tadox
TERI Advanced Oxidation Technology

POLICY BRIEF

TERI ADVANCED OXIDATION TECHNOLOGY (TADOX) TO TREAT TEXTILE AND DYEING WASTEWATER, ACHIEVE ZERO LIQUID DISCHARGE, AND ENHANCE WATER REUSE: **R&D-BASED POLICY RECOMMENDATIONS**

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1. INTRODUCTION

With the water crisis looming large and freshwater availability increasingly becoming scarce and costlier in the times to come, it becomes imperative for industries, especially a water guzzling industry, such as textile and dyeing, to reuse 'treated water'. However, at present the quality of treated water is not 'adequate' to be reused in the process and fresh ground water is required, or the water being recovered from nearby STP or tertiary treatment systems utilizing reverse osmosis (RO) and multi-effect evaporator (MEEs) etc., which are highly resource and energy intensive, incur huge land and O&M costs; thus the overall approach is highly unsustainable. Therefore, it is required that novel approaches and advanced technologies be integrated in current systems, which reduce overall load on tertiary treatment, and help achieve zero liquid discharge (ZLD) in a much affordable and sustainable manner.

In this pursuit, The Energy and Resources Institute (TERI), New Delhi has developed a novel technology called TERI Advanced Oxidation Technology (TADOX) (patent awaited and trademark accepted), which treats wastewater from grossly polluted industries such as textile and dyeing, tannery, chemical, pharmaceutical, oil and gas, MEE condensate, etc. and municipal sewage wastewater. These streams of wastewater effluents have high colour, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total organic carbon (TOC), dissolved organics, non-biodegradable and persistent organic pollutants (POPs). TADOX involves novel approaches that make use of very less number and amounts of chemicals in the overall treatment which produce bare minimum and non-toxic sludge, thus preventing secondary pollution. TADOX involves photocatalysis as an advanced oxidation nanotechnology (AON)–based process that causes oxidative degradation and mineralization of targeted pollutants. The TADOX-treated colourless and high quality water when it goes to downstream tertiary treatment involving RO, may prevent choking and bio-fouling of RO membranes, which thus enhances the life span and efficiency of RO systems, and reduces the overall load on subsequent evaporators such as multiple effect evaporators (MEE)/mechanical vapour recompressor (MVR)/thermal vapour recompressor (TVR), etc. enabling sustainable and affordable ZLD compliance with 85–90% enhanced water reusability. Having small footprint, it could be integrated and retrofitted in existing treatment trails depending on the nature and constitution of the matrix. For example, 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. It provides an opportunity where biological treatment stream could be completely bypassed, leading to reduced footprint and capital expenditure by 20–30%, operational expenditure by 30–40%, together making the overall wastewater treatment much more affordable and sustainable.

Thus, integration of TADOX in the textile wastewater treatment seems to be a promising approach in solving some of the most pertinent issues which hinder adoption and implementation of ZLD and enhancing water reuse. It becomes even more important to come forward with such R&D-based policy recommendations at a time when Ministry of Jal Shakti, Government of India has initiated national policy on 'Safe Reuse of Treated Water' and aims for water conservation as a 'Jan Andolan' (people's movement).

These findings are based on various case studies for treatment of real textile and dyeing industrial effluents conducted on individual units of Sonipat, Haryana; Guntur, Andhra Pradesh; and CETPs of textile and dyeing clusters of Jaipur, Rajasthan and Kanpur, Uttar Pradesh. The findings have also been peer reviewed in international publications in the area of textile wastewater treatment using TADOX technology (Bahadur and Bhargava 2019; Das et. al. 2019; Bahadur et. al. 2020; Das et. al. 2021; Bahadur 2020). Hence, such R&D-based interventions need to be reached out to relevant stakeholders and this policy brief could be the best possible medium for the same. Moreover, these policy recommendations are aligned towards meeting the goals of missions of national importance such as 'Namami Gange', 'Water Conservation' and 'Self-Reliant India' and also significantly contributing in SDG 6, in particular SDGs 6.3, 6.4, 6a and 6b, SDG 9, and SDG 11.

2. Indian Textile Industry and Environmental Challenge

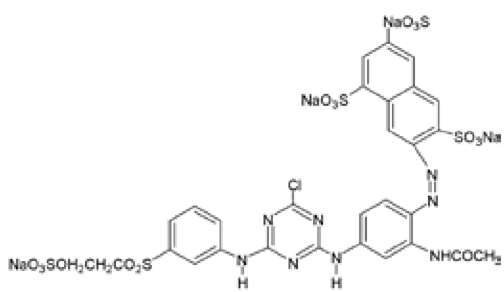
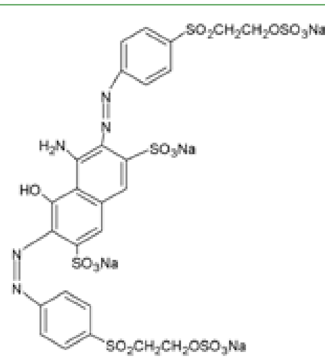
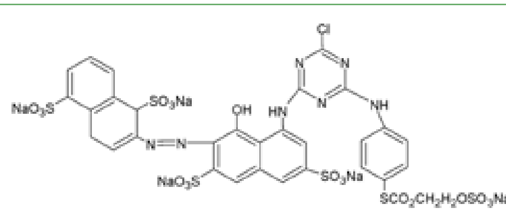
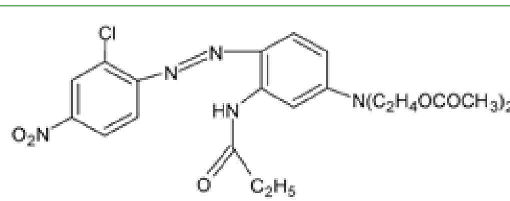
The Indian textile industry, on the one hand, plays a vital role in the economic growth, contributing around 14% to the industrial production, 4% to the gross domestic production (GDP), 17% to the country's export, and 21% employment (Satish Kumar 2018), while, on the other hand, is grappled with various challenges, such as high trade barriers, poor infrastructure, newer economic policies, and stringent environmental compliances. Among the key environmental challenges, which the industries face are waste and wastewater management and associated environmental compliances including achieving ZLD and enhancing treated water reuse.

