International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.9, No.11 pp 80-86, 2016

Zero Liquid Discharge (ZLD) Industrial Wastewater Treatment System

Ashok Kumar Popuri[1,3]*, Prashanti Guttikonda[2]

[1]VFSTR University, Vadlamudi, Guntur (Dist), Andhra Pradesh, India.
[2]VLITS, Vadlamudi, Guntur (Dist), Andhra Pradesh, India.
[3]S.V.U. College of Engineering, S.V. University, Tirupati, Chittoor (Dist), Andhra Pradesh, India.

Abstract : The goal of a well-designed Zero Liquid Discharge (ZLD) system is to minimize the volume of liquid waste that requires treatment, while also producing a clean stream suitable for use elsewhere in the plant processes. A common ZLD approach is to concentrate (evaporate) the wastewater and then dispose of it as a liquid brine, or further crystallize the brine to a solid. The evaporated water is recovered and recycled while the brine is continually concentrated to a higher solids concentration. The effluents are desired to be treated to meet the regulatory limits. Basically the levels of COD and total suspended solids are to be reduced to acceptable values given by the Pollution Control Board and pH to neutral. Treated water can be reused for activities such as gardening, boiler feed, etc. and the removed waste is classified as organic and inorganic waste and treated accordingly. Other by-products during treatment, such as hydro carbons, lead etc. are used or sold according to the need of the industry. Other than the necessity of meeting the pollution control board norms, treating the wastewater helps in reusing tons of water within the industry and not wasting a single drop and hence it is called Zero Liquid Discharge. The role of engineer in Zero Liquid Discharge plant is to optimize operating cost, to increase steam economy and to increase solvent recovery. In this work, equipment design is carried out to scale up 100 kl capacity plant to 300 kl capacity.
Keywords : ZLD, wastewater, volatile organic compounds, steam economy, process equipment design.

1. Introduction

1.1 Industrial Wastewater Treatment

Industrial wastewaters include those arising from chemical, pharmaceutical, electrochemical, electronics, petrochemical and food processing industries. Pharmaceutical industrial wastewater classified into low TDS and high TDS water. In low TDS water, TDS is less than 5000 ppm and in high TDS water it is greater than 5000 ppm. Low TDS water is subjected to primary-secondary-tertiary treatments. High TDS water is subjected to primary treatment and sent it to stripping column-MEE-agitated thin film dryer to change to low TDS water. The permit from tertiary treatment is sent to RO feed tank. The reject from RO plant is sent to high TDS feed tank and the permit from RO plant is reused in boiler[1-3].

1.2 Treatment Process

On the basis of total dissolved solids (TDS) concentration and chemical oxygen demand, the effluent is segregated as low TDS effluent (TDS should be less than 5000 mg/l and COD should be less than 15000 mg/l) and high TDS effluent (TDS above 5000 mg/l and COD above 15000 mg/l). High TDS water is subjected to primary treatment, then sent to stripping column, multiple effect evaporators, and agitated thin film dryer to change to Low TDS water. Low TDS water is subjected to primary, secondary and territory treatments, and then sent to RO plant.The permit water from RO plant is reused in boilers and reject water is sent back to high TDS holding tank[4-6].

1.3 High TDS Treatment

Transfer high TDS effluent from the high TDS pits at production area to high TDS equalization or neutralization tank at the effluent treatment plant. At ETP, high TDS effluent is collected in equalization tank, where effluent equalization is performed using a dry 10 HP surface floating aerator. Equalization pH should be 6.5-7.0, otherwise adjust the pH by dosing with acid or alkali. Collect sample and send it to the ETP lab for analysis of pH, TDS, TSS and COD. After neutralization, effluents are transferred to the flash mixer, where alum, polyelectrolyte solution is added for separation of suspended solids. Formation of flocks is carried out in flocculation tank.Overflow of the flocculation tank enters the primary clarifier, where suspended solids are settled down at the bottom of the clarifier and the clarifier overflow collected into the holding tank. Effluent is pumped from holding tank to stripper column, by passing through the pressure sand filter or press pressure filter and followed by sparkler filter for the removal of suspended particles.Further treatment at stripper column, from there to MEE and finally to agitated thin film dryer. Liquid filtrate is sent back to the high TDS equalization tank. Solid waste is collected in the HPDE and sent to the storage[7-9].

