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Scale-up and economic analysis of biodiesel production from recycled grease trap waste

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HIGHLIGHTS

- Scale-up and economic analysis of grease trap waste derived biodiesel were studied.
- Two production routes, esterification with and without co-solvent, were examined.
- The lowest break-even price of biodiesel obtained was US$1337.5/t.
- Environmental service providers are likely the potential biodiesel producers.

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ABSTRACT

Grease trap waste has been considered as a cost-effective feedstock for biodiesel production due to its high lipid content and relatively low cost for collection. However, the costly pre-treatment of this contaminated resource is currently the barrier to the commercialization of biodiesel. This study analyses the economic feasibility of biodiesel production from grease trap waste collected in Adelaide (South Australia), focussing on the environmental service providers as the potential biodiesel producers. Based on the experimental results, two different production routes with the same capacity of around 4400 t/year were simulated using Aspen Plus® V8.8, these being; esterification without using acetone as a co-solvent (1); and esterification using a co-solvent of acetone-ethanol (2). The best production price of biodiesel obtained was US$1337.5/t which would indicate that grease trap waste may be a promising feedstock for biodiesel production.

1. Introduction

Biodiesel is currently considered as one of the most potential fuels to substitute for mineral diesel due to its more favorable environmental parameters. It can be produced from a variety of renewable feedstocks, such as vegetable oils, animal fats, waste cooking oil, microorganisms, and wastewater grease. However, current commercial biodiesel production still relies significantly on refined edible and non-edible vegetable oils as the feedstocks. As a consequence, this contributed to the relatively high cost of biodiesel in comparison to mineral diesel, since feedstocks account for 70–95% of the production cost [1]. Moreover, the use of farmland for feedstock cultivation has also been criticized in terms of food security and soil impoverishment. Therefore, the use of waste resources, i.e., wastewater greases, as a cost-effective feedstock has been recently encouraged worldwide [2]. Miranda, da Silva Filho [3] and Giraçol, Passarini [4] reported the use of waste frying oil as the feedstock for biodiesel production in the Metropolitan Region of Campinas (RMC, São Paulo State, Brazil). They reported that approximately 15.784 million USD/year and environmental gains in the form of carbon credits can be saved for the city if waste frying oil is collected and utilized to produce biodiesel. In a recent study, Anderson, Addy [5] conducted a research to compare the benefits of waste-to-energy technologies, including incineration, anaerobic digestion, and biodiesel. Interestingly, they reported that the production of biodiesel using scum sludge was the most economic scenario, creating an added value of US $491,949 and US$610,624/year. In another study, Glisic, Pajnik [6] reported the production of "green biodiesel" from waste vegetable oil. They found that the economic feasibility of this biodiesel strongly

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depends on the process unit capacity and the cost of feedstock. They also reported that unit capacities which are below 100,000 t/year may result in negative net present values after running the project for 10 years.

However, among those recycled feedstocks, grease trap waste, collected from interceptors installed in the sewer pipes of many restaurants and food processing factories as a mandatory requirement to avoid sewer blockages, appears to have potential since it is currently generated in a relatively large amount, and contains a very high level of lipids. It was reported that lipids presented in the content of grease trap waste with a range of 0.1–40% [7]. The lipid content can increase to approximately 70% within the top layer of GTW, or after it has been concentrated [8]. Importantly, GTW can be collected at little or free of charge and, in the majority cases, the environmental service providers can also receive payment to collect and to treat this hazardous waste. The recycling of GTW will definitely benefit the environment in terms of solid waste reduction, pipe blockage prevention, and surface water protection. Moreover, the use of GTW can trigger an economic growth decoupled from the use of non-renewable resources or edible vegetable oils [9].

