Electrocoagulation and Electrodeionization Process for Dairy Wastewater Treatment using Copper Electrode

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Abstract— *The dairy industry is generally considered to be one of the largest food processing wastewater in many countries, especially in India. In dairy industry, in most cases, the wastewater generated is directly discharged into the nearby water bodies. Since the dairy waste water contains large concentration of COD, BOD, and oil, fats, chloride, and other elements along with several bacteria these may cause substantial health risk, and serious environmental issues.. In this paper EC and EDI techniques are used for the treatment of dairy waste water. The result shows that Copper electrodes has achieved a maximum turbidity reduction of 99.5%, COD reduction of 97.5% and BOD reduction of 90.94% in 30volt high stirring speed when the electrolysis time is set at 30 mins in electrocoagulation process. And copper electrodes yielded 97.5%, 84.84% and 99.5% removal efficiency in COD, BOD and turbidity respectively, under 30volt and 30 min electrolysis time in electrodeionization process. Both EC and EDI have achieved COD and turbidity removal up to 95-99% at high voltage and electrolysis time*.

Keywords— Electrocoagulation, Electrodeionization, Dairy Waste Water, Copper Electrodes

I. INTRODUCTION

The dairy industry is generally considered to be one of the largest food processing industry in many countries. As the importance of improved standards of wastewater treatment grows, process requirements have become more advanced [1]. The type of product being produced, the production methods, operating methods, design of the processing plant, the degree of water quality management being applied, and more, the quantity of water being conserved determines the concentration, volume, and composition of the effluents arise from this dairy industry. Due to the presence of organic load like carbohydrates, proteins and fats originating from the milk or dairy industry, effluents are concentrated in nature. However, the dairy wastewaters are characterized by high biological oxygen demand (BOD) and chemical oxygen demand (COD) concentrations, high levels of dissolved or suspended solids including fats, oils and grease, nutrients such as ammonia or minerals and phosphates and therefore it requires proper attention before they are disposed [2]. Due to the presence of organic load due to carbohydrates, proteins and fats originating from the milk, dairy industry waste effluents are concentrated in nature [3]. Since these dairy waste streams contain high concentrations of organic matter, these effluents may cause serious environmental issues. Introduction of Most of the wastewater volume generated in the dairy industry results from cleaning of transport lines and equipment between production cycles, cleaning of tank trucks, washing of milk silos and equipment malfunctions or operational errors [4-7].

Treating dairy wastewater is thus of great importance not only for the environment, but also for the purpose of using the recycled water for use in other industrial processes [8]. Nowadays, there are many physicochemical and biological methods are used for treating dairy effluents, with the aim of reducing the volume of the sludge produced. The physicochemical processes suffer lots of disadvantage such as reagent costs are high and the soluble COD removal is low [9]. Moreover, the chemical treatments can also induce a secondary pollution due to the fact that chemical additives used for treatment may contaminate the treated water. Moreover, high removal rates of the COD are obtained even though this process does not eliminate the phosphorus and nitrogen compounds present in the dairy effluents [10]. Implementation of another complementary physicochemical treatment would reduce phosphorus and nitrogen content.

In the field of electric field a number of technologies are developing for treating wastewater. Electrocoagulation and electrodeionization process are two among them. Electro coagulation is an electrolytic process that has been already experienced for the treatment of various liquid wastes [11]. Electrodeionization (EDI) is a process by which an electric field is used to remove ions and polar species from an aqueous stream by combined reverse osmosis and ion exchange method [12].

Electrocoagulation is the process of destabilizing suspended, emulsified, or dissolved contaminants in an aqueous medium by introducing an electrical current into the medium in an electrochemical cell, usually with an Al or Fe anode. Electrocoagulation involves the generation of coagulants in situ by dissolving electrically either aluminum or iron ions from aluminum or iron electrodes, respectively. The metal ions generation takes place at the anode, and hydrogen gas is released from the cathode. The hydrogen gas would also help to float the flocculated particles out of the water [13]. In its simplest form, an electrocoagulation reactor consists of an electrolytic cell with one anode and one cathode. When these electrodes connected to an external power source, the anode material will electrochemically corrode due to oxidation, while the cathode will undergo passivation [14].