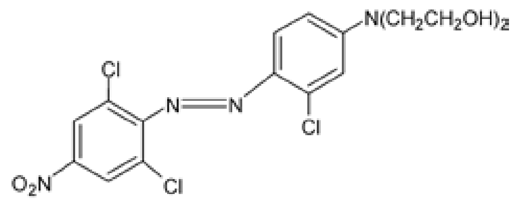
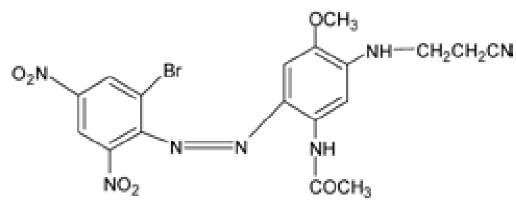
The threat of wastewater generated from the textile and dyeing industry is huge. Textile dyes form a large group of chemicals and comprise over 8000 different compounds with almost 40,000 commercial names. Among these, the most problematic dyes are the ones used widely, brightly coloured, water soluble, reactive, disperse, acidic, and metal complexed. The textile wastewater effluent contains odour, colour, high amounts of chemical reagents, suspended and dissolved solids, high BOD and COD, causing damage to the environment and human health. In most cases, BOD:COD ratios are found to be around 1:4, indicating the presence of non-biodegradable, highly recalcitrant, and persistent organic pollutants. The effluent treatment primarily relies on conventional and biological treatment methods, therefore these plants are not able to efficiently treat such wastewater. Also the wastewater has high shock loads and extreme variation in the constitution. During the dyeing process, it has been estimated that the losses of un-fixed dyes to the environment can reach 10–50% (Central Pollution Control Board 2014; IL&FS Ecosmart Limited 2010b). The most daunting task in the textile wastewater treatment is removal of colour, mainly because dyes and pigments are designed to resist biodegradation, inhibit biological activity, and remain in the environment for a long period of time (Holkar et al. 2016). **Hence 'inadequate' treatment is the root cause of point source pollution in textile and dyeing industry**.

3. Need to Adequately Treat Textile Wastewater

Wastewater generated from the textile and dyeing industry poses severe environmental concerns, majorly due to salts, and high colour and organic load from dyes, surfactants, and auxiliary chemicals used during various processes and finishing of products. Table 1 depicts some of the representative azo dyes widely used in the textile and dyeing industry, along with the complex molecular structure and molar mass.

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

S.No.	Chemical and common names of dyes	Molecular structure	Type/ Class of dye	Molecular weight (g/mol)
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

S.No.	Chemical and common names of dyes	Molecular structure	Type/ Class of dye	Molecular weight (g/mol)
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

Source: Bahadur et al. (2020)

The dye concentration in spent dyes in a dye house ranges from 0.01 g/L to 0.25 g/L depending on the type of the dye and the process carried out. High colour released in effluents is due to the presence of such complex dyes and pigments during dying processes, which affects the aesthetic value of water bodies, interferes with the aquatic biological processes, prevents penetration of light, and causes eutrophication in water bodies. Degradation of such complex molecules is not possible through conventional and biological treatment systems. The chemicals present in the dyes cause diseases including haemorrhages, ulceration of skin, nausea, severe irritation of the skin, and dermatitis. Presence of dyes increases the BOD of the receiving water, while the high amount of COD of these effluents is not only an indication of the presence of recalcitrant compounds that can be toxic to the biota but also lead to depletion of dissolved oxygen in the receiving water bodies. The suspended solid concentrations in the effluents play an important role in affecting the environment as they combine with oily scum and interfere with the oxygen transfer mechanism in the air–water interface. The textile effluents also contain trace metals such as Cd, Ni, Mn, Cu and Zn, excess concentration of soluble salts and inorganic chemicals, whose presence, even in a lower quantity, are found to be toxic to aquatic life.

The effects of the pollutants may not be quite evident immediately but with the passage of time they prove to be of fatal nature. Thus, textile organic dyes need to be separated, eliminated, and completely degraded, and removed before being discharged into drains and natural water bodies. Hence 'adequate' treatment of textile wastewater in terms of complete removal of both colour and COD is extremely important before being discharged into the environment.

4. Current Treatment Practices and Gaps

Textile industry is a wet fabric processing industry and includes de-sizing, scouring, bleaching, mercerizing, dying, printing, and finishing stages. During each stage different types of chemicals are used. In addition, tremendous quantity of unused salts such as sodium sulphate and sodium chloride reach the effluent stream which increases the TDS level in addition to the presence of sulphur, naphthol, vat dyes, chromium compounds, and heavy metals and certain auxiliary chemicals. All of these collectively make the effluent highly toxic. The mill effluent is often at a high temperature and pH, and the colloidal matter present along with colours and oily scum increase the turbidity and impart foul odour to the effluent (IL&FS Ecosmart Limited 2010b).

The effluent treatment comprises the following stages: primary, secondary, tertiary, and advanced. Primary treatment involves conventional chemicals, such as lime, alum, poly aluminium chloride (PAC), ferrous salts, which remove TSS, COD, and colour. The commonly used secondary treatment comprises biological systems, such as activated sludge process (ASP), extended aeration (EA), moving bed biofilm reactor (MBBR), submerged aerated fixed film (SAFF), sequential batch reactor (SBR), and membrane bioreactor (MBR). Both primary and biological treatments together are not able to break the bonds of organic dye molecules leading to persistence of high colour and COD in the effluent. In such cases BOD: COD ratio indicates low biodegradability and this is the reason for biological treatment proving to be inadequate.

Tertiary treatment involves chlorination, activated carbon filtration (ACF), pressure sand filtration (PSF), multi-grade filter (MGF), and dual media filter (DMF). These filtration processes aim to remove any suspended particles from water which cannot be removed through settling processes like tube settlers. Carbon filtration also aims to remove residual organics and residual colour from wastewater; however; it is limited to remove only suspended BOD and can only result in insignificant colour removal. Moreover, these filtration systems cause secondary pollution as they result in generation of spent carbon (hazardous waste) and spent membrane materials such as PTFE (polytetrafluoroethylene), PVDF (polyvinylidene fluoride). Advanced treatment involves ultrafiltration (UF), nanofiltration (NF), RO units, and various evaporators including MEE, MVR, TVR, which are primarily required to achieve ZLD and enhance water reuse. However, these have huge implementation challenges, described ahead, which hinders ZLD adoption and implementation.

