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PROCESS SIMULATION AND TECHNO-ECONOMIC ANALYSIS OF BIODIESEL PRODUCTION PLANTS USING WASTE SHARK LIVER OIL AND REFINED VEGETABLE OIL

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ABSTRACT

Use of a cheap, non-edible feedstock would reduce the biodiesel production cost and make the process economically viable. This study investigated the production of fatty acid methyl ester (FAME) using both acid (sulfuric acid, H_2SO_4) and base (sodium hydroxide, NaOH) catalysts. Techno-economic analysis was performed to assess the commercial feasibilities of acid-catalysed biodiesel production from waste shark liver oil (WSLO) and alkali-catalysed biodiesel production from refined vegetable oil in Oman. Historically, the discarded WSLO was used to proof wooden boats, but now these applications are no longer required as modern boats are made of fiberglass. Hence, the excess WSLO derived from these discarded shark livers in the fishing industry could instead be utilised for biodiesel production. This would be environmentally beneficial as it converts a waste into a product.

Aspen HYSYS-V9 was used to simulate both production types at plant capacity of 12,000 te/y and lifespan of 20 years. Net present values (NPVs) of US $34.8 and US $4.9 million were obtained for the acid-catalysed process using WSLO and the alkali-catalysed process using refined vegetable oil, respectively. The internal rate of return (IRR) was calculated to be 260% for the acid-catalysed process and 56% for the alkali-catalysed process. Sensitivity analysis was also conducted to show the effect of certain variables on the NPV of both biodiesel production types. It was concluded that the biodiesel selling price has more effect on the NPV than the glycerol variation price, whereas the triglyceride feedstock purchase prices have the largest influence on the NPV of the two processes.

Keywords: Biodiesel, Process simulation, Techno-economic analysis, Sensitivity analysis, Homogeneous acid and base catalysis

1. INTRODUCTION

Biodiesel is a renewable alternative to “petro-diesel”. There is an established conventional production technology based on refined vegetable oils. However, this is always more expensive than petroleum-based diesel, mainly due to the feedstock cost, and the biodiesel market is based on subsidies. Use of a cheap, non-edible feedstock would reduce the biodiesel production cost and make the process economically viable. Techno-economic analysis (TEA) is a vital tool for assessing the economic feasibilities of a project or an investment. In this study, TEA was used to assess the commercial feasibility of the proposed process for biodiesel production from WSLO, compared with conventional biodiesel production from refined vegetable oil (rapeseed oil) with alkali catalyst. Aspen HYSYS-V9 was used to simulate both plants. FAME production and techno-economic analysis of WSLO as a new glycerides feedstock has not been reported elsewhere. The simulated process flow sheet of acid- and base-catalysed transesterification of WSLO and refined vegetable oil for the productions of biodiesel is illustrated in Figure 1. The acid catalyst was selected for WSLO transesterification due to the high content of free fatty acid in the oil which cause saponification if reacted with alkali catalyst [1].The reactions involved in this transesterification process are shown in Equation 1. In the acid-catalysed reactions of WSLO with methanol, the free fatty acids (FFA) in the oil also reacts with methanol to produce FAME, as shown in the Equation 2.

$$\mathrm{TG} + 3\ \mathrm{MEOH}\ \leftrightarrow 3\mathrm{FAME}+\text{Glycerol} \qquad (1)$$

$$\mathrm{FFA} + \mathrm{MEOH}\ \leftrightarrow \mathrm{FAME} + \mathrm{H_2O} \qquad (2)$$

Where, TG=Triglycerides, FAME=Fatty acid methyl ester, MEOH=Methanol, FFA=Free Fatty acid.

The process simulations for both plants were based on the plant’ biodiesel production capacity of 12,000 te/y.

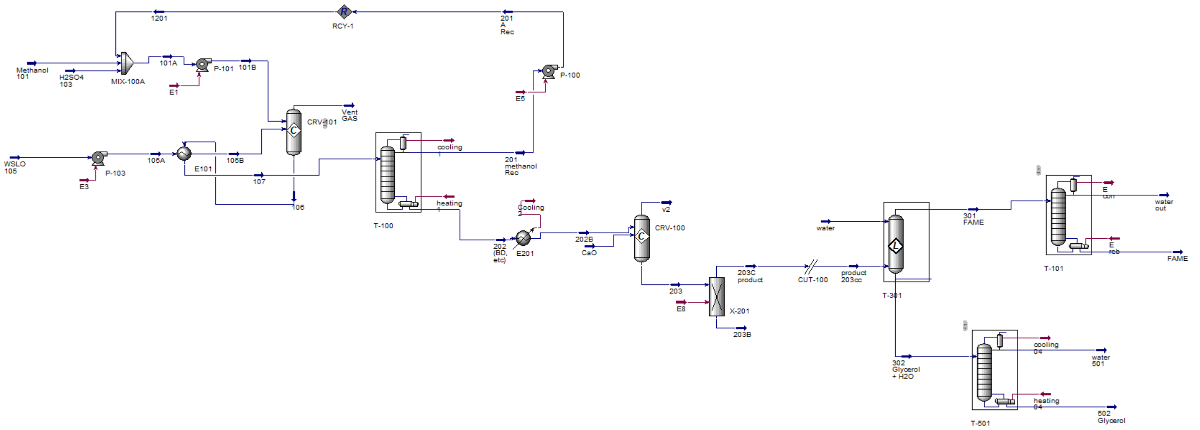


Figure 1. Aspen simulation for acid- and alkali-catalysed transesterification for the production of biodiesel

Non-random two liquid (NRTL) is the fluid package selected in this case due to the presence of polar components such as methanol and glycerol [2].

