Sustainable Technological Options for Industrial Effluent Treatment in Common Effluent Treatment Plants: A Review

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Abstract The Common Effluent Treatment Plants are considered an essential infrastructure for wastewater management worldwide. They provide an economical and one-point solution for wastewater by offering a specific treatment scheme for all types of industrial effluent having various characteristics. Developing countries like India are growing in the industrial sector vigorously. It is essential to meet the environmental effluent discharge standards for medium and small-scale industries. This study discusses the treatment schemes adopted by various CETPs in India. This review paper also discusses the multiple technologies CETPs use for industrial clusters. Since most of CETPs in India use conventional treatment methods, it is evident that innovative and efficient technologies must be deployed. This review study provides various advanced technologies, including advanced oxidation processes (AOPs) like Electro Fenton, Ozonation, Photocatalysis, Cavitation and Membrane technologies. Overall, the paper provides a brief overview of the current scenario in CETPs and the potential adoption of cutting-edge technology for improvements in wastewater treatment.

Keywords CETP · Advanced oxidation process · Membrane treatment · Chemical treatment

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1 Introduction

1.1 General

In recent times, developing countries like India have seen major industrial sector growth to meet the demand of their ever-increasing country population. More and more entrepreneurs and industrialists are establishing manufacturing facilities in India owing to government initiatives like “Make in India”. This enlargement of the industrial sector is constantly affecting the environment due consumption of resources, and the generation and discharge of industrial effluent into the water bodies severely affecting the natural ecosystem. In India, many industries are Micro, Small, and Medium enterprises (MSMEs). According to the Ministry of MSME, any manufacturing company with a turnover of less than 5 crores is classified as a micro industry, one with a turnover of less than 50 crores as a small industry, and one with a turnover of less than 250 crores as a medium industry. These MSMEs generate huge employment and contribute about 45% toward the country’s manufacturing output [25]. At the same time, these MSMEs produced more hazardous waste overall than major industries [6]. The industries also produce a large amount of industrial effluent and toxic chemicals. This kind of toxic discharge is extremely undesirable and poses a risk to human health [21]. These industries are mandated to treat the effluent at a certain level before discharging it into the water bodies. Common effluent treatment plants (CETPs) are the most preferred option to treat this wide range of wastewater. The CETPs not only provide an economical solution for the MSMEs but also facilitate the regulators to manage and inspect the treated wastewater at one location.

1.2 Status of CETPs in India

The concept of CETPs has been successfully implemented across India’s several industrial sectors, including tanneries, textiles, chemicals, pharmaceuticals, fertilizers, and many more. India today has several industrial sectors that regularly produce various types of wastewater. According to the Ministry of Environment, Resources, and Climate Change’s 2016 report, India presently has 193 CETPs in operation to treat industrial wastewater before discharging. Most of the time, for the installation and operation of CETPs, the central and state governments each contribute 25% of the overall costs, with member industries and financial institutions covering the remaining cost. It is observed that while the contribution to investment varies from nation to nation, the contributing party remains the same. The regulatory agencies have set the discharge standards in accordance with the Environment Protection Rules of 1986 in order to enhance the performance of the CETPs. The discharge standards for CETPs in India are shown in Table 1.

Table 1 Wastewater discharge standards

Parameters	Into inland surface waters	On land for irrigation	Into marine coastal areas
pH	5.5–9.0	5.5–9.0	5.5–9.0
BOD [3 days at 27 °C]	30	100	100
Temperature	Should not be greater than 40 °C	–	45 °C
Suspended solids	100	200	(a) For process waste water-100 (b) For cooling water effluent 10% above total suspended matter of effluent cooling water
Dissolved solids (inorganic)	2100	2100	–
Total residue chlorine	1.0	–	1.0
Ammonical nitrogen (As N)	50	–	50
Total Kjeldahl nitrogen (as N)	100	–	100
COD	250	–	250
Arsenic (As)	0.2	0.2	0.2
Mercury (Hg)	0.01	–	0.01
Lead (Pb)	0.1	–	1.0
Cadmium (Cd)	1.0	–	2.0
Copper (Cr)	3.0	–	3.0
Zinc (Zn)	5.0	–	15
Chloride (Cl)	1000	600	–
Fluoride (F)	2.0	–	15
Sulphate (SO4)	1000	1000	1000
Sulphide (as S)	2.8	–	5.0
Phenolic compounds (C_6H_5OH)	1	–	5.0

