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EFFECT OF DIFFERENT PARAMETERS ON CLARIFICATION EFFICIENCY OF MECHANICAL CLARIFIER

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Key words: mechanical clarification efficiency, centrifugation, sugarcane juice.

Abstract

Effects of parameters namely, height of agitator from lid (15, 16, 17 cm.), centrifugation speed (2500, 3000, 3500 RPM) and time of centrifugation (5, 10, 15 min.) on mechanical clarification of sugarcane juice were studied. Filtration was incorporated as a pretreatment which reduced the amount of impurities in the juice. Soluble solids, total solids, sediment obtained, optical density and percent transmittance were measured and used for determining the efficacy of mechanical clarification of sugarcane juice. Full factorial design was used for selecting the levels of parameters in the experiment. Full second order polynomial and best fit equations were developed to predict various responses and to study individual, square and interactive effects of parameters on the responses. The clarification efficiency ranged between 11.3-42.2% and Optical density varied between 1.52 and 0.92 for mechanical clarification of sugarcane juice. Minimum percent transmittance was 3 and maximum was 13. Minimum sediment per 20 ml. of juice due to centrifugal force was 0.989 g. and maximum was 2.358 g. for mechanical clarification. Centrifugation time had highly significant effect on clarification efficiency followed by centrifugation speed, and height of agitator in that order. However, centrifugation speed had significant effect on optical density and percent transmittance.

WPŁYW WYBRANYCH PARAMETRÓW NA EFEKTYWNOŚĆ MECHANICZNEGO OCZYSZCZANIA SOKU Z TRZCINY CUKROWEJ

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Słowa kluczowe: efektywność klaryfikacji mechanicznej, wirowanie, sok z trzciny cukrowej.

Abstrakt

Badano wpływ następujących parametrów: odległość mieszadła od nakrywy (15, 16, 17 cm), szybkość wirowania (2500, 3000, 3500 RPM) i czas wirowania (5, 10, 15 min), na proces mechanicznego oczyszczania soku z trzciny cukrowej. Filtrację włączono do procesu jako obróbkę wstępną redukującą sumę zanieczyszczeń w soku. Zmierzono ciała rozpuszczalne, sumę składników stałych, otrzymany osad, gęstość optyczną oraz współczynnik przezroczystości i oceniono skuteczność mechanicznej klaryfikacji soku z trzciny cukrowej. Do doboru parametrów eksperymentu zastosowano metodę pełnego planowania czynnikowego. Dopasowane do wyników wielomiany drugiego stopnia i równania pierwszego stopnia opracowano do oceny procesu mechanicznej klaryfikacji oraz zbadania indywidualnego, łącznego i krzyżowego wpływu na nią różnych parametrów eksperymentu. Efektywność oczyszczania mieściła się w zakresie: 11.3-42.2%, a gęstość optyczna w zakresie 1.52-0.92. Minimalny współczynnik przezroczystości był równy 3, maksymalny równy 13. Minimalny osad na 20 ml soku w zależności od siły wirowania wyniósł 0.989 g, natomiast maksymalny 2.358 g. Na efektywność klaryfikacji najbardziej wpływał czas wirowania, bardziej niż szybkość wirowania, która znacząco wpływała na gęstość optyczną i współczynnik przezroczystości. Najmniej znaczący wpływ na mierzone parametry soku miała wysokość mieszadła.

Introduction

Sugarcane (*Saccharum officinarum*), is an integral component of agriculture in our country, as an agro-industrial crop. Total production of sugarcane in 2005-06 was nearly 266.88 million tones that was higher by 15% vis-á-vis the production of 2004-05 (INDIA 2006). The sugar industry is the second largest agro-based industry in India, involving nearly 50 million farmers, their dependents and a large mass of agricultural laborers in sugarcane cultivation, harvesting and ancillary activities, constituting 7.5% of the rural population (JAIN 2004).

Both white sugar and jaggery production involves extraction of juice and its clarification. The clarification of juice depends on the composition of juice that affects the quality of sugar and jaggery. Besides sugars, it contains suspended impurities in the form of coarse particles and colloids. Soil particles, wax, fat, protein, gum, pectin, tannins, and coloring matters are extracted from the cane during juice extraction and they remain in colloid form (RAO 1984).

In general term clarification means the extraction or separation of desired material and discarding the rest in a particular system either by means of chemical treatment or by mechanical operation. At times both may be applied for ultimate degree of separation requirement. In the instant proposition the cane juice which is a colloidal suspension of inorganic and organic non-sugars along with dissolved impurities needs dual operation followed by thickening, crystallization and centrifugation for the manufacture of sugar.