During electrolysis, the positive side of EC cell undergoes anodic reactions, while on the negative side, cathodic reactions are undergone. Consumable metal plates, like iron or aluminum, are usually used as sacrificial electrodes so as to continuously produce ions in the water. The released ions neutralize the charged particles and thereby initiate coagulation. The released ions remove undesirable contaminants either by chemical reaction and

precipitation, or by causing the colloidal materials to coagulates, which can then be removed by flotation. In addition, as water containing colloidal particulates such as grease, oils, or other contaminants move through the applied electric field, a number of reactions can undergone such as ionization, electrolysis, hydrolysis, and free-radical formation which can alter the physical and chemical properties of water and contaminants. As a result of it, the reactive and excited state causes contaminants to be separated from the water and destroyed or made less soluble [13-14].

Electrodeionization is an advanced water treatment technology that utilizes electricity, ion exchange membranes and resin to deionize water and separate dissolved ions (impurities) from water. It differs from other water purification technologies in the sense that it is operated without the addition of chemical treatments and is usually a polishing treatment to reverse osmosis (RO). There are also referred to as continuous electrodeionization (CEDI) since the electric current regenerates the resin mass continuously. CEDI technique can achieve very high ultra-purity, with conductivity below 0.1 µS/cm [15].

Electrodeionization set up consist of an EDI stack, which has the basic structure of a deionization chamber. The chamber consists of ion exchange resin, packed between a cationic exchange membrane and an anionic exchange membrane. Only the ions can pass through the membrane the water is blocked. When flow enters the resin-filled diluting compartment, several processes are set in motion. Strong ions are scavenged out of the feed stream by the mixed bed resins. Under the influence of the strong direct current field applied across the stack of components, charged ions are pulled across the resin and drawn towards the respective, oppositely-charged electrodes. In this way these charged strong-ion species are continuously removed and transferred into the adjacent concentrating compartments.

As the ions go towards the membrane, they can pass through the concentration chamber but they cannot reach the electrode. They are blocked by another membrane, known as contiguous membrane that contains a resin with the same charge [16].

As the strong ions are removed from the process stream, the conductivity of the stream becomes quite low. The strong, applied electrical potential splits water at the surface of the resin beads, producing hydrogen and hydroxyl ions. These act as continuous regenerating agents of the ion-exchange resin. These regenerated resins allow ionization of neutral or weakly-ionized aqueous species such as carbon dioxide or silica. Ionization is followed by removal through the direct current and the ion exchange membranes [16].

II. MATERIALS AND METHODS

A. Collection of Sample

The first and preliminary step of the project was collection of diary wastewater from Milma Dairy plant, Thevally at Kollam district. The collected wastewater was carried and stored in the refrigerator at a temperature in the range below 4^oC.

B. Characterization of the Dairy wastewater

Here both physical and chemical characterization of dairy wastewater is done. Following are the various physicochemical parameters that are analyzed after the collection of sample. pH, electrical conductivity, turbidity, TS, TDS TSS, BOD, COD

C. Design of models

Both Electrocoagulation cell model and electrodeionization cell model is designed for the treatment of dairy wastewater. The study is conducted in batch experiments.

D. Electrocoagulation setup

Electrocoagulation is done using copper electrodes. Each electrode size is 5cm x 5cm x 1mm. The effective surface area of each electrode is $50cm^2$. Fig 1 shows copper electrodes.

Fig. 1: Copper Electrodes

Every EC run was conducted on 2L glass beaker.1L of waste water is treated in each run. The anode and the cathode leads were connected to the respective terminals of DC power supply. The Electrodes were spaced at 30mm distance. EC is conducted varying voltage, electrolysis time and stirring speed. Electrocoagulation reactor setup is shown in Fig 2.

