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Feasibility on Grey Water Treatment by Electrocoagulation Process: A Review

Khalid Ansari[1] and A.N. Shrikhande[2]
[1]Research Scholar, Department of Civil Engineering,
Kavikulguru Institute of Technology and Science, Ramtek (Maharashtra) India
[2]Professor, Department of Civil Engineering,
Kavikulguru Institute of Technology and Science, Ramtek (Maharashtra) India

(Corresponding author: Khalid Ansari)
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ABSTRACT: Accumulation of safe and adequate water is gearing up an exercise of different technologies for wastewater management by felicitous treatment approaching to recycle and reuse. Greywater can be one of the sustainable alternatives to increment the fresh water demand due to its low pollutants load. In view to reducing greywater pollution problem, the present paper reviews various treatment technologies and focused on electrochemical-based electrocoagulation process offering attractive and effective treatment. This reviewed approach highlights the recent electrocoagulation studies that have been utilized for greywater treatment, examined on electrode arrangement, cell design and treatment facilities, as well as economic concern with recommendations, are suggested to boost the technology to maximize resource conservation and water development at large surface.

Keywords: Greywater, Electrocoagulation, Reaction Condition, Water Quality

I. INTRODUCTION

Water shortage problem is achieving the worst situation in increasing population's world, which shows the path to active water sustainability and management strategies. This has given researchers a specific goal in obtaining cost-effective, economic, and environmentally friendly wastewater treatment technologies for reuse and recycles a huge amount of wastewater generated from domestic and industrial agencies [1]. Concerning the conservation and recycling issues, domestic wastewater can meet the challenge a high level of water demands which contribute to reducing public health risks and environmental pollution [2]. Aiming the potential for reuse, the separation of domestic wastewater can split into grey water and black water [3,32] depending on its characteristics, the household waste-water flows from kitchen sinks, hand basins, showers bathtubs, and laundry machines is said to be greywater and water which produced from toilet's are termed as black water [3-4]. In many countries like India, greywater combines with black water for single domestic treatment which again leads to energy and economic burden. Similarly, to promote the possibility of recycling and minimization of operational cost for domestic wastewater treatment, there must be source separation and decentralized approach between grey and black water [5-6]. Greywater from a household flow almost 50 to 80% of total waste volume [7,63,66] which contribute to a low level of pathogens and nutrients. Researchers conducted various studies on treatments facilities with different technologies summarized in Table 1 based on complexity and performance of greywater but lacks on evaluation of suitable technologies for greywater reuse and recycle [10]. However, a large range of technologies and recycling options of greywater is available from last five decades, with option of physical process alone is insufficient for greywater treatments and reuse [1-10]. According to several studies, [13-16] biological treatment process includes rotating biological contractors (RBC), sequencing batch reactor (SBR), constructed wetlands, up-flow anaerobic sludge blankets (UASB) with some innovative technologies like membrane bioreactors and reed beds, which often provides satisfactorily results in removing efficiencies of high strength greywater due to its process stability and pathogens removals. Another investigation of treatments studies, [17-19] includes chemical processes, such as coagulation, electrocoagulation, photocatalyticoxidation, ion exchange, and granular activated carbon which can reduce organic matters to certain level but failed to meet the reuse category for high loading greywater. Hence, to overcome safe and sustainable reuse conditions, literatures comes with combination process for treatment of greywater to produce low cost and low maintenance technologies for economic reasons. Many works done for Water quality monitoring over wireless sensor network and purification [68]. Among these, physicochemical process can effectively remove suspended solids, organic matter, and surfactants [20] in comparison with physical biological or chemical biological due to large surface area and retention time.

Table 1: Recent Studies Showing Treatment Options in Greywater.

