INNOVATION IN TEXTILE WASTEWATER TREATMENT: INTEGRATING ADVANCED OXIDATION TO ACHIEVE ZLD AND ENHANCE WATER REUSE EFFICIENCY

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Indian textile industry on one hand plays vital role in the economic growth and contributes around 14% to the industrial production, 4% to the gross domestic production (GDP), 17% to the country's export and 21% employment (S Kumar R, Trends Textile Eng Fashion Technol. 2018). On the other hand, is grappled with various challenges like high trade barriers, poor infrastructure, lack of advanced technologies, newer economic policies and stringent environmental compliances. Among key environmental issues, this industry faces major challenges of waste and wastewater management and associated environmental compliances, which includes inadequate treatment of wastewater, achieving Zero Liquid Discharge (ZLD) and enhance water reuse efficiency.

Hence this article focuses on innovation in Textile wastewater treatment with emphasis on integration of Advanced Oxidation Technology (AOT) leading to complete treatment and mineralization of dyes and chemicals, reduction in sludge generation, bypassing bioremediation or integrating AOT with existing biological treatment systems to improve biodegradability, reduce load on downstream tertiary treatment and help in achieving ZLD and enhance water reuse efficiency, together making overall wastewater treatment much more affordable and sustainable.

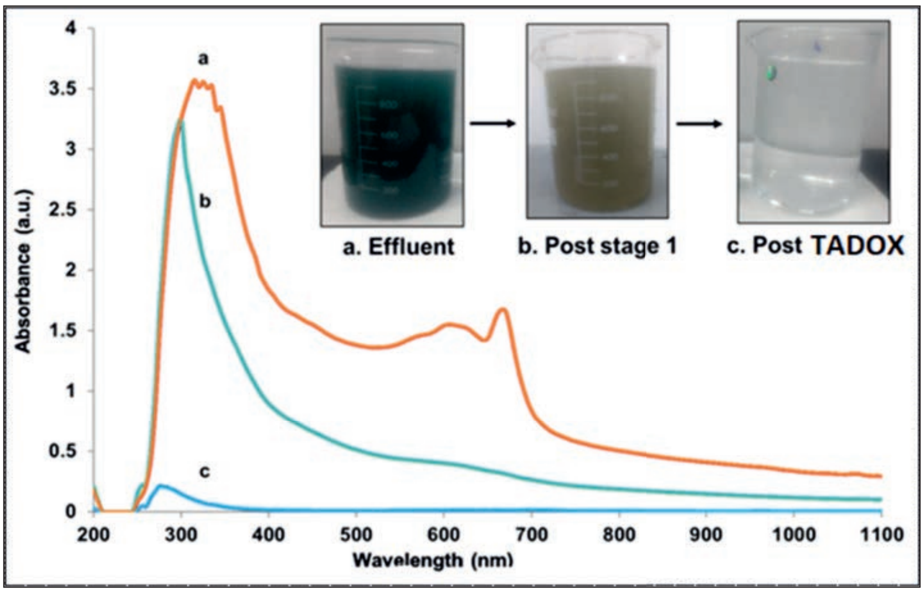


Figure 1. UV– Vis spectra of textile dyeing effluent (a) Untreated/Raw effluent (b) Post Stage 1 and (c) TADOX treated. Inset: Respective pictures of samples.

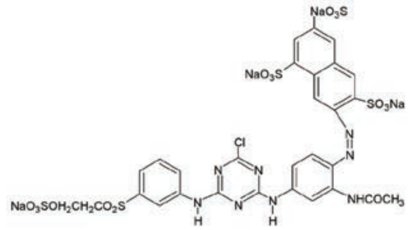
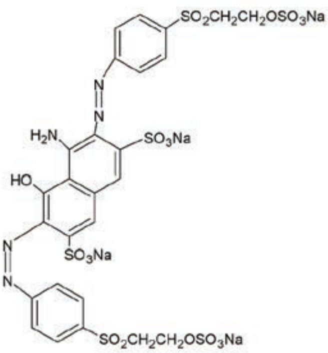
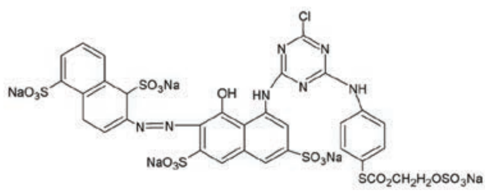
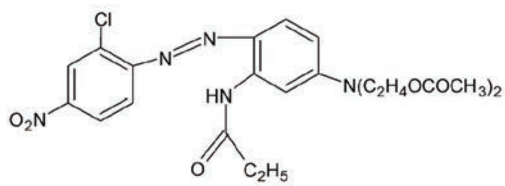
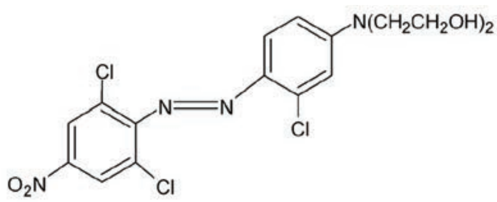
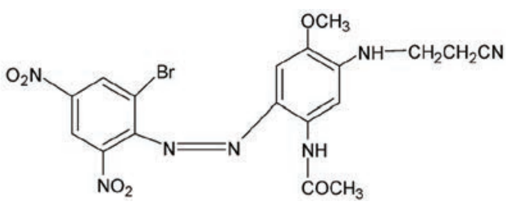
Key issues in Textile Wastewater treatment in India

