Open Access
Volume 4 Issue 3
Research Article

Journal of Water Engineering and Management
ISSN: 2582-6298

Techno-Economic Evaluation of Converting a Tannery CETP into a Zero Liquid Discharge (ZLD) System

Vijay Bassan[1], Arpan Herbert[1]

[1]Vaugh Institute of Agricultural Engineering and Technology, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, U.P., India

Article Info

Article History:
Received: August 25, 2023
Revised: September 20, 2023
Accepted: November 10, 2023
Published: December 31, 2023

Corresponding author: Arpan Herbert

Email: arpan.herbert@shuats.edu.in

How to Cite:
Bassan, V. and Herbert, A. 2023. Techno-Economic Evaluation of Converting a Tannery CETP into a Zero Liquid Discharge (ZLD) System. Journal of Water Engineering and Management 4(3): 1-6 DOI: https://doi.org/10.47884/jweam.v4i3pp01-06

Abstract

Tannery wastewater is one of the most challenging industrial effluents to treat due to its high organic load, dissolved solids, and toxic metal content. This study evaluates the performance of the 20 MLD Common Effluent Treatment Plant (CETP) at Uttar Pradesh, which treats effluent generated from the local leather cluster. The plant incorporates a multi-stage treatment system comprising primary, secondary, and tertiary units, designed to ensure compliance with environmental discharge norms. Influent and effluent samples were collected from critical treatment points and analyzed for key physicochemical parameters including pH, COD, BOD, TSS, TDS, and chromium. The results indicate that the CETP effectively reduces about 90–94% of COD, 85–90% of BOD, and over 95% of TSS through successive stages of coagulation, biological oxidation, and filtration. While pH and suspended solids remain within permissible limits, the final TDS levels exceed discharge standards, highlighting the need for advanced tertiary measures such as reverse osmosis or zero liquid discharge (ZLD) systems. The study concludes that the 20 MLD CETP demonstrates stable and efficient operation, substantially improving tannery wastewater quality and offering a replicable model for sustainable industrial effluent management.

Keywords: CETP: Tannery wastewater: Jajmau: Treatment efficiency: Industrial effluent: ZLD.

Introduction

"Water is the driving force of all nature," remarked Leonardo da Vinci, one of history's greatest artists and thinkers. Indeed, without water there would be no blue, no green, and no life on Earth. Water is indispensable in every aspect of human existence - from food production, household use, and gardening to industrial activities, energy generation, and manufacturing. However, the availability of freshwater has become a critical global concern due to poor wastewater management, ecological degradation, and industrial effluent discharge, all of which severely pollute this vital natural resource. In recent decades, industrial contamination of water resources has emerged as a serious hazard, threatening ecosystems and human health. In many developing countries, industries remain major sources of water pollution due to outdated technologies and inadequate wastewater treatment facilities. Financial constraints often prevent industries from adopting modern treatment systems, resulting in the direct discharge of untreated or partially treated effluents into surface and groundwater systems. Such practices have led to the progressive deterioration of groundwater quality, posing significant risks to drinking water safety and agricultural sustainability. In India, nearly 80% of the rural and urban population depends on groundwater for drinking purposes, making water quality a crucial public health concern. However, the uncontrolled release of industrial effluents, domestic sewage, and solid waste has resulted in widespread groundwater contamination.

A 1995 survey by the Central Pollution Control Board (CPCB) reported that groundwater pollution had reached critical levels in many parts of the country, with industrial effluents identified as the primary cause. The rapid and unplanned industrialization across India has further exacerbated the problem, pushing water quality in several regions to near-crisis levels.

