Design of small-scale electrocoagulation reactor for non-sugar removal of sugarcane juice

Noersatyo¹, Suprihatin² and Ade Iskandar²

¹ Post Graduate Program of Agroindustrial Engineering, IPB University, Bogor, ID
² Department of Agroindustrial Technology, Faculty of Agricultural Technology and Engineering, IPB University, Bogor, ID

Corresponding author: noersatyo07@gmail.com

Abstract. The most common sugarcane juice purification method practiced in Java is liming and sulphitation. In this research, electrocoagulation method was used to purify the sugarcane juice. This research purpose is to design an electrocoagulation reactor for the non-sugar removal of sugarcane juice. The design method of the reactor is based on IR-Drop and surface area per volume ratio (S/V) optimization. Electrode type and configuration was chosen considering the characteristic of sugarcane juice. A circulated vertical flow reactor type was built to conduct the electrocoagulation. The dimension of the reactor was 10 x 10 x 24 cm and had 8 electrodes installed with 1 cm inter electrode distance. The electrode was aluminium plate and arranged in bipolar configuration. The experiment used 35, 45, and 55 volt, flow rate of 40 L/min, and 30 minutes reaction time with 5 minutes interval. The result showed that an increase in voltage and reaction time increases the non-sugar removal efficiency. The mixed juice treated by electrocoagulation with 55 volt for 5 minutes could remove the non-sugar up to 21.47% and 33.49% for 30 minutes reaction time. The average of non-sugar removal by sulphitation in Java is 11.50% and 29.00% by carbonation. This study shows that electrocoagulation is more effective than the conventional method in removing the non-sugar. With the right scaling up method, electrocoagulation is possible to be practiced in a large scale sugar industry. Future studies are needed to evaluate the performance of electrocoagulation in terms of the clear juice quality and process efficiency.

Keywords: Electrocoagulation, Purification, Sugarcane juice

1. Introduction

In Java, most sugar factories clarify its sugarcane juice by means of liming and sulphitation. The Java average of non-sugar removal achieved in sulphitation factories is about 11.5% of non-sugar in mixed juice. Using this method, the clear juice goes to the next process which then produces a plantation white sugar. The clarification process determines the quality of the juice to produce sugar with high quality and efficiency [1,2].

The important factors of clarification by sulphitation are coagulation and adsorption in the defecation process. By adding lime in the form of milk of lime, coagulation occurs by neutralizing colloidal charge and precipitate of calcium phosphate (Ca₃(PO₄)₂) would adsorb molecule and colloidal particles [3]. pH control and phosphate content in the mixed juice are essential to this process. Problem faced with liming process in one of the sugar factories in Java is that isoelectric point of the mixed juice varies which was hard for operators to control the optimal pH for coagulation. Another
problem comes from the low content of phosphate in the mixed juice where the factory has to add soluble phosphate in the process.

An alternative technology introduced in this research is electrocoagulation. Different from the conventional coagulation in sugar factory, electrocoagulation uses electrode as anode and cathode where reduction and oxidation reaction occur. Hydrolysable species that could be used are $\text{Al}^{3+}$ or $\text{Fe}^{3+}$ to neutralize charges and creates insoluble amorphous species that precipitate causing sweep coagulation [4]. Electrocoagulation is commonly applied in wastewater treatment and has never been practiced in sugar factory to treat mixed juice.

This research aims to design a specific electrocoagulation reactor and study the application for the removal of non-sugar in sugarcane juice.

2. Materials and methods

2.1. Materials and equipment
The materials used were glass, glass glue, seal tape, PVC pipe, 2 mm aluminum plate, antifoaming agent, and sugar cane juice. Chemicals used for analysis include form A ($\text{AlSO}_4$) and form B (NaOH).

The equipment used were AC to DC switcher power supply, cables, alligator clip, water pump, digital flow rate meter, valve, grinding machine, drill, and glass cutter. Instruments used were a sucromat (Anton Paar MCP 250 sucromat) and digital avo meter (SANWA).