5. Requirement of ZLD

In view of the indiscriminate use of water, its insufficiency, its conservation, and the issues related to wastewater disposal and pollution of natural streams/rivers, Central Pollution Control board (CPCB), Government of India in 2015 came up with 'Guidelines on Techno – Economic Feasibility of Implementation of Zero Liquid Discharge (ZLD)' for 17 water polluting industries including textile and dyeing (CPCB 2015). According to which, *'Zero Liquid discharge (ZLD) refers to installation of facilities and systems which will enable industrial effluent for absolute recycling of permeate and converting solute (dissolved organic and inorganic compounds/salts) into residue in the solid form by adopting methods of concentration and thermal evaporation. ZLD will be recognized and certified based on two broad parameters, that is, water consumption versus wastewater reused or recycled (permeate) and corresponding solids recovered (per cent total dissolved/suspended solids in effluents)'.* ZLD is mandated in textiles units having effluent discharge more than 25 m^3/day and also for all textile units in clusters irrespective of their wastewater discharge. Hence, regulation of ZLD has thereafter been issued under various directions from all state pollution control boards, environmental impact assessment authorities (at state and central levels) along with stringent standards of treated water quality to be achieved by textile and dyeing units.

Key Implementation Challenges in ZLD

1. Most of the textile units in India are small scale and medium scale with land area below 10,000 yard^2. Putting up a ZLD compatible plant will require more land which would be very costly. Moreover, industries do not have land available in their premises or in adjoining areas, which limits ZLD implementation.
2. As a ZLD plant is a combination of RO and evaporators, a typical process house would be consuming 200 to 1500 m^3 of water daily. To treat such quantum of water and evaporate the same will require huge amount of electricity ranging from 3000 to 15000 kW/day. To produce such amount of electricity, a lot of fossil fuel, natural gas, or enriched uranium is required and subsequently instead of controlling water pollution we will contribute equally towards air pollution (Vyas 2016).
3. The cost of ZLD will escalate to such a level that production will not be globally competitive and the impact on cost of processing, i.e. implementing ZLD pushes up the cost of production by 25–30%.
4. ZLD results in generation of huge amount of hazardous solid wastes (particularly waste mixed salt) that cause disposal challenges, which is being stored in storage yards within the CETPs.
5. High carbon footprint of a ZLD facility is another major concern. Typical power consumption in a ZLD facility ranges from 8 to 10 kW/m^3. The thermal evaporators alone consume about 20–40 kw/m^3 in addition to several tonnes of firewood for the boilers.
6. The cost of ZLD plant includes the capital cost around ₹8-9 crore/MLD, land cost (which varies in different areas), cost of disposal of solid waste, the operating cost around ₹225/m^3 and depreciation. (Vyas 2016).
7. For efficient ZLD plant functioning, it is very important that primary and secondary treatments take place in efficient manner and continuous monitoring of biological plant is done. Any mistake may stop the functioning of the entire plant for several days. An RO plant needs maximum protection. Multiple evaporators will easily get scaled and choked. Any small mistake will easily damage all the membranes and substantial amount of money will be required for repairing.

6. TERI Advanced Oxidation Technology

Looking at various implementation challenges in achieving ZLD, it is required to integrate in current systems, novel approaches, and advanced oxidative treatment technologies, which could reduce the overall load on tertiary treatment and help achieve ZLD in a much affordable, acceptable, and sustainable manner.

It is in this pursuit, TERI has developed an end-to-end wastewater treatment technology called The TERI Advanced Oxidation Technology (TADOX) (trademark approved, patent pending) to treat industrial and municipal sewage wastewater, achieve ZLD, enhance water-reuse efficiency, and serve as advanced decentralized wastewater treatment (DWTT) option. TADOX is a clean, green, sludge free, highly resource, and energy-efficient technology which aims at oxidative treatment of wastewater effluent streams having high colour, COD, BOD, TOC, dissolved organics, non-biodegradable and persistent organic pollutants (POPs) The three-stage treatment is depicted in Figure 1. TADOX involves novel primary treatment approaches with newer formulations of coagulants and flocculants and makes very less use of chemicals in the overall treatment as compared to conventional chemicals.

The secondary treatment involves UV/n–TiO_2 photocatalysis as an advanced oxidation process (AOP), where suitable nanomaterials are used as adsorbents and photo-catalysts leading to oxidative degradation and mineralization of targeted pollutant dyes and auxiliary chemicals. Used nanomaterials are recovered using suitable filtration systems, regenerated and reused, and the treated water is colourless, odourless, and adequately treated, as tested by NABL accredited laboratories. Tertiary stage may require RO, followed by use of evaporators, depending upon point of use application. The technology has received several innovation and technology development awards and the work on the technology development has been published in the *Journal of Water Process Engineering* (Bahadur and Bhargava 2019).

The working principle of photocatalysis is described in Figure 2. In the presence of UV light irradiations, semiconducting nanoparticles are photo-excited and *in-situ* generates hydroxyl radicals ($OH^{\cdot}$), which have the potential to oxidize complex and difficult pollutants from wastewater (Kumar and Mathur 2004; Kumar and Mathur 2006; Kumar et al. 2014; Oturan et al. 2014; Bahadur et al. 2016; George et al. 2016; Das et al. 2019).