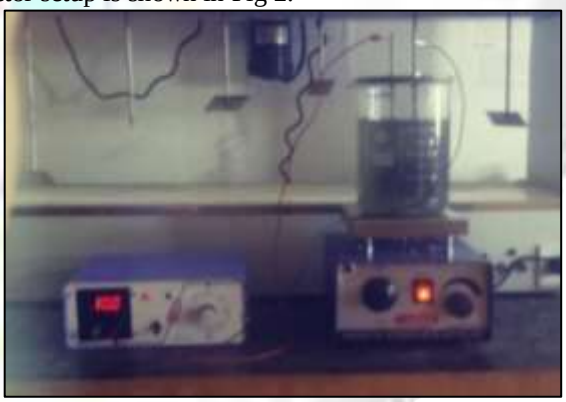

Fig. 2: Electrocoagulation reactor setup

E. Electrodeionization setup

Electrodeionization is done in a acrylic reactor of dimension 300mm x 50mm x 50mm using iron and copper electrodes. EDI reactor is subdivided into 3 compartments separated by filtrate membranes. Middle compartment is half filled with ion exchange resins where waste water is supplied for treatment. Fig 3 shows ion exchange resins.

Fig. 3: Ion exchange resins

The other two compartments is filled with distilled water. Each electrode size is 5cm x 5cm x 1mm. Effective Surface area of each electrode 50cm^2. Total capacity of the model was 750ml. 250mL of waste water is treated in each run. The anode and the cathode leads were connected to the respective terminals of DC power supply. Electrodes were spaced at 30mm. EDI is conducted varying voltage and electrolysis time. The treated water was collected under the middle compartment with the help of a collection tube valve. Electrodeionization reactor Set-up is shown in Fig 2.

Fig. 4: Electrodeionization reactor Set-up

F. Reactor Setup

After the design of the model, the both EC reactor and EDI reactor were setup for the treatment experiments. First the dairy wastewater is treated in the EC reactor and the percentage removal of were calculated. After that the wastewater is treated in the EDI reactor and the percentage removal were calculated for different electrodes varying the voltage, electrolysis time and mixing speed.

G. Analytical method

The pH of the sample will be measured using pH meter, turbidity by turbid meter, electrical conductivity by conductivity meter, TS by evaporation method, BOD by Winkler's method and the COD will be measured using the reflux titrimetric method. The analytical method will be done using the methods those mentioned in American Public Health Association (APHA).

III. RESULTS AND DISCUSSIONS

A. Initial Characteristics

The initial characteristic of diary waste water was carried and the pH of the leachate was slightly acidic in nature. Table 1 shows the initial characteristics of dairy waste water.

The electrochemical treatment of dairy industry wastewater by electrocoagulation and electrodeionization methods was investigated using an EC cell and EDI cell consisting of iron electrodes. The effects of voltage, electrolysis time and mixing speed on the removal efficiency were investigated. Thus there are 4 combinations and each having 9 runs.

1) Electrocoagulation at low stirring speed varying voltage & electrolysis time using copper electrodes.
2) Electrocoagulation at medium stirring speed varying voltage & electrolysis time using copper electrodes.
3) Electrocoagulation at high stirring speed varying voltage & electrolysis time using copper electrodes.
4) Electrodeionization varying voltage & electrolysis time using copper electrodes.

Table 2 table 3 and table 4 shows the reading by varying voltage and electrolysis time at low, medium and high stirring speed in EC process. Table 5 shows the reading by varying voltage and electrolysis time in EDI process.

