

Purification of Raw Sugar Beet Juice by Electrocoagulation

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Abstract

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Introduction. This research was carried out to study of electrocoagulation process as a new technique for removal of impurities and non-sucrose compounds from raw sugar beet juice.

Materials and methods. This study was performed in a batch chemical reactor equipped with a 5-liters tank containing 3 aluminium anode and 3 Iron cathode electrodes connected in parallel. Effects of voltage at 5, 10 and 15 volts; processing time at 15, 30 and 45 minute intervals; and pH value at 6, 7 & 8 levels on the purity, turbidity and colour of the sugar beet juice were investigated by the Box-Behnken response surface methodology statistical design on Minitab 17 statistical software.

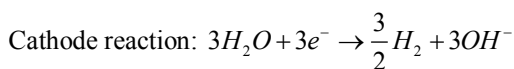
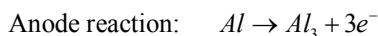
Results and Discussion. The results indicated that during the EC process, turbidity was reduced as the voltage increased. As the voltage rises, the solubility of the anodal electrodes also increases resulting in removal of a larger quantity of pollutants. Therefore, reduction in turbidity following the rise in voltage can be attributed to the increase in flake production, while changes in pH value had no significant effect on turbidity. Although the increase in voltage did not significantly effect the intensification of the colour, however it can be attributed to the increase in bubbles and the subsequent increase in enzymatic activity during floatation. It seems that the increase in enzymatic activity intensifies the melanin colour with the passage of time due to the openness of the reactor cell during floatation and aeration. Increase in the pH value, however, only slightly intensified the colour. The results indicated that the increase in voltage resulted in increase in the level of purity. The solubility of the anodal electrodes increases as the voltage rises and subsequently a higher quantity of impurities and polutants are removed by aluminium hydroxides produced. Increase in voltage also leads to production of greater quantity of bubbles which increase contact between aluminium hydroxides with the pollutants and impurities and facilitates the floatation of more of the produced sludge and thus removal of a greater quantity of the impurities. Increase in process time also resulted in an increase in the level of purity as an increase in reaction time results in more floating sludge is produced on the fluid surface. Increase in the pH value had no significant effect on the level of purity.

Conclusion. The results generally indicated that electrocoagulation process has positively affected on the turbidity reduction and increase the purity of the raw sugar beet juice during the process of purification though colour intensity was not so significantly influenced.

Introduction

Purification, removal of impurities, i.e. the non-sucrose compounds from sucrose, is one of the critical challenges facing the sugar industry. Raw sugar beet juice contains 50 non-sucrose and impurities such as reducing sugars, organic and non-organic acids, amino acids, proteins, starch, wax, resin, minerals such as potassium, magnesium, calcium, and silicon, colour and floating substances [7]. Obtaining a raw sugar beet juice with the highest degree of purity and least colour is the main objective in the purification stages. Purification by the conventional method (Liming – carbonization) requires a high degree of precision in the addition of lime and carbon dioxide as lack of precise control in the addition of these compounds can result in only partial separation of the impurities from the juice and the fragmentation of the colour compounds adsorbed from calcium carbonate crystals [8]. Traditional purification method also produces a large quantity of pulp due to high consumption of lime resulting in environmental problems. The most important disadvantage of this method is its high energy consumption [16]. Therefore, considering the abovementioned points, use of modern technologies such as the membrane process, electrocoagulation etc. in the sugar industry seems essential.

Electrocoagulation is a process in which suspended particles, emulsion or soluble pollutants are destabilized in an aquatic environment by an electric current. This process is beneficial in a wide range of water and sewage purification systems, and removal of mineral, pollutants and pathogens [5]. This process begins with the oxidation of anodes and the production of Al^{+3} and Fe^{+2} ions and continues with the combination of the metallic ions with hydroxyl ions resultant from water electrolysis in the proximity of the cathode and the production of metallic hydroxides which destabilize the pollutants and creates suspended particles or flakes. These flakes can float on the surface of the fluid aided by the hydrogen bubbles produced in the cathode due to the difference in density or be removed through precipitation [3]. In general, the impurities removal mechanism in the electrocoagulation process includes coagulation, adsorption, precipitation, and floatation which are performed in accordance to the reactions below in the electrodes thus follows:



