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RATE LIMITING MECHANISM FOR MASS TRANSFER OF PINEAPPLE JUICE EXTRACTION IN THE REVERSING CONTINUOUS COUNTERCURRENT EXTRACTOR

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ABSTRACT

The rate limiting mechanism for pineapple juice extraction in the reversing continuous countercurrent extraction system was investigated based on a backmixing-diffusion model at steady-state condition. Three parameters namely temperature, Peclet number, and Biot number were studied for yield and yield loss calculation using an experimentally verified steady-state backmixing-diffusion model. For simulation purpose, some parameters/factors based on previous experimental results were specified including equilibrium distribution coefficient, diffusivity, time of cell plasmolysis, characteristics length, draft, and overall mass transfer coefficient. It was found that, in most cases of the experimental range, solid-diffusion was rate limiting step while backmixing phenomenon strongly influenced the concentration profiles, yield and yield loss. Backmixing caused the reduction in driving force and the increasing in mass transfer. The combined effect of finite Biot number (Bi) and Peclect number (R) influenced the yield and yield loss. In majority of cases, in-solid diffusion was predominantly controlled-limiting step while the backmixing phenomenon caused the loss of concentration gradient of extraction system significantly. In some cases, where the backmixing was too strong, the yield loss could be as high as 40 %.

INTRODUCTION

According to the previous work, a diffusion-backmixing model was proposed to describe the kinetics of mass transfer in the continuous countercurrent extraction system (Rittirut *et al.,* 2010a). The model was then verified by simulation and application to apple, pear and pineapple juice extraction in a reversing continuous countercurrent extractor (RCCE). It was found that the predictions agreed well with the experimental data in the liquid phase and can also approximate a closed trend in the solid phase (Rittirut *et al.,* 2010b). Nevertheless, the rate limiting mechanism is still not mentioned. This communication, although does not improve the model, aims to describe the rate limiting mechanism to the extraction system where different backmixing extent are established. The simulations are carried out at steady state condition with different operating temperature and different Biot number through simulation concept of backmixing-diffusion model.

METHODS

For pineapple juice extraction, the rate limiting step was considered based on a backmixing-diffusion model at steady-state condition in the reversing continuous countercurrent extractor. The parameters like temperature, Peclet number, and Biot number were investigated for yield and yield loss and due to simulation purpose, some parameters/factors based on previous experiments were specified like equilibrium distribution coefficient, diffusivity, time of cell plasmolysis, characteristics length, draft, and overall mass transfer coefficient.

In estimating equilibrium distribution coefficient (m), solute diffusivity (D_s) and time delayed due to plasmolysis (j-factor), collection data from batch extraction experiments were used (Thummadetsak, 1996). For continuous countercurrent system, pineapple juice extraction parameters were applied. The values were as follow:-The characteristic length of slab (a) was 2.22 mm, the initial concentration of solid (x_{in}) and liquid phase (y_{in}) was 100 and 0 kg/m^3, respectively. Draft of extraction (α) was 1.6. Diffusivity (D_s) for 55, 62.5 and 70 ºC was 5.03×10^{-9}, 6.08×10^{-9} and 7.05×10^{-9} m^2/s, respectively. Volumetric overall mass transfer coefficient (k_a) was 4.47×10^{-4}, 5.42×10^{-4} and 7.05×10^{-4} s^{-1}, respectively. Biot number (Bi) was vary between 0 and 25. Peclet number for solid phase (P) was set up to 20 while, for the liquid phase, the value (R) was vary between 0.1 and 20.0. Yield and yield loss were then calculated to observe simulation results due to the influence of important system parameters like operating temperature, Biot number and Peclet number.

RESULTS AND DISCUSSION

In the reversing continuous countercurrent reactor (RCCE), the relationship to observe the correlation between backmixing and diffusion phenomenon was introduced by using Peclet number and Biot number (Siripatana, 1986; Rittrut, 2009). A higher Peclet number, a lower degree of backmixing was obtained; the system approaches plug flow. A higher Biot number, a lower external resistance of mass transfer was observed; the system was thus completely controlled by in-solid diffusion (the internal resistance). According to our simulation, the correlation between Peclet number (R) and Biot Number (Bi) on yield loss at different operating temperature of 55, 62.5, and 70 °C were shown Nevertheless, only graph at temperature of 55 °C were selected as representative of this work (Fig. 1).

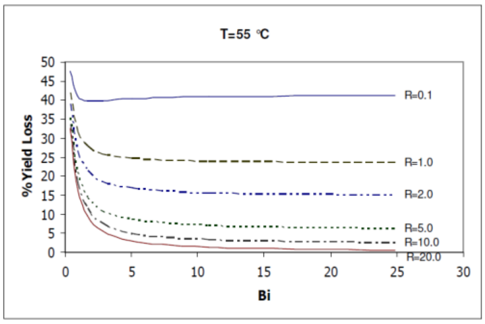

Fig. 1 The correlation between Peclet number (R) and Biot Number (Bi) on yield loss at temperature of 55 °C where maximum yield was 94.58%.