One of the most affected regions is Kanpur, Uttar Pradesh, located in northern India near the international boundary with Nepal. Kanpur is a well-known industrial hub, hosting a wide range of industries including agro-based units, cotton hosiery, textiles, jute, soap and detergent manufacturing, paints, and allied sectors. The city is globally recognized as the "Leather City of the World", owing to its dense cluster of tannery industries. These tanneries consume large volumes of groundwater and discharge equally large volumes of wastewater, often without adequate treatment, resulting in severe environmental pollution. Recognizing the issue, regulatory authorities have initiated stringent measures to control effluent discharge. Under the National Mission for Clean Ganga (NMCG), An Tannery Effluent Treatment Association is implementing a 20 MLD Common Effluent Treatment Plant (CETP) in Kanpur. The facility includes tertiary-level treatment with ultra-filtration in its first phase, with provisions for an additional modular reverse osmosis (RO) system in a subsequent phase to ensure compliance with environmental standards. Tannery operations are predominantly wet processes, consuming vast amounts of water and generating approximately 92% of their waste in liquid form (Chowdhury et al., 2013). Tannery effluents typically contain high levels of organic and inorganic pollutants, including total dissolved solids (TDS) and suspended solids (SS) (Buljan and Kral, 2011). Studies have shown that nearly 70–80% of the chemicals used in the tanning process are not absorbed by the leather but instead released as waste (Verma et al., 2008; Tabesh et al., 2011; Assefa Wosnie and Ayalew Wondie, 2014). These effluents contain a range of toxic substances such as lime, sodium salts, chrome salts, fat liquors, and dyes (Michalec et al., 1996; Nafaa et al., 2004), varying with the type of leather processed - whether from goat, sheep, or bovine sources (Bienkiewicz, 1983; Fernandez-Sempere et al., 1997). As a result, the tannery industry ranks among the highest polluting sectors worldwide (Ates, 1997). Effluents typically exhibit high color, pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD), and dissolved solids. Exposure to such pollutants has been linked to numerous, including dermatological, respiratory, and gastrointestinal disorders (Cooman et al., 2003; Tamburlini et al., 2002). The depends on pollutant concentration and duration of exposure (Upechella and Hyland, 1989; Akan et al., 2007). Therefore, effective, continuous monitoring, and are vital to mitigate pollution and safeguard groundwater resources. The proposed study aims to analyze the performance efficiency of the 20 MLD CETP in terms of removal of key pollutants (BOD, COD, TDS, TSS, and Cr^{6+}), hydraulic loading, treatment process optimization, and compliance with prescribed effluent standards. Present work is based on evaluating the efficiency of wastewater treatment plants as the design parameters and comparing it with Old CETP.

Material and Methods

Old CETP has a capacity of 36 MLD (9 MLD tanneries wastewater and 27 MLD of domestic wastewater) and is based on UASB (Upflow Anaerobic Sludge Blanket) Technology to treat wastewater. The pre-treatment system consists of screen, grit chamber, equalization tank, intermediate pumping station, mixing tank, main pumping station, UASB reactor. post-treatment consists of collection well, pre-aeration tank, flash air mixer, clariflocculators, sludge thickener. The individual tannery units are equipped with pre-treatment facilities to remove readily settleable solids, with or without chemical addition, before pumping the effluent into the CETP raw effluent collection and conveyance system. This ensures that the underground piping network remains free from blockages and overflow, while also maintaining the designed carrying capacity of the pipelines by preventing solid accumulation and scale formation. Additionally, it is proposed to establish a Zero Liquid Discharge (ZLD)-based field-scale pilot plant with a capacity of 200 KLD under this project to conduct research and development activities aimed at achieving high water recovery (>95%) and producing high-purity sodium chloride and sodium sulphate salts.The influent quality parameters are presented in Table 1. The treatment scheme includes a combination of unit operations and processes such as an Inlet Chamber, Odour Control System, Coarse Screen, Grit Removal, Sedimentation in Pre-Settling Tank, Fine Screen, Storage and Homogenization Tank, Primary Clariflocculator, two-stage Pre-Aeration Tank/Sulphide Removal System, Anoxic/Denitrification Unit, two-stage Extended Aeration Type Aerobic Biological Reactor, two-stage Secondary Clarification, Reactor Clarifier/LSS-based Hardness Removal System, Quartz Filter and Ultrafiltration System, and Mixing Tank. The treatment units located upstream of the SHT are designed to handle the peak flow. Sludge management involves gravity thickening followed by dewatering using a plate filter press and decanter (centrifuge).