While evidence has been provided that the environmental benefits of GTW-derived biodiesel are promising, the economic aspects appear to be more uncertain. The economic feasibility of biodiesel produced from wastewater residues has been the subject of numerous studies [10–15]. Due to the contaminated nature of GTW, the pre-treatment of this waste is necessary before further processes can be considered. The extremely high level of free fatty acids within GTW requires a glycerolysis or an esterification pre-treatment step to be performed, adding additional expense to the total production cost. Pokoo-Aikins, Heath [16] constructed a simulation model to estimate the production cost of biodiesel derived from the dry sludge using a two-step process, these being; solvent extraction and transesterification. The results showed that the cost of biodiesel production was approximately US$838/t, providing that dry sludge was collected free of charge. The calculated cost was far cheaper in comparison to biodiesel produced from other sources [17–20]. However, the authors did not include the cost of sludge drying in their consideration which may significantly increase the total production cost. In another study, Hums [19] found that the cost of GTW-derived biodiesel production could be partially covered by the fee charged by the State of Delaware, USA (US$0.016/kg approximately). This contributed to the relatively lower production cost of biodiesel, although the author also reported that the economic feasibility was strongly dependent on GTW consumption and the lipid content of the GTW oils. Olkiewicz, Torres [13] evaluated the economic potential of biodiesel produced from municipal wastewater sludge using only experimental data and computational scale-up in terms of the feedstock cost. The authors recommended the gate price of their biodiesel should be US$1232/t, which is also lower than the cost of mineral diesel and biodiesel produced from microalgae. These findings supported the potential for GTW-derived feedstocks in replacing traditional biodiesel feedstocks. Furthermore, future technical developments could also have a significant impact on the economic feasibility of GTW-derived biodiesel. Dufreche, Hernandez [21] estimated the cost of biodiesel would be US$930.7/t (US$3.1/gal), assuming a 7.0% overall yield of esters from dry sewage sludge on a weight basis was obtained. They advised that this cost could drop significantly if techniques were developed to improve the efficiency of the transesterification reaction. In a recent study, Hajjari, Tabatabaei [22] also reported that biodiesel could be produced at a reasonable price of US $0.611/l in Iran. The authors recommended that waste oil biodiesel utilization scenario will benefit the countries in which either edible oils and fried food are popular, farmland is limited to cultivate the oil-seed crops, or the use of renewable energy as well as the low-environmental impact fuels are regulated by law.

Recently, research has been conducted to study the potential for the production of biodiesel from recycled GTW in Adelaide, South Australia [23,24]. Two different techniques have been successfully developed for the pre-treatment of fats, oil, and grease (FOG) extracted from GTW, which are; esterification without using acetone as a co-solvent; and esterification using a co-solvent of acetone-ethanol. In those studies, the environmental service providers, i.e. the main GTW collectors in Adelaide, were considered likely biodiesel producers since they can collect GTW at little or no charge. Although the laboratory-based experiments proved that GTW is a promising feedstock for biodiesel production, the economic feasibility of the GTW-derived biodiesel should be addressed.

However, a specific economic model cannot be applied to all wastewater feedstocks due to the fact that the composition of GTW varies depending on its location. Furthermore, such factors as the production and processing of GTW, as well as the prevailing energy policy existing in the region where the GTW is to be utilized, also impact on the economic modeling and gate price estimation. In addition, previous studies have not considered the environmental service sector (the main GTW collectors in Australia) as potential biodiesel producers, resulting in over- or under-estimating the production cost. Therefore, further studies need to be carried out to clarify economic and affordable techniques which could be applied to biodiesel production, focusing on the environmental services as the potential producers. The purpose of this study was to evaluate the economic feasibility of the production of biodiesel from the GTW-derived feedstock, using ethanol as a reactant, based on the results collected from laboratory-based experiments and the information provided by the associated industrial sector. Two different production routes, classified by the pre-treatment step, were designed using a process simulator, Aspen Plus® V8.8. Based on the economic analysis, proper techniques will be evaluated which could be introduced to the environmental service sector to produce GTW-derived biodiesel at an affordable price.

2. Materials and methods

Two possible approaches for a production plant with a capacity of around 4400 t/year (approximately 12,000 tons GTW per year) were studied. The study was conducted based on the data obtained from laboratory experiments incorporated with the data provided by an environmental service provider in Adelaide, South Australia [23,24]. Based on the experimental data, two production processes were designed using the process simulator, Aspen Plus®, to meet the demand of this environmental service. Fig. 1 shows two different routes for biodiesel production plant utilizing GTW as the feedstock.

Due to economic factors and the location of the environmental services, the process proposed in this study focuses on two parameters, these being; to simplify the production technique as much as possible (1), and to minimize the energy requirement needed for the production process. A process model was constructed using Aspen Plus® V8.8 to study the scale-up effect and to generate the inventory data for economic calculation.

In route 1, GTW was collected and delivered to the treatment site using a 27-ton truck with three loadings per day. GTW was then concentrated in the storage tanks. The top layer of the tanks, which was rich in lipids, was collected while the middle and bottom phases (rich in water) removed and used for other purposes. Solvent extraction using hexane was then performed to extract the fats, oil, and greases (FOGs) from the lipid-rich GTW. The esterification process, using ethanol as an alcohol and H_2SO_4 as the catalyst, was undertaken to reduce the level of FFAs in the feedstock. The crude biodiesel oil, which had an FFA level less than 2%, was processed via a transesterification reaction in which the remaining glycerides were converted to ethyl esters in the presence of KOH as the catalyst. A further purification was also undertaken to remove the remaining contaminants, i.e. mainly sulphur, resulting in a biodiesel product that meets the mandatory standards. All solvents and excess ethanol used were recovered using a rotary evaporator. The acidic water stream generated in the esterification step was neutralized using the alkaline water stream generated in the transesterification