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Energy efficiency of the advance physical system for the complete treatment of dye-bath effluents

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ABSTRACT

A medium-scale advanced physical processes-based treatment plant was studied for its design, energy-use efficiency, and treatment efficacy to treat dye-bath effluents. Sampling from electrocoagulation system (ECS), dissolved air floatation system, sand-filter, lamella separator, moving bed biofilm reactor, and reverse osmosis I followed by RO-II was carried out. Moreover, the electrical energy consumption of all aforementioned processes was measured to work out cost-effectiveness. Water quality parameters such as temperature, pH, electrical conductivity, total dissolved solids, turbidity, salinity, and chemical oxygen demand (COD) were analyzed to check the % removal efficiency of each unit/step. The ECS unit resulted in 72.1% COD and 11.5% color removal. Whereas 85.6% COD and 44% color removal were obtained with the dissolved air flotation process. Lamella clarifier removed 87.8% COD and 73% color within 30 min retention time. Furthermore, the maximum removal efficiencies of COD and color were obtained through RO units of about 98.3% and 100%, respectively. Meanwhile, the energy consumption of the entire plant was estimated as 80 kW, with only ECS consuming 70 kW of total power. The plant treats 50 m^3/h water, with an operational cost of Rs. 25/m^3 of treated water. The electrical energy per order was 1.7 kWh/m^3, which appeared to be the most effective and eco-friendly and that could lead towards the reuse of the treated water within the industry.

Keywords: Energy efficiency; Advanced treatment; Textile effluent; Clean energy system; Cost-effective; Sustainability

1. Introduction

The textile sector is considered the most significant pillar to strengthen Pakistan's economy. Water consumption in various product manufacturing is about 1.18 MAF/y as stated in Pakistan Statistical Yearbook 2001. It is further highlighted that demand for industrial water use will be predicted up to 1.84 MAF by 2025 [1,2]. The textile industry's effluent comprises 115–175 kg COD/ton discharge, dyes, organic chemicals, salinity, and low biodegradability. The quality and quantity of effluent vary with the equipment used, type of fabric, and the process [3]. It is reported in many researches that 1 kg of fabric requires about 100–200 L freshwater based on process type [4,5]. Interestingly, sewage wastewater and effluent are directly discharged into main streams and used for irrigation purposes in Pakistan

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[6,7]. It is estimated that the average water-use efficiency in the textile dye industry is about 70–400 L/kg of the fabric, and effluent production in medium-scale industry contains 180–430 L/kg of the fabric, organic pollutants, dyes, color, detergents, salinity, and non-degradable [8–10]. Alkaya and Demirer [11] screened that consumption of industrial effluent is projected to increase up to 50% by 2030 across the globe.

The major challenge from the textile dye is treating the wastewater discharge prior to the environment. The availability of water is reducing on a daily basis as per capita. Therefore, there must be managed water resources effectively to make sure water is conserved for the future. Pakistan Water Situational Analysis stated that only three functional treatment plants are installed in Islamabad, two trickling filters in Karachi, including screening and sedimentation. Moreover, Lahore contains a grit removal and screening system [12–14]. Dehghani et al. [15] analyzed that flotation and coagulation processes are improved by using certain coagulants such as poly-aluminum chloride (PAC), iron sulfate, alum, and granular ferric hydroxide that considers as the most beneficial for the removal of color from textile effluents.

Numerous studies focused on these challenges of reuse and treatment effluents that membranes use to remove dissolved solids, metals, and colorants and reuse treated water for distinct processes. Certain advantages are less area used for the installation, maximum organic loading, and low sludge production [16–20]. In principle, Ali et al. [20] screened that membrane technology has been considered the best alternative to formerly used treatment plants with less cost-efficiency. This employs semipermeable and permeable membranes for nano-ultrafiltration and osmosis.

Li et al. [21] screened that anaerobic digesters have been used to treat textile effluents considered cost-effective but slow process. Islam and Mostafa [22] studied that almost 90 d were required to complete treatment by removing color and chemical oxygen demand (COD) from wastewater. Moreover, biochemical oxygen demand (BOD), oily substances, and color are minimized by secondary treatment in the presence and absence of oxygen. Additionally, reverse osmosis, ion exchange, and electrodialysis are the tertiary treatments for removing dyes and chemicals. Suspended particles, grease, and oil are removed from textile dye-bath effluents through primary treatment [22]. Sert et al. [23] evaluated that MBR/BWRO and MBR/NF were significantly effective for treating industrial wastewater through attaining % removal efficiencies of about 96%, 74%, 97%, 87%, and 90% for conductivity, COD, salinity, color, and total organic carbon, respectively.

The most pollutant-intensive process is dye washing, which consumes large amounts of water and produces effluent. This happens because 50% of dyes used are washed off during the process because of the high intensity and inefficiency of the dyeing process. The main types of dyes used were anthraquinone and azo-dyes that influence biodegradability, pH, turbidity, light penetration, photosynthesis, and stability of the aquatic ecosystem [24–27]. Dotto et al. [28] examined that the performance of various natural coagulants can maintain physiochemical characteristics of textile dye-bath effluents through coagulation and flocculation processes. Cinperi et al. [29] screened that treatment efficiency was improved effluent from woolen mills through reverse osmosis, moving bed biofilm reactor (MBBR), nanofiltration, ultrafiltration, and UV radiation techniques. In this regard, almost 52%–99% and 40%–99.5% removal of organic pollutants and color were carried out through MBR/RO and MBR/NF, respectively.

Behera et al. [30] estimated that by demonstrating modern and advanced techniques to abate and degrade the pollutants from textile dye-bath effluents through the novel and promising technology. Additionally, Atalay and Ersöz, [31] analyzed the most advanced oxidation processes with biological treatment for the removal of dyes through hybrid applications. At present, various physiochemical treatments are applied on the textile dye-bath effluents, including electrocoagulation, flocculation, dissolved air flotation, reverse osmosis, and advance oxidation processes [20,23,27,29,32–34]. These processes are quality-efficient, involve high costs, and consume energy. Hence, this advanced treatment physical system is one of the aforementioned systems that treat effluents up to the standards discharge limits according to Punjab Environmental Quality Standards (PEQs).

This study aims to find a feasible and more effective technique of treating dye-bath effluent successfully with the best operative conditions and calculate the energy requirement in each unit of treatment efficiency in an advanced treatment system. Although these technologies are well-known for treating textile wastewater, most research focused only on one or two treatment techniques used at lab-scale over limited periods. While comparing existing studies, this study sheds light on pollutant monitoring, elucidating the sequential series of effluent treatment plants (ETP), maintaining physiochemical parameters to analyze treatment efficacy and cost-effectiveness of medium-scale treatment plants for dye-bath effluents and meet the PEQs. In addition, treatment plant design and energy efficiency are also studied to produce a clean and sustainable energy system. To the best of our knowledge, this is the first time properly analyzing and monitoring the treatment efficiency of the electrocoagulation system (ECS)/dissolved air floatation (DAF)/lamella clarifier/RO stage I and II combination sequence with engineering data. This study will also pave the way for further research into finding alternative efficient treatment systems for the treatment of textile-dye effluent.