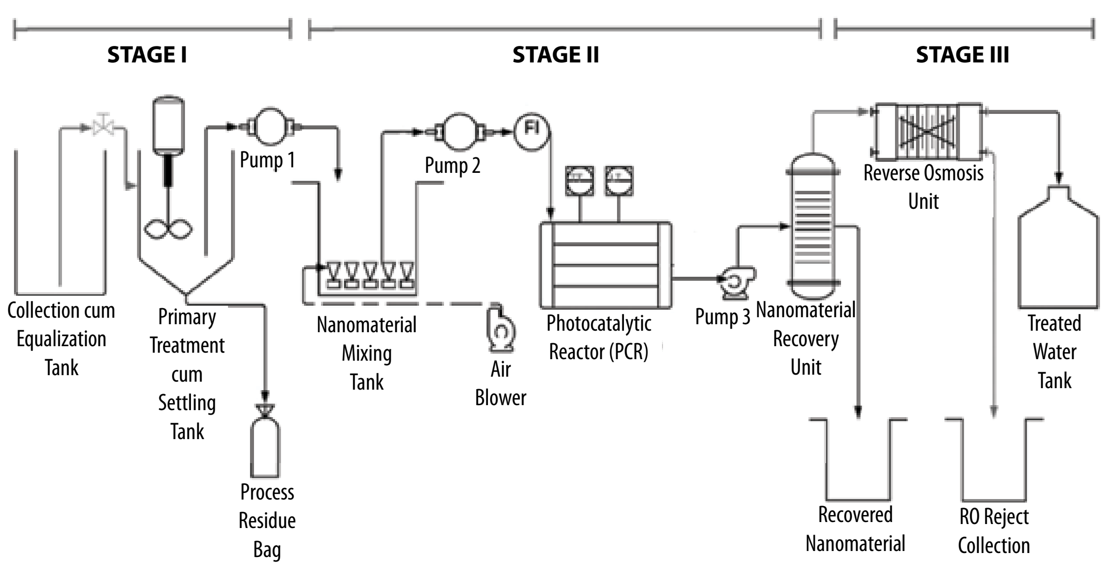


Figure 1 Three-stage TERI Advanced Oxidation Technology (TADOX) treatment

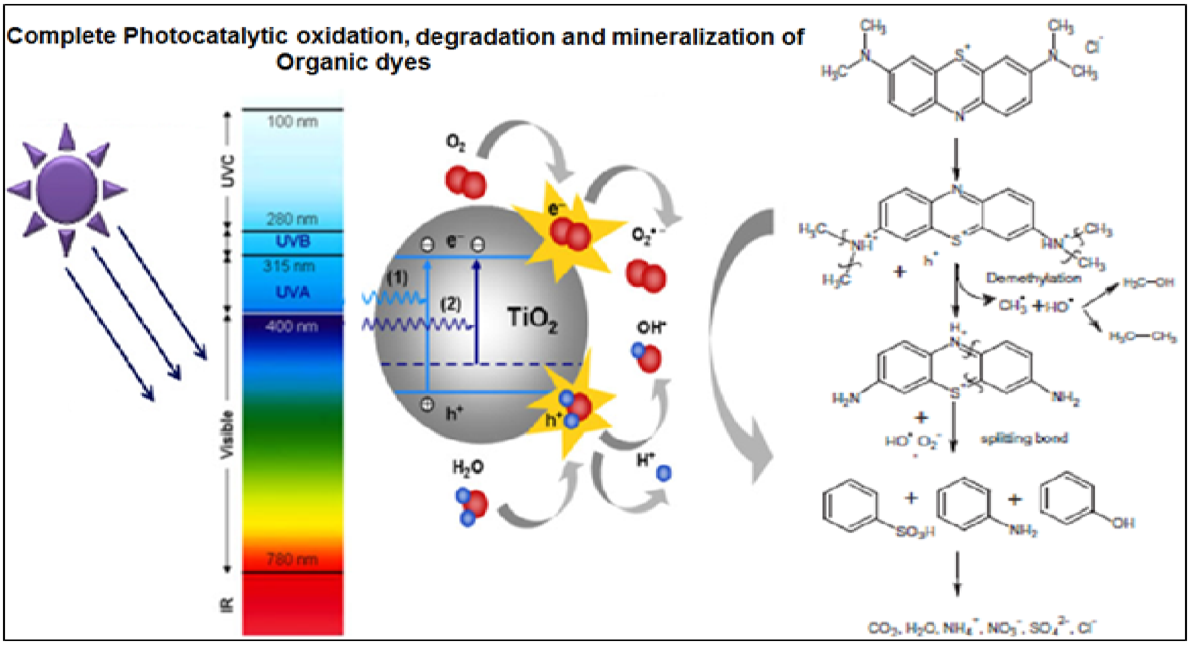


Figure 2 Working principle of UV-n TiO_2 photocatalysis for treating polluting dye stuff

10 KLD TADOX Wastewater Treatment Plant

In order to further the efforts, TERI has established 10 KLD wastewater treatment plant based on TADOX at TERI Gwalpahari, Gurugram campus as shown in Figure 3. Industries and ULBs are sending wastewater samples to assess techno-commercial feasibility towards TADOX treatment and field implementation. Based on the pilot trials, full-scale implementation could be planned.

Successful Case Studies of Textile Wastewater Treatment Using TADOX Technology

Effluent from individual effluent treatment plant

The samples were obtained from an individual effluent treatment plant (IETP), the equalization tank of a cotton and dyeing unit from Guntur, Andhra Pradesh. The

Figure 3 10 KLD TADOX plant working at TERI Gram, Gwal Pahari, Gurugram Campus samples were sent to the pilot facility at TERI Gurugram campus and treated as soon as received. The presented study is part of an international peer-reviewed published research paper in *Journal of Water Process Engineering* (Bahadur and Bhargava 2019). The complete end-to-end treatment took just 5 hours without using any kind of biological treatment method at any stage. The treatment photos alongside UV-Vis Spectra are shown in Figure 4. The changes taking place in the three stages of treatment can be seen in the figure. The complete decolourization took place as a 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 given in Table 2.