Clarification of sugarcane juice can be classified into two categories such as chemical clarification and mechanical clarification. Commonly vegetative clarificants are used in boiling pan. Some chemicals such as hydros (sodium hydro-sulphite), lime (calcium oxide), sodium bicarbonate, sodium carbonate, super phosphate and alum have been used in combination with the vegetative clarificants. A good flocculant should increase the settling rate of insoluble solids, decrease the mud volume, produce good clarity of clarified juice with the least turbidity and should produce good filterability of mud, with good clarity of filtrate.

Several of these have been already marketed under various trade names like Sedipur TF2, Mafloc – 985, Magnafloc LT 22, Magafloc LT 22 SP, Betz 1420, Midland PCS/ 3016, C5 Eugel Series, Biosugar (Seta Products) and ABC clarifiers. Most of them are polyacrylamide based compounds, while some are basically ion exchange resins.

Chemical clarificants adversely affect the health of human beings since traces of chemicals remain in the final product (ANJAL, TAGARE 1972). All these chemicals (except lime) brighten colour of jaggery initially, but the colour of the jaggery becomes dull during storage. So alternative methods of clarification such as centrifugation is being explored to alleviate the use of chemical clarificants (VISHAL 2003, TARAK 2006).

Centrifugation is one of the established unit operations in the sugar industry. Although the designing aspect as based on density difference has been utilized most successfully in separation of sugar crystals from massecuite and various trials were conducted by KIRBY et al. (1990) at the initial stage of sugar manufacture, its application has not yet been systematically applied.

Materials and Methods

The process of clarification is shown schematically in Figure 2. Juice was extracted from the sugarcane (Variety Co.66) using three roller crusher. It was filtered using a strainer to remove baggasse and then fed into centrifugal clarifier. Process variables were height of agitator, speed of agitator and time of centrifugation and their levels are reported in Table 1. Full factorial design was used for experimentation.

Table 1

Variables and their levels

Variables	Levels
Height of agitator (X_1), cm	15, 16, 17
Agitator speed (X_2), rpm	2500, 3000, 3500
Time of centrifugation (X_3), min	5, 10, 15

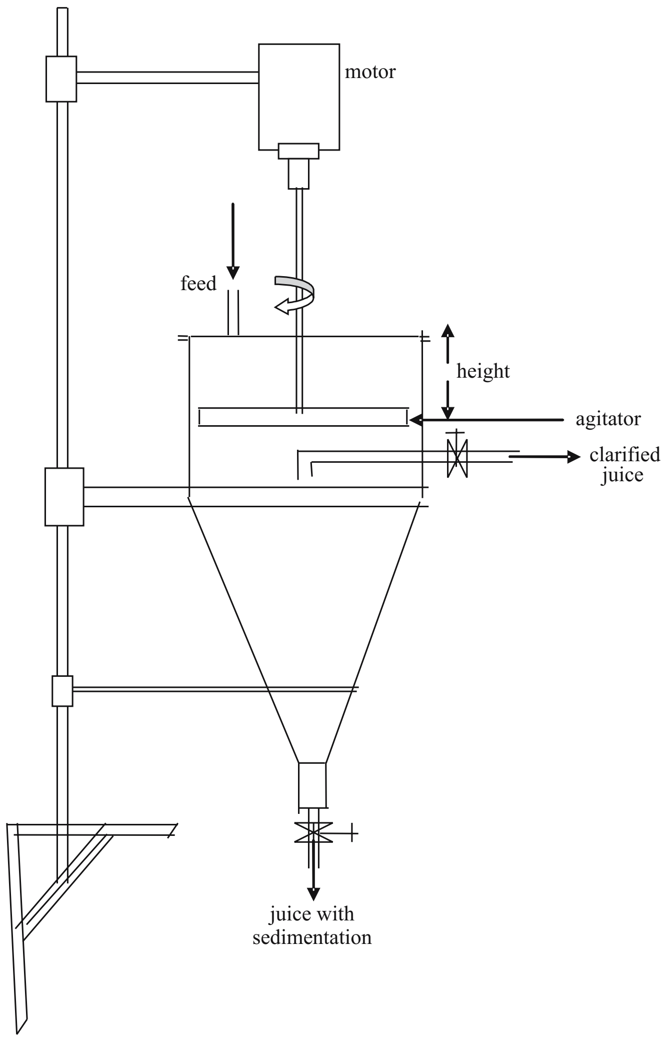

Fig. 1. Schematic diagram of the clarifier

The brix content, optical density (OD), percentage transmittance (%T), sediment obtained per 20 ml juice and solid content of the raw juice were measured. The brix content was measured by a hand refractometer. The OD and %T were measured by the colorimeter. For sediment obtained, 20 ml of juice was taken in a test tube and kept for 45 min for sedimentation. The clear juice from top of test tube was separated and the remaining sedimented juice was weighed. The OD was used as a measure for the degree of clarity of the juice. The OD of both raw and clarified juice was measured in a colorimeter at 540 nm and it was considered as the color of the sample.

