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Simulation study of the production of biodiesel using feedstock mixtures of fatty acids in complex reactive distillation columns

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ABSTRACT

Biodiesel can be produced from a number of natural, renewable sources, but vegetable oils are the main feedstocks. The current manufacturing biodiesel processes, however, have several disadvantages: expensive separation of products from the reaction mixture, and high costs due to relatively complex processes involving one to two reactors and several separation units. Therefore, to solve these problems, in recent years several researchers have developed a sustainable biodiesel production process based on reactive distillation. In this paper the production of biodiesel using feedstock mixtures of fatty acids is explored using reactive distillation sequences with thermal coupling. The results indicate that the complex reactive distillation sequences can produce a mixture of esters as bottoms product that can be used as biodiesel. In particular, the thermally coupled distillation sequence involving a side rectifier can handle the reaction and complete separation in accordance with process intensification principles.

1. Introduction

Biodiesel, a mixture of fatty methyl/ethyl esters derived from plant/animal triglycerides through transesterification with an alcohol, is a fuel that is under a great deal of consideration [1–4]. It has been assessed that biodiesel yields 93% more energy than that invested in its production, and relative to fossil fuels, greenhouse gases are reduced 41% by biodiesel production and combustion while less air pollutants are released per net energy gain. Although these benefits are very attractive, the current biodiesel final cost is prohibitively high without governmental subsidies. Much of the actual technological complexity, involving multiple steps on triglycerides pretreatment and biodiesel separation/purification, originates from contaminants in the feedstock (e.g., water and free fatty acids) or impurities in the final product (e.g., glycerol, methanol, and soaps). Therefore, to solve these problems, some authors have developed a sustainable biodiesel production process based on reactive distillation using acid catalysts [3,5]. Reactive distillation integrates reaction and separation in one unit. This intensifies mass transfer and allows *in situ* energy integration while simplifying the process flowsheet and operation. However, combining the two operations is possible only if the reactions show reasonable conversion and selectivity data at pressures and temperatures that are compatible with the distillation conditions. The reduction in the number of processing units and the direct heat integration between reaction and separation can reduce capital investment as well as utility costs. Increased overall conversion, as well as improved selectivity in competing reactions, can be achieved in reactive distillation by the continuous removal of products from the reaction zone of equilibrium limited reactions.

The design of new processes in chemical engineering takes into account policies of process intensification, which can be stated as any chemical engineering development that leads to a substantially smaller, cleaner, and more energy-efficient technology [6]. Distillation continues being the most used separation technique in chemical industry, and it is well known that requires large amounts of energy in order to achieve a given separation and the use of the energy is accompanied by a very low second law thermodynamic efficiency [7–10]. Considering these facts, several improvements have been made to distillation directed to reductions in both energy and capital costs that can be related to reductions in greenhouse gas emissions and usage of cooling water. Since process intensification takes into account reduction in energy consumption, miniaturization, integration of several operations into one equipment, safe operation and others, maybe the reactive distillation is the most representative operation in process intensification because the reaction and separation are carried in the same unit leading to energy savings due to internal integration and higher conversions in equilibrium reactions since products are removed as they are formed. Another important development in distillation is