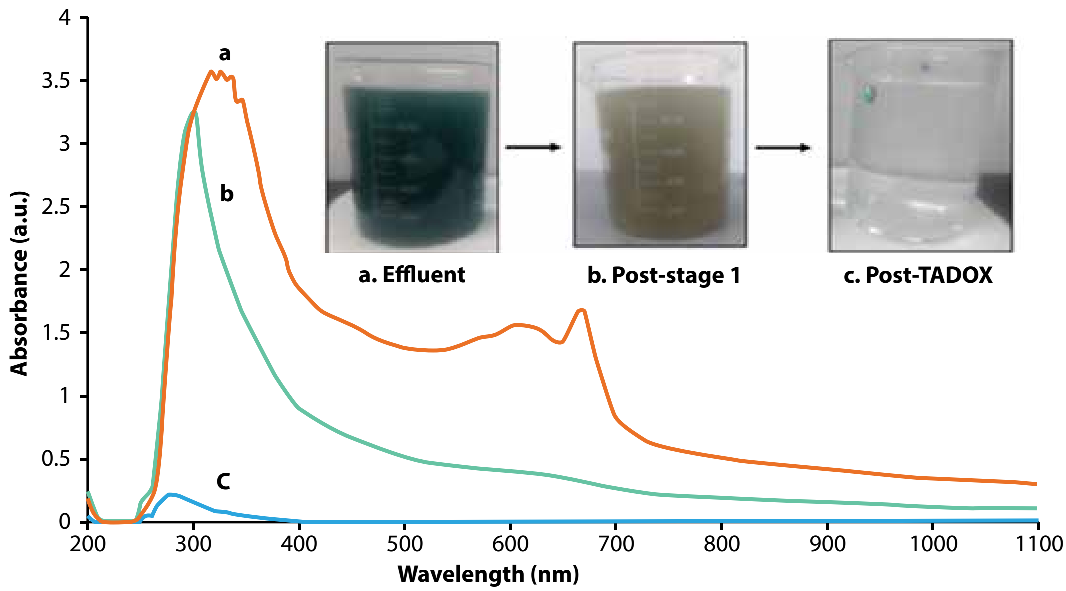


Figure 4 UV-Vis spectra of textile and dyeing effluent from an IETP (a) untreated/raw effluent, (b) post-stage 1, and (c) TADOX treated

Table 2. Wastewater characteristics of untreated and treated samples

S. No.	Parameter	Raw sample	Post-TADOX
1.	pH	7.62	9.1
2.	Salinity, *mg/L*	3470	130
3.	Conductivity, µmho/cm	7644	294
4.	Total suspended solids (TSS), *mg/L*	850	4
5.	Total dissolved solids (TDS), *mg/L*	3335	264
6.	Chloride, *mg/L*	240	30
7.	Total hardness, *mg/L*	60	ND*
8.	Calcium, *mg/L*	22	1.8
9.	Magnesium, *mg/L*	3.125	0.1
10.	Iron (Fe), *mg/L*	3.24	ND
11.	Total Chromium (Cr), *mg/L*	1.13	ND*

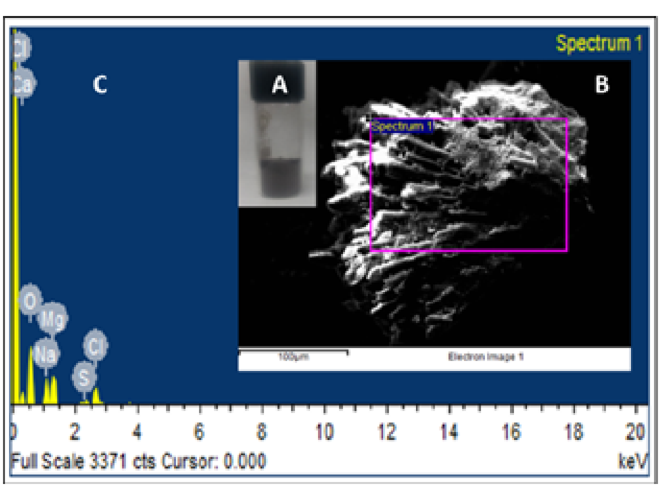
S. No.	Parameter	Raw sample	Post-TADOX
12.	BOD_5, *mg/L*	255	12
13.	COD, *mg/L*	1360	128
14.	Total Nitrogen, *mg/L*	158.4	60.7
15.	Total Kjeldahl Nitrogen (TKN), *mg/L*	102.1	3.4
16.	Nitrite Nitrogen (NO_2-N), *mg/L*	45.1	9.2
17.	Nitrate Nitrogen (NO_3-N), *mg/L*	11.2	48.1

* ND Not detectable

Table 2 presents significant removal of COD (90.5%), BOD (95.29%), iron (100%), total hardness (99%), total nitrogen (61.6%), total suspended solids (99.5%). Thus TADOX treated water achieved not just surface discharge norms of CPCB, Government of India but also ZLD and process water quality for reuse (Das, Bahadur and Dhawan 2019). For cases where discharge to downstream surface water body, cluster-level CETP, or in-land irrigation, etc. is required, pH could be adjusted to meet the regulatory norms; while for reuse of treated water in process, the attained water quality is adequate. In addition, RO was employed to further reduce TDS and polish TADOX treated water. Due to the high-quality water being fed to RO, there is improved efficiency in the system with respect to TDS removal and it is also expected to improve the life span of the RO membranes.

As sludge generation, disposal, and management is another major environmental concern and contributor to OPEX, therefore, key emphasis is laid on reduction of sludge quantum and reduce toxicity and improve nature and constitution of sludge residues during primary treatment. The obtained sludge from primary treatment was characterized using SEM-EDX technique and the results are depicted in Figure 5.

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/m^3, which is 100 times lesser than earlier reported sludge generation ratio (42.6 kg/m) as per one reported study from CETP, Tirupur. To further study the nature of the sludge, SEM analysis was carried



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 5 (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

out and is shown in Part B. The 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 hardness of water has come out from 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.

Effluent from Common Effluent Treatment Plant

Effluents were received from the CETP of a Textile Park in Jaipur, Rajasthan, which houses 17 small to medium scale dyeing and finishing units attached to the 500 KLD CETP for centralized wastewater treatment. The existing treatment trail involves aerobic activated sludge process, chemical treatment, chlorination, physico-chemical, followed by filtration using MGF, ACF, and UF and advanced treatment using RO. Direct TADOX treatment of the raw effluent is depicted in Figure 6 with change in UV-Vis spectra and the respective change in the colour of the samples. The treatment led to overall less number of stages, resulted in almost complete decolorization, from 3524.6 to 7.6 Pt-Co CU, 67% COD reduction from 4400 to 1440 mg/L and 85.5% BOD reduction from 365.5 to 53 mg/L. Thus TADOX treatment has enabled 85% BOD reduction without any biological treatment and the subsequent COD reductions could now be easily achieved using the existing biological system at the subsequent stage, followed by existing RO to achieve ZLD. The intermittent treatments involving chemicals and chlorination are no more required. Thus TADOX integration at pre-biological stage in a CETP has great potential to reduce load on tertiary and help achieve ZLD and enhance water reuse in true sense.