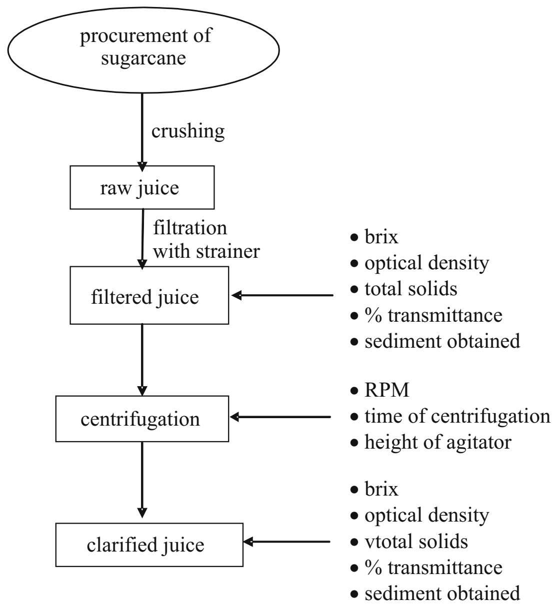

Fig. 2. Flowchart for mechanical clarification of sugarcane juice

The juice was fed to the clarifier. The height of agitator and its rpm were adjusted as per the design. The clarifier was operated for different centrifugation times as per the design. The clear juice was present on the upper part of clarifier. Juice samples were collected for the measurement of optical density, brix content, total solids and sediment.

Calculation for clarification efficiency

Amount of different types of solids in the juice were estimated using following relationships:

Total Solids = Soluble Solids + Non- Soluble Solids

Brix = Total Soluble Solids

Insoluble Solids = Total Solids – Brix

Soluble Solids other than Sucrose = Brix – Sucrose Content

Objective of centrifugal clarification was to remove only the insoluble solids.

Hence, the separation efficiency ($\acute{\eta}$) was defined as:

$$\acute{\eta} = \frac{S_r - S_c}{S_r} \cdot 100,$$

where:

$\acute{\eta}$ – separation efficiency, %,
S_r – insoluble solids in raw juice, g,
S_c – insoluble solids in clarified juice, g.

Results and Discussion

The clarification efficiency (η_i) varied from 11.3 to 42.2% by mechanical clarification which suggested that the clarification efficiency is affected due to height of agitator, agitator speed and time of centrifugation. The lowest clarification efficiency was 11.3% after 5 min at 2500 rpm and the highest was 42.2% after 15 min at 17 cm and 3500 rpm. Here agitator speed accounts for centrifugal force that increases the clarification efficiency of sugarcane juice.

Table 2

ANOVA for clarification efficiency, η_i

SOURCE	DF	SEQ SS	MS	F
Regression Error Total	9 17 26	1840.5 20.6 1861.2	204.50 1.21	168.04*

Significant at * 1% level

Clarification efficiency data were fitted into second order mathematical model using regression analysis and ANOVA is presented in Table 2. The coefficient of determination was 98.8%, suggesting the model could account 98.8% data. Therefore, the second order model was adequate in describing clarification efficiency. However it was observed that all the terms in the model were not significant. Therefore, best fit regression was carried out for clarification efficiency and the following best fit equation was obtained as:

$$\eta_i = 65.41111\text{-}17.1111\, X_1 + 0.005744\, X_2 + 3.35\, X_3 + 0.766667\, X_1^2 - 0.10733\, X_3^2 \quad (R^2 = 0.988) \tag{1}$$

The model indicates that the interactive effect of the variables was insignificant. Moreover, the effect of speed was insignificant at quadratic levels.