1.4 Low TDS Treatment

Check the pH and TDS of the effluent before sending it to the low TDS equalization/ neutralization tank at ETP. If TDS is >5000 mg/l and COD is >15000 mg/l send the effluent to high TDS or else to low TDS. Collect the MEE condensate water and ATFD condensate water into equalization cum neutralization tank. Run the JET mixture pumps continuously for unique equalization characteristics of effluent[10-12].

1.5 Primary Treatment for Low TDS

Inspect the tank for any floating solids in the tank, if so, take it out. Run the JET mixture pumps for 24 hours to set the effluent unique characteristics for the MEE condensate, ATFD condensate and low TDS from the production. pH value should be maintained at 6.0 to 6.5 by dosing with acid or alkali.Run the JET mixture pumps for three hours to set the pH to neutral. Check for pH analysis; if it passes the results then transfer the low TDS effluent into lamella. Check the level of alums and poly electrolyte in the holding tank and transfer lines to avoid the leakages and spillage. Check the working condition for the closing pumps for alum and polyelectrolyte.While transferring low TDS effluent from equalization cum neutralization tank into lamella add alum and poly electrolyte solution for the separation of colloidal and suspended particles. Adjust the flow rate of the transfer and dosing pumps so that the colloidal and suspended particles should be settled at the lamella clarifier and overflow of effluent should be fallen into aeration tank-1. Transfer continuously with constant flow rate to the lamella.In the aeration tank-1 aerators should be run 24 hours to bestow oxygen continuously to the effluent. Overflow of the aeration tank-1 enters into the primary clarifier where suspended solids are settled down at the bottom of the clarifier and clarifier overflow is collected in the aeration tank-2. Continuously run the bottom clarifier pump to remove the bottom sludge which is to be transferred into aeration tank-1, if required; otherwise send it to decanter to remove the solid and liquid separation[13-15].

1.6 Secondary Treatment for Low TDS

In aeration tank-2, aerators should run for 24 hours to bestow oxygen continuously to the effluent. Send the sample to the lab for analysis and check the pH, TDS, COD and MLSS/MLVSS in the aeration tank-2.Clarifier agitator and bottom clarifier pump should run continuously as to remove the bottom sludge which is to be transferred into aeration tank-2, if required otherwise send to decanter feed holding tank and to decanter to remove solids and liquid separation. Overflow of the aeration tank-2 enters the secondary clarifier where suspended solids settle down at the bottom of the clarifier and its overflow is collected in the intermediate sump tank[16-18].

1.7 Territory Treatment for Low TDS

The effluent from sump tank is sent to pressure sand filter (PSF) to remove dissolved salts. The permit from PSF is sent to activated carbon filter to remove free chlorine, organic matter, and color present in water, then sent to RO feed tank. From RO plant the permit water is reused for boiler and reject is sent back to high TDS holding tank. Rejected water is again subjected to the same treatment process as earlier studied[19-21].

2. Experimental

2.1 Operating Procedure of Stripper Column

Start the cooling water pump, treated effluent transfer pump, feed pump and keep the feed rate to the stripping column constant. After reaching 70% level in the kettle, stop the feed pump. Open the steam value (steam pressure should be 1.0-1.5 kg/cm²) to the reboiler and drain the condensate water by opening the bypass valve. After removal of the condensate water close the condensate bypass valve.Collect the top condensate in the collection receiver. Start the feed pump and keep the required feed rate by adjusting the flow meter. Start the stripper bottom pump and transfer the bottom with required flow rate. Collect the condensate in the collection receiver up to 50% of the level. Start the reflux and collection pump. Keep 75% flow rate as reflux and 25% as collection. Maintain the kettle and top vapour temperature around 105 ± 2^0C and 85 ± 5^0C respectively[22].