1.3 Characteristics of CETP

The CETPs are performing unsatisfactorily due to a wide range of issues. CETPs are meant to deal with such solutions and are designed to treat heterogeneous effluent efficiently [46]. Industrial wastewater comes a vast characteristic variation, making difficult for CETPs to treat and meet the discharge standards. Factors like the choking of the plumbing system, damages in treatment units, etc. can severely affect the treatment ability of the CETPs leading to the lower quality of the treated effluent [26]. The operation and maintenance of individual treatment units, a limitation of trained labour, and variations in influent quality and quantity are some other issues encountered by CETPs. The efficacy of CETP may potentially be impacted by wastewater containing organic pollutants and phenolic chemicals. The wastewater characteristics change from industry to industry. Table 2 shows the type of wastewater that different types of industries produce as effluent. Due to the enforcement of strict discharge standards, the CETPs need to treat the wastewater as per the norms effectively. The CETPs also struggle with operational cost funded by the member industries, because they are constantly concerned about the money being spent on wastewater treatment with their profits. Thus, in order to achieve the discharge norms, there is a great demand for newer technologies to treat various types of wastewater at a cheap cost and with minimal investment. Implementing a new technology can undoubtedly result in the efficient treatment of industrial wastewater and the preservation of the water bodies.

Table 2 Characteristics of various CETPs

Parameters	Moosvi and Madamwar [23]	Pathe et al.	Kumaret al. [13]	Sivgami et al. [43]	Rohitbhai et al. [36]	Singh and Kumar [42]
pH	7.5–8.0	5.5–10.8	7.7	–	7.33	9.2
COD (mg/L)	3000–5000	3253 ± 319	1727	1500–5000	1600	8100
Colour (NTU)	–	–	–	–	2124	550
TDS (mg/L)	–	14,625 ± 416	18,920	–	13,453	4761
BOD (mg/L)	500–650	1247 ± 99	–	–	–	4047
TS (mg/L)	24,000–33,000	–	–	–	–	–
TSS (mg/L)	5000–5400	5852 ± 377	–	200–700	–	19.51
Chlorides (mg/L)	1900–2000	8207 ± 1243	9017.2	–	–	57.14
Sulphates (mg/L)	2000–3500	1557 ± 46	374.2	–	–	238.09
Iron (Fe)	–	0.430 ± 0.032	–	–	–	15.54
Lead (Pb)	–	0.025 ± 0.0004	–	–	–	2.50
Zinc (Zn)	–	0.211 ± 0.014	–	–	–	0.0

2 Treatment Techniques

2.1 Coagulation and Flocculation

The coagulation and flocculation processes are the most popular and often employed methods for treating municipal and industrial effluent. The Egyptians are known to have used Alum (aluminium sulphate) for the settlement of the floating particles in the water as early as 1500 BCE. At present, this method is widely used to treat wastewater on a large scale for the removal of suspended particles and reduction of organic and inorganic pollutants [40]. Coagulation and flocculation can be divided into two parts: (1) intense mixing of the added coagulant with the wastewater by constant stirring, and (2) floc formation from the small particle by medium agitation. Following these two stages, flocs get settled in the form of sludge and the wastewater is sent to the next treatment unit for further processing [45]. The main aim of coagulation and flocculation is to remove suspended particles. These suspended particles always remain in suspension because they always repel each other due to their negative charge, hence coagulation and flocculation are essential to settle them [47]. In the coagulation process, chemicals and/or electric charges are used for the effluent treatment. Two types of coagulants are used primarily for the coagulation process (1) iron-based and (2) aluminium-based [31].

Numerous research has been done to establish the suitability of coagulation and flocculation in the existing treatment plants. Authors in Haydar and Aziz [12] treated the tannery wastewater by chemically enhanced primary treatment (CEPT) which earlier was treated without coagulation in the primary treatment plant. The utilization of alum showed excellent efficiency compared to ferric sulphate and ferric chloride. Also, the wastewater colours are not dark in the case of alum. Following the use of coagulation and flocculation by CEPT in tannery wastewater, the concentration of TSS and Chromium reduced below the discharge standards but further treatment was necessary to decrease the COD below standard limits [12, 29]. Additionally, it has been demonstrated that overdosing on coagulants can result in organic overloading while not influencing the effectiveness of the treatment. In a treatability study by Gotvajn et al., it was observed that ferric chloride could more efficiently treat tannery landfill leachate than alum [11]. Therefore, it is crucial to understand the sufficient dosage and the coagulant t is appropriate for adequate wastewater treatment (Table 3).

