Chemical Engineering Journal 278 (2015) 556–562

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Energy saving in a biodiesel production process based on self-heat recuperation technology

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HIGHLIGHTS

- Self-heat recuperation technology was applied on biodiesel production process.
- Both the sensible and latent waste heat was recirculated in the proposed process.
- Energy requirement was reduced by 71% by using self-heat recuperation technology.

ARTICLE INFO

Article history:
Available online 20 November 2014

Keywords:
Biodiesel production
Acid-catalyzed
Energy saving
Self-heat recuperation

ABSTRACT

Acid-catalyzed biodiesel production processes offer a competitive alternative for biodiesel production using waste cooking oil as raw materials and are less complex than alkali-catalyzed approaches. However, acid-catalyzed biodiesel processes are not yet commercialized because of high energy requirements, especially for the recovery of excess methanol and purification of the biodiesel and glycerol. We have developed an advanced biodiesel production process with energy savings through application of self-heat recuperation technology for methanol recovery and biodiesel and glycerol purification. Both the sensible and latent waste heat were recirculated within the proposed process, significantly reducing energy requirements. Simulation showed that the total energy requirement of the proposed process was 378.7 kW h per ton biodiesel, some 71% lower than that of the conventional biodiesel production process.

1. Introduction

Increasing competition for fossil fuels and the need to reduce carbon dioxide emissions from their combustion have increased the search for renewable fuels, such as biodiesel and bioethanol [1]. Biodiesel, comprising monoalkylesters of long chain fatty acids derived from renewable sources, is an attractive alternative fuel [2]. Compared with diesel produced from petroleum, biodiesel exerts a low impact on the environment, being biodegradable and non-toxic, and has low net emissions of carbon dioxide, particulate matter and unburnt hydrocarbons [3].

The relative commercial viability of biodiesel is still low because of high costs, attributed mainly to the high cost of virgin vegetable oil raw material. [4]. Reducing the cost of raw materials is one important approach to reduce the cost of biodiesel production. For example, the use of waste cooking oil as the raw material is an attractive way of reducing biodiesel production costs. Using waste oil could reduce overall production costs by 60–90% [5]. In addition, there is a positive effect on the environment in using a waste material [6].

The most common approach in producing biodiesel involves a transesterification process, in which triacylglycerols (the main component of vegetable oils) react with alcohol to produce fatty acid methyl esters (FAME, i.e. biodiesel) and glycerol [6]. Theoretically, 3 mol alcohol are required to react with 1 mol fat or oil, but excess alcohol is usually required to shift the equilibrium to the product side. In this process, catalysts are usually required to increase the reaction rate. Based on the catalysts used, the transesterification reactions can be classified as alkali-catalyzed, acid-catalyzed and enzyme-catalyzed [4]. In practice the enzyme-catalyzed method is not usually used because of the high cost of enzymes and low efficiencies [7].

The homogeneous alkali-catalyzed method is the most efficient way for biodiesel production usually conducted with 1 wt% catalyst, a 6:1 alcohol:oil molar ratio and at 60 °C and 1 atm pressure [3]. However, this process is very sensitive to the concentration of water and free fatty acid in the waste cooking oil [8]. The free fatty acids can react with alkali to produce soaps and water, not

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http://dx.doi.org/10.1016/j.cej.2014.11.027
1385-8947/

only consuming the alkali catalyst, but also inhibiting the separation of biodiesel, glycerol and wash water. To prevent saponification, the free fatty acid content must be <0.5 wt% [9]. The free fatty acid level in waste cooking oil is usually >2 wt% and pretreatment is required for fatty acid and water removal. The need for extensive pretreatment renders the process complex and increases the capital cost of the biodiesel production process [10].

An alternative method involves the use of acid catalysts. This process is insensitive to the content of fatty acid and water [11]. Zhang et al. investigated four different biodiesel production processes including alkali-catalyzed processes and homogeneous acid-catalyzed processes with different extraction methods, and concluded that the acid-catalyzed process was the most economically attractive [6]. However, one disadvantage of the acid-catalyzed option is the low conversion ratio and slow reaction rate found under mild conditions. To achieve a relatively high conversion rate, a high molar ratio (e.g. 50:1) methanol:oil is commonly used in the acid-catalyzed process, in contrast to the 6:1 ratio used in the alkali-catalyzed option. In addition, higher temperatures and pressure are required to improve the reaction rate. The large excess of methanol needs to be separated after reaction by distillation and recycling. These are both energy-intensive steps and this aspect has limited the commercialization of the process. Practical biodiesel production demands even more energy from other steps required for biodiesel and glycerol separation and purification. Heterogeneous acid-catalyzed methods, using a solid acid are attractive because of the ease of separation of the solid catalyst and the relatively low molar ratio methanol:oil involved [7]. It has been reported that a number of solid acids (e.g. ion-exchange resins, mixed metal oxides, sulfated metal oxides, zeolites and others) have the potential to be used in biodiesel production [12–14]. However, this approach cannot solve the high energy requirements in the separation and purification stages.