The dewatered sludge, having 20–25% solid content, is disposed of at a designated Treatment, Storage and Disposal Facility (TSDF), while the bio-sludge can be utilized as manure. Considering the highly corrosive and scale-forming nature of tannery CETP effluent due to the generation of H_2S gas and presence of dissolved salts, appropriate protective measures have been incorporated for structures in contact or partial contact with the liquid. Accordingly, non-corrosive materials such as high-grade stainless steel, or mild steel with epoxy/FRP coating, have been selected for mechanical components of the plant wherever applicable.

Sampling

Tannery effluent samples were collected from the outlets of all critical units, including the Inlet Chamber, Pre-Settling Tank, Storage and Homogenization Tank, Primary Clariflocculator, Anoxic/Denitrification Tank, two-stage Extended Aeration Type Aerobic Biological Reactor, two-stage Secondary Clarifier, Reactor Clarifier, Quartz Filter and Ultrafiltration System, and Mixing Tank.

The samples were collected within half an hour in airtight plastic cans. Each cane was rinsed two to three times with the effluent before final collection to ensure representative sampling. The collected samples were stored at 5°C to minimize biological activity, prevent hydrolysis of chemical compounds and complexes, and reduce the volatility of constituents. For heavy metal analysis, acid-rinsed (0.1 N HCl) bottles were used to collect the samples. A unique identification number was assigned to each sample bottle for proper tracking. All chemicals used during this research work were of analytical grade, supplied by Merck Chemicals.

For analyzing heavy metals, the samples were collected in bottles pre-rinsed with 0.1 N HCl, and 1.5 ml of concentrated nitric acid was added to every 1000 ml of the sample to preserve it. After completion of sample collection, all samples were immediately transported to the laboratory for detailed analysis.

Table 1 Design parameters of tannery effluent

S. No.	Parameter	Design Range
1	pH	7.5 – 9.0
2	Total Suspended Solids (mg/L)	3000 – 5000
3	Colour (Pt. Co)	300 – 500
4	Turbidity (NTU)	1000 – 1300
5	Chemical Oxygen Demand (COD), mg/L	4000 – 7000
6	Biochemical Oxygen Demand (BOD, 5 days @ 20°C), mg/L	1800 – 3000
7	Fixed Dissolved Solids (FDS), mg/L	20000 – 23000
8	Sulphate as Na_2SO_4, mg/L	2500 – 5000
9	Chloride as NaCl, mg/L	12000 – 13000
10	Total Chromium as Cr, mg/L	50 – 100
11	Fluoride as F, mg/L	0.6 – 1.0
12	Total Alkalinity as $CaCO_3$, mg/L	2000 – 2200
13	Total Hardness as $CaCO_3$, mg/L	1000 – 1200
14	Calcium Hardness, mg/L	300 – 400
15	Magnesium Hardness, mg/L	700 – 800
16	Carbonate, mg/L	1000 – 1200
17	Bicarbonate, mg/L	200 – 500
18	Sulphide as S, mg/L	100 – 300
19	Nitrate as NO_3, mg/L	400 – 500
20	Reactive Silica as SiO_2, mg/L	10 – 15
21	Ammoniacal Nitrogen as N, mg/L	250 – 500
22	Total Phosphorus as P, mg/L	5 – 10

Table 2 Target treated effluent characteristics

S.No.	Parameters	Performance guarantee as per this contract
1.	pH	6.5 – 8.5
2.	Total Dissolved Solids (TDS), mg/lit	< 2100
3	BOD @ 27°C for 3 days, mg/lit	< 5
4	COD, mg/lit	<160
5.	Total suspended solids (TSS), mg/lit	BDL
6.	Total Chromium, mg/lit	BDL

Results and Discussion

The variation of pH observed over ten weeks at different treatment stages of the 20 MLD Common Effluent Treatment Plant (CETP) at Uttar Pradesh indicates stable performance of the system. The pH of the inlet effluent ranged between 8.6 and 9.4, showing that the raw wastewater entering the plant was moderately alkaline due to the presence of lime and sodium-based compounds commonly used in leather processing. A slight dip in the inlet pH around the sixth week was noticed, which may be attributed to variation in industrial discharge load or changes in chemical usage.