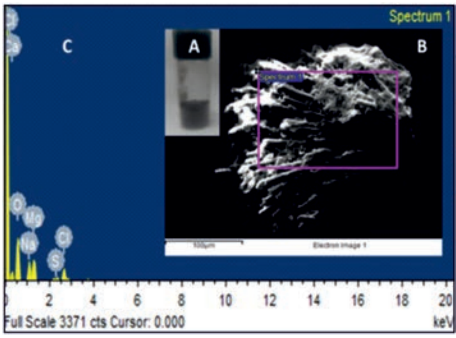
Wastewater generated from the textile & dyeing industry poses severe environmental concerns, majorly due to high color and organic load from dyes, surfactants, salts and auxiliary chemicals used during various processes and finishing of products. The high amount of Chemical Oxygen Demand (COD) of these effluents is not only an indication of presence of recalcitrant compounds that can be toxic to the biota but also leads to depletion of dissolved oxygen in the receiving water bodies.

Table 1 depicts some of the representative azo dyes widely used in textile & dyeing industry, along with the complex molecular structure and molar mass; degradation of such complex molecules is not possible through simple conventional and biological treatment systems. Also high color released in effluents due to such complex dyes during dying processes affects the aesthetic value of water bodies and interferes with aquatic biological processes and prevents penetration of light and causes eutrophication in water bodies.

Hence 'adequate' treatment of textile wastewater in terms of complete removal of both color and COD is extremely important before being discharged into the environment.

Table 1. Some of the representative azo dyes used in dyeing process in Industry

S.No.	Chemical and common names of the Dyes	Molecular Structure	Type/Class of Dye	Molecular Weight (g mol–1)
1	Drimaren Yellow CL–2R (Dispersed yellow 176)		Single Azo class	1025.26
2	Drimaren Navy CL–R (Reactive Black 5)		Double Azo class	991.82
3	Drimaren Red CL–5B (Reactive Red 241)		Single azo class	1026.41
4	Foron Rubine S–9053 (Dispersed Red 167)		Single azo class	519.93
5	Sodyecron Yellow Brown S.IN (Disperse Brown 1)		Single azo class	433.67
6	Sodyecron Navy S.IN (Dispersed Blue 281)		Single azo class	534.327



Elements D	Weight%	Atomic %
O	60.40	71.10
Na	14.76	12.09
Mg	14.80	11.47
S	1.03	0.60
Cl	8.17	4.34
Ca	0.84	0.39

Figure 2. A– Obtained Sludge residue (in a vial); B– SEM Image of the powdered residue; C– EDX spectra of the solid residue; D– Elemental composition obtained from EDX.

