmosis (RO) plant, several streams of water are produced during the treatment process.
These include:

- Feed water: This is the raw water that is supplied to the RO plant for treatment.
- Permeate: This is the purified water that passes through the RO membrane and is collected as product water.
- Reject or concentrate: This is the water that does not pass through the RO membrane and is discharged from the plant. It contains high levels of dissolved solids, salts, and other contaminants.
- Recirculation water: This is the water that is used to clean the RO membranes during the backwashing process. It is recirculated through the RO system to remove accumulated debris and fouling materials.

The calculation of each of these streams is important for the proper operation and maintenance of an RO plant in Figure 3. The following equations are commonly used to calculate these streams:

Permeate flow rate = Feed flow rate - Reject flow rate
Recovery rate = (Permeate flow rate ÷ Feed flow rate) x100%
Reject rate = (Reject flow rate ÷ Feed flow rate) x 100%
Concentration factor = (Feed TDS ÷ Permeate TDS) - 1
Total input to the RO plant per day: 30 M3
Working Hours: 15 Hrs
TDS: 3000 mg/lit
Flow Rate: (Total Input)/ (Working hours)
Flow = (30 m3)/ (15 Hrs)
Flow = 2.0 m3/hr

4.3. The 1st Stage RO will be Considered the Capacity of 2000 LPH

% Recovery = (Output)/(Input) x 100
The recovery from the 1st stage will be 60 %
Feed Water = 30000 Lit ≈ 30 KL
Permeate from 1st Stage RO = 18 KL
% Recovery = (Output)/(Input) x 100
% Recovery = (18)/(30) x 100 = 60 %
Reject from 1st Stage RO = 12 KL
% Reject Recovery = (12)/(30) x 100 = 40%
Permeate TDS = <100

4.4. The 2nd Stage RO will be Considered the Capacity of 1000 LPH

% Recovery = (Output)/ (Input) x 100
The recovery from the 2nd stage will be 50 %
Feed Water = 12000 Lit ≈ 12 KL
Permeate from 2nd Stage RO = 6 KL
% Recovery = (Output)/(Input) x 100
% Recovery = (6)/(12) x 100 = 50 %
Reject from 1st Stage RO = 6 KL
% Reject Recovery = (6)/(12) x 100 = 50%
Permeate TDS = <250

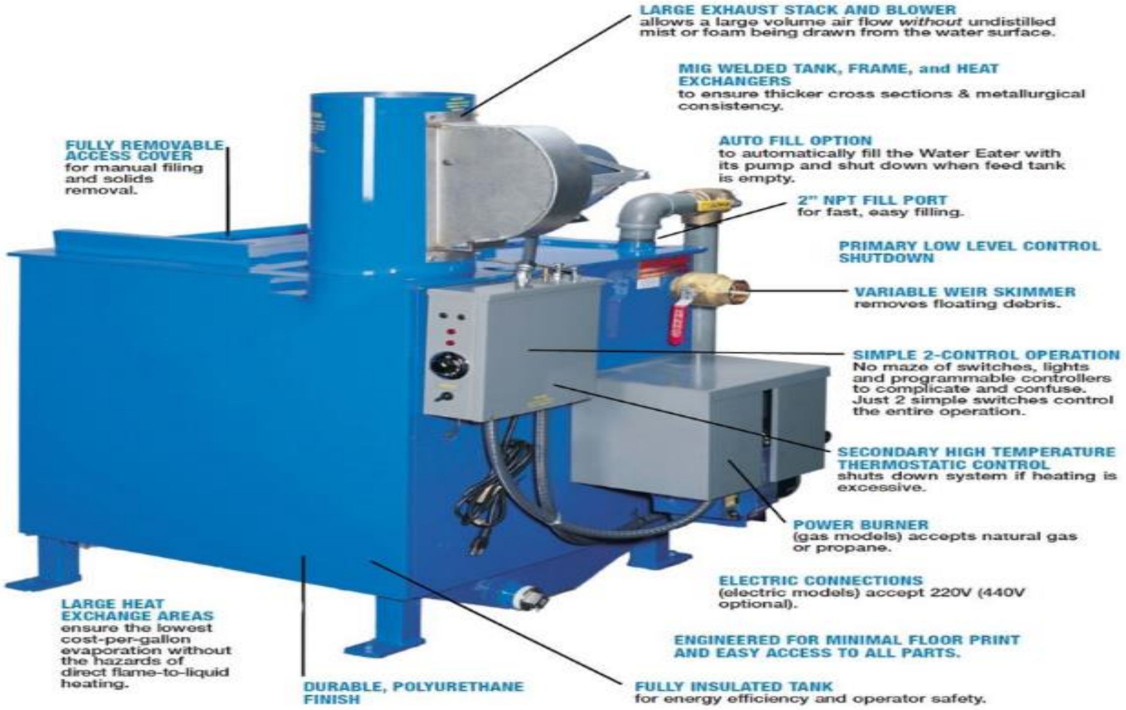

Figure 3 Final Reject Water from the 2nd Stage RO will be Sent to the Evaporator

4.5. Design Basis:

Rejected water from the 2nd stage RO – 6000 Lit
Evaporator Capacity: 6000 lit
Water evaporation rate: 400 ltr/hr
Operating Hours: 15 hours
Capacity of evaporator: 6000 litres
Composition: TDS 1% to 2%, water 98-99%
Output product composition: TDS- 80% and Water-20%
Source for heating: Electric Heater
Power Required: 2507 KW/day
Operating Temperature: 110-120 ℃
Operating Pressure: Atmospheric pressure
Efficiency of evaporator = (water evaporated)/(Feed) x100
Efficiency of evaporator = 5.4/6 x100 = 90 %
0.6 KG of Salts in the form of slurry will be sent to the Centrifuge for drying purpose.

4.6. Centrifuge Machine (drying)

As the concentrate moves through the centrifuge machine, the heavier solids are forced towards the outer edge of the centrifuge, while the lighter water is forced towards the center. The separated water is then collected and reused in the industrial process, while the solids are removed from the machine and disposed of or further treated in Figure 4.

Figure 4 Centrifuge Machine (drying)

The use of centrifuge machines in ZLD systems can significantly reduce the amount of waste generated by industrial processes, and it is an essential step towards achieving a more sustainable and environmentally friendly operation. Centrifuge machines can handle large volumes of wastewater and can achieve high levels of separation efficiency, making them ideal for ZLD applications. Capacity of drum: 75 lit, 600 Kg of salts will be removed in the Form of dry powder.

Conclusions

The installation of ZLD plant provides sustainable environmental, social and economic benefits. It demonstrates the industry's commitment to sustainable practices, responsible resource management and compliance with regulations. By designing the ZLD plant industry can minimize water consumption and eliminate liquid waste discharge by maximizing water reuse and resource recovery.

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