Physical process	Removal efficiency at effluent	Description	References
Soil Filter (HRT= 0.086 $m^3/m^2/day$)	78% (removal) TSS (mg/l) 84% (removal) COD (mg/l) 67 % (removal) BOD (mg/l)	Studied on high strength kitchen GW for 0.086 $m^3/m^2/day$ Remove nutrient and surfactants Operational and maintenance cost is low Fail in reducing microorganism, but adding disinfection process results improved Fail to meet reuse standards	[51]
UF membrane (0.05 micrometer pore size)	49% (removal) TSS (mg/l) 53% (removal) COD (mg/l) 55 % (removal) BOD (mg/l)	Studied on high strength laundry GW for 150 min at flux for 130 $L/m^2/h$ Fail in removing organic surfactants Sludge production is less Operating cost is more than conventional method Fail to meet reuse standards No result on microorganism removal	[18]
After UF membrane RO membrane	100 % (removal) TSS (mg/l) 100 % (removal) Turbidity (NTU) 93 % (removal) COD (mg/l) 87 % (removal) Anionic ….Surfactant (mg/l)	Studied on high strength laundry GW for 130 min at flux for 37 $L/m^2/h$ Removed anionic and organic surfactants Good results shown in removing color Sludge production is less Operating cost is more than conventional method No result on microorganism removal	[18]
UF membrane	74 % (removal) COD (mg/l) 80 % (removal) BOD (mg/l)	Studies on Mixed GW No result on microorganism removal	[54]
Chemical process	**Removal efficiency at effluent**	**Description**	**References**
Photo catalytic oxidation	78% (removal) COD (mg/l)	Studies on low organic loading of laundry GW 51% removal efficiency found in coagulation	[55]
Electrocoagulation	86 % (removal) Turbidity (NTU) 70 % (removal) COD (mg/l) 99 % TC (CFU/100)	Studies on Mixed organic loading of GW for 60 min Less volume of sludge produced Analysis on voltage system of (6, 8.5, 10) Volts Energy consumption for COD removal is 0.3 kWh/m^3 Operating cost 0.18 US$/$m^3$ Meet reuse standard in characteristic of pathogens	[32]
Magnetic Ion Exchange	83 % (removal) Turbidity (NTU) 66 % (removal) COD (mg/l) 83 % (removal) BOD (mg/l)	Studied on low organic strength GW (bath, shower, hand basin of 18 flats) Shows some good results for organic removal Fail to meet reuse standards	[19]
Biological process	**Removal efficiency at effluent**	**Description**	**References**
MBR	97 % (removal) Turbidity (NTU) 86 % (removal) COD (mg/l) 98 % (removal) BOD (mg/l) 99 % FC (CFU/100)	Studied on 0.1 micrometer membrane pore size for low strength GW with permeate flux ranged from 8-10 l/m^2h Fraction of ammonium to TKN increase to 100% on 122days Meet the reuse standards	[56]
Constructed Wetland	83 % (removal) Turbidity (NTU) 98 % (removal) TSS (mg/l) 81 % (removal) COD (mg/l) 99 % (removal) BOD (mg/l) 99 % TC (CFU/100)	RVFCW was used for high strength GW performing at 8-24 hours retention time Good treatment performance with recycle rate of 390 L/h Operating and maintenance cost is very low Meet the reuse standards acquiring 210 m^3 of GW per year	[57]
Horizontal flow Reed beds	81 % (removal) Turbidity (NTU) 65 % (removal) TSS (mg/l) 76 % (removal) COD (mg/l) 66 % (removal) BOD (mg/l) 99 % TC (CFU/100)	The reed used is Phragmites australis for low strength greywater for nine month. Shows limited scope for removing organic pollutants Shows respective results in removing total coliform, *E coli* and faecal enterococci.	[58]
Vertical flow Reed beds	96 % (removal) Turbidity (NTU) 78 % (removal) TSS (mg/l) 94 % (removal) COD (mg/l) 96 % (removal) BOD (mg/l) 99 % TC (CFU/100)	The reed used is Phragmites australis for low strength greywater for nine month. Shows good results for removing organic pollutants and in removing total coliform, *E coli* and faecal enterococci Shows no evidence of clogging on bed surface	[58]