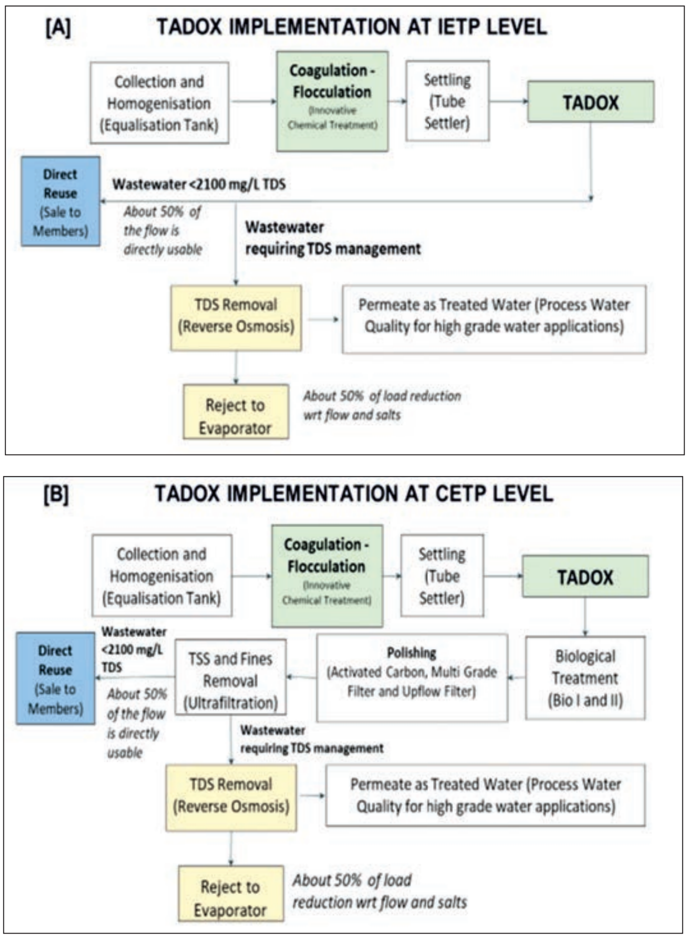


Figure 3. Showing the possible implementation of TADOX at large scale textile and dyeing units at Individual ETP (IETP) scale [A] and at Common ETP scale [B].

The dye concentration in a dye house ranges from 0.01g/L to 0.25 g/L depending on the type of the dye and the process carried out. Textile dyestuffs are found to contain a large amount of organic substances which are difficult to degrade and are resistant to aerobic degradation. They are also found to be reduced into carcinogenic agents under anaerobic conditions. Hence the effects of the pollutants may not be quite evident immediately but with the passage of time their imperceptible effects are of fatal nature.

Thus, textile organic dyes need to be separated, eliminated and completely degraded and removed before discharge into drains and natural water bodies.

TERI Advanced Oxidation Technology (TADOX)

It is in this pursuit, TERI has developed an end–to–end wastewater treatment technology called The TERI Advanced Oxidation Technology (TADOX) (patent and trademark awaited), to treat Industrial and Municipal Sewage Wastewater, achieve Zero Liquid Discharge (ZLD), enhance Water Reuse Efficiency and serve as Advanced Decentralized Wastewater Treatment (DWTT) option.

TADOX is clean, green, sludge free, highly resource and energy efficient technology which aims at complete end–to–end treatment of wastewater effluent streams having high color, COD, BOD, TOC, dissolved organics, non–biodegradable and persistent organic pollutants (POPs), generated from highly polluting industries like Textile & dyeing, Tannery, Oil & Gas, Chemical, Pharma, etc. In case of Municipal/ Sewage wastewater treatment, the innovation component involves direct treatment at inlet, bypassing any kind of bioremediation, reducing treatment time from 24 hours to 6 hours along with resource and energy efficiency and removal of micropollutants and chemicals of emerging concern.

TADOX involves novel primary treatment approaches with newer formulations of coagulants and flocculants as compared to conventional chemicals and make very less use of chemicals in the overall treatment. The secondary treatment involves Photocatalysis as an Advanced Oxidation Process (AOP), leading to oxidative degradation and mineralization of targeted pollutants. The integration of such an AOP will reduce load on downstream tertiary treatment involving RO/MEE, enabling sustainable and affordable ZLD compliance.

Having small footprint, it could be integrated and retrofittable in existing treatment trails depending on the nature and constitution of the matrix; e.g. at pre–biological for streams having high COD; at post–biological for streams having high BOD and at polishing stage to improve quality of treated water. In case of Municipal/ Sewage wastewater treatment, it could serve as DWTT option in Smart Cities; Micro STPs for Open Drains, Townships, Malls, Green Buildings etc.

This technology has been developed under Water Mission, Water Technology Initiative (WTI) Programme of Department of Science & Technology (DST), Govt. of India. This technology has received following Awards at various forms: (i) 'Design and Manufacturing Technologies for 'Make in India' by Ministry of Science and Technology, Govt. of India during IISF–Dec. 2015; (ii) STE Water Award 2019 for Technological Innovation in Wastewater Treatment; (iii) Aqua Excellence Award 2019 for 'Development of Technology' by Mr. Gajendra Singh Shekhawat, Union Cabinet Minister, Ministry of Jal Shakti, Govt. of India in World Aqua Congress.