2.2. Methods
To design an efficient electrocoagulation reactor, the following factors have to be considered such as minimizing IR-drop on the electrode, minimizing accumulation of $\text{O}_2$ dan $\text{H}_2$ gas on the electrode surface, and minimizing blocking of the mass transfer process across the area between electrodes [5].

The IR-drop value depends on the conductivity of the electrolyte solution, the distance between electrodes, and the geometrical shape of the electrode. The distance between electrodes and the effective surface area depends on the electrode assembly construction. The variation in voltage-drop ($\eta IR$) regulated by the following equation [5]:

$$\eta IR = (I \times d)(S \times k)^{-1}$$

Where:

- $\eta IR$ = IR-Drop (V)
- $I$ = current (A)
- $d$ = inter electrode distance (cm)
- $S$ = active electrode surface (cm$^2$)
- $k$ = specific conductivity (mS/cm)

Electrocoagulation efficiency is strongly related to electrode dissolution and the production of large amounts of aluminum metal ions, which is strengthened by increasing the number of plates to obtain a larger active surface. The greater the electrode surface area per reactor volume, the more efficient it is in eliminating impurities in a solution [6].

Choices of electrode type should consider the content of the treated sample. Sugarcane juice contains phenol that causes increase in color with the reaction of ferric ion [7], therefore electrodes based on iron should be avoided. Initial pH of the solution also affects the efficiency of different types of electrode used.

There are two electrode configurations in designing electrocoagulation reactors namely monopolar and bipolar in series or parallel circuits. Monopolar configuration connects all cells as anode and cathode to the power supply one by one in sequence whereas bipolar only connect the two ends. Each configuration has advantages and disadvantages as needed [4].
2.3. Electrocoagulation treatment
This experiment used 5 liter of sugarcane mixed juice to be clarified by the electrocoagulation reactor. The sample was taken from the milling station and filtered by a 90 mesh sieve for any fine particle. The sugarcane sample was treated with 35, 45, and 55 volt, flow rate of 40 L/min, and reaction time of 30 minutes with 5 minutes interval. Each interval, a sample was taken to analyze the pol and brix using sucromat. The pol and brix value would represent the purity of the sample where purity is pol divided by brix and multiplied by 100. The sample’s purity then used for the non-sugar removal calculation by the following equation [1]:

\[
Non - sugar \text{ removal} = \frac{(1-P_{mj}) (1-P_{cj})}{1-P_{mj}} \times 100
\]

Where:
\( P_{mj} \) = Purity of mixed juice (%)
\( P_{cj} \) = Purity of clear juice (%)

3. Results and discussion
3.1. Electrocoagulation reactor
The electrocoagulation reactor type was vertical flow plate reactor designed for 2 liter working volume. The electrocoagulation reactor was made of glass. The sugarcane mixed juice introduced from the bottom of the reactor by a pump and then overflow from the top to a buffer tank. From the buffer tank, it would then reintroduce back to the electrocoagulation cell as seen in Figure 1.

The electrocoagulation cell where electrocoagulation took place had a dimension 10 x 10 x 24 cm (2400 cm³). Each plate dimension was 10 x 0.2 x 25 cm (50 cm³). Inter electrode distance used was 1 cm [8]. With 1 cm inter electrode distance used, the maximum electrode installed was 8 unit for the highest surface area per volume (S/V). This would give the reactor working volume of 2 liter. The electrode plate used was aluminium considering the initial pH of sugarcane juice at 4.0-4.5. Dissolution of Al anode enabled at low pH due to Al³⁺ hydrolysis generating H⁺ and precipitating Al(OH)₃ [9]. The potential pH diagram of aluminium electrode can be seen in Figure 2. Iron electrode was avoided because of the phenolic content in the mixed juice that causes color with reaction of ferric ion. The electrode plates were connected to a DC power supply in a bipolar configuration. Bipolar configuration setting was simpler and had higher increase in pH considering the final pH of the clear juice had to be around 7.0-7.2.