2.2 Operating Procedure of Multiple Effect Evaporator

Start cooling water pump, treated effluent feed pump and fill the effluent in the phase separator (PS-I) up to the 50% of the view glass. Start recirculation pump-I, effluent treatment pump-I and transfer the effluent from PS-I to PS-III and fill the 50% of the view glass. Start the recirculation pump-III, ETP-III and transfer the effluent from PS-III to PS-I and maintain the 50% of the view glass. Recirculate the effluent by maintaining the levels in the phase separators.Start the vacuum pump and maintain vacuum up to 600-650 mmHg. Open the steam valve and keep the steam pressure 1.5-2.0 kg/cm² and temperature < 85^0C. Collect the vapour condensate in the vapour condensate collection receiver and feed the effluent simultaneously. Send the MEE concentration, mass and vapour condensate samples to ETP lab for analysis. When the MEE concentration mass is around 2 lakh ppm start collecting the concentrated mass to storage tank. Start the pump to transfer the condensate H_2O to LTDS neutralization tank. Stop the recirculation pumps[23].

2.3 Operating Procedure of Agitated Thin Film Dryer (ATFD)

Start the cooling water pump. Keep the interlock switch in “ON” position. Open the steam to the top and bottom jacket of the dryer and drain the condensate water by opening the by-pass valve, after removal of the condensate water close the condensate by-pass valve.Start the air blower then the agitator. Start the feed rate 300-500 l/hr to the dryer when the vapour temperature reaches 95^0C. Collect the vapour condensate in the low TDS collection tank using pump. Check the pH, TDS of vapour condensate and water content in the solid waste collected at the bottom and record the same. Collect the solid material and transfer to the hazardous waste storage shed[24].

2.4 Operating Procedure of Reverse Osmosis Plant

Treated effluent is collected in the storage tank for further treatment. Send the sample to the lab for checking of pH, TDS, COD and TSS to meet the operating properties of the RO plant feed. Adjust the pH of the effluent to 6.5 prior to feed in the system. Clean all the filter cloths and cartridges before starting the system. When pressure increases gradually the effluent separates as permeates and reject. Permeates and reject are collected in respective tanks. Send to lab to meet the output specifications. Otherwise send the permeate water to RO feed plant for further treatment and record the analysis[25].

3. Results

- The stripper and multiple effect evaporators (MEE) are used for treating high total dissolved solids.
- The condensate from MEE and condensate from the utilities are collected on day to day basis and analysed, where various methods are applicable for the reduction of the organic content present in the effluent waste by filtration, aerobic degradation electrochemical treatment and biological methods.
- These methods can reduce the COD up to 80-90% in the effluents.
- On daily observations it has been noticed that

Equipment	P^H	TDS (ppm)	COD (ppm)
Equalisation Tank-1	6.67	24400	75164
Equalisation Tank-2	6.98	59450	95735
Clarifier	6.41	40700	93362
Stripper Distillate	8.43	6550	533016
MEE Condensate	9.27	876	37186
ATFD Condensate	7.41	6134	66461
RO Feed	6.82	6152	5459
RO Reject	6.93	14012	10681
RO Permit	5.94	74	198

- These methods contribute to better environmental conditions which can be easily maintained and very economical.
- The effluent water reduced in COD, BOD, TSS and TDS content can be recycled to different utilities.
- In this plant the treated water is used only for boiler.

Theoretical Results:

Feed flow rate: 300 kl/day
Input: TDS - 100000 ppm - 30000 l/day - 1250 kg/hr
COD – 130000 ppm - 39000 l/day - 1282 kg/hr
Output: TDS - 0 (as 100% collected at ATFD bottom)
COD - 70 kg/hr remains in stripper bottom

Process equipment design results:

Stripping column

Height-9.5 m
Diameter-0.85 m
No. of trays-20
Plate spacing-0.45 m

Multiple effect evaporators

No of stages-3

Stage -1

Area-170 m^2
No. of tubes N_t-232
Diameter-650 mm

Stage-2

Area-145 m^2
No. of tubes Nt-194
Diameter-600 mm

Stage-3

Area-150 m^2
No. of tubes Nt-200
Diameter-600 mm

Agitated thin film dryer

Area-76.8 m^2

Cooling tower capacity

For stripper condenser-115 TR
For MEE condenser-360 TR
For ATFD condenser-230 TR
Total-705 TR