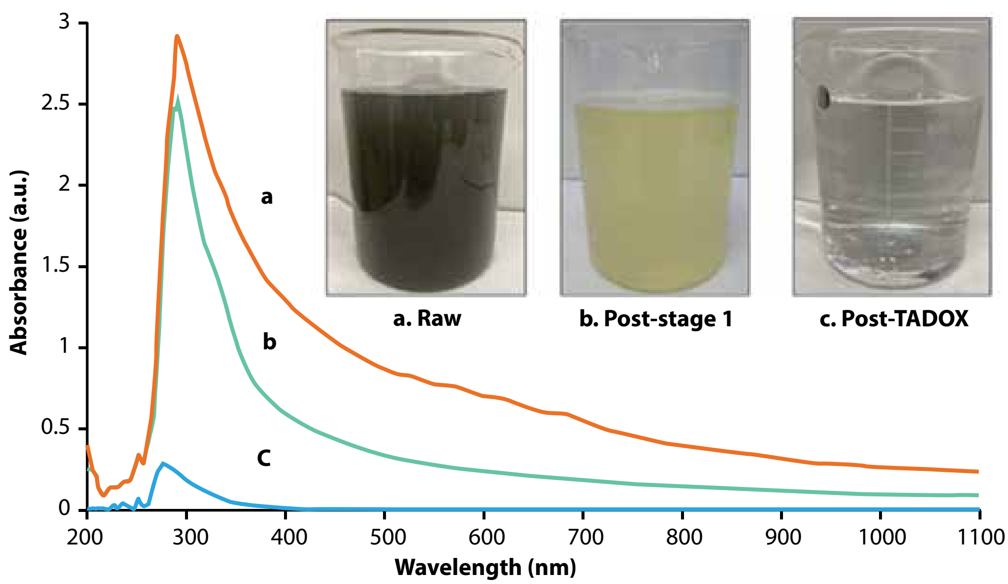


Figure 6 UV-Vis spectra of textile and dyeing effluent from a CETP (a) untreated/raw effluent, (b) post-stage 1, and (c) TADOX treated water

7. Key Findings

The benefits of TADOX integration in textile wastewater treatment are as follows:

1. TADOX involves novel primary treatment approaches with newer formulations of coagulants and flocculants as compared to conventional chemicals and makes very less use of chemicals in the overall treatment.
2. One of the most critical issues that TADOX implementation is able to address is complete removal of colour and substantially reduce COD and BOD, which is not taking place in conventional treatment.
3. TADOX implementations significantly improve the treated water quality and enhance the reuse efficiency of water even without RO/MEE. Therefore, it is able to produce water with moderate TDS levels and this water is compatible to be reused in most cases. 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.
4. With TADOX treatment, additional requirement of chemicals/ozonation for oxidation, carbon/sand filtration and chlorination for disinfection is not required at all, in both cases of IETP and CETP.
5. 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.
6. The secondary treatment involves photocatalysis as an advanced oxidation process (AOP), leading to oxidative degradation and mineralization of targeted pollutants.
7. Having small footprint, it could be integrated and retrofitted in existing treatment trails depending on the nature and constitution of the matrix. For example, 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.
8. TADOX implementation ranges from as low as 2 KLD plant for micro-scale industries and could be scaled up to 2 MLD for textile cluster CETPs.
9. TADOX could treat textile effluent with TDS below 8000 mg/L while COD could be as high and more than 100,000 mg/L.
10. The obtained sludge characteristic through elemental analysis shows that it is free from heavy metals, and toxicity characteristic leaching procedure (TCLP) analysis shows that residues are non-toxic as per schedule II of the Hazardous and Other Wastes (Management and Transboundary Movement) Rules 2016. Hence re-use applications could be explored on a case-to-case basis and till such time it is expected to be disposed off as per HOWM Rules 2016 (H&OWM 2016).
11. For individual ETPs and smaller dyeing clusters/ units, end-to-end TADOX treatment is sufficient, and bioremediation of any kind is not required. This may help MSMEs, already having small land and limited capital and resources, to adopt such advanced and modular WWT options and treat wastewater sustainably at source. The scheme is depicted in Figure 7A.

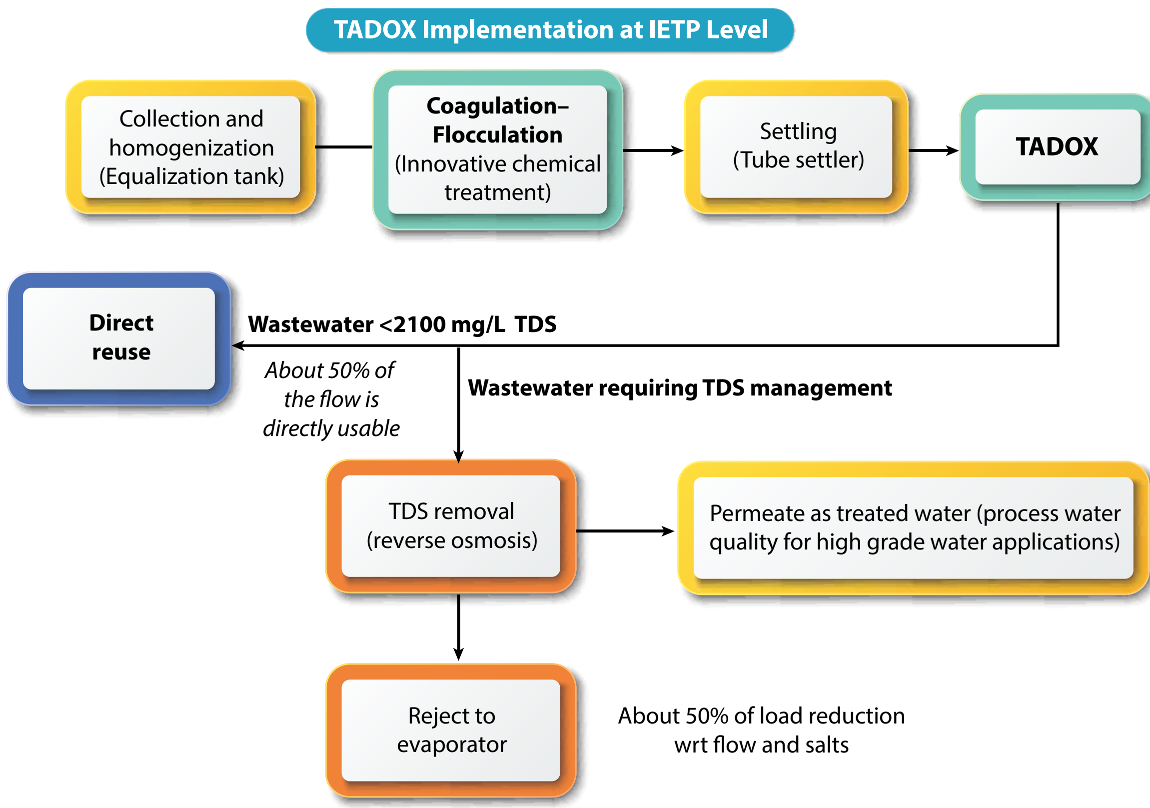


Figure 7A Showing the possible implementation of TADOX at large-scale textile and dyeing units at individual ETP (IETP) scale

12. While for large-scale industrial clusters having CETPs, integration of TADOX at the pre-biological stage is expected to improve the overall biodegradability and enhanced shock load-bearing capacity, enabling overall good health and longevity of the plant. The scheme is depicted in Figure 7B.

