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FULL LENGTH ARTICLE

Economic feasibility study of biodiesel production by direct esterification of fatty acids from the oil and soap industrial sector

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Abstract Industrial production of biodiesel fuel in Egypt by the transesterification of vegetable oils is being faced with the problem of feedstock shortage. Egypt imports annually about 90% of its needs as edible oils for human consumption. The production of biodiesel by direct esterification of fatty acids that can be obtained from the oil and soap industrial sector in huge quantities each year (around 16 thousand tons) may be a proper solution to this problem. According to results of a previous study [1], the biodiesel produced following this approach and using methyl alcohol was quite efficient as an alternative fuel for diesel engines. However, the process should be economically feasible for application on an industrial scale. The present study assessed the economic feasibility of biodiesel production by direct fatty acid esterification. Complete process simulation was first carried out using the process simulation software, Aspen HYSYS V7.0. The process was then designed comprising four main steps being esterification, solvent recovery, catalyst removal and water removal. The main processing units include the reactor, distillation column, heat exchangers, pumps and separators. Assuming that the rate of fatty acids esterified was 2 ton/h, all process units required have been sized. Total capital investment, total manufacturing cost and return on investment were all estimated. The latter was found to be 117.1% which means that the production process is quite economically feasible.

1. Introduction

Concern about the depletion of petroleum reserves, rising prices of crude oil, environmental impact and global warming is driving the research toward finding alternates to petrol fuels. Biodiesel fuel, an environmentally friendly product, is considered the most promising fuel substitute for diesel fuel obtained

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from petroleum. It has several advantages over regular diesel fuel. For example, it has more lubricity which reduces the wear rate of engine parts. Also it has a higher flash point than diesel fuel which makes it safer. It is also free from sulfur which usually forms acidic oxides upon oxidation in the engine. Thus, the use of biodiesel fuel in place of regular diesel fuel will reduce the corrosion rate of the engine parts by the action of acidic gases in the combustion exhaust. The absence of sulfur oxides in the combustion exhaust besides the fact that biodiesel is biodegradable make this fuel more environmentally friendly compared to regular diesel fuel (petro-diesel).

Biodiesel fuel can be prepared via one of two ways, either by transesterification of vegetable oils with alcohols [2,3] or by direct esterification of fatty acids with alcohols [1]. Egypt imports annually huge quantities of edible oils to cover more than 90% of the consumption needs as vegetable oils. Therefore, if biodiesel is to be produced in Egypt on an industrial scale by oil transesterification, vegetable oils of non-edible grade rather than edible ones should be used. Examples of these oils are highly acidic ricebran oil [4], jatropha oil [5], high erucic acid rapeseed oil [6] and used cooking oil [7]. However, the quantities currently available in Egypt of such non edible oils are not enough to feed an industrial unit of an acceptable production capacity of biodiesel fuel.

On the other hand, biodiesel fuel can be produced in Egypt by direct esterification of fatty acids that can be obtained from the waste of the industrial oil and soap in the industrial sector. A major step in the industrial sector processing crude vegetable oils to yield edible grade oil is the alkali refining step whereby crude oils are treated with caustic soda to neutralize free fatty acids. This step ends up with neutralized oil which goes to further processing steps (bleaching and deodorization) in addition to a heavy dark soapy liquor (mucilage). The latter can then be acidulated to release the fatty acids back. The estimated quantity of fatty acids that can be produced from the oil and soap industrial sector in Egypt was found to be around 16 thousand tons annually.

The utilization of this waste using methanol as well as ethanol as esterifying alcohols to produce biodiesel has been studied [1]. Both biodiesel; methyl and ethyl esters have been evaluated as alternative fuels for diesel engines according to their fuel properties compared to standard diesel as well as the performance of a diesel engine running using 50% blend of biodiesel with regular diesel fuel. Results have proved that the fuel obtained by esterification with methyl alcohol is quite efficient as an alternative fuel for diesel engines. However, application of this process on an industrial scale could not be recommended until it is proved that it is economically feasible. It is the purpose of this paper to explore whether biodiesel production in Egypt by direct esterification of fatty acids is economically feasible or not. This will be made through three consecutive steps; process simulation, process design and then economic assessment.

2. Process simulation

To assess the commercial feasibilities of the proposed process, complete process simulation was first carried out. Despite some expected differences between process simulation results and actual process operation, most current simulation softwares can provide reliable information on process operation because of their comprehensive thermodynamic packages, vast component libraries and advanced calculation techniques. The process simulation software, Aspen HYSYS V7.0, was used in this study.

The procedures for process simulation mainly involve defining chemical components, selecting a thermodynamic model, determining plant capacity, choosing proper operating units and setting up input conditions (flow rate, temperature, pressure, and other conditions). Information on most components, such as methanol, sulfuric acid, sodium hydroxide and water, is available in the HYSYS™ component library. Regarding the fatty acid feedstock, oleic acid ($C_{18}H_{34}O_2$) was considered as the raw material in this process because it is the most common monoenoic fatty acid in plants and animals [8]. Accordingly, methyl oleate ($C_{19}H_{36}O_2$) was taken as the resulting biodiesel product and its properties were available in the HYSYS™ component library. For those components not available in the library, such as sodium sulfate, they were defined using "the Hypo Manager" tool in HYSYS™. For sodium sulfate, its molecular weight is 142 g/mol. Its normal boiling point and density were defined as 1429 °C and 2664 kg/m^3, respectively [9]. Other physical properties, such as critical temperature, pressure and volume, were estimated by HYSYS™.

Due to the presence of methanol which is a highly polar component, both the non-random two liquid (NRTL) and universal quasi-chemical (UNIQUAC) thermodynamic/activity models were recommended to predict the activity coefficients of the components in a liquid phase [10]. Detailed descriptions of these models were provided by Gess [11]. The NRTL model was used in this study.

The industrial scale production of biodiesel in Egypt is in its first steps. The plants are built with small or medium capacities. This study is passed on 2 ton/h of oleic acid as a feedstock to produce nearly 2.1 ton/h biodiesel or 16,800 ton/year.

The main processing units include reactors, distillation column, heat exchangers, pumps and separators. Because detailed information on the kinetics was not available, a simple conversion reactor model with 100% acid conversion to FAME was used to describe the esterification reaction. It was assumed that the reactor was a continuous, stirred tank reactor and the fill factor of the reactor (the ratio of reaction components to reactor volumes) was set at 0.75.

Multi-stage distillation was used for methanol recovery. Although the boiling point of methanol (65 °C at 1 atm) is much lower than that of FAME (approximately 320 °C at 1 atm), simulations suggested that the desired purity of biodiesel could not be achieved by a simple flash unit. The ASTM standard for purity of biodiesel product (i.e., 99.65 wt.%) was applied to the process in the present study. However, the large difference in the boiling points of the components facilitates distillation; only five or six theoretical stages in the columns are sufficient to yield high quality biodiesel. In our simulations, we assumed a tray efficiency of 60–70%. Because FAME is susceptible to thermal decomposition above 250 °C, vacuum operation for the FAME purification was necessary to keep the temperature at suitably low levels [12].

After the input information and operating unit models were set up, the process steady-state simulation was executed by HYSYS™. Mass and energy balances for each unit, as well as operating conditions, were obtained.