Removal of Melanoidin from Wastewater in Sugar Factories by Continuous Foam Fractionation Column

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1, Introduction

Melanoidin is a dark brown colored substance generated by Maillard reaction of amino acids and carbohydrates. The wastewater containing melanoidin discharged from sugar factories seriously contaminates rivers, lakes, and marshes in Southeast Asian countries. It is, therefore, desired to develop a simple and economical technique to treat and to decolorize this wastewater, because of cheapness of raw sugar product and of the economic states of these countries. There have been several studies to treat this wastewater: the absorption of melanoidin by activated carbon [1)], the decomposition by ultraviolet ray [2)], the removal of melanoidin by foam fractionation [3)]. Foam fractionation in the last study is a quite convenient separation technique. In this thesis, the continuous operation was applied to the foam fractionation of melanoidin from wastewater. In the first, the effects of operation factors on the performances were studied experimentally. Secondly, the countercurrent multistage foam fractionation process removing melanoidin was synthesized and was simulated with the experimental results.

2, Continuous Foam Fractionation of Melanoidin

Experimental apparatus and conditions are shown in **Fig.2-1** and **Table 2-1** respectively. The model wastewater and gas ware fed to the middle and bottom of the column, respectively. The foam rich in melanoidin was withdrawn from the top and the treated wastewater, from the bottom. The flow rate and the melanoidin concentration of the respective streams ware measured after attainment to a steady state. The concentration of melanoidin was determined by a spectrophotometer.

Table.2-1 Experimental Conditions

pH	[-]	1.82±0.05
d	[m]	0.026
Surfactant		Sodium Dodecyl Sulfate
C_S	[kg/m^3]	0.125, 0.250
C_F	[kg/m^3]	1.25～10.77
H_f	[m]	0.180～0.800
H_L	[m]	0.150～0.820
H_S	[m]	0.180, 0.465
F_G	[m/h]	2.26～7.91
F_F	[m^3/h]	2.46×10^{-4}, 7.56×10^{-4}
T	[K]	293±5 (Room temperature)

The effects of superficial gas flow rate, F_G, on the flow rate from the top of the column, $F_D \cdot A$, and mass transfer rate of melanoidin, $F_DC_D \cdot A$, are shown **Fig.2-2** and **Fig.2-3**. F_D and F_DC_D increased with the F_G. The feed flow rate, F_F, and the heights of liquid and the foam beds in the column did not affect $F_D \cdot A$ and $F_DC_D \cdot A$ in the range of this work. If the melanoidin concentration in the interstitial liquid of foam equals that in the liquid from bottom, C_W, $F_DC_D \cdot A$ can be written as,

$$F_D C_D \cdot A = F_D C_W \cdot A + \Gamma S \tag{2-1}$$

where Γ is the surface excess of melanoidin and S is the transfer rate of surface area in the foam. $F_DC_D \cdot A$ is plotted against $F_DC_W \cdot A$ in **Fig.2-4**. The slope of this plots was unity, so that the ΓS was constant, i.e., the intercept on the vertical axis, independently of C_W. **Table 2-2** summarizes the effects of various operation factors on the concentration ratio, α and the yields, Y_M, Y_W.

Table. 2-2 Effects of each parameter on α, Y_M and Y_W.

		α [-]	Y_M [-]	Y_W [-]
H_L	↑	—	—	—
F_F	↑	↑	↓	↑
H_f	↑	—	↓	↑
C_F	↑	—	—	—
F_G	↑	↓	↑	↓
C_S	↑	—	↑	↓

3, Countercurrent Multistage Foam Fractionation Process

Figure 3-1 shows the outline of the process. The feed wastewater is introduced to the middle of the cascade and the gas, to the bottoms of the respective stages. The material balances of the total flow and melanoidin for the respective stages are,

$$F_F + F_{W,k+1} + F_{D,K-1} = F_{D,k} + F_{W,k} \tag{3-1}$$

$$F_{F,k}C_{F,k} + F_{W,k-1}C_{W,k-1} + F_{D,k+1}C_{D,k+1} = F_{D,k}C_{D,k} + F_{W,k}C_{W,k} \tag{3-2}$$

Eq.2-1 was rewritten for the respective stages as,

$$F_{D,k}C_{D,k} \cdot A = \Gamma S_k + F_{D,k}C_{W,k} \cdot A \tag{3-3}$$

These basic equations are solved simultaneously to simulate the process. In this simulation, $F_{D,k}$ and ΓS_k are estimated from the above experimental results under condition of C_S=0.250 kg/m^3 as a function of $F_{G,k}$. The effects of feed flow rate, F_F, and the gas flow rate in the top stage (stage 1), $F_{G,1}$, on the specific concentration of melanoidin, α, are shown in **Fig.3-2**. α increased with the F_F. As $F_{G,1}$ increased, that is, the reflux ratio decreased, α increased. **Fig.3-3** shows the relation among the yield of wastewater, Y_W, F_F, and $F_{G,1}$. Higher Y_W was obtained under the condition of larger F_F, and lower $F_{G,1}$, namely, higher reflux ratio.