2KLD TADOX Wastewater Treatment facility

In order to further the efforts, TERI has established 2 KLD wastewater treatment facility based on TERI Advanced Oxidation Technology (TADOX) at TERI Gwalpahari, Gurugram campus as shown in Figure 4. Industries and ULBs are encouraged to send wastewater samples to assess techno–commercial feasibility of towards TADOX treatment and field implementation. Based on the pilot trials, full scale implementation could be planned.

Case study of Textile Wastewater Treatment

Here is presented one particular case study of textile wastewater treatment using TADOX Technology, without involving any biological treatment at any stage, which is the key innovation component. The samples were obtained from the equalization tank of the cotton & dyeing Industry of Andhra Pradesh. The samples were sent to pilot facility at TERI Gurugram campus by air and treated as soon as received. Also the presented study is part of an International peer reviewed and published research paper in the Journal of Water Process Engineering, 32 (2019) 100934. The treatment photos alongside UV–Vis Spectra is shown in Figure 1. It could be clearly seen, the changes taking place in the three stages of treatment.

The complete decolourization has taken place as the result of TADOX treatment, which could be attributed to oxidative degradation and mineralization of the complex dye components present in the matrix. Detailed wastewater quality parameters were analysed for the raw and treated samples from accredited NABL Laboratory and the results are tabulated in Table 2.

Table 2. Wastewater characteristics of Untreated and Treated samples

Parameters, unit	Results		
	Raw Sample (a)	TADOX Treated (c)	CPCB Standards for treated effluents from Textile Units
pH	7.62	9.1	6.5–8.5
Salinity#, ppm	3470	130	–
Conductivity#, µmho/cm	7644	294	–
Total Suspended solids (TSS), ppm	850	4	100
Total Dissolved Solids (TDS), ppm	33350	264	2100
Chloride#, ppm	240	30	–
Total Hardness#, ppm	60	ND	–
Calcium#, ppm	22	1.8	–
Magnesium#, ppm	3.125	0.1	–
Iron (Fe) #, ppm	3.24	ND	–
Total Chromium (Cr), ppm	1.13	ND	2
BOD5, ppm	255	12	30
COD, ppm	1360	128	250
Total Nitrogen#, ppm	158.4	60.7	–
Total Kjeldahl Nitrogen (TKN), ppm	102.1	3.4	50*
Nitrite Nitrogen (NO_2–N) #, ppm	45.1	9.2	–
Nitrate Nitrogen (NO_3–N) #, ppm	11.2	48.1	–

ND– Not Detectable. *Ammoniacal Nitrogen has been notified in the prescribed standard. #Standards not notified by regulator for textile sector.

Figure 4. Photo of Pilot facility at TERI Gram, Gwal Pahari Campus, Gurugram – Faridabad Road, Gurugram.

From Table 2, it is clear that the treated water achieved not just CPCB, Government of India discharged norms but also achieved process water quality, where this water could be reused in process and achieve ZLD; Presented data shows significant removal of COD (90.5%), BOD (95.29%), Iron (100%), Total hardness (99%), Total Nitrogen (61.6%), Total Suspended Solids (99.5%).

The obtained treated water is directly reusable in process. As the objective of this case study required TDS removal of a high order, thus RO was additionally employed to further polish TADOX treated water; thus, the RO was able to remove 99% TDS as well. Due to the high–quality water being fed to RO, there is improved efficiency of RO with respect to TDS removal and it is also expected to improve the life span of RO membranes.

Also there was no use of any kind of bioremediation method at any stage of treatment and complete end–to–end treatment took just 5 hours.

As sludge generation, disposal and management is another major environmental concern and contributor to the OPEX, therefore, key emphasis is laid on reduction of sludge quantum and reduce toxicity and improve nature and constitution of sludge residues during our primary treatment. The obtained sludge from primary treatment was characterized using SEM–EDX technique and the results are depicted in Figure 2.

Part A of the figure shows dried powdered sludge residue obtained after primary treatment. It weighed about 4 g (obtained while treating 10 L effluent) i.e. dried sludge generation ratio of 0.4 kg/KL, which is 100 times lesser than earlier reported sludge generation ratio (42.6 kg/KL) as per one reported study from CETP, Tirupur.

To further study the nature of the sludge, SEM analysis was carried out and is shown in Part B; EDX analysis was carried out to understand the nature and elemental composition of the powder as depicted in Part C. The interpretation of the EDX is tabulated in Part D, wherein results clearly indicate the breakdown of suspended solids and hardness present in wastewater.

