SHORT, NON-REFEREED PAPER

SIMULATION OF MULTI-STAGE DIFFUSERS: CONNECTIONS AMONG STAGES THAT FAVOURS THE SYSTEM'S OPTIMALITY

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Abstract

In this paper, a model for the simulation of an extraction process in a multi-stage diffuser was developed considering the possibility of connection among all diffuser stages. Multi-objective optimisations in two specific operating conditions (i.e. a typical operating condition and a flooding regime condition) were performed, varying randomly the connections among the extraction stages. Results show that new connections among the diffuser stages can optimise the extraction process. Considering the optimisation under typical operating conditions, the optimized diffuser results in recirculation of the fluid to the same stage in 8 out of 10 stages of the diffuser. In addition, 7 out of 10 stages of the diffuser were also connected to previous stages. The new configuration of the diffuser can decrease the solute concentration in the biomass by 13% and increase the solute concentration in the extracted juice by 2%. In the case of the optimisation of the diffuser operating under a flooding regime, the results show that this condition can be reversed if new connections among the stages are considered.

Keywords: diffusers, connections among stages, multiobjective optimisation, recirculation, extraction efficiency

Introduction

Diffusers can be employed for extracting sucrose from sugarcane and sugar beets, tannin from black acacia bark, and vegetable oil from oleaginous plants. Considering sugarcane factories, the extraction of juice is one of the first and key stages of sugarcane processing for sugar and ethanol production and can be done by mills and diffusers (Rein, 1995). Techno-economic studies show that, if low percentages of residual sucrose in bagasse are to be obtained, which is essential to produce cellulosic ethanol for instance, current extraction technologies will result in excessively expensive equipment. In the case of diffusers, one possible option to increase extraction rates without modifying the diffuser physical structure is to monitor the changes in operating conditions and flow patterns and alter the connectivity among different stages of the equipment accordingly. The main objective of this paper is to model the extraction process in a multi-stage diffuser and to perform a multi-objective optimisation, considering all possible connections among the diffuser stages.

Methodology

A ten-stage diffuser was modelled in LabVIEW® and the principles of operation of the modelled diffuser are similar to the ones of a typical multi-stage industrial diffuser (Breward *et al.*, 2012) except for the possibility of connection among all diffuser's stages. The values considered for simulating the diffuser were taken from an industrial black acacia diffuser because the authors did not have access to sugarcane industrial diffuser data. However, the black acacia diffuser itself and its operation for tannin extraction presents the same characteristics and principles of sugarcane diffusers.

After developing the simulation model, multi-objective optimisations were done to maximise solute concentration in the liquid and to minimise solute concentration in the final biomass. Two cases with different operating conditions were optimised. The first case considers exactly the same operating conditions of a typical diffuser. The second case, however, presents a flooding regime in stage four. For the optimisation of both operating conditions, the variables that can be changed are the connectivity coefficients of each of the diffuser's stages that might assume random values between zero and one in each program iteration using a Monte Carlo approach. The main constraint of the optimisation is to guarantee the non-occurrence of a flooding regime that is implemented in the model setting a maximum value of 1.5 m for the dynamic height of liquid in the biomass bed.

Results and Discussion

For the typical operating condition, even though the diffuser is already designed for optimal operation, the authors investigated the possibility that connecting all the extraction stages would change the optimal configuration of the diffuser. The optimisation of the diffuser under typical operating conditions has shown that this possibility has changed the optimal design of the connections of the different stages of the diffuser. The new connections for the diffuser are shown in Figure 1.