Biological process	Removal efficiency at effluent	Description	References
Submerged Membrane Bioreactor	88 % (removal) TSS (mg/l) 95 % (removal) COD (mg/l) 97 % (removal) BOD (mg/l) 99 % TC (CFU/100)	Studied on mixed organic loading of GW at 0.071 m^3/day with pore size of 0.4 micrometer Performance done on steady state and unsteady state SMBR shows good performance at steady state as compared to unsteady state Shows Good removal efficiency with MF and UF membranes followed by disinfection	[59]
Combined process	**Removal efficiency at effluent**	**Description**	**References**
Sand filter+ Membrane+Disinfection	100% (removal) Turbidity (NTU) 72% (removal) COD (mg/l) 68% (removal) BOD (mg/l)	Studies on low organic loading of GW at 4.37 m^3/d Fail in reduction of nutrient and surfactants Meet non-restricted non-potable reuse standard in characteristic of turbidity and BOD standards Require smaller reactor	[62]
Electrocoagulation + Disinfection	91% (removal) Turbidity (NTU) 69% (removal) TSS (mg/l) 58% (removal) COD (mg/l) 61% (removal) BOD (mg/l)	Studies on low organic loading of GW at EC cell at 1.2-1.4 m3/h which was disinfected by (NaClO) Meet reuse standard in characteristic of turbidity Operating cost for 8m^3 unit is U.S $ 0.27/m^3	[17]
Rotating Biological Contractor + sand Filter + Chlorination	97% (removal) Turbidity (NTU) 81% (removal) TSS (mg/l) 75% (removal) COD (mg/l) 95% (removal) BOD (mg/l) 99% (removal) FC	Studies on High and Medium pollutants loading GW at 2.1 m3/day Provide Economic and feasibility solution for GW recycling	[61]
Rotating Biological Contractor + sand Filter + UV disinfection	82% (removal) TOC (mg/l) 82% (removal) COD (mg/l) 94% (removal) BOD (mg/l) 99% (removal) FC	Studies on Low pollutants loading GW (Shower and Handbasin) Provide Economic and feasibility solution for GW recycling	[60]

In pastscenario, performance based on electrocoagulation (EC) process which involves the coagulation, floatation and electrochemistry offers numerous returns including affluence of operation, strength to varying reaction conditions and effluent types, less retention time, speedy sedimentation of the electrogenerated flocculants, less sludge production, and lesser space requirements and capital costs [21] in large scale of applications. The prime objectives of this review study is to discuss the importance of electrocoagulation process in treating the greywater and to evaluate the performance of each operating process in highlighting the efficiency and reuse conditions.

II. BACKGROUND OF ELECTROCOAGULATION (EC)

Literature studies show that the EC process satisfactory been applied for decades to treat wastewater. Electrocoagulation (EC) is becoming a viable alternative demand in handling of water and wastewater technologies due to its attractive advantages of higher efficiencies and simple operation of reactor made up of electrolytic cell of an anode and cathode which involves formation of coagulants at the sacrificial electrode by electrolytic oxidation, destabilizing particulate suspension, emulsified dissolved contaminants in the aqueous form like flocs with the application of electric current. The mechanism involved in the EC process is summarized in three steps such as electrode oxidation at sacrificial anode, gas bubble depending upon the size formation like hydrogen bubble at cathode, flocs formation because of coagulation which creates sludge blanket and can be removed by the filtration process [22-23]. The simple arrangement of EC process is shown in Fig. 1 [1].

A. Electrocoagulation Application in Greywater Treatment

Electrocoagulation proofs to be effective advanced technologies in the treatment of water and wastewater produced from various sources.

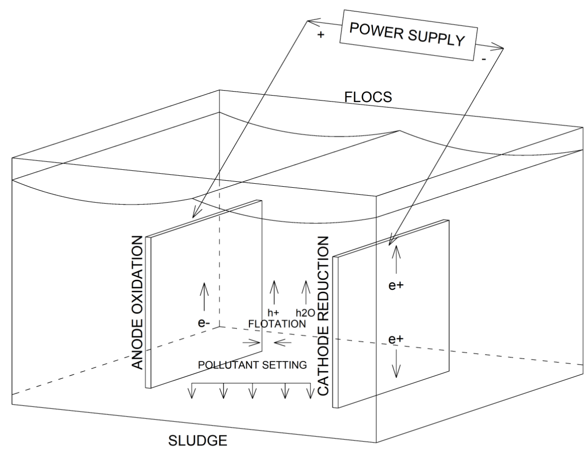

Fig. 1. A systematic representation of EC process.

However, very limited literature contributes in treatments of greywater by EC methods covering surfactants, oil and grease, suspended solids even turbidity and organic pollutants generate from a volume of water vary 90 to 120 l/p/d depending on the quality of lifestyle, living standards, age factors, social and cultural traditions, availability, and consumption of fresh water [26] distinguished between dark and light greywater.

Dark Greywater from laundry, kitchen sinks, and dishwasher is more polluted due to variation in concentration of pollutants than light greywater coming from showers, bathtubs, wash-basins. The characteristics is summarized in Table 2.