It was found that at no external resistance of mass transfer ($Bi \geq 20$) where the in-solid diffusion was obviously rate-limiting step, the results shown that, higher backmixing increased the yield loss. Similar results were also obtained at all range of Biot number (0-25). Nevertheless, at low range of Biot number (0-10), for each constant degree of backmixing, the higher Biot number led to the lower yield loss. In addition, a higher temperature, a lower yield loss was obtained due to the increase in solute diffusivity and mass transfer coefficient, as this results also correspond to what was observed in the previous work (Rittirut *et al*, 2010b) at higher temperature.

Focusing on each mechanism in the RCCE, for three common cases of backmixing extent, namely: completely mixed reactor, plug-flow reactor, and backmixing-diffusion reactor. For completely mixed extractor (Fig. 2), the higher temperature, the higher yield loss was obtained, especially at Biot number greater than 2.0. The results were contrast to those of plug flow system where the higher temperature provided the lower yield loss (Fig. 3). In plug flow system, only diffusion mechanism play a major role and no backmixing in this kind of reactor. In the completely mixed system (high backmixing system), although higher temperature provided higher diffusivity and overall mass transfer coefficient, the extent of very high backmixing dominated these effects which led to the lower yield and higher yield loss. It is also interesting to notice that, according to our simulation, at very high backmixing ($R \leq 0.1$), the simulation predicted that higher Biot number will increase yield loss rather than reduce it as also appeared in higher Peclet number. This implies that in the system where a very high extent of backmixing exist, Biot number in the lower range (0 – 10) contributes strongly and negatively to the yield loss whereas at higher Peclet number ($R \geq 0.5$) higher Bi has a positive effect on the yield loss. In the plug flow system, the temperature and Biot number effect dominated the extraction efficiency (thus the yield) because of no backmixing to play its role. Nevertheless, in some case where backmixing cannot dominate temperature effect of diffusion, the higher temperature still provided lower yield loss (Fig. 4).

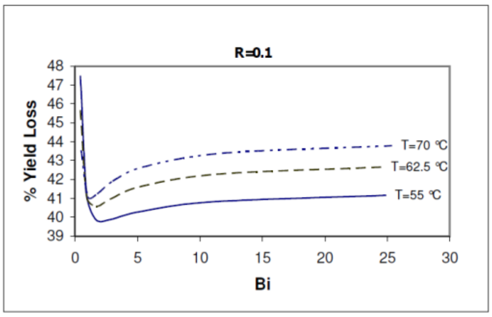

Fig.2 The effect of operating temperature and Biot Number (Bi) on yield loss in completely mixed reactor of RCCE ($R = 0.1$).

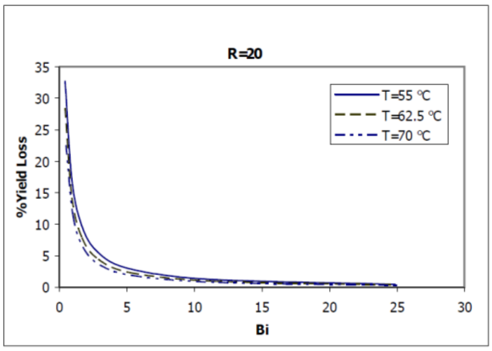

Fig. 3 The effect of operating temperature and Biot Number (Bi) on yield loss in plug flow reactor of RCCE ($R = 20$).

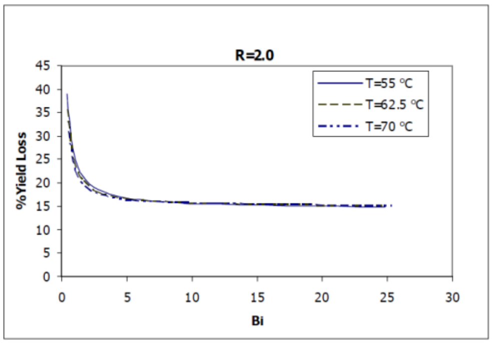

Fig 4 The effect of operating temperature and Biot Number (Bi) on yield loss in backmixing-diffusion reactor of RCCE ($R = 2$).

It was stated that extraction mechanism that occurred because of the solubility of the solute in the cells or its miscibility with solvent without reaction of the solvent with constituents of the solid material to produce compound solubles was , in most cases, subjected to the rate controlling by diffusion phenomenon (thus Bi approaches infinite) (Schwartzberg, 1980). However, this statement should be used carefully and should be verified sufficiently if process analysis, design or optimization is to be performed by simulation based on this assumption. In case of the reversing counter current extractor (RCCE), the authors have come across a wide range of Bi number. It should be reminded that, in the medium range of Biot number (3 – 10), one should not ignore the effect of external resistance. Here, besides the simulation results based on the parameters estimated from the actual extraction operations, the experimental results also corresponded to the extraction of pineapples juice in RCCE as shown in the previous work (Thummadetsak's , 1996).

CONCLUSION

Backmixing caused the reduction in driving force and the increasing in mass transfer. The combined effect of finite Biot number (Bi) and Peclect number (R) influenced the yield and yield loss. The rate limiting mechanism was considered and the results showed that, in majority of cases, in-solid diffusion was predominantly controlled-limiting step while the backmixing phenomenon caused the loss of concentration gradient and the yield, thus increased the yield loss of extraction system significantly.

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