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Economic evaluation of biodiesel production from palm fatty acid distillate using a reactive distillation

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Abstract

Economic evaluation of a reactive distillation for biodiesel production is performed. Palm fatty acid distillate (PFAD) consisting of a mixtures of triglycerides, moisture and free fatty acids is considered a feedstock. A simulation model of the biodiesel production process based on a reactive distillation is developed using Aspen Plus. Effect of key operating parameters, such as the number of reactive stages and liquid holdup, is investigated. The economic analysis considers total investment costs, operating costs and economic indicators, such as return on investment (ROI) and net present value (NPV). Performance of the reactive distillation processes is compared with a conventional process using two continuous reactors. The simulation results show that a single step acid – catalyzed process can be carried out in a reactive distillation for higher biodiesel productivity and purity. Although the conventional process has lower total production cost, the reactive distillation process is more economical process providing a higher ROI and NPV. The biodiesel production using a reactive distillation without recycling upstream is the most preferred configuration. Furthermore, the reactive distillation process can save the energy requirement of 51.2% compared with the conventional process.

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Keywords: Economic evaluation, Palm fatty acid distillation, Biodiesel production, reactive distillation

1. Introduction

Biodiesel is an alternative fuel that can replace petroleum diesel. Traditionally, it is produced from transesterification between refined vegetable oils and methanol in the presence of basic catalysts. A large excess methanol is generally required due to the chemical equilibrium of the transesterification.

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Therefore, a number of unit operations is required for a purification process. A reactive distillation that is one of a process intensification can conquer the drawback of a conventional process. It can improve the productivity and purity of biodiesel [1]. Although a reactive distillation cannot completely separate glycerol that is a byproduct from the transesterification, it can separate water that is byproduct from esterification of oleic acid [2]. In previous studies, biodiesel production from pure vegetable oil and fatty acids was investigated. Furthermore, high free fatty acid contents and moisture in feedstock are not mentioned. Biodiesel production from palm fatty acid distillate (PFAD) using a reactive distillation is an interesting option although it is still not commercialized [3]. In general, the reactive distillation is run under high pressure and methanol is vaporized before it is fed into the reactive distillation, leading to a low liquid holdup within the trays. In the previous studies, the effect of key parameters on the reactive distillation performance was investigated in terms of conversion, yield and purity to determine its optimum conditions. However, an economic study is also great importance to evaluate the feasibility of biodiesel production. The feasibility study of the biodiesel production from cottonseed oil consisting of mixed triglyceride and oleic acid was evaluated in term of total annualized cost [4] and the results indicated the advantage of the reactive distillation process over a batch process. To date, there is no detail in the economic evaluation of reactive distillation for biodiesel production from PFAD. In this work, a single step biodiesel production process from PFAD using a reactive distillation is preliminary designed. Two configurations of the reactive distillations, i.e., the reactive distillation with and without upstream recirculation, is analyzed. Economic analysis based on total investment, total production cost and economic indicators of biodiesel production using a reactive distillation is performed and compared to a conventional biodiesel process using two – steps catalyzed process.

2. Methodology

2.1 Process Modelling

Material and energy balances of a biodiesel production process is performed by Aspen Plus process simulator. In this work, triglyceride with three identical fatty acid chains is considered. Therefore, tripalmitin is assumed to be a triglyceride in PFAD. The composition of PFAD is identified according to [3]. Because tripalmitin and fatty acids are pseudocomponents in Aspen Plus, some binary interaction parameters for vapor – liquid equilibrium are not available in the database. Here, NRTL is used to predict thermodynamic properties and equilibrium calculation while UNIFAC – LL is used to predict two liquid phases. Fig. 1(a) shows that NTRL prediction is found to be a good agreement with experimental data [5]. Kinetic parameters for acid – catalyzed esterification of PFAD is verified with [6] in term of conversion. Fig. 1(b) shows liquid – liquid equilibrium between methanol, methyl linoleate and glycerol.

2.2 Process design

Fig. 2 shows the flowsheet of a conventional biodiesel production process. PFAD (stream 1) is preheated through a heater (B5) and sent to an esterification reactor (B1) while methanol (stream 3) is mixed with H_2SO_4 (stream 11). The ratio of methanol to PFAD is three according to [6]. The products are send to distillation (B2) to remove excess methanol that is recycled back to the reactor. This column consists of five stages including a total condenser and a partial reboiler. The downstream of distillation is fed to a transesterification reactor (B6) with additional methanol. The distillation column (B4) is employed to remove excess methanol which is recycled back to the second reactor. Therefore, a decanter (B10) is required to separate glycerol. Other distillation columns (B13 and B14) involve a purification process