2. Methodology

2.1. Survey and effluent samples collection

A designed medium-scale treatment plant was studied for the treatment of dye-bath effluents, and the components of ETP were ECS, DAF system, sand-filter, lamella separator, MBBR, and reverse osmosis I followed by RO-II. Furthermore, the energy efficiency and efficacy of advanced wastewater treatment plants were studied to work out the cost-effectiveness of the treatment plant. About 70–80 L of water is consumed for one kilo of fabric in this industry regularly. In addition, about 60 types of dyes such as active, disperse, red, blue, black, green dyes are used according to requirement. In this regard, almost 5 L wastewater samples were taken from the inlet, electrocoagulation system, dissolved air flotation system, lamella filtration, and reverse osmosis in the local textile and dyeing industry involved in the dyeing of fabrics and installed the most advance physical treatment for dye-bath effluents. The samples were collected in pre-washed containers and transported to the laboratory for further analysis. In order to prevent contamination and reactions, these were stored at 4°C or –20°C without adding any preservatives.

2.2. Chemicals used in ETP

Certain chemicals were used in the complete treatment of dye-bath effluents to make water clean and apparent. In this regard, coagulant and anionic polyelectrolyte (type-1) dosing were added to the chemical platform for agglomeration of the particles to form flocs. Additionally, the dissolved air flotation unit was dosed with a cationic polymer, aluminum chloride ($AlCl_2$), PAC liquid that was added to remove negative particles and flocculation of suspended solids. Thus, the dyeing industry utilized various chemicals in three treatment process shifts summarized in Table 1.

2.3. Description of ETP based on design parameters

The 20–25 m^3/h effluent sample is treated, and the time required for treatment by ETP is about 120 min. The effluent is collected in a rectangular shaped inlet from the dyeing industry. Fig. 1 succinctly depicted the overall advanced physical treatment of textile dye-bath effluents, including raw inlet water, ECS, DAF, lamella clarifier, reverse osmosis unit, treated water. The block diagram of the advanced ETP system is represented in Fig. 2. The untreated effluents contain a huge amount of total suspended solids, various concentrations of dyes, auxiliaries and chemicals, toxic metals, and a high level of BOD. The equalization tank acts as a buffer and is used for temporary water storage, and its storage capacity is 1,000 gal. It is used to control pH about 6–9 by adding HCl or H_2SO_4 and NaOH based on textile wastewater's acidic and alkaline nature, respectively. The equalized dye-bath effluent is then pumped into an electrocoagulation tank to pass high voltage DC electrical current to break down metallic bonds and remove contaminants from textile effluents. As a result, this current cause a huge difference in discharge and separate sludge.

Table 1
Chemicals used during treatment of effluents

Chemicals	Shift A	Shift B	Shift C	Total	Average
PAC liquid, kg	8.5	9.5	9	27	9
Polyelectrolyte, kg	7.5	7	6.5	21	7
Coagulant, kg	7	7.5	6.5	21	7
Anionic polymer, kg	6	5.5	6.5	18	6
Cationic polymer, kg	4.5	5	5.5	15	5

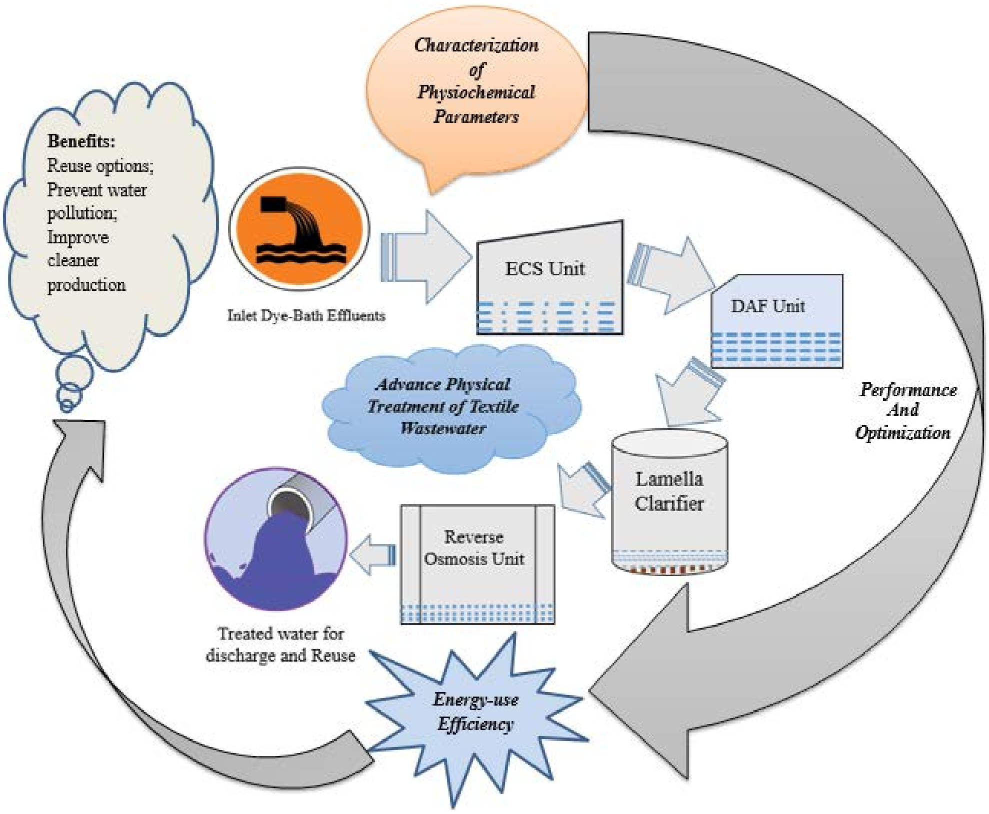

Fig. 1. Illustration of advanced physical treatment of textile dye-bath effluents including inlet raw water, electrocoagulation system (ECS), dissolved air flotation (DAF), lamella clarifier, reverse osmosis unit, treated water (temperature 25°C; initial pH: 12.38).