After primary treatment through the clariflocculator, the pH decreased to between 7.5 and 8.0, suggesting effective neutralization and chemical settling of alkaline residues. In the secondary clarifier, which represents the biological treatment phase, the pH further stabilized within 7.4 to 7.8, reflecting an efficient and well-buffered biological process perating under near-neutral conditions. The tertiary treatment outlet recorded a pH between 7.6 and 8.0, showing a slight rise during the ninth and tenth weeks, possibly due to residual coagulant or lime addition during the polishing stage. Overall, the plant effectively reduced and maintained the pH within the permissible limit of 6.5 to 8.5 prescribed by CPCB standards (Fig. 1).

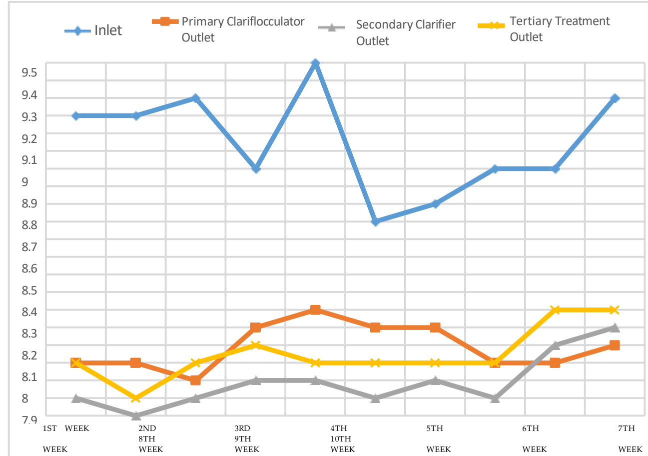

Fig. 1 pH variations across different treatment stages

The maximum difference of about 1.5 pH units between theinlet and final outlet demonstrates successful moderation of alkalinity. The consistent pH at the secondary and tertiary stages indicates stable operational control and efficient process management. Hence, it can be inferred that the CETP is functioning satisfactorily in terms of pH regulation and effluent quality compliance, ensuring environmentally safe discharge to the receiving water body. The Fig. 2 shows the variation of Total Suspended Solids (TSS) at different stages of treatment for ten consecutive weeks in the 20 MLD Common Effluent Treatment Plant (CETP) located at Uttar Pradesh.

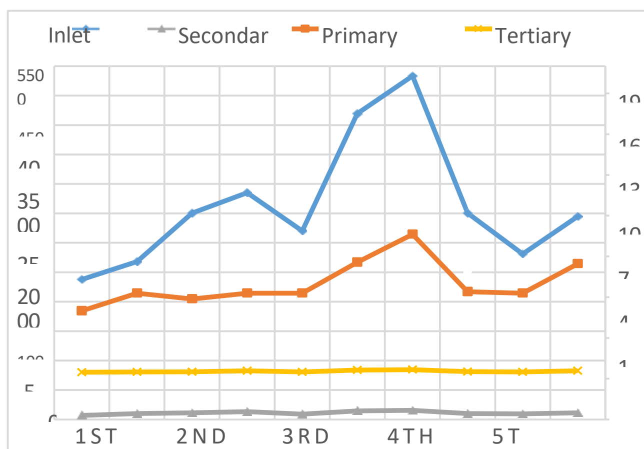

Fig. 2 Total suspended solids (TSS)

The inlet TSS concentration fluctuated widely between about 2,000 mg/L and 5,000 mg/L, indicating highly variable raw wastewater quality and irregular solids loading from the leather processing units. A pronounced rise in TSS was observed between the fifth and seventh weeks, when the concentration peaked above 5,000 mg/L, suggesting a temporary surge in industrial discharge or inadequate equalization at the inlet. After the primary clariflocculation process, the TSS level dropped markedly to around 600–900 mg/L, demonstrating effective removal of coarse and settleable solids through coagulation and sedimentation. The efficiency of the primary stage was relatively stable across most weeks, although a slight increase in solids during the sixth and seventh weeks reflected the impact of the high influent load. In the secondary clarifier, TSS values reduced drastically to below 100 mg/L, confirming good biological settling and separation of fine suspended matter.