2.2 Fenton Process

The Fenton process is a combination of chemical treatment processes aimed to remove organic and inorganic pollutants from water and wastewater using an oxidation process with hydroxyl radicals. •OH. Fenton's technique involves the use of iron salts and hydrogen peroxide to generate hydroxyl radicals. A ferrous ion is oxidized by hydrogen peroxide to a ferric ion, a hydroxyl radical, and a hydroxyl anion. When Fe^{2+} and H_2O_2 react under acidic conditions, a large amount of •OH is generated.

Table 3 Wastewater treatment by coagulation-Flocculation

Treatment	Type of wastewater	Optimum parameters	Parameters	Result/ observation	References
Coagulation	CETP wastewater	pH 9.5 Alum dosage 200 mg/L	Turbidity	98.7%	Haydar and Aziz [12]
			TSS	94.3%	
			COD	58.7%	
			Chromium	99.4%	
Coagulation-flocculation	Petroleum refinery wastewater	$CuSO_4$ Dose 0.74 g/L pH 11	COD	55%	Singh and Kumar [42]
			Turbidity	97.8%	
			TDS	92.2%	
			Colour	94%	
		$FeCl_3$ = 0.20 g/L pH 7	COD	52%	
			Turbidity	80%	
			TDS	95.5%	
			Colour	92%	
		$CuSO_4$ + $FeCl_3$ = 0.20 g/L pH 7.122	COD	81%	
			Turbidity	93%	
			TDS	95%	
			Colour	95.2%	
Coagulation	Palm oil mill biogas plant wastewater	$FeCl_3$ = 8000 mg/L	Colour	82.6%	Zahrim et al. [51]
Coagulation	Tannery landfill leachate	$FeCl_3$ = 100 mg/L	TSS	97%	Gotvajn et al. [11]
			COD	45%	
			Turbidity	99.5%	
Coagulation	Synthetic wastewater	Alum dose 0.4 g/L pH 7	Turbidity	97.96%	Kumar Karnena et al. [14]
Coagulation	Textile industry wastewater	$FeCl_3$ = 4000 mg/L pH 4	COD	54%	Rana and Suresh [34]
Coagulation	Dairy industry wastewater	Alum 240 mg/L	COD	35%	Qasim and Mane [32]
	Sweet snacks industry wastewater		COD	67%	
	Ice-cream industry wastewater		COD	58.76%	

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \bullet OH + OH^-$$

The Fenton process produces little iron sludge, has a wide working pH range, and the catalyst can be easily removed after the reaction (Table 4).

Table 4 Wastewater treatment by fenton process

Treatment	Type of wastewater	Optimum parameters	Parameters	Result/ observation	References
Fenton	CETP dye wastewater	pH 3–5 Agitation speed 100 rpm	COD	39%	Rohitbhai [36]
			Colour	59%	
Fenton	CETP wastewater	pH 4 Contact time 60 min H_2O_2 = 4 ml $FeSO_4$ = 1 mg room temperature	COD	64.35%	Lalwani and Devadasan [17]
			BOD	68.57%	
Fenton	Textile wastewater	pH 3 $FeSO_4$ = 0.2 gm/lit H_2O_2 = 0.1 ml/lit Mixing at 130 rpm for 2 min Slow mixing at 30 rpm for 18 min	COD	98%	Patil and Raut [30]
			Colour	89%	
Fenton	Dye intermediate	pH 3 Fe^{2+}: H_2O_2 3:3 Retention time 60 min	COD	75.8%	Pani et al. [27]
			NH_3-N	78.6%	
Fenton	Dye intermediate	20 mL H_2O_2 (30%) • 10 mL Fe^{+2}(2%) • Treatment time 20 mi	COD	86%	Patel and Patel [28]
Fenton	Pharmaceutical wastewater	H_2O_2/COD ratio = 3 H_2O_2/Fe ratio = 1 pH = 3	COD	66.5%	Chavan et al. [5]
			Colour	99%	
Fenton	Tannery wastewater	H_2O_2/COD = 0.875 • Sorbent mass concentration was 12.66 mg/L • Contact time 120 min	COD	58.4%	Vilardi et al. [48]
			Total Phenol	59.2%	
Fenton	Chemical lab	Fe^{2+} 50 mg/L H_2O_2 50 mg/L pH 2.8 at 80 °C	TOC	88%	Ramirez [33]