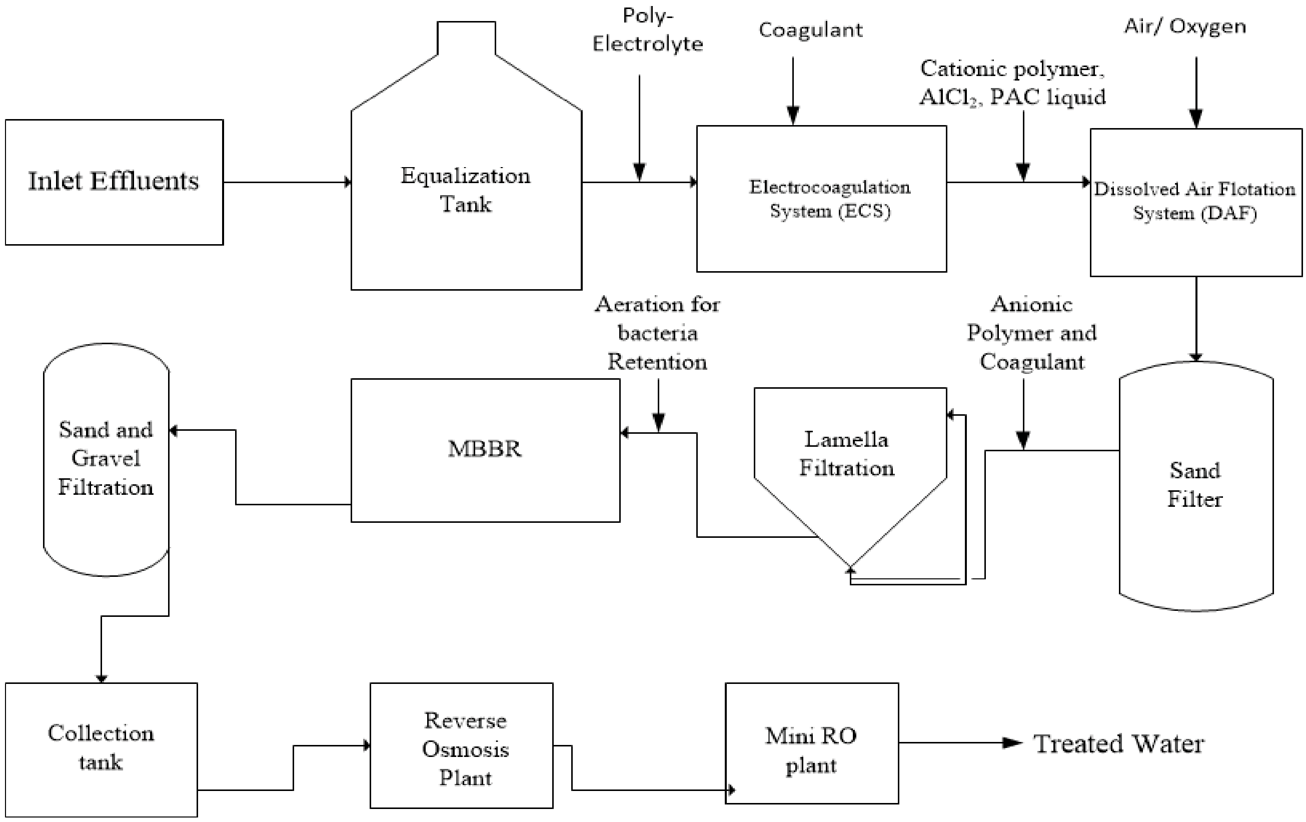

Fig. 2. Block diagram of the advanced system of the effluent treatment plant.

ECS unit consists of a feeding tank, the reaction chamber, vertically arranged electrodes, and the development tank with the initiation of reactions complete in the reaction chamber and sludge separation unit. It had a 30 m^3 capacity with 3 pairs of Al electrodes. This aluminum (99% of analytical grade) as cathode and Iron as anode were utilized in electrical conductivity (EC) unit mono-polar parallel (MP-P) mode of connection of the electrode used. The inter-electrode distance of 1 cm was kept constant to reduce ohmic overpotential that minimized overall power consumption. The total area of both anode and cathode was 360 cm^2. Power supply source of 380–400 V voltage along adjustable, stable current and voltage source was utilized as DC power supply. The volume of treated water from ECS was 1,000 mL. In ECS, the solution was vigorously stirred at 350 rpm with the magnetic stirrer for maintaining uniformity in wastewater solution. The current density of ECS was 1,816 A/m^2 with a current intensity of 124 A at pH 9.73. Coagulant and anionic polyelectrolyte (type-1) dosing are added in the chemical platform for agglomeration of the particles to form flocs through the slow-moving flocculation process before entering wastewater in the ECS unit. These flocs are then removed from the downstream ineffective settling system performed by gravity (Wang et al. [35]). The electrocoagulation unit has an average capacity of 30m^3/h, and the retention time is 60 min. ECS has approx. 70–80 KW power to run this unit. The Al and Fe electrodes were rinsed with acetone and 0.5 M H_2SO_4 and the distilled water to eliminate impurities and grease prior to initiating the next experiment. Sludge is separated in Tank 1, and the remaining scraped sludge in Tank 2. In this regard, treated effluent is released at the bottom of Tank 1 and is considered gravity-fed towards the next step for further purification.

Effluent is then pumped into a dissolved air flotation system, where it removes suspended solid particles with the help of aeration. The air flotation chamber is rectangular in shape with achieving maximum residence time. The screen is installed at an inclination angle of about 60° with respect to horizontal and length is approx. 30–50 cm. The chamber's width is 8 m based on the type of substance for the scraping floating material. The maximum diameter is 20 m, and the retention time is around 15 to 30 min. The dissolved air flotation unit is dosed with a cationic polymer, aluminum chloride ($AlCl_2$), PAC liquid used to remove negative particles and flocculate suspended solids [36]. An intense mixing speed was 400 rpm that was followed by the flocculation interval of 5 min. The power supply for DAF was 2 kW and voltage 400 V to run this experiment. The temperature and pH at the time of sampling were 25°C and 8.5, respectively.

Treated effluent is pumped in an air drum at which compressed or pressurized air is introduced to form saturation. Additionally, this air-saturated water is then recycled in front of the float chamber. It moves in a pressure reduction valve, resulting in tiny bubbles having a diameter of 10 to 50 µm. These bubbles remove suspended materials to flow towards the surface and make a froth layer that is removed through a skimmer. Finally, DAF removes the froth-free water from the chamber. Various DAF system designs use different sorts of plate packing substances, lamellas for separation of the surface and increase the removal efficiency in wastewater.

DAF unit requires coagulants and flocculants having less operation cost, ready to operate, service, and maintenance. It has almost 95% removal efficiency and lowers the COD. The power of the DAF unit is about 2 kW. The optimal foam concentration is 3%–3.5% in terms of suspended solids that increase with polyelectrolytes. Fine bubbles are produced in the depressurized system and capture maximum solids containing oil and grease concentration of 10–25 mg/L in wastewater. The water tank is placed to store treated effluent from DAF temporarily and has a storage capacity of 1,000 gal.

The effluent treatment plant has 2 sand filters composed of PVC or concrete material boxes and particular sand substances. The typical sand filter is a concrete- or PVC-lined box filled with a specific sand material. The depth of media varies between 24 and 42 inches. The grain size must be larger to increase the speed of effluents flow to prevent clogging. Sand filter unit contains 240 gal/d water for 200 ft^2 sand filter (14 × 14 ft). The effluent from DAF is filtered using plate settler or lamella filter having maximum separation surface area. This lamella filtration unit contains plates at the inclination angle of 45°–60°, and space among plates is about 40–120 mm that is used for the efficient separation of effluents. Moreover, the retention time for treatment by lamella filtration is about 20 min. Anionic polymer and coagulant are added to separate settleable and colloidal particles from the textile wastewater. These density-dependent solids are larger than 50 μm.