Utility line sizing
For stripper condenser-5 inch
For MEE condenser-9 inch
For ATFD condenser-7 inch

Energy consumptions
Steam used in stripping column-1022 kg/hr
Steam used in MEE-2836 kg/hr
Steam used in ATFD-1420 kg/hr

Steam economy in MEE
Total evaporation-8470 kg/hr
Total steam consumed-2836 kg/hr
MEE economy-2.98
Steam economy in overall ZLD
Total evaporation-10910 kg/hr
Total steam used-5278 kg/hr
Economy-2.06

Comparison of existing 100 kl plant with theoretical 300 kl plant design

Process equipment	Existing 100 kl	Theoretical 300 kl
Stripper column		
Height	7 m	9.5 m
Diameter	600 mm	850 mm
Evaporation	405 kg/hr	1211 kg/hr
Steam consumed	450 kg/hr	1022 kg/hr
Multiple effect evaporator		
Stages	3 stages	3 stages
Evaporation	2725 kg/hr	8470 kg/hr
Total area	200 m^2	460 m^2
Steam consumed	1880 kg/hr	2836 kg/hr
Steam economy	1. 45	2. 98
Agitated thin film dryer		
Area	30 m^2	77 m^2
Evaporation	450 Kg/hr	1250 Kg/hr
Steam consumption	670 kg/hr	1420 kg/hr
Cooling tower capacity	500 TR	760 TR

4. Discussion

The present investigation is directed towards the study of wastewater treatment in the angle of continuous improvement and confirming to the norm prevailing as per the national standards. This cost effective treatment leading to further reduction of COD, BOD, TDS, and SS and make use of the treated water for hygienic appellation such as agriculture, washing, and gardening.

From the experimental study

- The process requires up-gradation of secondary stripping column for 100% recovery of solvents.
- Reduces volatile organic compounds (VOC) which causes obnoxious smell in the entire plant area. This can be done by keeping the effluent in an enclosed space and the vapours are burnt to reduce VOC.
- In ZLD treatment plant cooling tower water is contaminating due to usage of barometric condenser for the purpose of vacuum creation by condensing MEE 3rd stage vapours. This problem is overcome by using external vacuum pump connected to shell and tube condenser to create vacuum and parallelly condensing 3rd stage vapours.

References

1. Suguna P. Industrial Waste Water Management-Zero Liquid Discharge System. International Journal of Commerce, Business and Management, 2016, 5(2): 332-349.
2. Ashok Kumar Popuri, Ramesh Naidu Mandapati, Bangaraiah Pagala, Prashanti Guttikonda. Color Removal from Dye Wastewater using Adsorption. International Journal of Pharmaceutical Sciences Review and Research,2016,39(1): 115-118.
3. Marimuthu KN, Ruby Thomas, Yamini B, Bharathi S, Murugavel K. Water Pollution due to Dying Effluents in Noyyal River, Tirupur-A Case Study, International Journal of ChemTech Research, 2015, 7(7): 3075-3080.
4. Ashok Kumar Popuri, Prashanti Guttikonda. Sequestering Nickel (II) Ions from Aqueous Solutions using UlvaLactuca as a Low Cost Sorbent. Research Journal of Pharmacy and Technology, 2016, 9(1): 49-52.
5. Natthapong Sueviriyapan, Uthaiporn Suriyapraphadilok, Kitipat Siemanond, Alberto Quaglia, Rafiqul Gani. Industrial Wastewater Treatment Network Based on Recycling and Rerouting Strategies for Retrofit Design Schemes. Journal of Cleaner Production, 2016, 111(A): 231–252.
6. Ashok Kumar Popuri, PrashantiGuttikonda. Removal of Toxic Metal Chromium(VI) from Industrial Wastewater using Activated Carbon as Adsorbent. Journal of Chemical and Pharmaceutical Research, 2015, 7(12): 78-83.
7. SudarshanKumarasamy, Kotteeswaran P, Murugan A. Treatment of Activated Sludge Lagoon Inlet Wastewater in Pulp and Paper Industry. International Journal of ChemTech Research, 2016, 9(7): 318-323.
8. Ashok Kumar Popuri, PrashantiGuttikonda. Use of Agricultural Waste (Fly Ash) for Removal of Nickel Ions from Aqueous Solutions. Research Journal of Pharmacy and Technology, 2015, 8(12): 1665-1668.
9. SengodagounderRajamani. Novel Industrial Wastewater Treatment Integrated with Recovery of Water and Salt Under a Zero Liquid Discharge Concept. Reviews on Environmental Health, 2016, 31(1): 63–66.
10. Ashok Kumar Popuri, Prashanti Guttikonda. Removal of Nickel(II) using Fly Ash as Adsorbent. International Journal of Pharmaceutical Sciences Review and Research**,** 2015, 35(2): 107-109.
11. Chandrakanth G, Srimurali M, Vivek Vardhan CM. A Study on Domestic Wastewater Treatment by Pilot-Scale Constructed Wetlands. International Journal of ChemTech Research, 2016, 9(6): 376-383.
12. Ashok Kumar Popuri, Prashanti Guttikonda. Removal of Nickel(II) using Lotus Stem Powder as Adsorbent. Journal of Chemical and Pharmaceutical Research, 2015, 7(10): 621-625.
13. Tiezheng Tong, Menachem Elimelech. The Global Rise of Zero Liquid Discharge for Wastewater Management: Drivers, Technologies, and Future Directions. Environmental Science & Technology, 2016, 50: 6846−6855.