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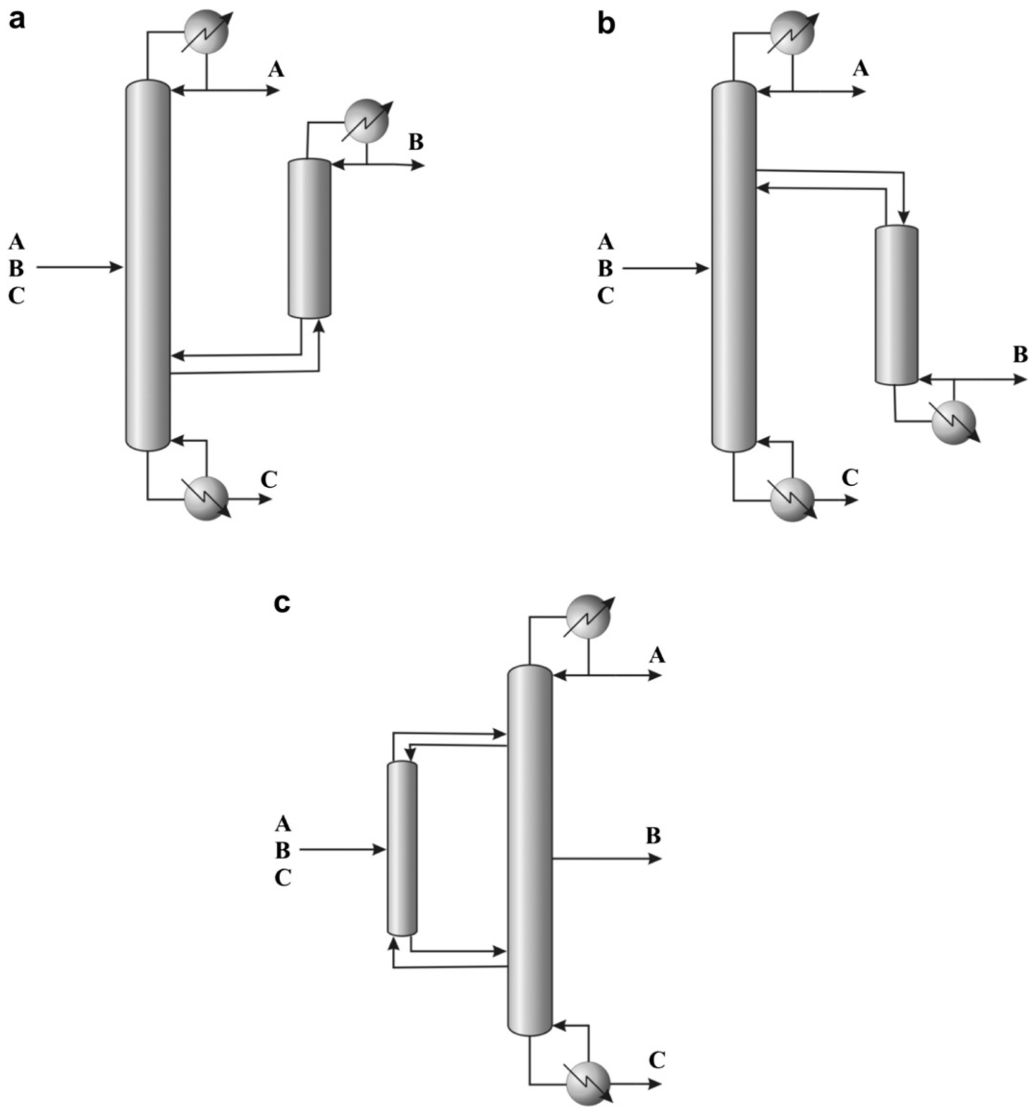

Fig. 1. Thermally coupled distillation sequences for the separation of ternary mixtures: (a) side rectifier, (b) side stripper and (c) fully thermally coupled.

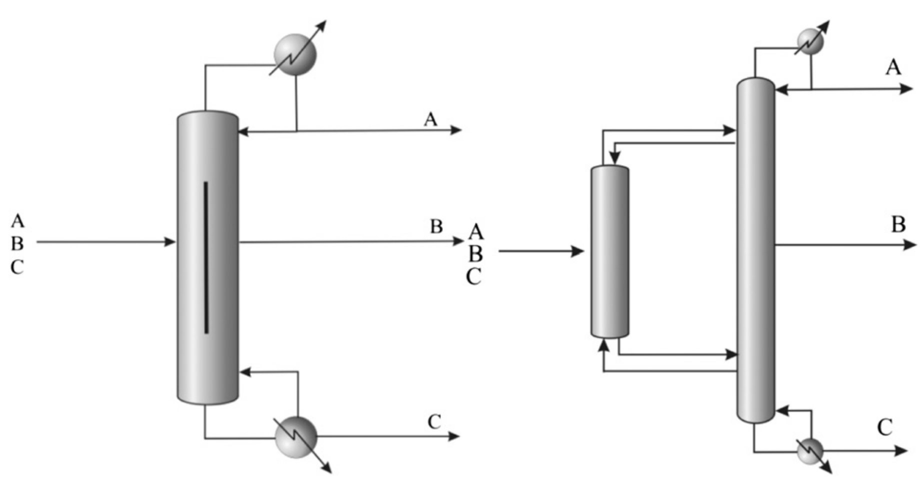

Fig. 2. Dividing wall distillation column and Petlyuk column.