MBBR unit is designed to employ various benefits for activated sludge and biofilm to treat wastewater effectively. This system is considered an advanced treatment process through aeration by using microbes such as bacteria. The survival temperature for bacteria is 25°C–40°C, and residence time is around 2–4 h. Therefore, this unit is feasible for maintaining total suspended solids (TSS), BOD, and COD in wastewater. In addition, this unit is designed to remove the impurities and contaminants for further purification of wastewater.

The latest version of the reverse osmosis plant is installed to remove the total dissolved solids (TDS) from lamella permeate in the range 300–400 mg/L that is present below 3,500 mg/L in PEQs. There is mandatory to remove TDS from effluent to make the water consumable. RO unit contains security filters, booster pumps, valves, high-pressure pumps, wash-water pumps, membrane elements, pressure metes, and pipes. The systematically arranged RO involved primary UF tank, booster pumps, security filters with a pore size of 5 μm, high-pressure pumps, RO devices, and RO tank. This unit removes all types of mineral salts and produces the highest purity [29,37]. It is an energy-intensive unit because of high pressure that is about 10.5 kg/cm^2. The height is 10–12 ft. and 0.5 HP motor is adjusted in this plant. The RO plant has a power of 15.5 kW. The specifications of this RO plant include maximum pressure 150 psi, maximum temperature 100°F, maximum flow 6.75 GPM, maximum water capacity 1,000 gal, voltage 372 V, electrical current 31 A, the capacity of tank 20 L, recovery rate 80%–85%, pH 7.5–7.8, COD 13 mg/L, TDS 350–400 mg/L and TSS 169.5 mg/L.

RO-II is designed to remove TDS further up to 130 mg/L, which is below 3,500 mg/L in National Environmental Quality Standards (NEQs). A mini RO plant is installed for further treatment of wastewater and then drains into the nearby stream. The main specification of this RO unit includes maximum pressure 150 psi, maximum temperature 100°F, maximum flow 6.75 GPM, maximum water capacity 1,000 gal, voltage 395 V, electrical current 13.8 A, the capacity of tank 15 L, recovery rate (RR) 85%–90%, pH 7.5–7.7, COD 11 mg/L, TDS 130 mg/L, and TSS 169.5 mg/L.

2.4. Analytical techniques

After a detailed study of ETP, certain physiochemical parameters were selected to analyze sample effluents. The effluents are characterized with respect to the total quality of sample, type, and concentration of sample effluent. The characterization was carried out to access pollution load that is significant to optimize the design and operations in ETP. These parameters, including electrical conductivity (EC), temperature, pH, TDS, salinity, TSS, turbidity, and COD, were analyzed following Standard Methods for the examination of water and effluent [38]. In addition, the percentage removal efficiency was also measured by the use of atomic absorption spectrophotometer (Hitachi Z-8230; Tokyo, Japan). However, the remaining lamella clarifier, RO stage I and II had not required any dilution due to removing suspended solids and organics by treating the ECS unit.

2.5. Calculation of energy requirements

Finally, the energy efficiency, flow rate, and treatment efficiency were calculated. The operation costs are influenced directly by treatment performances of applicable processes of treatment. In order to readily compare the reaction efficiencies, effective and powerful scale-up parameters known as electrical energy per order (EE/O) values, which is electrical energy provided to eliminate the pollutant from one order magnitude in 1 m^3 of the wastewater, have been calculated by using the following empirical formula in Eq. (1) [39,40].

$$\frac{EE}{O}\left(\text{kWh/m}^3\right) = \frac{P \times t \times 1{,}000}{V \times 60 \times \log\left(C_0 / C_t\right)} \tag{1}$$

where P = power input in kW; t = time required in treatment in min; V = volume of sample effluent in L; C_0 = initial concentration of pollutant in COD (mg/L); C_t = final concentration of pollutant in COD (mg/L).

3. Results and discussion

Treatment of textile dye-bath effluents is a cumbersome phenomenon due to high TDS, TSS, turbidity, salinity, electrical conductivity, pH, and COD. Therefore, for the quality maintenance and process optimization, the industry was used to assess the treated water from the ETP to ensure that it meets the National Environmental Quality Standards.

3.1. Characteristics of textile wastewater

The characterization of textile dye-bath effluents to optimize the values is listed in Table 2. For this study, water quality parameters were analyzed in a lab to determine the treatment efficiency of the treatment system. Additionally, results of wastewater samples were compared with National Environmental Quality Standards (NEQs) and analyzed influent samples of textile wastewater from previous research studies. Firstly, the pH of Textile wastewater was acidic in nature and converted into basic after applying advanced treatment while, pH range of effluent in other studies was 8.0–10.3, basic. Following tests were conducted to check the quality of textile effluent from raw inlet water, ECS, DAF clarifier, lamella filtration, reverse osmosis units 1 and 2. Consequently, the water quality parameters of final treated water were determined as; temperature (14°C), pH (7.75), electrical conductivity (0.146 mS/cm), TDS (13.7 mg/L), turbidity (0 NTU), salinity (0.1 ppt), and COD (11 mg/L). In this regard, advance physical treatments effectively decrease COD, TDS, TSS, COD, and other parameters based on mentioned considerations.

Reaction pH is considered a significant parameter that influences the treatment processes of wastewater [39]. The pH in inlet water was 12.42 ± 0.02 that is alkaline only because of various dyes and chemical processes in the textile industry. The pH was reduced to 7.01 ± 0.007 without adding H_2SO_4, and the complete treatment consumed 90 kW of electricity. However, after treatment of effluent through different stages in ETP, its pH was reduced to meet the standards after the treatment with DAF, lamella filtration, RO-1, and RO-2. Similarly, the effect of variation in pH reported by various studies shows quite a similar trend [40,61,63]. Fig. 3 represents a significant increase in removal efficiency of pH from 21.6% to 43.5% to maintain the pH for the effective treatment of dye-bath effluents. Additionally, results indicate 31.5%, 35.1%, and 38.8% removal from dissolved air flotation, lamella clarifier, and RO-I, respectively. It is apparent from Fig. 3 that reverse osmosis stages I and II showed maximum removal efficiency.

The effect of temperature (°C) is illustrated in Fig. 4. It is depicted from recorded temperatures of influent was slightly high of about 41.25°C ± 0.6 that is greater than the permissible limit. After the coagulation and flocculation

Table 2
Concentration of different parameters in various components of ETP with NEQs

Parameters	Advanced treatment units						NEQs*
	Inlet	ECS	DAF	Lamella filtration	RO-I	RO-II	–
Temperature (°C)	41.25 ± 0.6	37.4 ± 0.02	30.02 ± 0.3	27.5 ± 0.3	25.5 ± 0.7	25 ± 0.07	40
pH	12.42 ± 0.02	9.73 ± 0.02	8.5 ± 0.07	8.05 ± 0.02	7.6 ± 0.07	7.01 ± 0.007	6–9
EC (mS/cm)	3.54 ± 0.01	3.27 ± 0.04	1.06 ± 0.07	0.252 ± 0.001	0.152 ± 0.007	0.146 ± 0.001	0.325
TDS (mg/L)	3570 ± 0.3	2090 ± 0.7	905 ± 0.2	214 ± 0.07	95.1 ± 0.2	13.7 ± 0.1	3500
Salinity (ppt)	2.0 ± 0.07	1.4 ± 0.01	0.7 ± 0.02	0.15 ± 0.01	0.1 ± 0.007	0.0	0.15
Turbidity (NTU)*	28.44 ± 0.02	21.5 ± 0.2	19.2 ± 0.1	9.3 ± 0.1	0	0	2
TSS (mg/L)	360 ± 1.4	330 ± 0.3	260 ± 0.2	90 ± 0.7	10.8 ± 0.4	10 ± 0.1	200