It is also evident that no toxic elements are present in the residue, making management of such sludge residues easier.

It is clear that the harness of water has come out from the primary treatment and therefore the proposed treatment led to an almost sludge free process and the minimal residue can be easily managed due to its low toxicity.

Cost of TADOX Treatment and Implementation

The capital cost of implementing the TADOX based ZLD solutions (including RO and MEE) for the textile sector is estimated to be around 12 Crore INR/ MLD, whereas the overall cost of operation is expected to be 170–190 INR/ KL, which is about 25–30% lower in terms of capital cost and 35–40 % lower than the operational costs as compared to the other solutions providing similar quality water in the market.

Integration of TADOX in existing installations or installations not requiring downstream RO/ MEE have even lower capital and operation costs at 6 Crore INR/ MLD and 95–110 INR/ KL.

Therefore, this is expected to improve the quality of treated water, reduce freshwater consumption and make the industry eco friendly in a much affordable manner.

Benefits of TADOX Integration in Textile Wastewater Treatment

Integration of TADOX in the textile sector aims to solve some of the most pertinent issues in wastewater treatment plants which hinder actual ZLD.

- One of the most critical issue that TADOX implementation is able to address is adequate and complete treatment of dissolved organics which is not taking place in conventional biological treatment plants, RO plants or MEE/ MVR units; these units merely transfer pollutants from wastewater to concentrates, salts and sludges.
- TADOX implementations significantly improve the treated water quality and enhance the reuse efficiency of water even without RO/ MEE stage. Therefore, it is able to produce water with moderate TDS levels and this water is compatible to be reused in most cases, and for sensitive applications industry can go for optional RO/ MEE. Hence, there is substantial reduction in the cost of ZLD implementation because there is lesser pollution quantum and load on tertiary units.
- It is even more important to note that TADOX integration in existing facilities is especially beneficial for increasing throughput of the plant by debottlenecking the biological plant and also improving the biodegradability of effluent sent to the bioreactor.
- Moreover, TADOX is able to improve the downtime of biological plants as it is able to assimilate the toxicity of wastewater and eliminate these recalcitrant before biological treatment. With this, existing units based on conventional biological systems may be modernised into more efficient plants by applying TADOX in series of the treatment. Or TADOX may be applied in parallel to the existing treatment scheme to augment the overall capacity of treatment plants. The treated water quality so obtained is fit for reuse in the process.
- In case of treating effluents from individual units, bioremediation of any kind is completely bypassed. Whereas, in case of a CETP, such a treatment may prove to be enhancing biodegradability and may be integrated at the pre–biological treatment stage; the two cases have been depicted in Figure 3A and 3B.

The extensive work done in the area of textile wastewater treatment on the effluents obtained from ETPs of individual units (IETPS) of Industrial areas of Sonepat, Haryana, Guntur, Andhra Pradesh, and CETPs of Textile Clusters of Jaipur, Rajasthan and Kanpur, UP have proven that TADOX integration could revolutionise wastewater treatment in India with high potential in both greenfield and brownfield plants.

About the Organization

TERI is an independent, not–for–profit, multi–dimensional organization, with capabilities in research, policy, consultancy and implementation. Engaged inter alia in developing workable solutions in the fields of energy, environment, climate change and sustainability space, having pioneered conversations and action in these areas for over four decades. https://www.teriin.org/

About the Author:

Dr. Nupur Bahadur is working as Fellow in the area of Integrated Wastewater Management, Sustainable Habitat Programme in The Energy and Resources Institute (TERI), New Delhi. Also she is Vice–Chair, International Water Association (IWA)–India and Member, Programme Committee, Singapore International Water Week 2021. She has obtained her Ph.D. in Chemistry from IIT Roorkee in 2005 working in the area of Photochemistry and Photocatalysis for Wastewater Treatment. She is Inventor of TERI's patented technology, TERI Advanced Oxidation Technology (TADOX), to treat Wastewater, achieve Zero Liquid Discharge (ZLD), enhance water reuse efficiency and serve as Decentralized Wastewater Treatment (DWWT) option in Smart Cities. TADOX is clean, green, sludge free, highly resource and energy efficient technology which aims at complete end–to–end treatment of wastewater effluent streams having high color, COD, BOD, TOC, dissolved organics, non–biodegradable and persistent organic pollutants (POPs), generated from highly polluting industries and/or mixed streams having municipal sewage.

To know more about the contributor of this case study, you can write to us. Your feedback is welcome and should be sent at: deepak.chaudhary@eawater.com.