Table 3

Contour equations for varying X_3 for clarification efficiency

X_3	Contour equations
5	$\eta_i = 79.485 - 17.11\, X_1 + 0.0057\, X_2 + 0.766\, X_1^2$
10	$\eta_i = 88.21 - 17.11\, X_1 + 0.0057\, X_2 + 0.766\, X_1^2$
15	$\eta_i = 91.585 - 17.11\, X_1 + 0.0057\, X_2 + 0.766\, X_1^2$

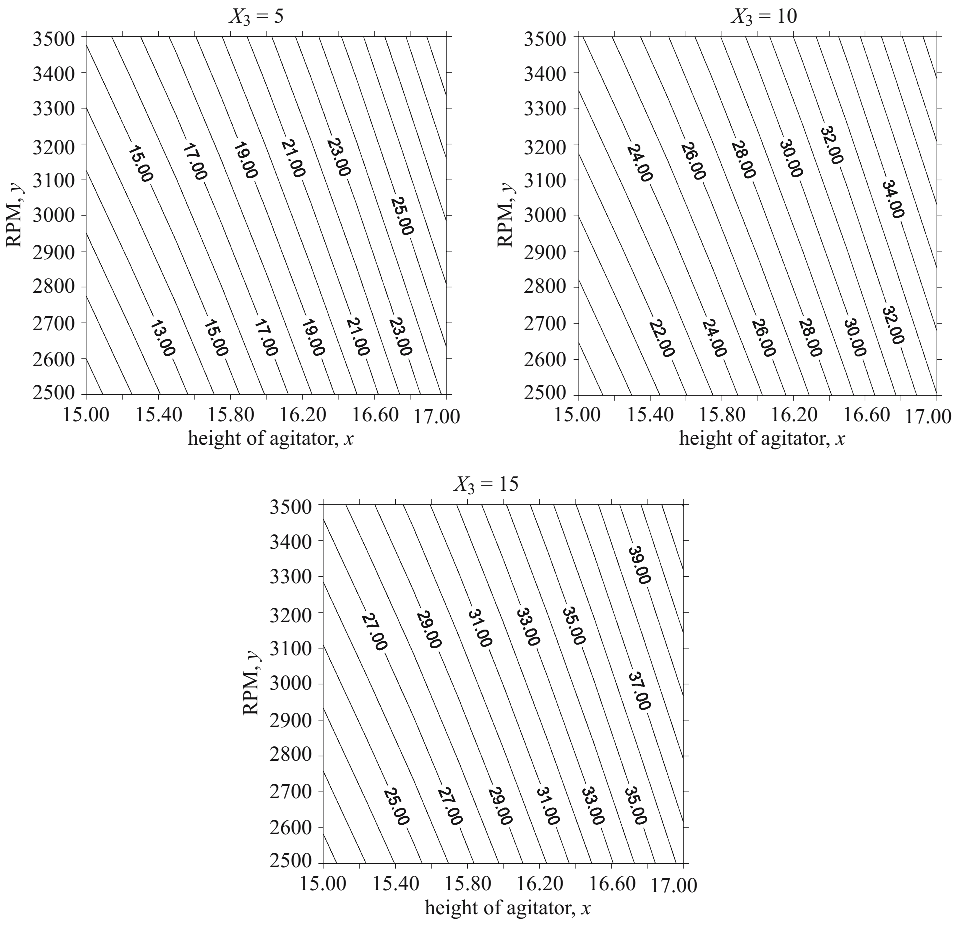

Fig. 3. Contour plots for clarification efficiency (η_s) with respect to height of agitator and centrifugation speed

The contours are shown in Figure 3 for various combinations of time of centrifugation. It is clear from the figures that the clarification efficiency was minimum at low levels of height of agitator and centrifugation speed. It increased with increase in their levels and was maximum at high levels of height and centrifugation speed. This is as expected since increased height of agitator enhances more juice towards centrifugal force while increased centrifugation speed imparts more centrifugal force for separation of particles

The optical density (OD_i) varied from 1.63 to 0.92 for mechanical clarification, suggesting that the optical density decreased due to centrifugal force. The highest optical density was 1.63 before clarification and the lowest optical density was 0.92 after 15 min at 17 cm and 3500 rpm.

Table 4

ANOVA for optical density, OD_i

SOURCE	DF	SEQ SS	MS	F
Regression	9	1.67	0.186	90.95*
Error	26	0.06	0.002	
Total	35	1.74		

Significant at * 1% level

Optical density data were fitted into second order mathematical model using regression analysis and ANOVA is presented in Table 4. The coefficient of determination was 96.38%, suggesting the model has the ability to account 96.38% data. Therefore, the second order model was adequate in describing optical density. However it was observed that all the terms in the model were not significant. Therefore, best fit regression was carried out for clarification efficiency and the following best fit equation was obtained as:

$$OD_i = 1.7475\text{-}0.0031 X_1 - 2.6\text{E-}05 X_2 + 0.1285 X_3 + 0.0011 X_3^2 - 0.0099 X_1 X_3 + + 7.1\text{E-}06 X_2 X_3 \quad (R^2 = 0.963) \tag{2}$$

The model indicates that the interactive effect of height of agitator and speed of agitator were insignificant. Moreover the effect of height of agitator and speed of agitator individually were insignificant at quadratic levels.