*NEQs: National Environmental Quality Standards; NTU: Nephelometric turbidity units

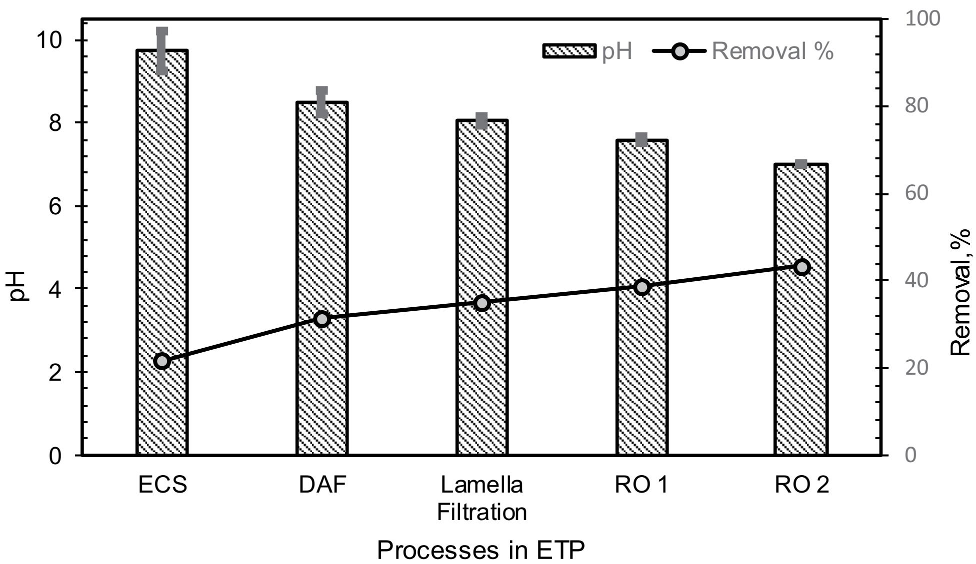

Fig. 3. Effect of pH on textile dye-bath effluents (temperature 25°C; initial pH: 12.38).

unit, the temperature has lowered the value around 37.4°C ± 0.02 in the ECS tank, which is moved towards optimization [41,42]. In addition, the DAF unit has more significantly lowered the temperature, which is beneficial for wastewater treatment. Meanwhile, a heat exchanger was used to maintain the temperature and optimize operational processes regarding variations in inlet raw wastewater quality and flow rate from primary to secondary clarifier treatment [20]. Additionally, % removal gradually increased after treatment with each component of the ETP. Moreover, results show the increase in % removal efficiency from 9.4% in ECS to 40% RO-II in maintaining temperature for optimizing wastewater treatment.

The effect of turbidity and % removal for this aforementioned parameter is illustrated in Fig. 5. The turbidity values are lowered from 28.44 ± 0.02 NTU to 0 NTU, which is quite significantly efficient for treating sequential processes in ETP. Firstly, ECS unit has relatively less contribution to reducing the turbidity. While DAF has been contributing about 19.2 ± 0.1 NTU through treatment with aeration by removing suspended particles, and it will move towards sustainable development through reuse and recycling. Significantly, the main contributing unit for the >95% treatment of dye-bath effluents is reverse osmosis stages I and II. Turbidity and TDS are removed completely to become transparent and clean water for reuse and discharge purposes [20,29]. Turbidity was higher in inlet due to the maximum concentration of dyes and chemicals used in the dyeing industry and then decreased after physical treatment and eventually met the standardized value.

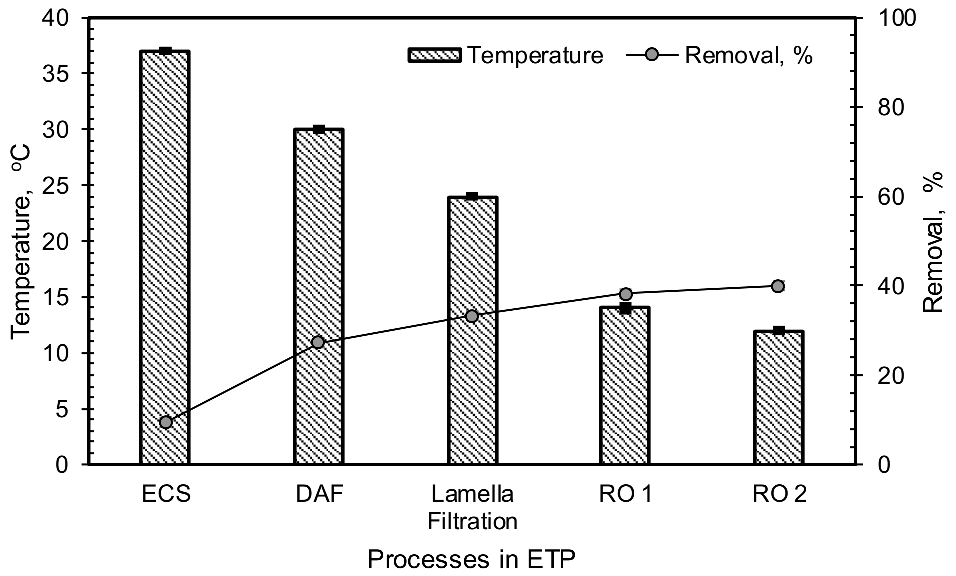

Fig. 4. Effect of temperature (°C) on wastewater.

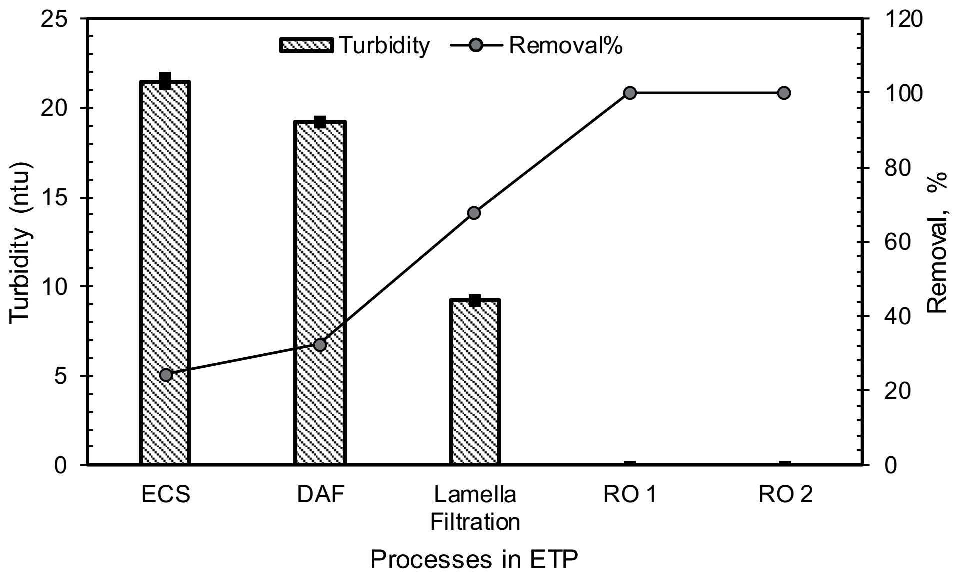

Fig. 5. Effect of turbidity on wastewater.