2.3 Cavitation

Cavitation is the phenomenon through which bubbles develop, expand, and then instantly collapse at various locations in the reactor in nanoseconds, producing significant energy. Cavitation is further divided into four categories. Acoustic cavitation (AC), Hydrodynamic cavitation (HC), Optical cavitation, and Particle cavitation are the four types of cavitation. Due to their simplicity in implementation and operation as well as their ability to produce good cavitational ability, hydrodynamic and acoustic cavitation are frequently chosen over all other modes.

Hydrodynamic cavitation was used to treat the pesticide industry's effluent for a variety of time periods. After 75 min, 90.55% of the COD and 83.21% of the colour removal were observed [9]. The breakdown of p-nitrophenol was observed by using hydrodynamic cavitation, and it was also observed that the consumption of energy was two times lower than the acoustic cavitation [4]. Sivakumar and Pandit [44] treated the cationic dye rhodamine B using HC. In their study, and it was observed that HC is more energy efficient than AC. Also, HC was shown to treat more effluent in a single operation (50 L), while acoustic horn treated only 1.5 L of effluent [44]. Effluent from the wood finishing industry was treated with an HC reactor, where its COD reduction was observed until 2200 rpm [10]. Hydrodynamic cavitation can also be combined with Fenton to improve the effectiveness of pollution removal. Ultrasound and HC with Fenton were used to treat municipal and industrial wastewater. The COD removal of 24.9% from municipal wastewater was observed by using ultrasound treatment, while 44.3% COD removal was obtained for industrial effluent when treated with HC and Fenton combined [10] (Table 5).