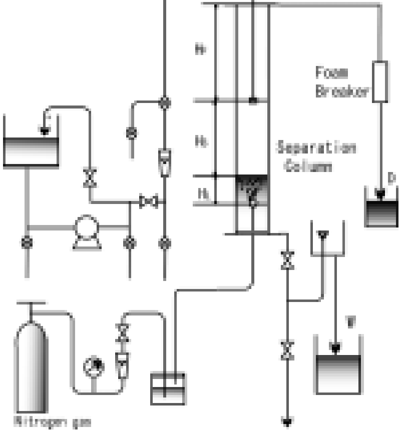

Fig.2-1 Experimental Apparatus (The column was made of acryl resin. Foam was coalesced by heating.)

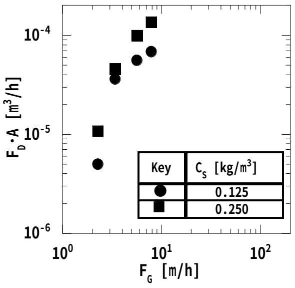

Fig.2-2 Effects of F_G on F_D·A (pH=1.78±0.06, C_F=5.88±0.20, H_L=0.44, H_S=0.465, H_f=0.445, F_F=2.46×10^{-4}, d=0.026, T=293±5.)

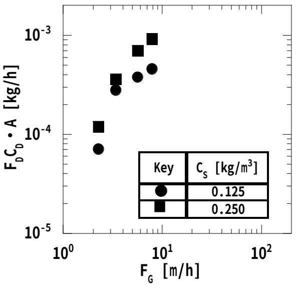

Fig.2-3 Effect of F_G on mass transfer rate of melanoidin (Conditions are the same as in **Fig.2-2**)

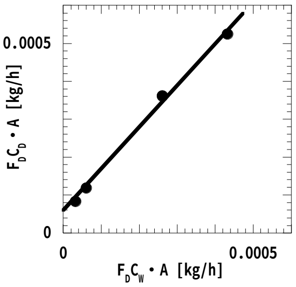

Fig.2-4 F_DC_W·A vs. F_DD_D·A plots for estimation of ΓS (pH=1.85±0.03, F_G=3.39, C_F=5.88±0.20, H_L=0.44, H_S=0.465, H_f=0.445, F_F=2.46×10^{-4}, d=0.026, T=293±5)

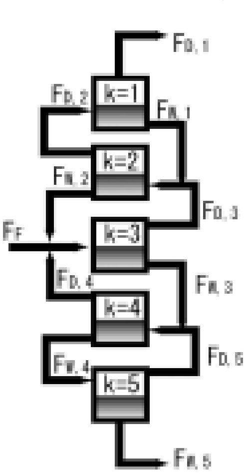

Fig.3-1 Outline of multistage continuous foam fractionation process

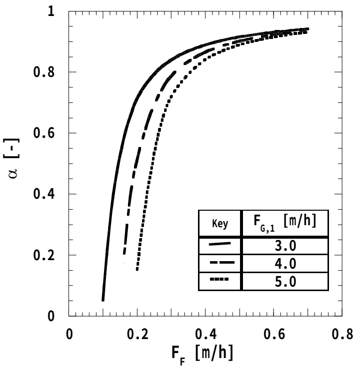

Fig.3-2 Effects of F_F and $F_{G,1}$ on α (C_S=0.250, $F_{G,k}$=8.0, C_F=6.0, d=1.0, n=24, n_F=12)

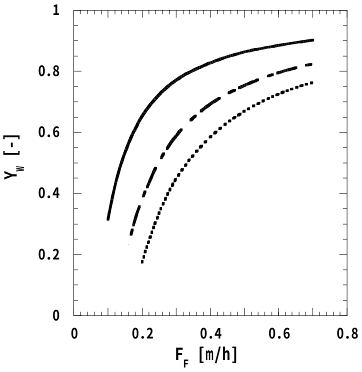

Fig.3-3 Effects of F_F and $F_{G,1}$ on Y_M (Keys and conditions are the same as in **Fig.3-2**.)

4, Conclusion

The effects of various operation factors were clarified by the experimental runs. Melanoidin could be removed from the wastewater by this technique in the process simulation.

Reference

1) Bernardo, E. C., R. Egashira and J. Kawasaki; "Decolorization of Molasses' Wastewater Using Activated Carbon Prepared from Cane Bagasse," Carbon, 35, (9), 1217～1221 (1997)
2) J. Movillon, Bulletin of INCOCSAT, 3,97 (1997)
3) 清水郁子, 岩久保純子, 江頭竜一; "泡沫分離法による粗糖工場排水の処理," 化学工学会つくば大会研究発表講演要旨集, B113, p40 (2000 年 7 月 17 日, 18 日)

Nomenclature

A= Cross sectional area of separation column [m²], C= Concentration [kg/m³], d= Diameter of column [m], F= Flow rate [m/h], H= Height [m], n= The number of stages [-], n_F= The feed stage number [-], S= Surface transfer rate [m²/h], Y= Yield [-], α= Concentration ratio α=$C_{W,n}/C_F$, [-]

Subscripts

D= Top, f= Foam F= Feed, G=Gas, k= k-th stage, L= Liquid pool, S= Surfactant, W= Bottom