The Al^{3+} and OH^- ions produced during above reactions are formed into monomers such as $Al(OH)^{2+}$, $Al(OH)_2^{+2}$, $Al_2(OH)_2^{4+}$ and $Al(OH)_4^-$ and or polymers such as $Al_6(OH)_{15}^{3+}$, $Al_7(OH)_{17}^{4+}$, $Al_8(OH)_{20}^{4+}$, $Al_{13}O_4(OH)_{34}^{7+}$, and $Al_{13}(OH)_{34}^{5+}$ which are eventually changed into $Al(OH)_3$ and become precipitated [9]. Insolubility of iron and aluminium hydroxides in water, availability and the low cost of these metals in comparison to metals with similar characteristics has resulted in their more widespread use in the process of electrocoagulation [10 & 11]. Other advantages of this method also include: use of simple equipment, low initial investment and operation costs, unnecessary of chemical substances, low sludge production, production of larger, more stable and acid resistant flakes, faster filtration, elimination of small colloidal particles, and low repair and maintenance care [4]. The research by Shivayogimath and his collaborator, where they

exploited electrocoagulation in the purification of the sugar industry wastewater, is among many examples of the application of this method. Their results indicated that the electrocoagulation process incorporating iron electrodes can be used as an affordable substitute for the traditional methods of purifying sugar industry wastewater [12]. Xu et al., (2002) also applied electrocoagulation in order to retrieve useful compounds from the wastewater produced by egg processing plants. Their results indicated that the use of this process in the egg processing industry can be very successful and lead to the recovery of fractions such as protein and highly digestible fat. Bazrafshan et al, (2013) used electrocoagulation in order to purify dairy wastewater and found that this is a suitable method for the removal of BOD₅, COD and other pollutants.

With regard to the high potential of EC process in removing impurities, the purification of raw sugar beet juice was investigated in this study through applying aluminium anode and iron cathode electrodes under the influence of parameters such as voltage, pH value, and process time in a batch chemical reactor.

Materials and methods

Material

The raw sugar beet juice was prepared from Chenaran sugar plant. Also, all the chemical material, component and reagent for determination of Turbidity, color and purity was purchased from Merck company.

Methods

EC process

This study was carried out in experimental form on a laboratory scale in a batch pilot. Properties of the raw sugar beet juice are given in Table 1. As shown in Figure 1, the electrocoagulation system consists of a 5 liter tank in which 3 aluminium electrodes as anode and 3 iron electrodes as cathode have been placed alternatively at a distance of 0.015m from each other with a lateral surface area of 0.01875m² for each electrode connected to an electrical power supply in a unipolar form. The tests were performed at three voltage levels (5, 10 and 15 volts), three pH levels (6, 7 and 8) and three time intervals (15, 30, 45 minutes). Firstly, pH of juice was adjusted with 0.1M NaOH, then five liters of raw sugar beet juice was poured into the electrocoagulation cell at each stage and the effects of the abovementioned parameters evaluated. At the end of the process, samples were taken from the mid-cell area and turbidity, colour, and purity of the raw sugar beet juice was tested after the precipitation of coagulums and filtration.

Table 1

Initial Properties of Raw Sugar Beet Juice

Variable	Unit	Value
Turbidity	NTU	166
PH	-	6
Colour	ICUMSA	10520
Pol	%	13.2
Brix	%	14.9
Degree of Purity	%	88.6