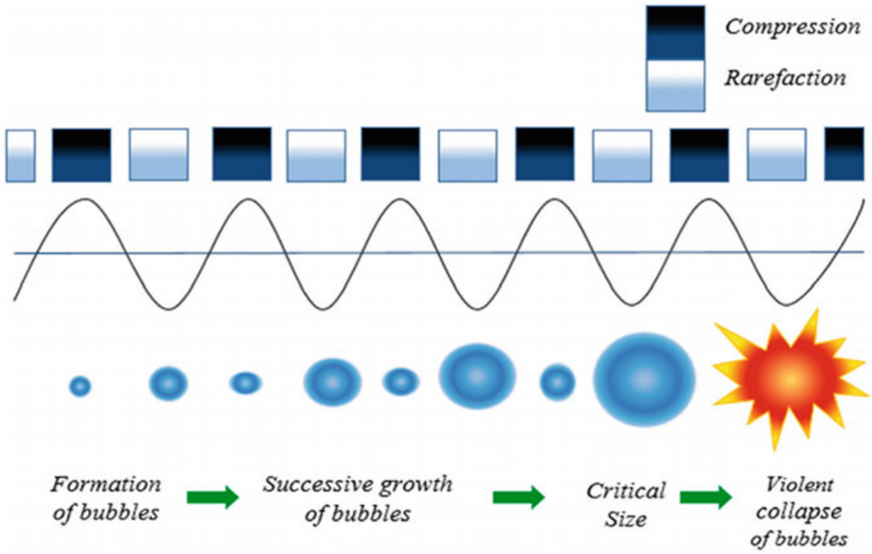

Table 5 Wastewater treatment by cavitation process

Treatment	Type of wastewater	Optimum parameters	Parameters	Result/ observation	References
AC/Fe (II)/ H_2O_2	CETP wastewater	Fe(II):H_2O_2 = 1:5 Power = 125W Frequency = 22 kHz pH = 3 Time = 60 min	COD	83.53%	Lakshmi et al. [16]
AC/O /MgO	CETP wastewater	pH = 9 Time = 60 min	COD	88.66%	Agarkoti et al. [1]
AC/Fe2 + / H2O2/Air	CETP wastewater	Fe(II)/H_2O_2 = 0.1 Power = 150W pH = 2 Time = 60 min	COD	95.2%	Agarkoti et al. [2]
HC/Fe(II)/ H_2O_2	CETP wastewater	pH 3 Inlet pressure 4 bar	COD	87.4%	Lakshmi et al. [16]
HC/O/MgO	CETP wastewater	pH = 9 Time = 60 min	COD	88.336%	Agarkoti et al. [1]
HC/Fe2 + / H2O2/Air	CETP wastewater	Fe(II)/H_2O_2 = 0.1 Power = 150W pH = 2 inlet pressure = 4 bar Temperature = 30 ± 2 °C Time = 60 min	COD	97.28%	Agarkoti et al. [2]
HC	Pesticide wastewater	Time = 75 min	COD	90.55%	Gaekwad and Patel [9]
			Colour	83.21%	
HC/Chlorine	Dye intermediate wastewater	pH 6.9 Time 60 min	COD	74.15%	Shah [41]
			Color	84.06%	
HC	Pharmaceutical wastewater	Time 90 min	COD	80.36%	Brahmbhatt [3]

2.4 *Ozonation*

In recent times, ozonation has become a perfect and effective alternative to chlorination. The ozonation is a quick process and requires less reaction time (approx. 10 to 30 min). Along with odour removal and toxic contaminants reduction ozone can also remove colour and produce less sludge. Heterogeneous and homogeneous catalytic ozonation are the two primary forms of catalytic ozonation used in wastewater treatment.

In their study, Qian [50] showed that ozonation combined with a biological aerated filter could lower the COD in textile wastewater below 50 mg/L. Ozonation can be used for pharmaceutical wastewater treatment. For pharmaceutical wastewater, it has been found that ozonation can remove 97% of the chemicals, and its removal effectiveness rises when combined with H_2O_2, which exhibits a 99% removal efficiency [35]. Adsorption on the surface of activated carbon in combination with ozonation has been suggested as a promising approach for the removal of organic pollutants [35]. In a sewage treatment plant effluent, the impact of ozone exposure on wastewater was investigated. It has been found that exposure to ozone for even a brief period of time can result in significant reductions in pollutants like COD, TN, TOC, colour, and turbidity [18]. Combining ozonation and phytoremediation can eliminate 90% of the inorganic carbon, 60% of colour, and 84% of COD from tannery wastewater [39] (Table 6).

2.5 Photocatalysis

Photocatalysis is a new process that is being researched for large-scale implementation. In this technique, wastewater is exposed to ultraviolet (UV) radiation in addition to Fe2 + and H_2O_2 to speed up the oxidation process. According to the studies, photocatalysis is the most prominent technology among the AOPs, followed by hydrodynamic cavitation. This process produces nearly no waste, making it ideal for creating a sustainable and environmentally beneficial solution.

Authors in [49] reported 79% colour removal from the distillery effluent while using solar radiation as a source of external energy in the photocatalytic process Vineetha et al. [49]. Methylene blue was degraded using N-doped TiO_2 as a photocatalyst. After 180 min of irradiation, there was full decomposition [20]. The biochar and TiO_2 combination was used to remediate the textile wastewater. It was found that using a hybrid composite system may produce 99.2% photodegradation efficiency, compared to 42.6% for TiO_2 and 85.2% for pure biochar when used individually [8].

2.6 Membrane Techniques

Membrane technologies have recently caught the research community's attention, raising their authentications in real-world scenarios due to their ability to treat wastewater. In the event of primary and secondary treatment failure, tertiary treatment processes like membrane technologies can be used to fulfill the discharge regulations. Based on pore size and membrane pressure, they can be divided into four major classes 1. Micro Filtration (MF), 2. Ultrafiltration (UF), 3. Nanofiltration (NF), and 4. Reverse Osmosis.