Parameter	Value
pH	5.72
Electrical conductivity(µS/cm)	861
Turbidity	203
Total solids (mg/L)	1610
Total suspended solids (mg/L)	980
Total dissolved solids (mg/L)	590
BOD_5 (mg/L)	1337.8
COD (mg/L)	1920

Table 1: Initial characteristics of dairy waste water

Voltage	Time	pH	EC µs/cm	Turbidity (NTU)	TS (mg/L)	COD (mg/L)	BOD_5 (mg/L)
10V	10min	8.45	778	67	1500	252	810.81
	20min	8.75	720	18	980	206	608.17
	30min	8.81	725	8	800	168	648.65
20V	10min	8.6	804	16	1300	184	729.7
	20min	8.72	764	9	960	136	608.1
	30min	8.82	718	4	860	96	567.56
30V	10min	8.7	837	10	780	160	486.5
	20min	8.86	898	6	570	128	405
	30min	8.92	892	3	580	88	287.3

Table 2: Reading by varying voltage and electrolysis time at low stirring speed in EC

Voltage	Time	PH	EC µs/cm	Turbidity (NTU)	TS (mg/L)	COD (mg/L)	BOD_5 (mg/L)
10V	10min	8.45	718	29	820	160	608
	20min	8.41	758	16	570	152	527.02
	30min	8.73	781	13	410	144	445.9
20V	10min	8.79	861	12	790	136	689.19

	20min	8.81	865	9	680	144	486.48
	30min	8.88	879	6	390	120	405.41
30V	10min	8.9	891	8	370	112	486.48
	20min	8.96	901	5	320	104	445.94
	30min	9	920	4	180	96	202.7

Table 3: Reading by varying voltage and electrolysis time at medium stirring speed in EC

Voltage	Time	PH	EC µs/cm	Turbidity (NTU)	TS (mg/L)	COD (mg/L)	BOD_5 (mg/L)
10V	10min	8.91	1003	11	640	208	324.3
	20min	8.99	1054	6	740	184	283.8
	30min	9.01	1114	4	570	112	162
20V	10min	9.05	1054	8	710	180	283.8
	20min	9.08	1075	5	570	160	202.7
	30min	9.1	1116	2	290	96	202.7
30V	10min	9.1	1138	5	460	144	192.8
	20min	9.18	1279	3	210	56	162.2
	30min	9.28	1308	1	90	48	121.2

Table 4: Reading by varying voltage and electrolysis time at high stirring speed in EC

Voltage	Time	PH	EC µs/cm	Turbidity (NTU)	TS (mg/L)	COD (mg/L)	BOD_5 (mg/L)
10V	10min	6.84	411	8	510	120	810.8
	20min	6.92	459	4	600	112	689.2
	30min	6.98	489	2	420	108	608.8
20V	10min	6.88	658	7	300	184	729
	20min	6.95	743	3	360	88	445.9
	30min	7.04	768	1	290	64	284.9
30V	10min	6.98	605	6	390	120	608.8
	20min	7.14	755	2	300	72	202.7
	30min	7.26	789	1	270	48	162.2

Table 5: Reading by varying voltage and electrolysis time in EDI process using copper electrodes.

B. Influence of voltage on electrocoagulation process

The voltage is a parameter that has a major effect on the electrocoagulation efficiency. Therefore, experiments were carried out by varying the voltage between 10v to 30v in order to investigate its effect on COD, BOD and turbidity removal for iron electrodes. Copper electrodes has achieved a maximum turbidity reduction of 99.5% COD reduction of 97.5% and BOD reduction of 90.94% in 30volt at high stirring speed when the electrolysis time is set at 30mins in electrocoagulation process.