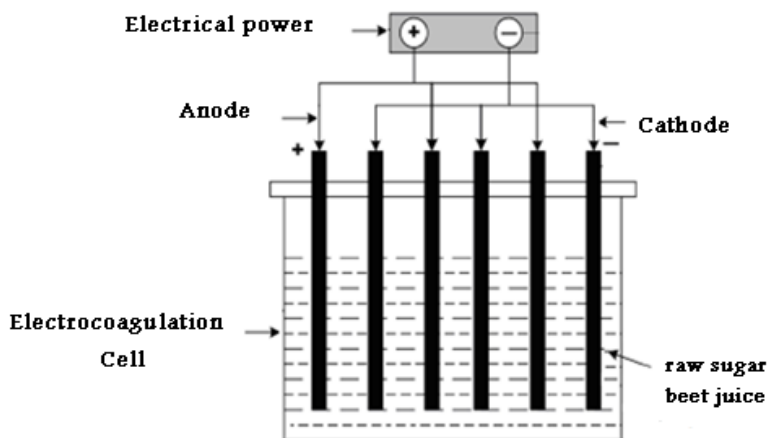


Figure 1. Electrocoagulation pilot schematic

Measuring the colour

The colour was measured following the absorption value reading taken at a wavelength of 420nm by the spectrophotometer model UNICO 2100 and evaluated according to the ICUMSA Standard using equation 1 below [15].

$$Color (ICUMSA) = 10^5 \times \frac{A}{L \times RDS \times \rho} \quad (1)$$

where:

A = Light absorption, L = Cell Length, RDS= Refractometric Dry Solid and ρ = Density

Turbidity

Turbidity of the raw sugar beet juice was directly measured using the turbidimeter (Aqualytic™ AL450T-IR model) according to the NTU unit [14].

Purity

Purity was determined using equation 2 following the evaluation of Pol (percentage of sucrose) by NIR W2 Saccharometer and the percentage of solid matter by NAR-1T Refractometer [13].

$$Q = \frac{pot}{Brix} \times 100 \quad (3)$$

Experimental design

Effects of independent variables: voltage, processing time, and pH value on the purity, turbidity and the colour of the raw sugar beet juice were examined in this study by the Box-Behnken response surface methodology statistical design subject the full quadratic model (equation 3) on Minitab 17 statistical software.

$$f = b_0 + b_1V + b_2V^2 + b_3T + b_4T^2 + b_5P + b_6P^2 + b_7VT + b_8VP + b_9PT \quad (3)$$

where:

V= Voltage, T= Time and P= pH

Run numbers, experimental treatments and replicate runs designed by RSM is summarized in Table 2.

Table 2

Experimental runs, independent variable levels and replicate runs in RSM (box-bhenken)

Run Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Voltage (volt)	5	15	15	15	5	15	5	15	10	10	10	10	10	10	10
Time (min)	15	15	45	45	30	30	30	30	15	45	15	45	30	30	30
pH	7	7	7	7	6	6	8	8	6	6	8	8	7	7	7

Results and discussion

Investigation of the effect of independent variables on raw sugar beet juice turbidity changes

Turbidity is one of the most important factors that occurs in purification of the raw sugar beet juice. Turbidity can result from residual mud on the sugar beet, organic compounds, insoluble cellular compounds, beet plant fragments etc. As shown in Figure.2, the results indicated that during the EC process, turbidity was reduced as the voltage increased. As the voltage rises, the solubility of the anodal electrodes also increases resulting in removal of a larger quantity of pollutants. Therefore, reduction in turbidity following the rise in voltage can be attributed to the increase in flake production. In electrocoagulation process for the removal of seasonal turbidity from drinking water was found that the removal rate of turbidity significantly increased as the voltage increased.

Increase in EC process time also led to an increase in coagulation and a higher rate of impurity removal. Efficacy of impurity removal is directly dependent upon the concentration of the ions produced on the electrodes, and as the concentration of the metal ions and hydroxide coagulums increases along with time increase, their rate of such removal also rises [1].