Table 2: The Characteristic of Greywater Generated.

Parameters	Dark GW	Light GW	Mixed GW
pH	6.3-8.5	6.4-7.6	6.3-8.1
Turbidity(NTU)	50-2131	12-375	29-375
TSS	68-1300	11-505	25-183
BOD	40-890	23-424	47-466
COD	58-2000	55-645	100-700
TN	8.8-57.7	4.1-16.4	1.7-34.3
TP	0.11-48.8	0.69-51.58	0.11-22.8
MBAS	11.1-118.3	3.3-61	0.3-118.3
O & G	181-328	77-164	7-328
TC (CFU/100ml)	200.5-2.4E8	10-2.4E7	56-8.03E7
FC (CFU/100ml)	50-1.4E3	0-3.4E5	0.1-1.5E8

* Units in brackets, all other units in mg/l except Ph.

Based on the literature [9,10,26,27], the mean found in greywater as follows. Moreover, the quantitative and qualitative characteristic of greywater produced shows substantial differences originating from different countries. [10-29]. Recently some studies show the application of electrocoagulation systems on treatment of greywater shown in Table 3.

III. TREATMENT PARAMETERS

The feasibility of the EC process treatments depends strongly on various operational parameters which effect the removal treatments and efficiency of pollutants in greywater; which discussed as follows.

A. Electrode Materials

Electrode Materials is the heart of EC process. The selection of appropriate electrode material is very crucial, which determines the electrochemical reactions in EC process, typically made-up from aluminum, iron, copper, steel, and, graphite showing different chemistries and applications. Mainly Al and Fe electrodes and a combination of both are studied in greywater treatments proving better results of COD removal by only iron electrodes than Al electrodes due to bubble production and higher oxidation potential.

Table 3: Recent Studies in Greywater Treatment by EC Method.

Pollutant	Electrode Material	Treatment parameter	Removal Efficiency	Summary	References
Domestic Greywater	Al-Fe Hybrid Combination	Initial pH, current density, electrolyte concentration, electrode combination, energy and electrode consumption	For Al-Fe-Al-Fe at pH 7.62 98 % -Turbidity (NTU) 98 % -COD (mg/l) 92 % -TP (mg/l) 84 % -TN (mg/l) 98 % -MBAS (mg/l) 99 %-TSS (mg/L)	Highest COD removal efficiency were found with initial pH 7.621 having current density of 1 mA/cm^2 Al-Fe-AL-Fe combination Energy Consumption were found out to be 9.46 KWh/m3 for Al-Fe-Al-Fe hybrid combination	[26]
Restaurants Wastewater	EC-EO process under Al or (iron) and Graphite electrode	Applied current, Electrolysis Time, Initial pH,	98 % -Turbidity (NTU) 90 % -COD (mg/l) 98 % -O & G (mg/l) 88.5 % -TP (mg/l) 98 % -MBAS (mg/l) 76.6 % -TS (mg/L)	The best performance was obtained in removing COD, BOD, and O&G is by applying current of 0.4 A with adjust pH 7.0 during 90 min	[30]
Domestic Greywater	Al bipolar electrode	Applied Current & Voltage Initial pH, Reclaimed Water Cost	60 % -COD (mg/l)	For 28 m^3/day capacity of onsite greywater required 0.27 U.S. Dollor /m3 with an applied current of 3 A, performing with applied voltage of 135 V to give good removal efficiency of COD	[31]
Domestic Greywater	Al electrode and Combination of AL-Graphite Electrode	Applied Voltage, Current density, energy consumption	86 % -Turbidity (NTU) 70 % -COD (mg/l) 99 % -TC (CFU/100)	Al is more effective. Over 70% removal of COD, covering high pathogens removal of 99.9% with an energy consumption of 0.3 KWh/m3 at operating cost of 0.18 U.S. Dollor/m3 performed at different voltage less than 12 V.	[32]
Greywater	EC-SMBR with Al electrode	Applied Voltage	97 % -Turbidity (NTU) 88.9 % -COD (mg/l) 96 % -MBAS (mg/l) 99.9 % -TC(CFU/100) 99.9 % -TC (CFU/100)	EC SMBR shows good results in achieving 13% reduction in membrane fouling compared to SMBR. The results obtained from EC-SMBR is better than SMBR for COD, turbidity, and colour removal	[20]
Grey Wastewater	Stainless Steel	Applied current, Electrolysis Time, Initial pH, Electrode distance	95 % -Total Solids (mg/l) 95% -COD (mg/l) 96 % -FC (CFU/100)	The result found at condition initial pH of 7, current density of 20 mA/cm^2, electrode distance of 5 cm and electrolysis time of 20 min	[49]