8. Benefits of TADOX Integration in Achieving ZLD and Enhancing Water Reuse

1. TADOX treated water could be directly reusable in various processes, thus reducing freshwater withdrawals and also where freshwater is available on payment basis and even enabling better water management and conservation.
2. Less use of chemicals and less amounts of chemicals are expected to reduce sludge quantum, ease of disposal and management, and issues of secondary pollution.
3. Reduction in overall hydraulic retention time (HRT) further aids in high resource and energy efficiency.
4. In large-scale ZLD units, TADOX integration is expected to enhance the purity of recovered salts from MEE rejects due to oxidative degradation and removal of dissolved organic load during the upstream treatment.
5. TADOX enables complete decolourization, substantial reduction in COD and BOD, and 30–40% TDS removal, therefore for individual textile &and dyeing units, this treatment is just sufficient to meet discharge norms and enhance water reuse in various processes.
6. While in the case of CETPs, where ZLD is required, the integration of TADOX reduces the overall load on tertiary treatment, leading to energy and resource efficiency and ultimately leading to reduction in CAPEX and OPEX.

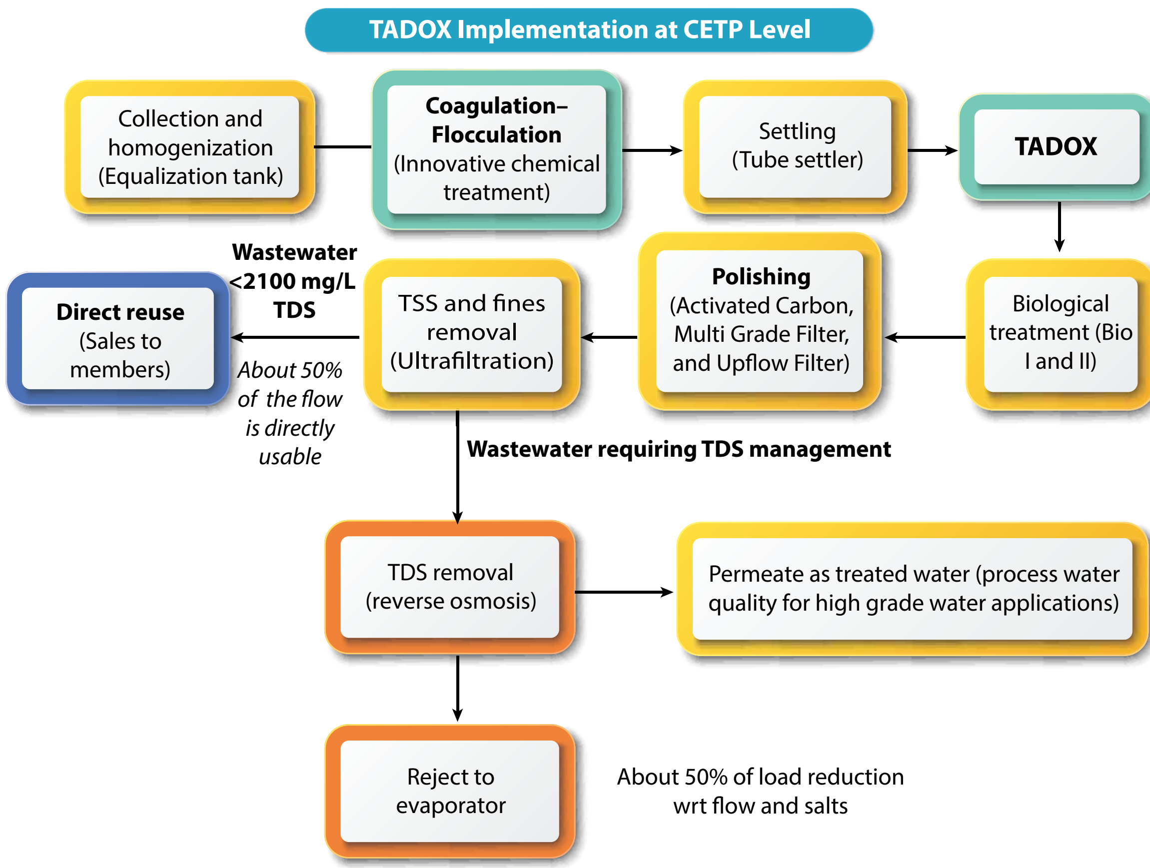


Figure 7B Showing the possible implementation of TADOX at large-scale textile and dyeing units at common ETP scale

7. From key findings and Figures 7A and 7B, it is evident that TADOX integration and the quality of water obtained as a result of TADOX treatment is expected to substantially reduce load and flow rate requirement of RO and MEE. In other words, now smaller RO and MEE will be required for same capacity of treatment and enhancing water reuse.
8. For a typical 100 KLD ZLD installation with treatment, conventional setup may require 180–200 kW connected load; however, with TADOX integration the connected load is expected to be reduced to 150–160 kW, thus reducing power requirement by 20–25%.
9. Looking at the cost of treatment and achieving ZLD in general in the textile and dyeing industry, the existing market value comes out to be ₹16 crore/MLD as capital (CAPEX) and ₹180–220 /m^3 as operational (OPEX) expenditure. On the other hand, TADOX with ZLD is expected to cost ₹12 crore/MLD as CAPEX and ₹170–190/m^3 as OPEX. TADOX alone is expected to cost ₹6 crore/MLD as CAPEX and ₹95–110/m^3 as OPEX. Thus, TADOX integration in ZLD is expected to reduce the overall CAPEX by 25–30% and OPEX by 30–40%.