Turbidity imparts removal of 24.4% in ECS and 32.4% in DAF. Additionally, treatment water from DAF showed an enormous increase in removal efficiency of about 67.3%. It is clearly observed that complete turbidity removal was obtained with treatment using RO stage I and II that would be significant and feasible technology towards sustainability (Fig. 5). Other researchers were noticed quite a similar trend for turbidity removal from textile wastewater by using physical treatment [43–45,62]. Turbidity data represented that RO was an effective and promising technology to remove suspended solids from textile dye-bath effluents.

The effect of salinity in textile dye-bath effluents is illustrated in Fig. 6. It is demonstrated that influent water had significantly higher salinity than the standard limit because of the increased amount of dyes used in the dyeing process [46]. Several researches [47,62–64] reported a similar trend under optimal conditions. Salinity was gradually declined after treatment with ECS, DAF, lamella clarifier, and RO plant of about 1.4 ± 0.01, 0.7 ± 0.02, 0.15 ± 0.01, and 0.1 ± 0.007 ppt, respectively. Meanwhile, the components of the advanced treatment system effectively remove the salinity so that the values meet the NEQs. In addition, about 30%, 65%, 92.5%, and 95% removal of salinity from ECS, DAF, lamella clarifier, and RO-I were obtained, as shown in Fig. 6. Thus, complete and successful desalinization was observed through RO-II, which would be a feasible opportunity to treat wastewater and meet the NEQs to achieve sustainability.

Fig. 7 illustrates the effect of electrical conductivity on effluent. This showed significantly high because

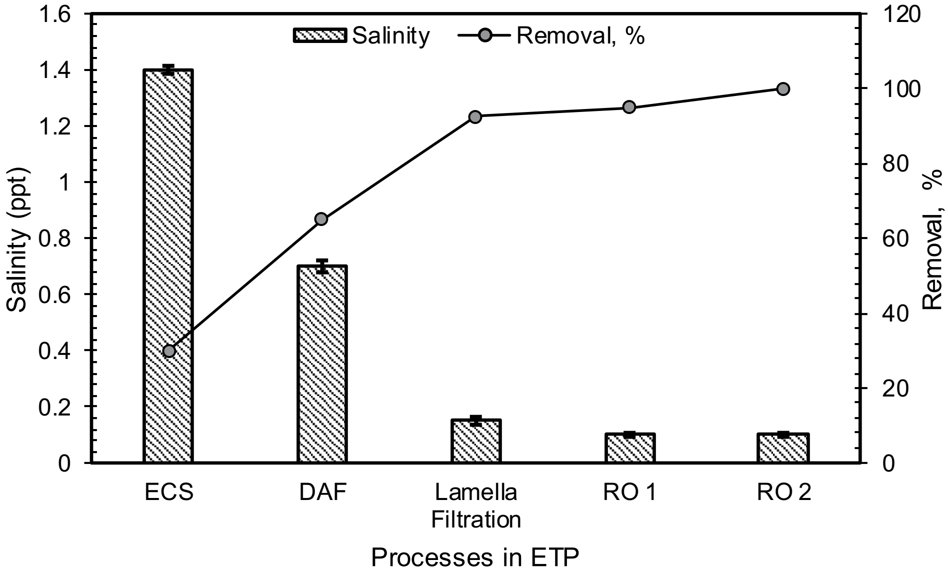

Fig. 6. Effect of salinity (ppt) in textile wastewater.

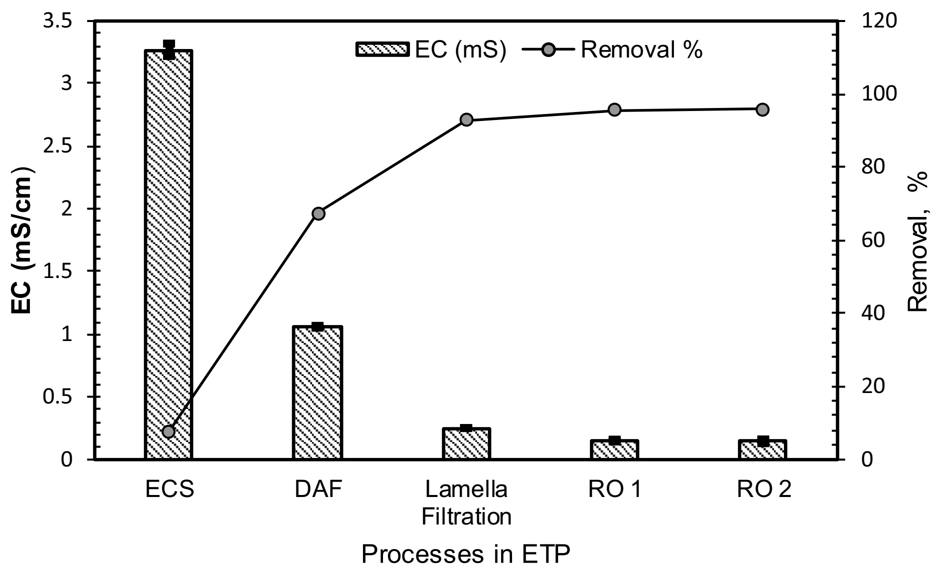

Fig. 7. Effect of EC (mS/cm) on textile dye-bath effluents.

of increased chemicals used in the dyeing process. In the electrocoagulation unit of ETP, conductivity was varied from standard limit to maintain electrical conductivity at its set point by adding NaCl. As a result, electrocoagulation shows maximum EC during the moving process due to the agglomeration of suspended particles, dyes, and various chemicals. In this regard, NaCl pump speed was remained low for maximum effectiveness and to get desired results [47]. Additionally, satisfactory results were obtained by using a lamella clarifier. Furthermore, the best efficiency was achieved with the reverse osmosis unit in ETP from 3.54 ± 0.01 to 0.125 ± 0.007 in order to maximum removal of suspended particles to form apparent water for discharge and reuse [48]. However, their concentration decreased, and water running out of the treatment system has to value below the specified standards. It is shown that EC (mS/cm) imparts relatively great removal from wastewater in DAF with a comparatively high removal rate from the ECS unit. Moreover, it is demonstrated from Fig. 7 that RO stages I and II showed almost 95.7% and 96% removal of EC from the textile wastewater that would be very feasible and meet NEQs. Other researches depicted that electrical conductivity is an obvious parameter in treating wastewater and maintaining it with reverse osmosis and other physical technologies [29,49,57,61].