Figure 1. Schematic of the electrocoagulation reactor.
In the electrocoagulation process, other reactions will occur besides coagulation including the generation of metal oxides and hydroxides on the electrode surface. O\textsubscript{2} and H\textsubscript{2} gas accumulation on the surface of the electrodes must be minimized for an efficient electrocoagulation process. The decrease in efficiency due to this process called passivation. To overcome this problem, agitation carried out in the reactor to create friction between the solution and the electrode wall. This agitation was done by circulating the sample in and out of the reactor by circulating pump. An increase in the circulating flow rate will result in a high degree of mixing in the electrocoagulation unit that can facilitate the process of transporting colloidal pollutants to be absorbed into the active coagulant site. In addition, in observing the surface of the electrode, the layer formed tends to be less in the reactor with given flow. In turbulent flow, mixing coagulant and other particles is better and particles on the surface of the electrode can be separated [10]. The maximum circulating flow for this design was 40 L/min.

![Potential pH diagram for Al-H\textsubscript{2}O system.](image)

**Figure 2.** Potential pH diagram for Al-H\textsubscript{2}O system.

### 3.2. Non-sugar removal

The non-sugar removal was calculated by the difference in purity of the mixed juice and the clear juice. The pol and brix value stands for the sucrose and soluble solids content in the sugarcane juice. By using the formula given (2), each sample observed shows an increase in non-sugar removal every 5 minutes as seen in Figure 3.

![Non-sugar removal by electrocoagulation at various voltage and reaction time with standard deviation.](image)

**Figure 3.** Non-sugar removal by electrocoagulation at various voltage and reaction time with standard deviation.

Electrocoagulation is an electrochemical wastewater treatment method which releases active coagulants in the form of metal ions and electrolysis reactions in the form of the release of hydrogen
gas. In the electrocoagulation process using aluminum electrodes, electrolyte dissolution from aluminum anodes results in cationic monomer species such as Al$^{3+}$, AlOH$^{2+}$, and Al(OH)$_2^+$ at low pH. At the appropriate pH value, it is transformed into Al(OH)$_3^-$, Al(OH)$_4^-$, Al(OH)$_2^{4+}$ according to several hydrolysis reactions. The release of metal ions in electrocoagulation follows Faraday's law. This means that the higher the current used in the electrocoagulation and the longer the reaction time the more active the coagulant is. As the voltage increases, the current also increases which causes more coagulant in the sugarcane juice [11].

An increase in the purity during purification is indicated by the removal of the non-sucrose soluble and insoluble compounds. The results according to Figure 3 indicate 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 are removed by aluminium hydroxides produced. Because sucrose does not have any electric charges, sucrose cannot be coagulated in the process. As the purity increases, it indicates the non-sugar removal. The higher the purity gap, the higher the non-sugar removal. Figure 3 shows that the higher the voltage used the more non-sugar were removed. Also, longer reaction time removed more non-sugar in the sugarcane juice.

In Java, the average of non-sugar removal is approximately 11.50% for sulphitation and 29.00% for carbonatation. Using electrocoagulation with 55 volt and 5 minutes reaction time could remove non-sugar up to 21.47% and 33.49% for 30 minutes of reaction time. Other studies of electrocoagulation application on sugarcane juice were very limited in number. Others conducted in a laboratory scale and analyzed for the sugarcane juice quality such as turbidity, color, phenolic content, etc. With this design, further studies have to be made on the quality of the sugarcane juice and also the process efficiency.

4. Conclusion
The best result is obtained by 55 volt for 30 minutes with 33.49% non-sugar removal. This study shows that electrocoagulation is more effective than the conventional method in removing the non-sugar. With the right scaling up method, electrocoagulation is possible to be practiced in a large scale sugar industry. However, to decide whether electrocoagulation method is suitable for sugarcane clarification, future studies have to consider the quality of the treated sugarcane juice and the process efficiency.

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