To reduce the energy requirement of biodiesel plants that use waste cooking oil as raw material, some heat-integrated processes have been proposed, these being focused mainly on supercritical processes or reactive distillation columns [15–19]. However, in all these studies, essentially only sensible heat could be recovered, with thermodynamic limitations preventing the recovery of latent heat. Recently, a self-heat recuperation technology has been developed to reduce the energy requirements of chemical processes [20–22]. In this option, the vapor streams, after separation, are first

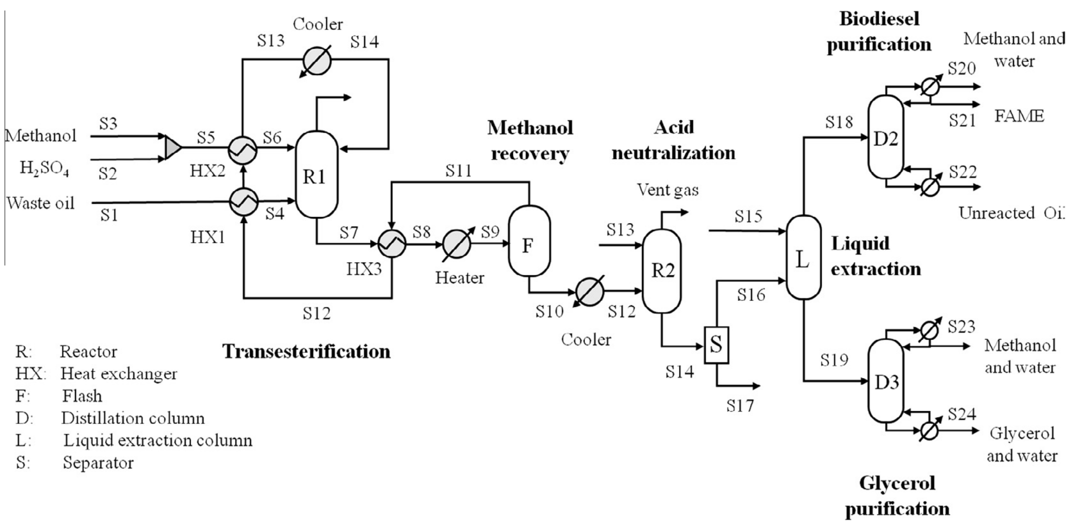

Fig. 1. Flow diagram of the conventional acid-catalyzed biodiesel process.

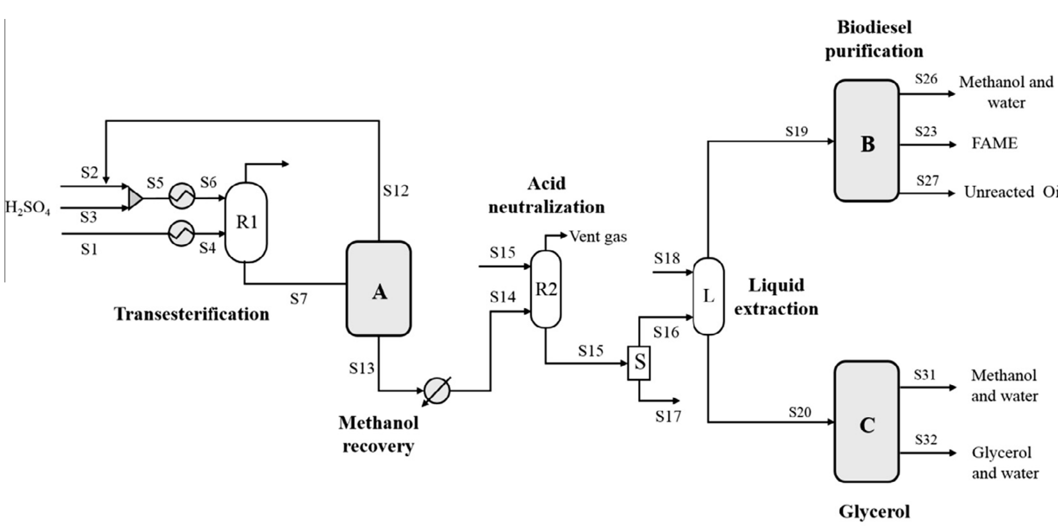

Fig. 2. Flow diagram of the proposed biodiesel production process.