The effect of TSS (mg/L) on wastewater is represented in Fig. 8. The pollution load of the dyeing process was observed as higher value with around 360 ± 1.4 mg/L to 530 ± 0.3 mg/L because of the various unfixed hydrolyzed dyes and auxiliaries in effluents such as NaCl, leveling agents, and Na_2CO_3 that were utilized in dyeing liquor to fix the color. This effluent from dyeing was more contaminated

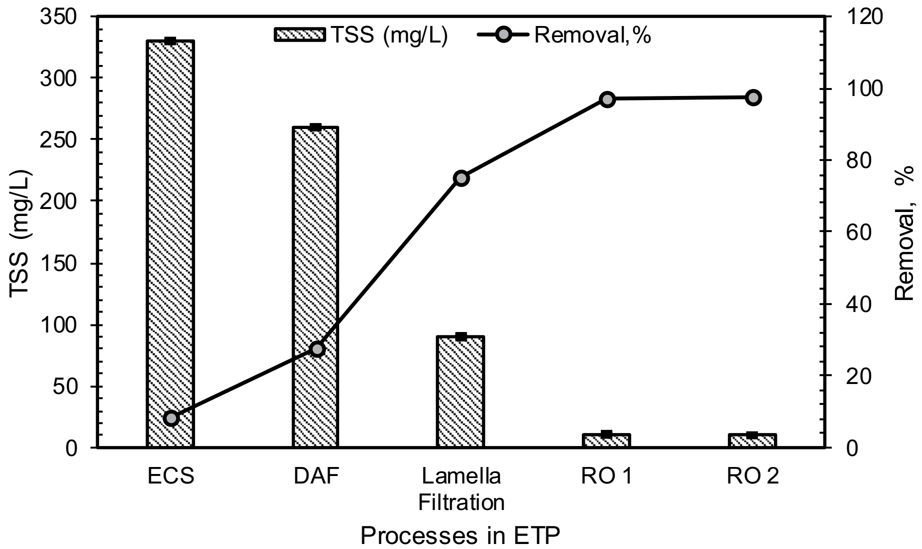

Fig. 8. The effect of TSS on textile wastewater.

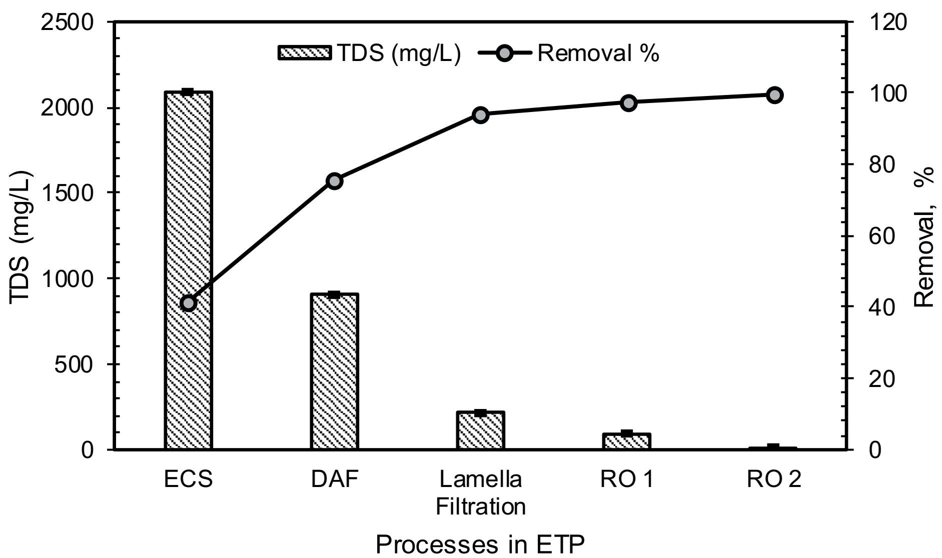

Fig. 9. Effect of total dissolved solids (mg/L) on wastewater.

than the continuous batch process because less water was exposed to pollution load [20,50,51,63]. Meanwhile, treated water from DAF, lamella clarifier, and RO plant lowered the TSS values of 260 ± 0.2, 190 ± 0.7, and 10 ± 0.1, respectively, which met the quality standards well below 200 mg/L. TSS in effluent was much high, but its values lowered after the treatment compared with NEQs. Additionally, TSS (mg/L) imparts 8.3%, 27.7%, and 75% removal from ECS, DAF, and lamella filtration. Interestingly, it is clear that reverse osmosis I and II showed maximum removal efficiency of about 97%, which would be a quite effective and sustainable option for treating textile dye-bath effluents.

Fig. 9 depicts the effect of total dissolved solids (mg/L) on wastewater. TDS of textile dye-bath effluents was obtained from ETP that varies from 8,000 to 11,000 ppt. In this regard, the dyeing process is used metal salts as an alternative [52]. In the current study, the Electrocoagulation unit was not removed the TDS, RO stage I and II were especially used for the treatment of wastewater in order to remove TDS (mg/L) from 3,570 ± 0.3 mg/L to 13.7 ± 0.1 mg/L and formed transparent, colorless water at the flow rate of 6.75 GPM. This permeate was then reused for washing, dyeing, and rinsing processes in the textile industry. In this regard, ETP could be achieved as an eco-friendly process and independent of the consumption of outside water sources [49,53,61]. Maximum removal of TDS in ETP was obtained of about 97.3% and 99.6% removal from reverse osmosis stages I and II, respectively. That is the most significant contributing factor to almost removing all the suspended particles and TDS. However, the minimum TDS value should be present because organics available in textile wastewater may produce excess fouling layer upon membrane surface, enhance pressure in the inlet, and reduce inorganic concentrate in wastewater [43,54]. Hence, this produces a feasible and promising option for the treatment of dye-bath effluents.

3.2. Chemical oxygen demand

The most significant parameter is COD, which was 72.1% reduced after ECS treatment [20]. The treatment efforts concerned physical treatment such as ECS unit that was more feasible for around 70%–75% removal of COD load, whereas the remaining pollution load (25%–30%) was minimized through dissolved air flotation, lamella clarifier and RO stage I and II. Moreover, COD values were reduced from 680 to 11 mg/L (98.3% removal) that could be a feasible option. Fig. 10 represents that the COD level was higher in the inlet sample and reduced to meet the standard limits after the physical and efficient treatment system.

The emulsion and waxy precipitates were observed in the primary and secondary clarifier that may ultimately transfer into RO membranes filter results fouling issue [55]. It was noticed that waxy dyestuff was released in the inlet from the dyeing and finishing unit. For this purpose, the local softener was used to reduce this problem. In addition, RO feed was analyzed to represent the reduction of TDS and COD from 4790 to 13.7 mg/L and 680 to 11 mg/L, respectively. Partially treated effluent was put into a sand and gravel filter (5 μm) to prevent membrane chocking and fouling problems [53,56,62–64]. This pre-treated water was then pumped into a 2-stage RO unit that was designed to recover 90% and 100% removal of color, as shown in Table 3.