9. Policy Recommendations

The following are the recommendations to the Government of India related to the articulation of policies pertaining to adoption of newer and cleaner technologies like TADOX, which have huge potential to revolutionize wastewater treatment in India and help achieve ZLD and enhanced water-reuse efficiency in a coloration industry like textile and dyeing:

1. Creation of a reliable and comprehensive database for the entire textile sector regarding current wastewater generation, treatment, technology options, challenges, gaps, and end use of treated water.
2. Stream segregation based on biodegradability and dissolved solids should be made mandatory for industries prior to treatment in ETPs.
3. Primary treatment involving novel approaches, less number and less amounts of chemicals leading to lower sludge generation should be encouraged.
4. Feedback loop mechanisms through use of online monitoring data should be implemented in wastewater treatment plants in industries for achieving better resource and energy efficiency.
5. Given the scenario wherein textile industries, essentially comprising SMSEs, operate largely in clusters through mechanism of CETP, ZLD for these industries may always not be a financial and technologically viable solution and can only be looked on merits of individual cases. TERI's TADOX process, tested on pilot scale, may be one of the promising clean and new options towards attainment of twin goal of ZLD or near ZLD scenario and thus expected to reduce load on tertiary treatment and promote water-use efficiency in one of the polluting industry sectors.
6. For individual units having ETP, TADOX treatment is sufficient as an end-to-end treatment technology.
7. In the case of a CETP having a large number of member units, TADOX may be integrated at a pre-biological stage to improve biodegradability, remove colour, enhanced shock load-bearing capacity, enabling overall good health and longevity of the plant.
8. 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, a CETP based on conventional biological systems could be augmented into more efficient plants by applying TADOX in series of the treatment. TADOX may also be applied in parallel to the existing treatment scheme to augment the overall capacity of treatment plants.
9. Suitable treatment schemes should be provided to treat wastewater coming from different sectors, only after understanding the nature and constitution of the effluent and also be decided based on the end-use application. For example, treatment for textile and dyeing wastewater should be different from that given to wastewater from dairy industry.
10. Thus Regulatory authorities such as Central Pollution Control Board (CPCB), State Pollution Control Boards (SPCBs), Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India should come up with a database and a regulatory mechanism to validate and approve suitable treatment technologies and schemes for appropriate applications for various wastewater streams across different polluting sectors.
11. Use of nanotechnology for wastewater treatment should be encouraged with appropriate funding schemes under Department of Science & Technology (DST) Water Mission and Nano Mission, Ministry of Science and Technology, Government of India.
12. Financial support from various international organizations such as the EU, GIZ, and river cleaning and rejuvenation programmes of the Government of India such as the Namami Gange and National Water Mission, Ministry of Jal Shakti may supplement efforts in this direction.
13. Various agencies under the Ministry of Textiles, Government of India such as the North Indian Textile Research Association (NITRA), South Indian Textile Research Association (SITRA), Ahmedabad Textile Industry's Research Association (ATIRA) should encourage and help with funding support towards

promotion, adoption, and implementation of such cleaner and greener technologies at pilot scale.

14. The end-user, the textile and dyeing industry and the Textile Association of India, should be brought on one platform and made aware of such technological innovations, and mandated to facilitate and provide on-site pilot scale demonstrations.
15. Industrial units coming forward for piloting and adopting newer and cleaner indigenous technologies for treating wastewater should be incentivized with low-cost interest rates on loans from banks with fast track facility.
16. Incentivization should include rebate on electricity charges for quick adoption and promotion of cleaner and greener technologies.
17. Corporate social responsibility (CSR) funds of large wastewater treatment companies/textile parks/ clusters and integrated units should be appropriately allocated for R&D-based technological interventions in addressing wastewater treatment and reuse challenges.
18. R&D institutions and NGOs coming up with such innovative solutions having the potential to revolutionize textile wastewater treatment should be attached to and promoted by incubation centres for textiles and apparels.
19. Start-ups on wastewater treatment technology implementation should be given a boost through Start-Up India Grants and Challenges, Invest India Fund, etc.
20. Micro and Small Enterprises–Cluster Development Programme (MSE-CDP) Scheme (MoT 2017a) could address common issues of improving skills and capacity building in technology upgradation and understanding of newer and cleaner technology options in wastewater treatment and reuse.
21. Under the Scheme of Integrated Textile Parks (SITP) (MoT 2017b), the newer and upcoming textile parks should be incentivized to adopt newer and cleaner technology options like TADOX.
22. Such cleaner technology options like TADOX should be considered for Technology Upgradation Fund Scheme (TUFS) (MoT 2017c), which aims to catalyse investment in the textile sector by providing subsidies and assistance to upgrade existing technologies, which may be used in point-source pollution control and prevention. Under TUFS, it is possible to improve the quality of the entire value chain, reduce sludge, chemicals, cost, and secondary pollution.
23. Cleaner technology like TADOX should be part of centrally sponsored scheme for Integrated Processing Development (IPDS) setup for water and waste management. This will help in bridging the gap between early technology adopters and providers in the area of wastewater treatment for textile sector (MoT 2017d).

Conclusion

This policy brief dwells upon the policies and programmes on 'Wastewater Treatment in Textile and Dyeing Industry' and how integration of TADOX, which comes under the category of AON, could help achieve ZLD and enhance treated water-reuse efficiency in much more sustainable, affordable, resource, and energy efficient manner. It highlights R&D-based interventions and results published in peer reviewed international journals. It focuses on innovation in textile wastewater treatment with emphasis on integration of TADOX at secondary treatment stage or at pre-biological stage, leading to oxidative treatment and mineralization of dyes, and auxiliary chemicals enabling enhanced biodegradability and reduce load on downstream tertiary treatment. Moreover, it provides an opportunity where bioremediation could be completely bypassed, leading to reduced footprint, capital expenditure, operational expenditure, together making the overall wastewater treatment much more affordable and sustainable. It recommends various funding options in bridging the gap between early technology adopters and technology providers. Encouragement and incentivization is required for industries, which can come forward for piloting and demonstrating novel technologies involving nanotechnology for wastewater treatment in a highly polluting and water guzzling industry such as textile and dyeing. Extensive R&D work has proven that TADOX integration could revolutionize wastewater treatment in India with high potential in both greenfield and brownfield projects.

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