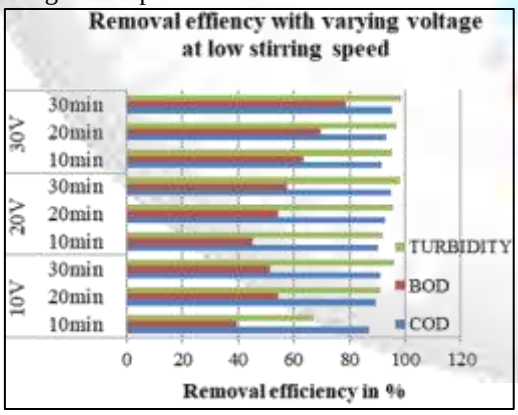

Fig. 6: Removal efficiency of electrocoagulation with varying voltage at low stirring speed

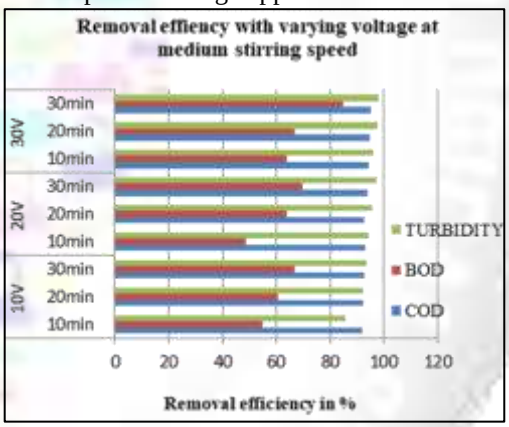

Fig. 7: Removal efficiency of electrocoagulation with varying voltage at medium stirring speed

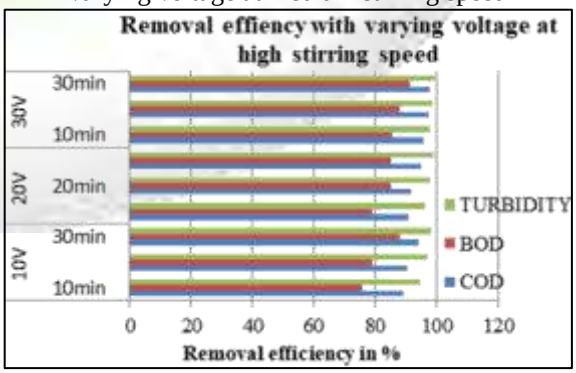

Fig. 8: Removal efficiency of electrocoagulation with varying voltage at high stirring speed

This result agrees with previous investigations that an increase in the voltage produces higher removal efficiencies. Conversely, if the voltage decreases, the time

required to achieve similar efficiencies increases. Fig 5, fig 6 and Fig 7 shows removal efficiency of electrocoagulation with varying voltage at low, medium and high stirring speed respectively.

C. Influence of electrolysis time on electrocoagulation process

The electrolysis time is also an important parameter that has a major effect on the electrocoagulation efficiency. Therefore, experiments were carried out by varying the electrolysis time between 10min to 30min in order to investigate its effect on COD, BOD and turbidity removal for copper electrodes. Copper electrodes has achieved a maximum turbidity reduction of 98.52%, COD reduction of 95.41% and BOD reduction of 78.52% in 30volt at low stirring speed when the electrolysis time is set at 30mins in electrocoagulation process. Likewise Copper electrodes has achieved a maximum turbidity reduction of 98.02%, COD reduction of 95.1% and BOD reduction of 84.84% in 30volt medium stirring speed when the electrolysis time is set at 30mins in electrocoagulation process. Also Copper electrodes has achieved a maximum turbidity reduction of 99.5%, COD reduction of 97.5% and BOD reduction of 90.94% in 30volt high stirring speed when the electrolysis time is set at 30mins in electrocoagulation process. Fig 9, Fig 10 and Fig 11 shows removal efficiency of electrocoagulation with varying electrolysis time at low, medium and high stirring speed using iron electrodes respectively. From the graph it is observed that the removal efficiency increases with increase in electrolysis time and vice-versa. From the graph it is observed that the removal efficiency increases with increase in electrolysis time and vice-versa.