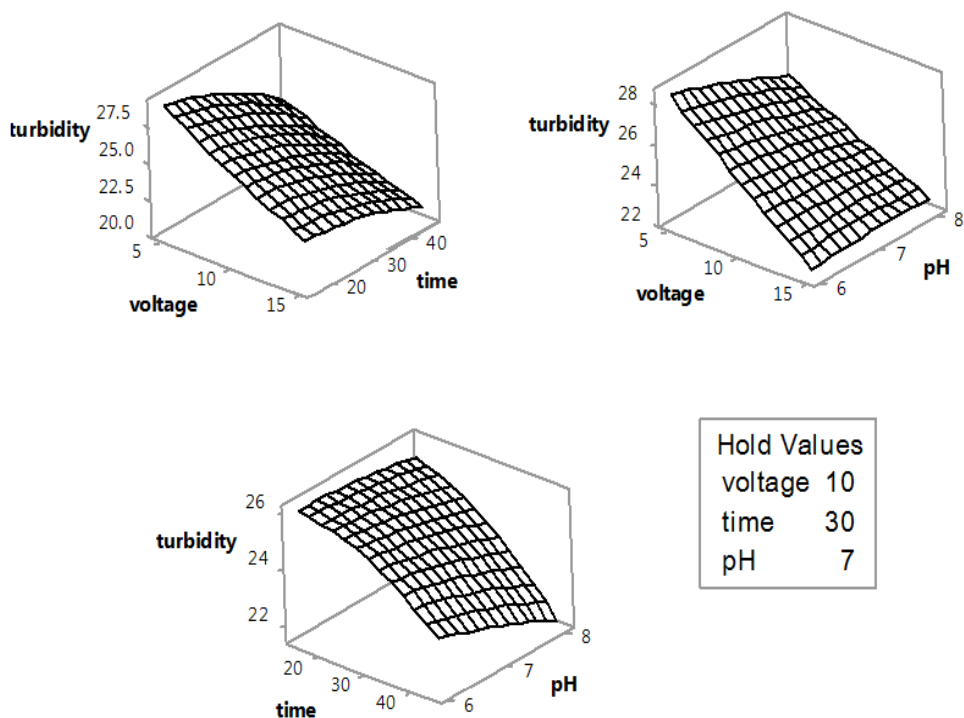


Figure 2. Effects of voltage, time and pH on variability of juice turbidity

Shivayogimath et al., (2012) found during the investigation of purification of the sugar industry sewage by electrocoagulation that the rate of removal of Turbidity increases with time and declared that the maximum amount of turbidity (92.4%) is achieved after four hours. Higher efficiency of the higher rate of turbidity removal can also be attributed to the Faraday law. According to the Faraday law, $m = \frac{MIt}{zF}$ the quantity of metal ions (m) is dependent upon the intensity of the applied current (I) and electrolysis time (t). So, concentration of coagulants increases along with an increase in the above parameters.

However, in this research no significant increase was observed in turbidity changes as the pH value increased. The Al^{+3} and OH^- ions produce various monomeric species such as $Al(OH)^{2+}$, $Al(OH)_2^{+}$ and polymeric species such as $Al_6(OH)_{15}^{3+}$, $Al_7(OH)_{17}^{4+}$ and $Al_{13}(OH)_{34}^{5+}$ when the pH varies between 4 to 9 in value, which eventually transform into insoluble $Al(OH)_3$ flake through chemical reactions precipitation/polymerization. $Al(OH)_3$ coagulums

contain a larger surface which is suitable for the absorption of soluble organic compounds and trapping colloidal fragments. Therefore, the concentration of the coagulants such as $Al(OH)^{2+}$ and $Al(OH)_3$ are similar in this range of the pH value [6].

Investigation of the effect of independent variables on raw sugar beet juice colour changes

Colour is another one of the important factors in the purification of the juice. Melanins formed as the result of the enzymatic browning reactions are among the most important colour substances formed in the syrup by diffusion. Although these colour compounds are superficially absorbed by the calcium carbonate crystals during the later stages, the results however indicated that during electrocoagulation the colour intensifies as the voltage and time are increased (Figure 3).

Although the increase in voltage did not significantly effect the intensification of the colour, however it can be attributed to the increase in bubbles and the subsequent increase in enzymatic activity during floatation. It seems that the increase in enzymatic activity intensifies the melanin colour with the passage of time due to the openness of the reactor cell during floatation and aeration. Increase in the pH value, however, only slightly intensified the colour. These results correspond with the results of the research carried out on the elimination of colour from coloured wastewater through electrocoagulation [6].