At the tertiary treatment outlet, TSS remained consistently below 100 mg/L throughout the observation period, showing efficient polishing and compliance with the CPCB discharge standard of 100 mg/L for treated industrial effluent. Overall, the plant achieved an average TSS removal efficiency of more than 95 percent, highlighting excellent performance in solids reduction. The brief peaks at the inlet emphasize the need for better influent equalization and sludge management, but the steady performance at secondary and tertiary stages indicates that the CETP is operating efficiently and maintaining consistent effluent quality suitable for safe disposal into the environment. The Fig. 3 shows the variation of Total Dissolved Solids (TDS) at the inlet and after dilution outlet of the 20 MLD Common Effluent Treatment Plant (CETP) at Uttar Pradesh, over ten weeks.

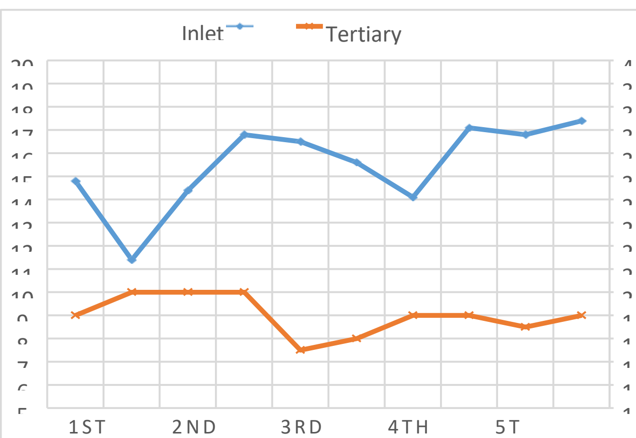

Fig. 3 Total dissolved solids (TDS)

The inlet TDS values remain very high, ranging between 10,000 and 13,500 mg/L, due to the heavy use of salts and chemicals in tanning operations. After dilution, the TDS concentration reduces notably to between 2,800 and 9,800 mg/L, with the lowest values in the 2nd and 3rd weeks, indicating effective dilution with domestic sewage. However, TDS rises again between the 6th and 9th weeks, suggesting increased salt load or reduced dilution water. Although dilution lowers the concentration, the outlet TDS remains above the CPCB limit of 2,100 mg/L, emphasizing the need for advanced treatment measures such as reverse osmosis (RO) or salt recovery systems to achieve compliance and ensure sustainable operation of the CETP. The variation of Chemical Oxygen Demand (COD) at different treatment stages of the 20 MLD CETP at Uttar Pradesh over ten weeks is shown in Fig. 4.

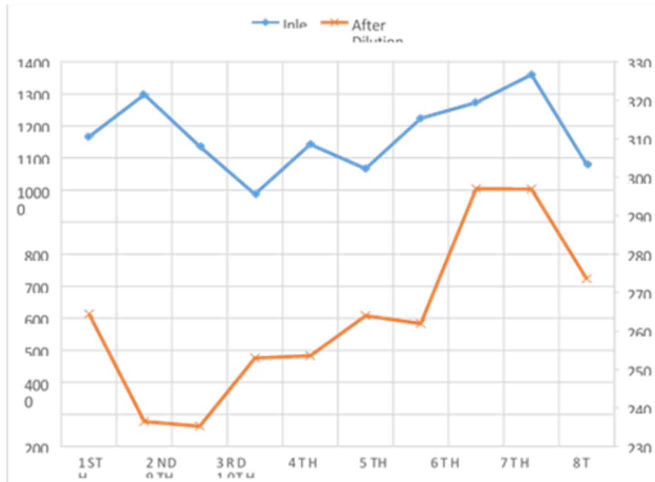

Fig. 4 Variations of COD

The inlet COD ranged between 4,500 and 6,500 mg/L, indicating high organic pollution typical of tannery effluent. After primary treatment, COD reduced to 1,500–2,000 mg/L, and further dropped below 600 mg/L after secondary treatment, reflecting effective biological oxidation. The tertiary outlet maintained COD below 400 mg/L, with minor fluctuations in later weeks. Overall, the plant achieved around 90–94% COD removal efficiency, showing stable performance and near compliance with discharge standards, though improved inlet equalization could enhance consistency. The inlet BOD fluctuated between 1,100 and 1,700 mg/L, indicating a high organic load typical of tannery wastewater (Fig. 5).

