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Removal of TSS from Dairy Wastewater by Hybrid Iron-Based Electrocoagulation with Nanofiltration Membrane Processes

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ABSTRACT
In this study, treatment of dairy wastewater using a electrocoagulation – nanofiltration (EC-NF) hybrid system was investigated. The performance of electrocoagulation (EC) using iron-stainless steel electrodes as a pretreatment step for the nanofiltration process was studied. By increasing residence time and voltage, the amount of iron released into solution by electrolytic oxidation of the anode material increased. At the optimum residence time and voltage, TSS removal by the electrocoagulation process was 93.8%. The effect of operating pressure in the nanofiltration process on TSS removal was investigated. The experiments were carried out at three pressures of 9, 12 and 15 bar. Removal of TSS increased with increasing applied pressure. The reported results demonstrate that an EC – NF hybrid system can be a promising candidate for dairy wastewater treatment.

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INTRODUCTION

The reuse of wastewater has become an absolute necessity. There is, therefore, an urgent need to develop innovative, more effective and inexpensive techniques for treatment of wastewater. A wide range of wastewater treatment techniques are known which includes biological processes for nitrification, denitrification and phosphorous removal; as well as a range of physico-chemical processes that require chemical additions. The commonly used physico-chemical treatment processes are filtration, air stripping, ion-exchange, chemical precipitation, chemical oxidation, carbon adsorption, ultrafiltration, reverse osmosis, electrodialysis, volatilization and gas stripping. A host of very promising techniques based on electrochemical technology are being developed and existing ones improved that do not require chemical additions. These include electrocoagulation, electroflotation, electrodecantation, and others [1].

Even though one of these, electrocoagulation (EC), has reached profitable commercialization, it has received very little scientific attention. This process has the potential to extensively eliminate the disadvantages of the classical treatment techniques [1].

Electrocoagulation involves the generation of coagulants in situ by dissolving electrically either aluminium 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. The materials can be aluminium or iron in plate form or packed form of scraps such as steel turnings and millings [2].

In this method, a convenient current is imposed on soluble anodes like aluminum, iron or their alloys in an electrochemical cell acting as the reactor for the experiment separated by filtration, depending upon their density. The electrocoagulation results in the dissolution of the electrode to yield metal ions (Fe^{2+}, Fe^{3+} or Al^{3+}) which are active coagulants precursors involved in the neutralization of the negative charges on the colloids of the effluent. These metal ions then react with the hydroxyl colloidal particles is specific in each of these processes [3].

EC has been applied to treat water containing foodstuff wastes, oil wastes, dyes, treat wastewater from pulp and paper industries, yeast wastewater, urban wastewater, restaurant wastewater, tar sand and oil shale wastewater, nitrate containing wastewater solutions, arsenic containing smelter wastewater, mining and metal-

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processing industries, suspended particles, chemical and mechanical polishing waste, organic matter from landfill leachates, defluorination of water, synthetic detergent effluents, mine wastes and heavy metal-containing solution [1, 4].

Membrane separation processes offer a number of advantages: they require less energy, have a reduced environmental impact, the selective transport and efficient separation in compare with other unit operations, separations with membranes do not require additives, and require less capital investment [5, 6]. Due to the unique properties of membranes, upscaling and downscaling of membrane separation processes as well as their integration into other separation or reaction processes are easy. A membrane can be described as an interphase, usually heterogeneous, acting as a barrier to the flow of molecular and ionic species present in the liquids and/or vapors contacting the two surfaces [5]. The major disadvantage of these technologies lies in the filling of the membrane pores leading to a reduction of flow rate. This performance decrease is the result of the development of fouling or biofouling on the membrane surfaces. So, the goal of obtaining an efficient treatment of highly polluted waters implicates the use of hybrid or hyphenated processes where the first process acts as a pretreatment. The reduction of fouling and biofouling is the main objective in order to improve the efficiency of membrane separations. The coupling of electrocoagulation with membrane separation has already been performed [7].

Results of previous studies indicate that use of EC pretreatment for membrane processes can be very efficient and leads to reduced fouling, increased removal of impurities, reduce energy consumption and therefore reduce costs [8-14].

The purpose of this paper is to optimize the EC process using Fe-SS electrodes as a pre-treatment of NF process on the treatment of an untreated dairy effluent.

MATERIALS AND METHODS

The wastewater used in this work was taken from the local dairy factory in Iran (Golestan province), with total suspended solids (TSS) equal to 1150 mg/l (mean value). All materials were purchased from Merck.

2-1- Electro-Coagulation (EC):

The experiment was setup in the static method where the EC and wastewater batch test are performed in a glass cell (volume 5,000 mL). Three anodes and three cathodes made of iron and stainless steel plates were connected in parallel and the monopolar to a digital DC power supply (0-50 V, 30 A). The total effective electrode area was 400 cm2.

At EC process residence time and voltage parameters were studied. After TSS removal amounts were measured in each case. Different scenarios of experiments can be seen in Table 1.

Table 1: Different scenarios of experiments.