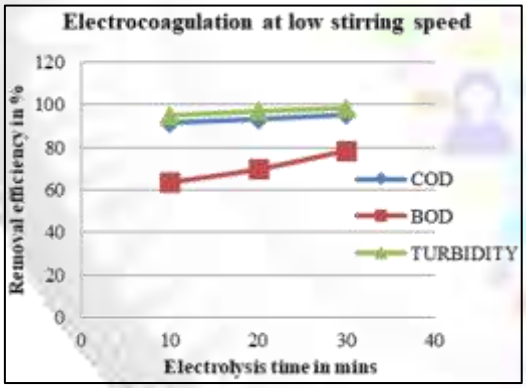

Fig. 9: Removal efficiency of electrolysis time at low stirring speed

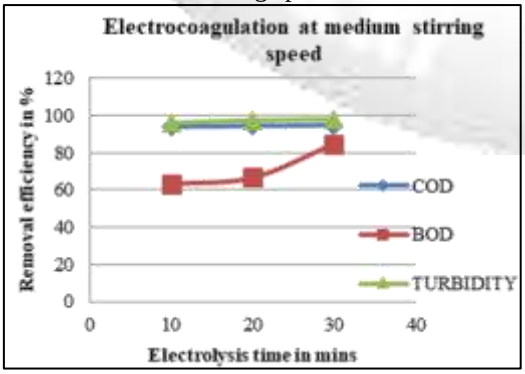

Fig. 10: Removal efficiency of electrolysis time at medium stirring speed

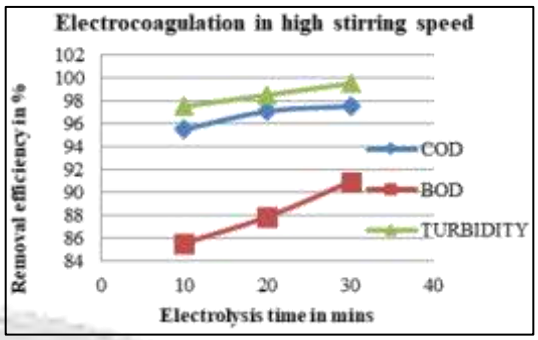

Fig. 11: Removal efficiency of electrolysis time at high stirring speed

D. Influence of stirring speed on electrocoagulation process

From the study, it is observed that stirring or mixing speed has a great influence in the removal efficiency. Therefore, experiments were carried out by varying the stirring speed say low, medium and high stirring speed in order to investigate its effect on COD, BOD and turbidity removal for copper electrodes. When Copper is used as electrodes, has achieved a maximum turbidity reduction of 98.52%, COD reduction of 95.41% and BOD reduction of 78.52% in 30volt at low stirring speed when the electrolysis time is set at 30 mins in electrocoagulation process. Fig 12 shows the removal efficiency of EC at varying stirring speed.

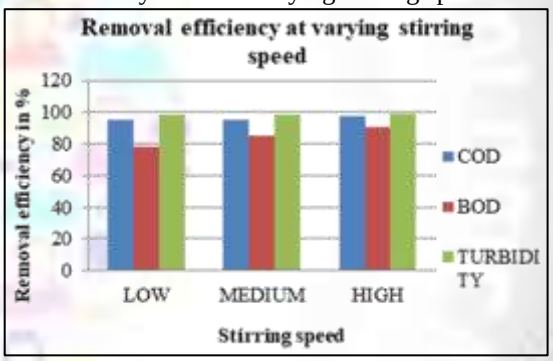

Fig. 12: Removal efficiency of EC at varying stirring speed

E. Influence of voltage on electrodeionization process

Likewise in EC process, voltage has a major effect on the electrodeionization efficiency also. Therefore, experiments were carried out by varying the voltage between 10v to 30v in order to investigate its effect on COD, BOD and turbidity removal for copper electrodes. Copper electrodes yielded 97.5%, 84.84% and 99.5% removal efficiency in COD, BOD and turbidity respectively, less than 30volt and 30 min electrolysis time in electrodeionization process. Fig 4.16 shows the removal efficiency of electrodeionization at varying voltage. Fig 13 shows the removal efficiency of electrodeionization at varying voltage. From graph it is clear that removal efficiency increases with increases in voltage.

