Evaluation of Combined Ozonation and Activated Carbon Adsorption for Eco-Efficient Color Removal in Sugar Refining

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Abstract. The color of sugar crystals is one of the most important determining parameters in the quality of white sugar. Conventional decolorization methods in sugar refinery units require the use of chemicals and may lead to environmental pollution (as a result of the production of sulfur dioxide gas). Using ozone for decolorization is one of the promising methods in this field. In the present research, laboratory-scale experiments were carried out on operational liquor samples from sugar refinery unit to assess the feasibility of ozonation as an alternative decolorization process. To optimize the combined process, independent variables including activated carbon dosage and contact time were selected, while the percentage of color removal was considered as the response factor. Based on the analysis of variance (ANOVA), the linear model for color removal was statistically significant ($p < 0.05$), confirming the adequacy and reliability of the fitted model. Optimization of contact time and adsorbent dosage yielded a target color removal efficiency of approximately 55%. The results demonstrate that integrating ozonation with activated carbon adsorption not only enhances color reduction but also decreases ozone demand and operational costs, presenting a technically feasible and eco-efficient alternative for sugar refinery unit.

Keywords: Ozonation, Activated Carbon, Sugar Refinery, Sulphitation, Environmental Sustainability.

1 Introduction

The color of sugar crystals plays a decisive role in determining the overall quality of refined sugar. Conventional decolorization methods in sugar refinery units (particularly the application of sulphitation during the decolorization process) require sulfur-containing reagents, and the associated release of SO_2 has intensified environmental and sustainability concerns. Moreover, the ineffectiveness of these methods in completely removing some color precursors and impurities during the decolorization process is obvious. Therefore, in order to maintain competitiveness in the sugar market, it is necessary to investigate new technologies and techniques in order to produce the best quality product at the possible lowest cost [1-3].

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Using ozone for decolorization is one of the promising oxidative methods. Although ozone has long been employed for water decolorization and sterilization [4], its application in the sugar industry has received substantial attention in recent years due to its strong oxidative capability, environmentally benign characteristics, and potential to serve as an alternative to conventional chemical treatments. Ozone can effectively oxidize colorants without producing harmful residues, particularly sulfur-based contaminants, thereby enhancing both process efficiency and environmental sustainability. Therefore, the use of ozone compared to sulfur dioxide gas has an environmental advantage, because the instability and decomposition of ozone molecules into oxygen causes no residual sulfur-containing compounds in the produced white sugar [5, 6].

In the present research, the aim is to investigate the feasibility of ozonation as an alternative decolorization process. The objective was to reduce chemical consumption (particularly that of activated carbon) and to decrease the environmental impact associated with the sulphitation process.

2 Materials and Methods

This study was carried out at the laboratory scale using the clarified liquor from the sugar refinery unit. At first, the clarified liquor samples were exposed to direct ozonation process (Figure 1) [7, 8]. Then, to evaluate the effect of ozone treatment in combination with activated carbon adsorption, 100 mL of the ozonated clarified sugar liquor was used in each experiment. The temperature of the liquor was adjusted to 80 °C using a thermostatic water bath prior to the adsorption step. Predetermined dosages of powdered activated carbon (Shanghai Activated Carbon Co., China) were added to the liquor, and the suspensions were maintained for the specified contact time (t = 5-10 min).

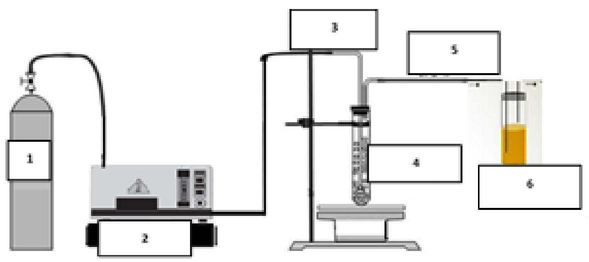

Fig. 1. A schematic illustration of the setup of ozone (1- Oxygen Cylinder, 2- Ozone Generator, 3- Ozone inlet, 4- Reactor, 5- Residual ozone outlet and 6- Ozone destruction bottle).