From the results above, it can be concluded that almost all the parameters were met with NEQs for textile sector. Therefore, this combination of ECS, DAF, lamella filtration, and 2-stage RO unit is feasible for textile ETP, accomplishing great pollution load recovery and allowing reuse options in the textile processes.

3.3. Comparing electrical energy requirement

The energy consumed by the treatment plant was calculated at about 80–90 kW, with ECS consuming 70–80 kW of total power. The plant treats 25–30 m^3/h water, with an operational cost of Rs. 30–35/m^3 (0.196–0.22 USD) water treated. Energy requirements by this whole system and the order of magnitude regarding pollutant concentration removal are combined in a single function known as electrical energy per order of contaminant removal in kWh/m^3. EE/O measures process treatment rates achieved in optimal

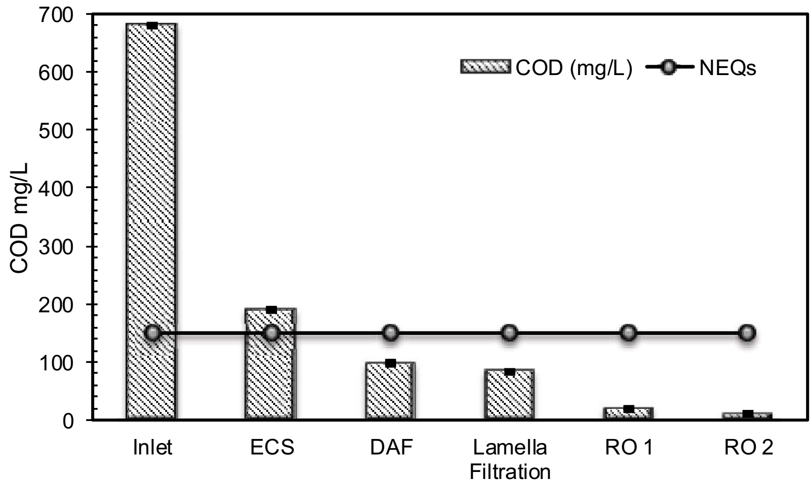

Fig. 10. Effect of COD (mg/L) of different components in ETP compared to NEQs.

volume of polluted effluents as a function of applied fixed energy. It acts as a scale-up parameter for energy use efficiency [39,59].

Overall, the energy requirements in the treatment plant are about 1.7 kWh/m^3, which is quite efficient towards sustainability. While ECS units required more electrical energy for dyes and COD removal. Meanwhile, DAF unit and RO have almost equal energy consumption and are more feasible for COD (99.8% removal) and color (100% removal), as shown in Table 3. Thus, advanced physical treatment installed to remove dye-bath effluent proved the best option for energy consumption and percentage removal efficiency [57,60,64]. On the other hand, it is quite evident that COD removal requires more electricity than color removal. Fig. 11 shows the effect of each unit of ETP on color (100%) and COD (98.3%) removal of treated effluents.

4. Conclusion

It is concluded from this study that treatment with an electrocoagulation system, dissolved air flotation, lamella clarifier, and reverse osmosis was deemed and evaluated as a promising option in the textile sector. This plant is the first one as combined techniques with advanced physical treatment in Pakistan. In ETP, all processes were successfully treated with environmentally friendly processes. All processes in ETP depicted a great performance to treat completely, maintained all water quality parameters, and significantly reduced operational cost. Significantly, ECS unit was designed to reduce the physicochemical parameters and also minimize COD. Minimum time was required to treat effluent, and more electricity was consumed than other units in ETP. The recovered water was pumped into the DAF unit for further water purification by using the aeration process and took maximum time for the removal of COD and color of almost 85.6% and 44%, respectively. Moreover, DAF was designed to remove the pollutant almost 70%, while % removal efficiency of RO is 100% that meets completely with NEQs but requires more energy consumption of 1.7 kWh/m^3. RO reduced COD up to 98.3% and TDS up to 99.6% from textile effluent. RO permeate was reused in textile processes or irrigation purposes. Therefore, there was no need for any dependency on raw water supply, and in this regard, this can be achieved by the most effective treatment and feasible treatment processes.

The conclusion can be drawn from this study that the advanced treatment system for the treatment of textile wastewater had the most energy-effective processes in ETP. The electrical energy consumed more by electrocoagulation unit and lamella showed quite significant results and consumed minimum electricity. This process will obtain maximum pollutant load removal, and the treated wastewater can involve in reuse. It is highly recommended to install physical treatment to ensure wastewater recovery and reuse of wastewater and process modification to conserve water. Thus, achieving sustainability in terms of clean and affordable energy in this sector will better achieve the sustainable development goals (SDGs).

Table 3
Electrical energy requirements of ETP and results of % removal of COD and colour

Processes	EE/O (kWh/m^3)	COD removal (%)	Colour removal (%)
ECS	1.26	72.1	11.5
DAF	0.22	85.6	44
Lamella	0.01	87.8	73
RO-1	0.25	97.2	100
RO-2	–	98.3	100
Overall	1.7	99.8	100

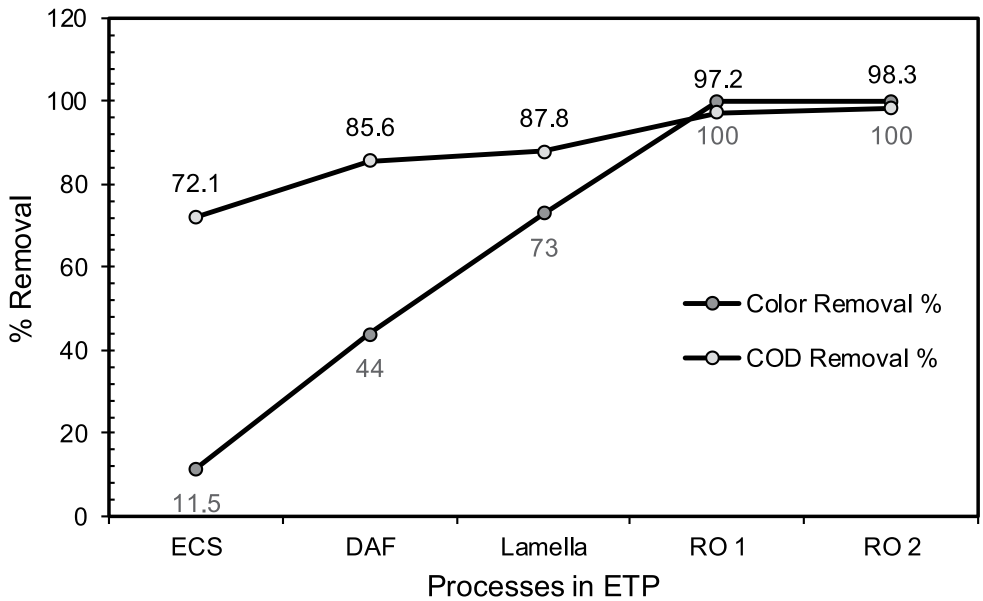

Fig. 11. Effect of COD and color on ETP processes of treated effluent.

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