2. PROCESS DESCRIPTION

2.1 Acid-Catalysed Transesterification of WSLO to Biodiesel

The simulated process flow sheet of acid-Catalysed transesterification of WSLO for the production of biodiesel is illustrated in Figure 1. The reactions involved in this process are shown in Equations 1 and 2. The reaction was performed with a methanol-to-oil molar ratio of 10.3:1, 6.5 h reaction time, 60 °C reaction temperature, and 5.9 wt% H_2SO_4 catalyst concentration. The glycerides (TG, DG and MG), free fatty acid, biodiesel, glycerol, water and H_2SO_4 were as defined in the components list in Aspen HYSYS-V9 as triolein, oleic acid, m-oleate, glycerol, H_2O, and H_2SO_4, respectively.

As shown the methanol and H_2SO_4 catalyst were mixed and pumped to the reactor CRV 301. The WSLO was pumped and preheated in heat exchanger E-101 to 60 °C prior to entering the reactor. After the reactor, the reactor downstream was used to heat the WSLO entering from the reactor (heat integration), and then routed to the distillation column T-100 in order to separate the excess methanol from the product stream. In T-100, five theoretical stages and a reflux ratio of two were used to obtain good separation between the methanol and other reaction mixtures, based on the findings of [3]. Stream 201 methanol is recycled back to the reactor CRV 301 to reduce the overall cost of the methanol used.

The bottom stream of the distillation column was progressed to the acid removal unit CRV-100. The sulfuric acid was neutralised using calcium oxide (CaO) to produce $CaSO_4$ and H_2O, as shown in Equation 3. A gravity separator was employed to remove the calcium sulphate $CaSO_4$. The remaining stream, which consists mainly of FAME, water, glycerol and water, is routed to the water washing stage using liquid-liquid extraction column T-301.

$$\mathrm{H_2SO_4} +\ \mathrm{CaO}\ \rightarrow\ \mathrm{CaSO_4} + \mathrm{H_2O} \qquad (3)$$

The main purpose of the water washing stage is to separate the FAME from glycerol and water. Water was added as a solvent to wash the FAME in four theoretical stages in the liquid-liquid extraction column. The same stages were used to separate FAME from glycerol and water, based on the findings of [4]. In order to obtain a final biodiesel product adhering to ASTM specifications (more than 96.5% purity), a FAME distillation column with five theoretical stages and a reflux ratio of two were employed. The distillation column was operated under vacuum to reduce thermal stress and avoid FAME degradation. Water was removed from the FAME and the final FAME purity was 99.9%.

The bottom stream of the water washing unit, which consists of glycerol and water, is forwarded to the glycerol purification distillations column T-501. The distillation column consists of five theoretical stages and a reflux ratio of two. The glycerol was separated from water with 99.0% purity.

2.2 Alkali-Catalysed Transesterification of Refined Vegetable Oil

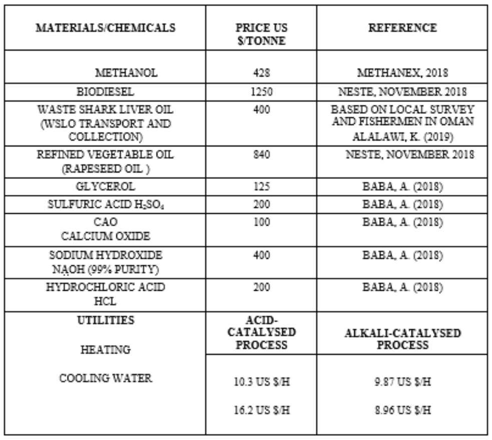
The simulated process flow sheet for the conventional biodiesel production using alkali-catalysed transesterification of refined vegetable oil was conducted with a methanol-to-oil molar ratio of 6:1, 1 h reaction time, 60 °C reaction temperature and 1.5 wt.% NaOH catalyst concentration; these are the conventional conditions used for transesterification of soybean oil [5]. The triglycerides, biodiesel, glycerol, water, NaOH, HCl, and NaCl were as defined from the components list in Aspen HYSYS-V9 as triolein, m-oleate, glycerol, H_2O, NaOH, HCl and NaCl, respectively. The reaction conversion for both plants was assumed to be 99%. The process flow of alkali Catalysed transesterification is similar to the acid-Catalysed transesterification in section 2.1.