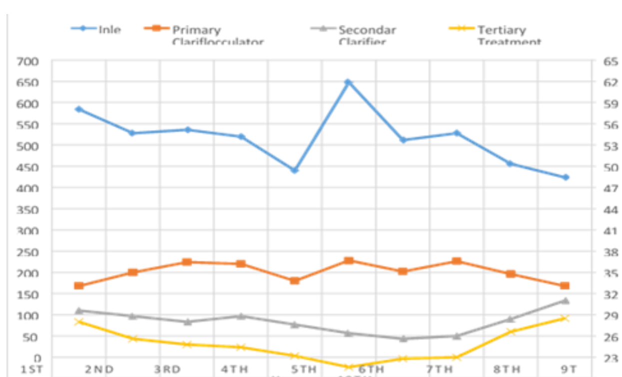

Fig. 5 Variations of BOD

After tertiary treatment, BOD values consistently remained below 1,000 mg/L, mostly within 800–950 mg/L, showing effective organic matter removal. Minor variations correspond to changes in influent strength, but overall, the plant achieved around 85–90% BOD reduction, reflecting stable and satisfactory biological and tertiary treatment performance.

Conclusions

The results of this study indicate that the overall performance of the 20 MLD Common Effluent Treatment Plant (CETP) depends on multiple interrelated factors. The variation in influent quality is primarily governed by the effluent characteristics and preliminary treatment efficiency within individual industries. Therefore, the installation, operation, and strict supervision of effective preliminary treatment units at the industry level are essential to ensure uniform influent quality reaching the CETP. In the future, a techno-commercial feasibility study can be undertaken to explore the conversion of the existing 20 MLD CETP into a Zero Liquid Discharge (ZLD) system. Such an assessment, supported by data from pilot-scale ZLD units, would help determine the technical viability, cost implications, and environmental benefits of achieving complete wastewater recycling and reuse within the leather cluster.

Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research received no external funding.

References

Agarwal, M. C., Katiyar, V. S. and Ram Babu. 1988. Probability analysis of annual maximum daily rainfall of U.P. Himalaya. Indian Journal of Soil Conservation, 16(1): 35–42.

Asati, S. R. 2012. Analysis of rainfall data for drought investigation at Brahmapuri. Journal of Hydrology and Environment, 1: 1–8.

Bara and Lal. (2008). Probability analysis for prediction of rainfall, Uttar Pradesh, India. Journal of Hydrology and Environment, 121: 20–40.

Barkotulla, M. A. B., Rahman, M. S., & Rahman, M. M. 2009. Characterization and frequency analysis of consecutive days maximum rainfall at Boalia, Rajshahi, Bangladesh. Journal of Development and Agricultural Economics, 1: 121–126.

Benson, M. A. 1968. Uniform flood frequency estimating methods for federal agencies. Water Resources Research, 4(5): 891–908.

Bhakar, S. R., Bansal, A. N., Chhajed, N. and Purohit, R. C. 2006. Frequency analysis of consecutive days maximum rainfall at Banswara, Rajasthan, India. ARPN Journal of Engineering and Applied Sciences, 1(3): 64–67.

Bhakar, S. R., Iqbal, M., Devanda, M., Chhajed, N. and Bansal, A. K. 2008. Probability analysis of rainfall at Kota. Indian Journal of Agricultural Research, 42: 201–206.

Chow, V. T. 1951. A general formula for hydrologic frequency analysis. Transactions of the American Geophysical Union, 32: 231–237.

Chow, V. T. 1964. Handbook of Applied Hydrology (Chapter 8). McGraw-Hill Book Co.

Dalabehra, M., Sahoo, J. and Bala, M. K. 1993. Probability models for prediction of annual maximum rainfall. Indian Journal of Soil Conservation, 21(3): 71–76.

Dingre, S. and Shahi, N. C. 2006. Consecutive days maximum rainfall predicted from one-day maximum rainfall for Srinagar in Kashmir Valley. Indian Journal of Soil Conservation, 34(2): 153–156.

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusudan, M. S. and Xavier, P. K. 2006. Increasing trends of extreme rain events over India in a warming environment. Science, 314: 1442–1445.

Gumbel, E. J. 1958. Statistics of Extremes. Columbia University Press.