14. Ashok Kumar Popuri, Prashanti Guttikonda. Treatment of Textile Dyeing Industry Effluent using Activated Carbon. International Journal of Chemical Sciences, 2015, 13(3): 1430-1436.
15. Shamsa Al Sadi, Feroz S, Nageswara Rao L. Treatment of Industrial Wastewater by Solar Nano Photocatalysis. International Journal of ChemTech Research, 2015, 8(7): 177-182.
16. Ashok Kumar Popuri, Prashanti Guttikonda. Treatment of Textile Dyeing Industry Effluent using Activated Carbon Prepared from Agriculture Waste (Sawdust). Research Journal of Pharmaceutical, Biological and Chemical Sciences, 2015, 6(4): 1165-1175.
17. Dalan JA. 9 Things to Know About Zero Liquid Discharge. Chemical Engineering Progress, 2000, 96(11): 71-76.
18. Ashok Kumar Popuri, Hemalatha.V. Adapa, Bangaraiah Pagala. Treatment of Textile Dyeing Industry Effluent using Coagulation Technique. International Journal of Pharma and Bio Sciences, 2015, 6(3):(B): 1006-1019.
19. Valliammai S, Nagaraja KS, Jeyaraj B. Removal of Acid Blue 113 Dyes from Aqueous Solution by Activated Carbon of Varagu Millet Husk: Equilibrium, Kinetics and Thermodynamic Studies, International Journal of ChemTech Research, 2015, 8(12): 329-341.
20. Ashok Kumar P, Prashanti G.Removal of Phenol from Wastewater using Tamarind Nut and Commercial Activated Carbons. International Journal of Chemical Sciences, 2015, 13(1): 257-264.
21. Heijman SGJ, Guo H, Li S, Van Dijk JC, Wessels LP. Zero Liquid Discharge: Heading for 99% Recovery in Nanofiltration and Reverse Osmosis. Desalination, 2009, 236(1-3): 357-362.
22. Popuri Ashok Kumar, Pagala Bangaraiah. Treatment of Effluent from Dyeing Industry using Adsorption Technique. International Journal of Pharma and Bio Sciences, 2014, 5(3B): 368-375.
23. Alexander Robertson, Long Duc Nghiem. Treatment of High TDS Liquid Waste: Is Zero Liquid Discharge Feasible?. Journal of Water Sustainability, 2011, 1(2): 1-11.
24. Ashok Kumar Popuri, Bangaraiah Pagala. Color Removal From Dye Effluent By Using Coagulation Technique. International Journal of Pharma and Bio Sciences, 2013, 4(4B): 1091-1099.
25. Chun Deng, Xiao Feng, JieBai. Graphically Based Analysis of Water System with Zero Liquid Discharge. Chemical Engineering Research and Design, 2008, 86(2): 165-171.

*****