A hybrid electrode combination of Al and Fe removes both turbidity and COD (96%) with high efficiency [24-26] unpaid by the electrochemical properties of the electrolyte cells. Some studies show that aluminum electrode is better than iron electrodes with regards to efficiency and produced high quality of metallic sludge in greywater treatment with no color appearance at sacrificial anode [31-33].

B. Effect of pH

The pH of a solution is also one of the key factor that govern the removal performance of greywater in EC process as it effects the stability of hydroxide species that are formed. Generally, pH of treated greywater changes during process depending upon type of electrode, number of electrode and initial pH of solution [24-26]. The properties of pH have been examined [26] with hybrid electrode at acidic and basic range to shows maximum removal efficiency of COD, turbidity and other parameter as well as minimum energy and electrode consumptions with minimum sludge formations at pH around 7-8 [30-41]. Generally, the treatment efficiency clearly increased when pH is acidic, neutral or scarcely alkaline and subsequently dropped down at highly alkaline pH due to no formation of coagulants and adsorption of organic pollutants at low and high pH values [35]. Literature additionally suggested that as the pH increased, the energy consumption withal increases due to conductivity and nature of electrode materials [36].

Hence in a nutshell, optimum operating pH range for greywater EC treatment is 6-9 to ascertain consummate efficiency and thus, initial pH of waste need no adjustments to final pH to avoid operational costs.

C. Effects of Current Density

Another vital operating parameter that significantly influences the reaction rate in an electrochemical process is the density of current applied at the electrodes surface [23-26] determines the amount of Al^{3+} or Fe^{2+} ions get dissolved to increase the coagulants production rate, bubble formation rate, their size and flocs growth [23]. Predicated on the literature studied it is observed, when the current density of 1-20 mA/cm^2 is applied the % COD and sludge production removal efficiency increases [26,30,31], but for higher current densities of 40-50 mA/cm^2 removal efficiencies started decreasing. Additionally, increasing the current density, bubble rate increases and their size decrease resulting in faster removal of pollutants and $H_{2(g)}$ flotation which lead to remove metal hydroxide from solution to reduce collision between pollutants and coagulants ensuing in reduction of flocs formation which indirectly causes increase in an energy consumption [23-39]. In same actions turbidity, surfactants, color, oil & grease and other characteristics of greywater shows similar results as COD removal efficiencies. In conclusion, current density shows great potential in efficiency and operational costs with different changing conditions like electrode distance, applied voltage, pH, flow rate etc. [24-40].

D. Electrode Arrangement

The arrangement of the electrode in the EC reactor must be simply placed between anode and cathode in monopolar either (parallel or series connection) and bipolar (series connection) design pattern as shown in Fig. 2 in the direction to understand the electrode arrangement and electrode gap [43]. Most of the researchers have applied monopolar arrangement to treat greywater for reasons such as low voltage and higher current mechanisms, maximum removal efficiency than bipolar series arrangements [42-43]. Literature studies lack on the treatments of greywater resulting all three-combination of electrode connections. Regardless, it is very difficult to compare the congruous electrode arrangement as it must depend upon the mode of treatments with less maintenance and overall operating cost [43].

E. Types of Current Supply

In EC system, direct current (DC) is traditionally performed between the electrode in contaminated water which results in the formation of an impermeable oxide film on the cathode resulting in cathode passivation and corrosion development due to oxidation layer on anode [23,24,41,51,52].