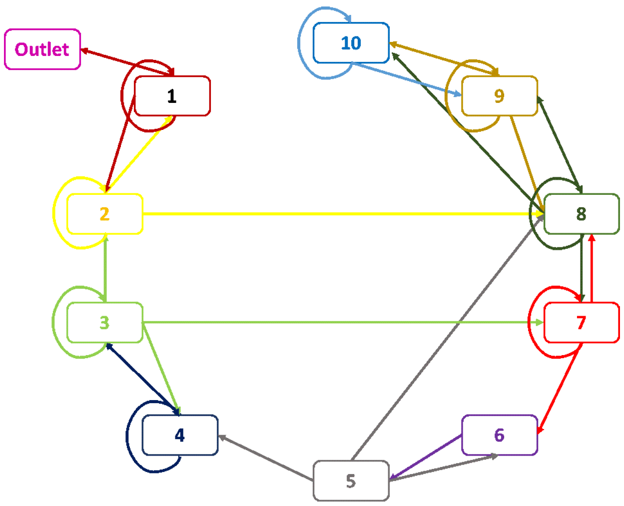

Figure 1. Representation of all connections among the stages of the optimised typical operation.

Besides the connection of each stage to itself, 7 out of 10 stages of the diffuser were also connected to previous stages after optimisation. The reason for this type of connection with previous stages is explained by the fact that pumping the percolating fluid to a previous stage increases the residence time in the diffuser and the percolating velocity along the equipment. The optimised diffuser also showed recirculation of the fluid to the same stage in 8 out of 10 stages of the diffuser, which shows that some degree of recirculation of the percolating fluid to the same stage can increase extraction efficiencies. The new configuration of the diffuser can decrease the solute concentration in the final biomass by 13% and increase the solute concentration in the final extracted juice by 2%.

In the case of the optimisation of the diffuser that operates with a flooding regime in stage four, the flooding condition created a different dynamic in the connection between the stages and different connections occur in order to solve the flooding regime problem. Figure 2 shows a scheme with the optimised connections among the diffuser that was previously operating under a flooding regime.

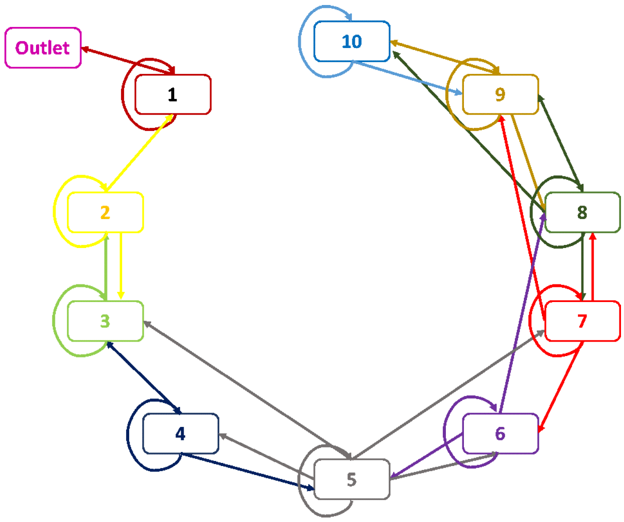

Figure 2. Representation of all connections among the stages of the optimised diffuser previously operating under a flooding regime.

Figure 2 shows that, with the flooding regime, all the stages connected in a particular way in the diffuser. Stages 5, 7 and 8, for example, present at least four connections: a connection to a further stage, a connection to the stage itself and a connection to the other two previous stages. Furthermore, all the stages showed recirculation of the fluid to the same stage. This new configuration increased the tannin concentration in the final extracted juice by 1.1% when compared with the diffuser operating under typical conditions.

Conclusions

With this study, the main objective of modelling the extraction process in a multi-stage diffuser and performing its optimisation, considering all possible connections among the diffuser's stages, was achieved. The multi-objective optimization of the typical operation of a diffuser and of a diffuser operating under a flooding regime show that the redesign of connections among the stages can bring efficiency gains in extraction efficiencies. The optimal design of typical diffusers can increase the tannin concentration in the final liquid 2.3%. Furthermore, in the case of a diffuser under a flooding regime, the redesign of the connections among the stages can not only solve the flooding problem but also can increase the tannin concentration in the final extracted juice by 1.1% when compared to the typical diffuser operation. Even though the data used for the simulation is from a black acacia diffuser and not from a sugarcane industrial diffuser, the conclusions obtained in this study are general for any type of multi-stage industrial diffuser that operates in countercurrent flow.

Acknowledgement

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