Table 5

Contour equations for varying X_3 for optical density (OD_i)

X_3	Contour equations
5	$OD = 2.414 - 0.052 X_1 - 0.000061 X_2$
10	$OD = 3.137 - 0.102 X_1 - 0.000097 X_2$
15	$OD = 3.914 - 0.15167 X_1 - 0.000132 X_2$

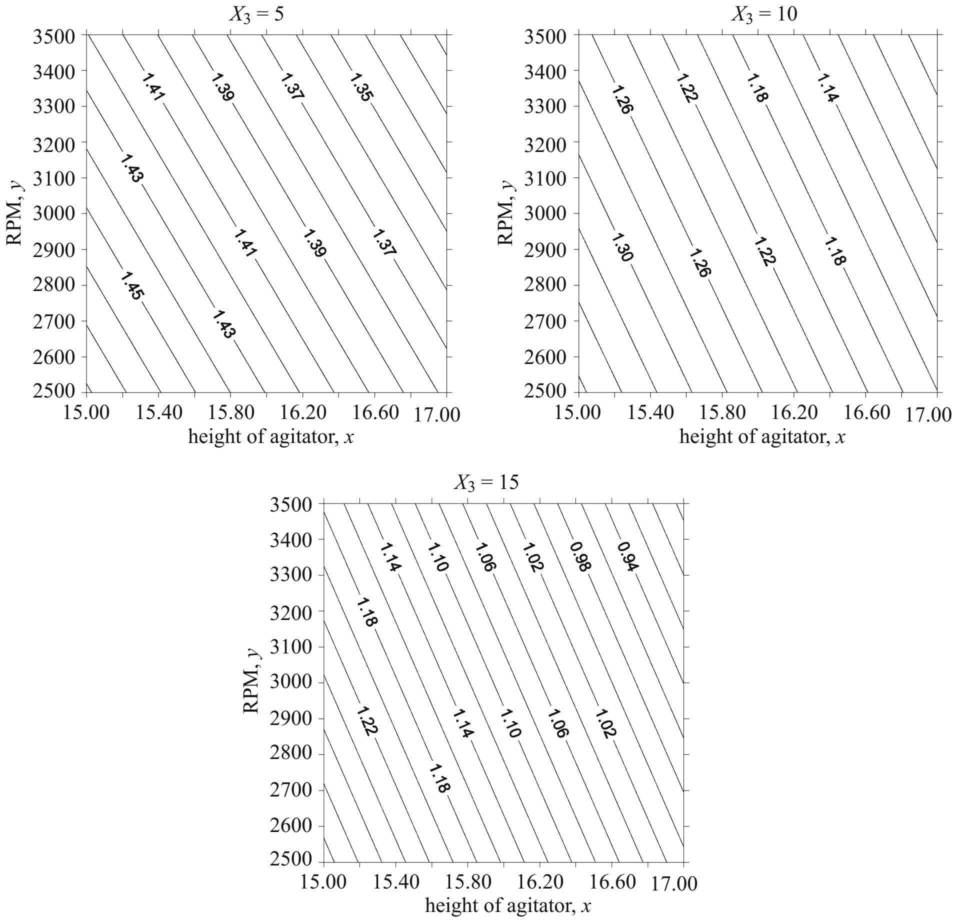

Fig. 4. Contour plots for optical density (OD_i) with respect to height of agitator and centrifugation speed

The contours are shown in Figure 4 for various combinations of time of centrifugation. It is clear from the figures that the optical density was maximum at low levels of height of agitator and centrifugation speed. It decreased with increase in their levels and was minimum at high levels of height of agitator and centrifugation speed. This is as expected since increased height of agitator enhances more juice towards centrifugal force while increased centrifugation speed imparts more centrifugal force for separation of particles

Conclusions

It may be concluded from above presentation that the centrifugal clarification has an edge over chemical methods with proven advantages. If the speed of agitator will be made more and proper design of agitator can be done for the above clarifier then better clarification efficiency can be achieved.

It has been observed on the basis of practical and theoretical approach that in case of cane juice clarification the mechanical means have an edge over chemical process for its better control without affecting the system. However these approaches need detailed study. The proposed alternative for this purpose is the centrifugation of cane juice in which the past work lacks the systematic approach and improvement as compared to that in the case of centrifugation of massecuite. In the present paper a critical analysis of cane juice centrifugation as carried out by above clarifier has been studied.

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