Number	Residence Time (min)	Voltage (V)	The Anode Electrode
1	20	5	Fe
2	20	10	Fe
3	20	15	Fe
4	30	5	Fe
5	30	10	Fe
6	30	15	Fe
7	40	5	Fe
8	40	10	Fe
9	40	15	Fe

Later effluent from the EC with the highest percentage removal by nanofiltration process was purification.

2-2- Nanofiltration (NF):

The nanofiltration membrane (NF2) was used in this investigation. The membrane was supplied by Sepro. Filtration experiments were performed with a cross-flow filtration setup. The cross-flow cell housed flat sheet membrane pieces with an effective area of 28 cm2. The experiments were carried out at three pressures of 9, 12 and 15 bar.

2-3- TSS Measurement:

For TSS measurements, the first is the weight of a dry filter paper. After 100 CC of the wastewater sample was filtered at low vacuum pressure, then dried and weighed. TSS is calculated according to the following equation:

$$\text{TSS (mg/lit)} = \frac{(B-A)\times 1000}{V}$$

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Where B is final weight of filter paper (mg), A is initially weight of filter paper(mg), and V is the volume of wastewater sample (lit).

RESULTS AND DISCUSSION

3-1- Effect of voltage and residence time on the EC:

The effect of residence time and voltage in the EC process on the TSS removal efficiency was investigated. Fig. 1 shows the change of TSS removal efficiencies as a function of residence time and voltage. It is clear that TSS removal efficiency is increased from 90.8% at 20 min residence time to reach a maximum of 93.8% at 40 min residence time (at constant voltage equal to 15 V). The same is true for the effect of increasing residence time on the efficiency of TSS removal at another voltage.

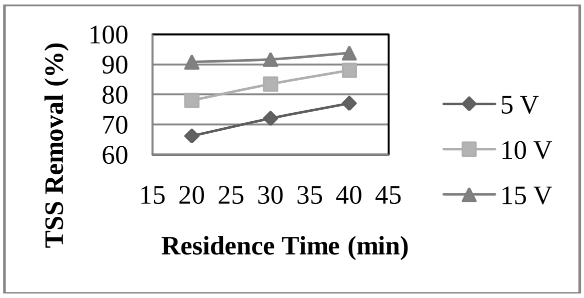

Fig. 1: Change of TSS as a function of residence time and voltage.

Also, the relationship between the TSS removal efficiency and voltage is depicted in Fig. 1. The figure shows that as the voltage increased from 5 to 15 V, removal efficiencies increased from 77.0% to 93.8% and from 72.0% to 91.7% and from 66.2% to 90.8% for the residence times of 40, 30, and 20 min, respectively.

With increasing voltage is changed coagulant production rate, the production rate of bubbles, the size of the clot and the clot growth rate. By increasing residence time and voltage, the amount of iron released into solution by electrolytic oxidation of the anode material increased. Therefore the concentration of metal hydroxides in solution increases [15]. The hydroxides are reduced TSS by neutralizing the surface charge of the particles and their absorption.

The highest removal efficiency (93.8%) occurred at a voltage of 15 V and residence time 40 min.

3-2- Effect of operating pressure on the performance of NF:

After pretreatment by coagulation process, effluent with the highest percentage removal was purified by nanofiltration process at pressures of 9, 12 and 15 bar.

The removal of TSS as a function of applied pressure is shown in Figs. 2. As illustrated in Fig. 2, removal of TSS increased with increasing applied pressure. The concentration of suspended solids in the permeate decreased with increasing flux. When the applied pressure was increased, permeate water flux through the membrane increased, while the TSS flux remained virtually unchanged, resulting in lower TSS concentration in the permeate.

The results show that with the increase of operating pressures, increases removal efficiency and water flux. In contrast, operating costs increased due to higher energy consumption.

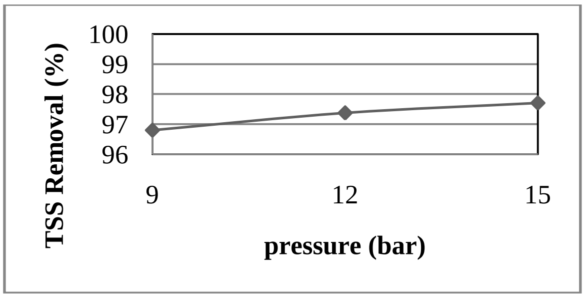

Fig. 2: Change of TSS as a function of pressure.

Conclusions:

This study examines the use of EC-NF hybrid system for the TSS removal of dairy wastewater. The effect of key operational parameters including residence time and voltage on the performance of the EC process was investigated. Integration of EC and NF was successfully used in removal of TSS in a dairy wastewater. By increasing residence time and voltage, the amount of iron released into solution by electrolytic oxidation of the anode material increased. As a result, TSS removal efficiency increases. The EC process was optimized with respect to operating parameters. The percentage of TSS removal at the optimized condition was found to be 93.8% (At a voltage of 15 V and residence time 40 min). Further refinement was brought about by nanofiltration. The effect of operating pressure in the nanofiltration process on TSS removal was investigated. The experiments were carried out at three pressures of 9, 12 and 15 bar. Removal of TSS increased with increasing applied pressure. The results show that with the increase of operating pressures, increases removal efficiency and water flux. In contrast, operating costs increased due to higher energy consumption.

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