After completion of the contact period, the suspensions were filtered carefully to prevent the passage of fine carbon particles into the filtrate. The resulting filtrates were collected and analyzed for color intensity based on the ICUMSA standard method, using spectrophotometric absorbance at 420 nm in 1 cm pathlength cell [9]. The percentage of color removal (DECOL %) was calculated according to Equation (1) for samples before and after treatment [10] :

$$(DECOL\ \%) = \frac{ICUMSA1\ COLOR - ICUMSA2\ COLOR}{ICUMSA1\ Color} \times 100 \quad (1)$$

A two-factor, two-level factorial experimental design was developed using Minitab software to systematically evaluate the effects of the studied variables on color removal efficiency [11].

3 Results and Discussion

In this study, the levels of the independent variables and their corresponding coded values were summarized in Table 1. The independent variables were the activated carbon concentration and contact time, whereas the percentage of color removal was selected as the response factor for evaluating the treatment performance.

It is noteworthy that, for the integrated ozonation–adsorption process, the color removal during the ozonation stage was maintained at an average level of approximately 34%. This was accomplished by reducing the ozone exposure time to half of the duration applied in the individual ozonation experiments. The overall sequence of the combined treatment process is illustrated in Figure 2.

Table 1. The levels of the independent variables and their corresponding coded values.

Independent variables	Range and level	
	-1	+1
Activated carbon concentration (ppm)	100	200
Contact time (min)	5	10

Fig. 2. The sequence of steps in the decolorization phase using ozonation and activated carbon.

As shown in Table 2, the linear regression model developed for predicting color removal was statistically significant ($P < 0.05$), indicating the adequacy and reliability of the fitted model. The significant model terms included contact time and adsorbent concentration ($P < 0.05$), confirming their dominant influence on the decolorization performance. Additionally, the obtained values of R-sq=0.9499 and R-sq(adj)= 0.9123, both greater than 0.8 and close to each other, further confirm the strong predictive capability of the model without the unnecessary inclusion of non-significant variables [2]. Figure 3 illustrates the effects of these parameters on the percentage of color removal through contour plot. As the results demonstrate, increasing the adsorbent dosage and contact time positively influences the decolorization efficiency. Moreover, the target color removal level of 55% was achieved at the minimum adsorbent concentration of 150 ppm and a contact time of 5 minutes.

Table 2. The analysis of variance (ANOVA) results.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	404.130	134.710	25.28	0.005
Linear	2	403.987	201.993	37.91	0.003
Adsorbent concentration (ppm)	1	166.258	166.258	31.20	0.005
Contact time (min)	1	237.729	237.729	44.62	0.003
2-Way Interactions	1	0.143	0.143	0.03	0.878
Adsorbent concentration (ppm)* Contact time (min)	1	0.143	0.143	0.03	0.878
Error	4	21.313	5.328		
Total	7	425.443			

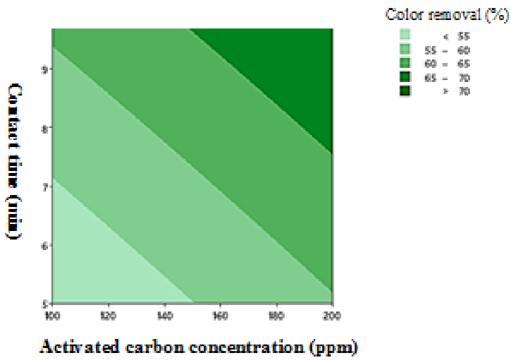

Fig. 3. Contour plot for decolorization as a function of adsorbent concentration and contact time.

4 Conclusion

In the combined ozonation–activated carbon treatment, decolorization was achieved within half of the contact time required for individual ozonation phase, and a target color removal of 55% was obtained at the minimum adsorbent dosage and contact time. The obtained results demonstrate that integrating ozonation with activated carbon adsorption not only enhances color reduction but also reduces ozone consumption and associated operational costs at large-scale implementation. Also, these findings suggest that ozonation can be proposed as a potential alternative to conventional sulphitation process in sugar refinery unit.

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Disclosure of Interests.
The author has no competing interests to declare that are relevant to the content of this article.

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