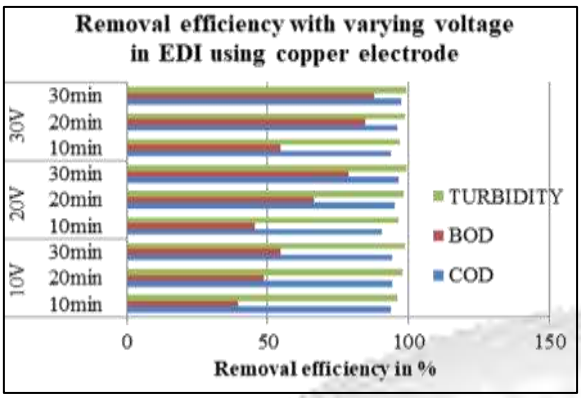

Fig. 13: Removal efficiency of electrodeionization with varying voltage.

F. Influence of electrolysis time on electrodeionization process

The electrolysis time is also an important parameter that has a major effect on the electrocoagulation efficiency. Therefore, experiments were carried out by varying the electrolysis time between 10min to 30min in order to investigate its effect on COD, BOD and turbidity removal for copper electrodes. Copper electrodes has achieved a maximum turbidity reduction of 97.5% , COD reduction of 95.5% and BOD reduction of 85.58% when the electrolysis time is set at 10mins. Copper electrodes has achieved a maximum turbidity reduction of 98.5% , COD reduction of 97.08% and BOD reduction of 87.87% when the electrolysis time is set at 20mins. Copper electrodes has achieved a maximum turbidity reduction of 99.5% , COD reduction of 97.5% and BOD reduction of 90.94% when the electrolysis time is set at 30mins. Fig 14 shows the removal efficiency of electrodeionization at varying electrolysis time. From graph it is clear that removal efficiency increases with increases in electrolysis time.

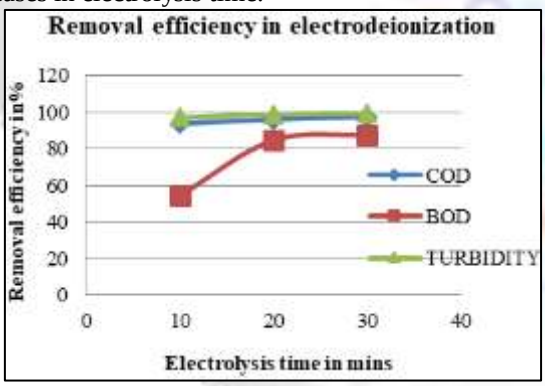

Fig. 14: Removal efficiency of EDI at varying electrolysis time.

IV. Conclusion

Electrocoagulation and electrodeionization are feasible process for the treatment of the dairy waste water, characterized by the high COD, BOD and SS Concentrations. The Treatment of Dairy Waste water using iron electrodes was affected by the voltage, the electrolysis time and stirring speed. The result shows that Copper electrodes has achieved a maximum turbidity reduction of 99.5%, COD reduction of 97.5% and BOD reduction of 90.94% in 30V high stirring speed when the electrolysis time is set at 30mins in electrocoagulation process. With increase in voltage and electrolysis time, COD, BOD and turbidity of treated effluent increased. And copper electrodes yielded 97.5%, 84.84% and 99.5% removal efficiency in COD, BOD and turbidity respectively, under 30V and 30mins electrolysis time in electrodeionization process. So it can be concluded that EDI is better than EC for the treatment of dairy waste water for BOD reduction. But in consideration with feasibility EC is better option for the treatment of waste water. In both process the treated effluent can be used in the industries for cooling purpose as well as irrigation purpose, landscaping, gardening, washing motor vehicles, flushing toilets etc.

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