Table 6 Wastewater treatment using ozonation

Treatment	Type of wastewater	Optimum parameters	Parameters	Result/ observation	References
Ozonation	Tannery effluent	pH 7.6 Ozone 1.5 g O3/g of COD Time 90 min	COD	60	Saranya and Shanthakumar [39]
Ozonation and phytoremediation			Inorganic carbon	90%	
			Colour	60%	
			COD	84%	
Ozonation-biological aerated filter (O3-BAF)	Textile wastewater	Ozone dose 35 mg/L Retention time 2.5 h	Colour	90%	Wu et al. [50]
			COD	35%	
Ozonation	Winery wastewater	pH 4 Reaction time 180 min Ozone dose 100.1 mg/min	COD	12%	Lucas et al. [19]
Ozonation	Textile wastewater	pH 7 Reaction time 50 min Ozone dose 7 mg/L	Colour	100%	Constapel et al. [7]
Ozone/UV	Winery wastewater	pH 4 Reaction time 180 min Ozone dose 100.1 mg/min UV lamp 36W	COD	21%	Lucas et al. [19]
Ozone/UV	Olive mill wastewater	pH 3 Reaction time 180 min Ozone dose 12 g/L UV lamp 14 W	COD	29%	Lafi et al. [15]

The use of membranes is an appealing method that is rapidly being employed to replace traditional techniques in wastewater treatment. Using nanofiltration, COD and TDS in the effluent can be eliminated up to 96–99.5% and 98–99.5%, respectively. This technology can be used to achieve both low discharge norms and zero liquid discharge circumstances. Moreira et al. [24] tried to achieve ZLD conditions

Table 7 Wastewater treatment by membrane process

Treatment	Type of wastewater	Optimum parameters	Parameters	Result/ observation	References
MF-NF	Textile wastewater	–	Colour	98.5%	Moreira [24]
			Dye	92%	
Ceramic micro-filtration	Textile wastewater	Porosity 40.2% Mean pore diameter 0.27 μm Flexural strength 55 MPa	COD	25%	Saini [37]
			TDS	31%	
			BOD	39%	
			Turbidity	21%	
			Sulphates	34%	
			Chlorides	33%	
			Colour	26%	
			TSS	100%	
Ceramic microfiltration	Textile wastewater	Porosity 48.15%, Pore size 1.12 μm, Water permeability 922 L h – 1 m-2 bar-1 mechanical strength 6.1 MPa	Turbidity	99.9%	Manni et al. [22]
			COD	69.7%	
UF polymeric membrane (100 kDa)	Oily wastewater		TSS	94.1%	Salahi et al. [38]
			TDS	31.6%	
			Turbidity	96.4%	
			Oil & grease	97.2%	

for textile wastewater treatment. They obtain a 98.5% of colour removal and 92% of Dye removal by utilizing the combination of membranes and AOPs in their experiment. This membrane technology can also achieve up to 97.2% removal efficiency for oil and grease [38]. The main disadvantage of membranes is that they are very expensive and emit fouling odours after a short period of use, demanding frequent cleaning, which increases the expense of maintenance (Table 7).

3 Conclusion

The common effluent treatment plants play a crucial role in the ecosystem of industrial wastewater management. To decrease pollution as much as possible, rules and enforcement are becoming more stringent. Due to technological advancements, regulators are now continuously monitoring the performance of CETPs in India through online monitoring systems. As a result, CETPs around the country are now constantly monitored, ensuring that they function properly. The efficiency of CETPs in treating wastewater must be maintained and improved if regulatory standards have to be met. Due to increased influent volume, ageing infrastructure, and poor operation and maintenance of existing CETPs, a massive amount of substandard effluent is currently being discharged into the environment. The present review discusses the novel techniques currently being used in the CETPs. AOPs like Fenton, Photocatalysis, Cavitation, and Ozonation are some of the promising technologies which have been discussed and that can be applied individually or with a combination of the existing technology with a high potential of reducing the contaminants. It has been observed that photocatalysis provides a better option in the case of all AOPs. Fenton has been widely applied to reduce COD and colour from the colourant. Many studies have demonstrated the benefit of combining two or more techniques to enhance pollution removal efficiency. The combination of Fenton and UV has shown enhanced efficiency, suggesting a possible treatment approach that can be employed in CETPs. It has been found that CETPs in Gujarat have implemented newer technologies such as Fenton and hydrodynamic cavitation in their existing facilities. This shows that CETPs are actively seeking the adoption of more unique technology in their existing plants to cut operating costs and improve reliability to meet standards. Overall this paper has highlighted the importance, and recent findings and covered sustainable options for treatment which if applied can be beneficial for the operating CETPs in terms of finances and will help achieve the discharge standards.

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