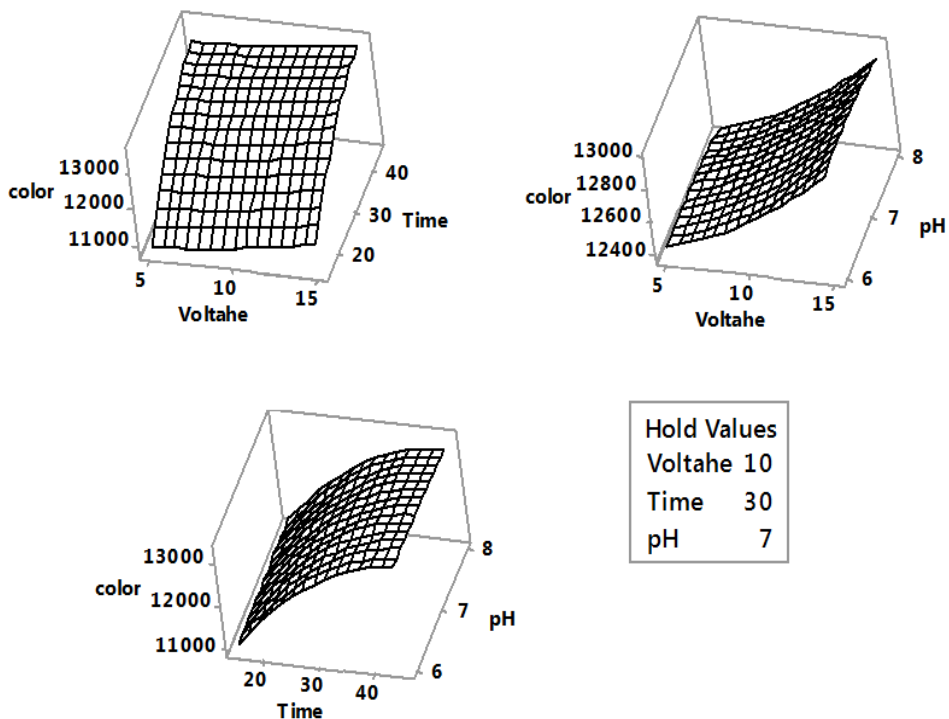


Figure 3. Effects of voltage, time and pH on variability of juice color

Investigation of the effect of independent variables on raw sugar beet juice purity changes

An increase in the purity level of the raw sugar beet juice during purification is indicative of desirable removal of the non-sucrose soluble and insoluble compounds. The results according to Figure 4 indicated that the increase in voltage resulted in increase in the level of purity. As explained previously, the solubility of the anodal electrodes increases as the voltage rises and subsequently a higher quantity of impurities and pollutants are removed by aluminium hydroxides produced. Increase in voltage also leads to production of greater quantity of bubbles which increase contact between aluminium hydroxides with the pollutants and impurities and facilitates the floatation of more of the produced sludge and thus removal of a greater quantity of the impurities. Increase in process time also resulted in an increase in the level of purity as the an increase in reaction time results in more floating sludge is produced on the fluid surface. Increase in the pH value had no significant effect on the level of purity.