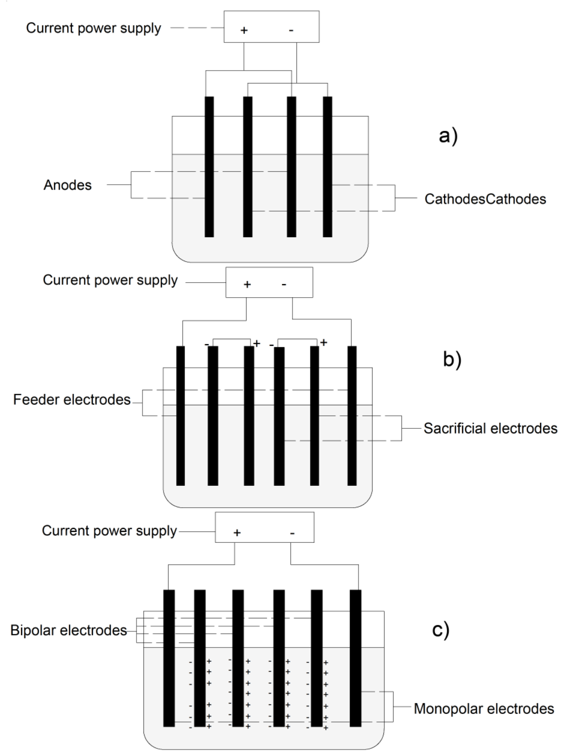

Fig. 2. Monopolar Electrode a) in parallel connection b) in series connection; c) bipolar electrode in series connection [43].

Passivation generated at the cathode cuts the movement of currents which transfers between two electrodes effecting metal dissolution and avoiding metal hydroxide formation which in turn decreases the performance and efficiency of EC process [45]. However, researchers have overcome (DC) supply by applying alternate current or alternate pulsed current (AC) to constraints cathode passivation's, stability with less operating cost when applied in industrial wastewater, [23-47] but unfortunately no data is available exhibiting treatment of greywater by AC supply.

Moreover, associated with the performance of industrial wastewater related to pollutants removal efficiency with deference to operating time, AC shows good impact results than DC.

F. Operating Time

Another consequential parameter which effects on EC process is the operating time because coagulants dosing of metal ions and other reactions taking place in the system is directly depends upon treatment time [48,53]. The operating time rests on certain design issues like reactors geometry, inter-electrode gap, pollutant type, stirring rate, current density, electrode materials etc. Predicated on the researcher's experiences for greywater treatment, the optimum operating time must be selected to abstract maximum pollutants with minimum energy consumptions which in turn relates to operational cost [23].

G. Operating Cost

The demerit of this technology is influenced by total operating cost including electrode material, consumption of energy, skilled workers, sludge analysis produced with different electrode arrangement actively performed in different operating time and current density [2]. Few attempts have been made to incorporate the cost-effective options applied by [17] designing a unit of capacity 28m^3/day with required area of 8 m^3 claiming a total cost of 0.27\$/m^3 which includes capital and operating cost proofing lower cost than chemical coagulation. Again [26] had carried out experiment showing the total cost of 1.44 Euro/m^3 at optimum condition including electrode consumption and energy cost. Hence operating cost is a very important concern in design the EC reactors to satisfy the required condition of treatments in order to reduce the maintenance as well as chemical cost of treatment which is used as coagulants aids.

IV. CONCLUSION

Based on the literature research, it is evident from Table 1. that greywater shows different characteristics by susceptibility to variability, reflecting potential options for sustainable water management. However, researchers have focused on various methodologies to treat greywater using simple and physical technologies showing restricted results of treatments, whereas biological process gains a good impact in succeeding the abstraction of organics matter with low operating costs but reflects in time consuming process sometimes become less attractive [30,49,52] Although chemical technologies, have overcome the obstacles in low strength of greywater but fails to reduce impurities from high strength greywater unless comes with hybrid process to meet the desired reuse standards [17,30]. Hence among most wide spread electrochemical process, electrocoagulation summarized in Table [3] shows an attractive and effective way to treat the contaminated water due to its several advantages over conventional methods. The common operating parameter in EC process performed by various researchers depends on number of factors and nature of liquid affecting the efficiency of treatment in removing the pollutants from greywater proving more sludge engenderment with no chemical cost as in case of coagulation process. Moreover, many studies showed the results on small scale batch process but lack on continuous flow mode which again curtains the large-scale application of reuse and recycle issues. Another issue relates to design and developing a scientific and operative EC reactors which must reduce the burden of financial crisis in maintenance and operation of process to pick this treatment technology. Furthermore, investigations showed better results when EC system is combined with other system showing pollution reduction, reuse and recycling and good alternatives to optimize operating cost. These will encourage researchers to generate reliable and scientific slant for sustainable water management outcomes.

Conflict of interest: No

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