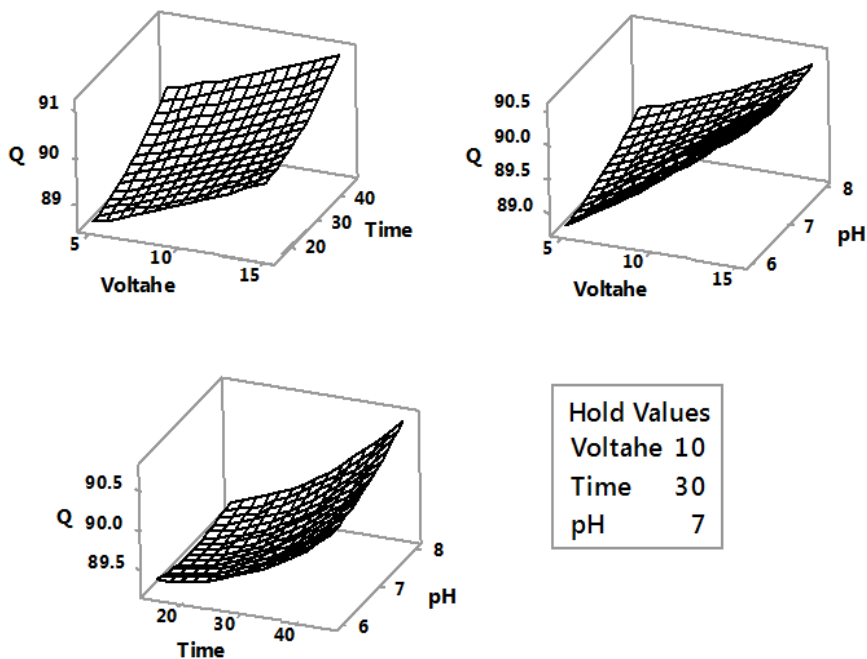


Figure 4. Effects of voltage, time and pH on variability of juice purity Comparison EC process with traditional refining method

For the judgment of EC process performance to refining the sugar beet juice, the properties of obtained sugar juice by EC process was compared to properties of thin juice from Chenaran sugar plant by traditional method. As seen in the table 3 purity reached to the purity of thin juice approximately. EC process to removal of turbidity was very successful, too. But removal of color by this method not suitable because of flotation and Intensification of enzymatic browning. Although, it can hoped that color would removed by supplementary process as filtration.

Table 3

Compare the properties of refined sugar beet juice by EC process with thin juice (traditional method)

Properties	Raw sugar beet juice	EC process	Traditional process
Turbidity (NTU)	166	20	19
Color (ICUMSA)	10520	11500	1400
Purity (%)	88.6	91	91.5

Table 4

Analysis of operational parameter and coefficient of full quadratic model

Source	DF	Turbidity			Color			Purity		
		Ss	P-value	Coefficient	Ss	P-value	Coefficient	Ss	P-value	Coefficient
Model	9		74.9597	0.009		11091621	0		7.08433	0.018
Constant		24.9		0	12635.5		0	89.600		0.000
Linear										
V	1	-2.408	46.3685	0.001	276	609463	0	0.700	3.92	0.002
T	1	-1.648	21.7140	0.003	1092.2	9543664	0	0.575	2.645	0.004
P	1	-0.506	2.5088	0.130	-16.4	2155	0.461	0.125	0.125	0.317
Quadratic										
V·V	1	0.1	0.0369	0.835	71.4	18817	0.065	0.063	0.01442	0.721
T·T	1	-0.590	1.2853	0.252	-487.8	878715	0	0.213	0.16673	0.255
P·P	1	-0.145	0.0766	0.763	-29.2	3140	0.380	0.113	0.04673	0.527
Interaction										
V·T	1	0.460	0.8464	0.341	-43.9	7709	0.192	-0.025	0.00250	0.881
V·P	1	0.655	1.7161	0.195	1.3	7	0.967	-0.175	0.12250	0.321
T·P	1	-0.315	0.3969	0.504	-38.3	5868	0.245	0.125	0.06250	0.467
Residual	5		11.765			16395			0.50500	
Lack-of-fit	3		3.8295	*		16395	*		0.50500	*
Pure error	2		0.000			0.000			0	
Total	14		78.7892			11108556			7.58933	
R ² (%)			95.14			99.85			93.35	
Adj-R ² (%)			86.32			99.57			81.37	

Conclusion

The results generally indicated that electrocoagulation process has positively affected the reduction in turbidity and increase in the purity of the raw sugar beet juice during the process of purification though colour intensity was not so significantly influenced. Investigation of the independent parameters indicated that increases in the voltage and process time of coagulation significantly affected the reduction in turbidity and increase in purity such that the turbidity was reduced by 87% in comparison with the initial raw sugar beet juice while the purity increased by three units. Changes in the pH in the 6-8 range however, had no noticeable effect on Turbidity, colour, and purity. Although the results of this research indicated only a slight increase in the colour intensity of the raw sugar beet juice due to floatation and enzymatic browning, it is hoped that the colour produced can be removed by absorption on the surface of bentonit powder or active carbon by filtration. The operational parameters in this research were effective on the variations of color, turbidity and purity with appropriate R^2 . Analysis of operational parameters effectiveness subject the full quadratic model summarized in table 4. This process can be offered as an effective method in the purification of the raw sugar beet juice in combination with other purification methods.

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