2.3 Economic analysis

Economic analysis was conducted to assess the profitability of the acid-Catalysed biodiesel plant using WSLO and compare it with the conventional biodiesel production using refined vegetable oil (rapeseed oil) with an alkali catalyst. The economic analysis was based on the following assumptions: (a) A biodiesel plant production capacity of 12,000 te/y; (b) A plant life time of 20 years; (c) An operation of 100% of the plant capacity all the time; (d) A discount rate of 15%; (e) Raw material/feedstock (waste shark liver oil) costs mainly associated with the logistic cost.

The plant life time, discount rate and plant operation are assumed based on a similar biodiesel production plant using palm oil [3].

Table 1 presents a summary of the materials and chemicals used to produce the biodiesel, and utilities such as heating energy and cooling water. The cost of the utilities is based on the cost of heating and cooling.

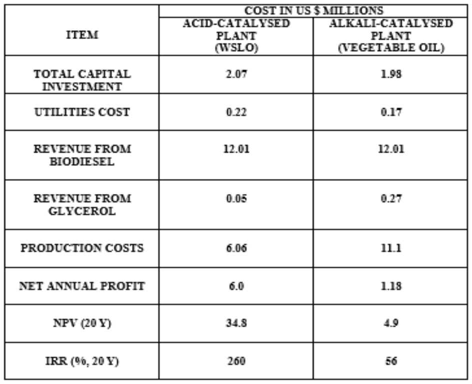


MATERIALS/CHEMICALS	PRICE US $/TONNE	REFERENCE
METHANOL	428	METHANEX, 2018
BIODIESEL	1250	NESTE, NOVEMBER 2018
WASTE SHARK LIVER OIL (WSLO TRANSPORT AND COLLECTION)	400	BASED ON LOCAL SURVEY AND FISHERMEN IN OMAN ALALAWI, K. (2019)
REFINED VEGETABLE OIL (RAPESEED OIL)	840	NESTE, NOVEMBER 2018
GLYCEROL	125	BABA, A. (2018)
SULFURIC ACID H_2SO_4	200	BABA, A. (2018)
CAO CALCIUM OXIDE	100	BABA, A. (2018)
SODIUM HYDROXIDE NAOH (99% PURITY)	400	BABA, A. (2018)
HYDROCHLORIC ACID HCL	200	BABA, A. (2018)
UTILITIES	ACID-CATALYSED PROCESS	ALKALI-CATALYSED PROCESS
HEATING	10.3 US $/H	9.87 US $/H
COOLING WATER	16.2 US $/H	8.96 US $/H

Total capital investment (TCI) in biodiesel production consists of the total equipment cost, installation costs, and other indirect costs (such as engineering, construction, contractors, and contingency costs). The production costs include those of total raw materials added to the total operation and maintenance costs. Overall utilities costs and the revenue generated from biodiesel and glycerol were calculated based on the quantity of product and the selling price shows the total capital investment, and costs of utilities and production, as obtained from Aspen HYSYS-V9. Net present value (NPV) is a useful tool to determine the profitability of a project or investment. A positive NPV shows a profit, while a negative NPV indicates a loss. It is calculated based on the difference in the present value of cash inflow and outflow over a period of time. Table 2 shows a positive NPV of US $34.8 and US $4.9 million for the acid-catalysed process and alkali-catalysed process, respectively.

Internal rate of return (IRR) is a discount rate that makes the NPV of all cash flow equal to zero. IRR is used to evaluate the profitability of potential investments. The IRR in this project was calculated to be 260% for the acid-catalysed WSLO process and 56% for the alkali-catalysed vegetable oil process. It is clear that the acid-catalysed process is more attractive than the alkali-catalysed process due to the higher IRR% of the acid-catalysed process. The break-even price is the minimum selling price required to have a positive NPV for the process. The break-even price for the biodiesel obtained from the acid-catalysed WSLO process is 600.3 US $ /te. In other words, the minimum price for selling biodiesel and making a profit is 600.3 US $/te. If the selling price is lower than this, the project is not profitable. The break-even price for the biodiesel obtained from the alkali-catalysed process is US $1,100 which is US $150 lower than the current market price of biodiesel (Neste, November 2018).

Table 2: Economic analysis for the biodiesel production capacity of 12000 te/y



ITEM	COST IN US $ MILLIONS ACID-CATALYSED PLANT (WSLO)	COST IN US $ MILLIONS ALKALI-CATALYSED PLANT (VEGETABLE OIL)
TOTAL CAPITAL INVESTMENT	2.07	1.98
UTILITIES COST	0.22	0.17
REVENUE FROM BIODIESEL	12.01	12.01
REVENUE FROM GLYCEROL	0.05	0.27
PRODUCTION COSTS	6.06	11.1
NET ANNUAL PROFIT	6.0	1.18
NPV (20 Y)	34.8	4.9
IRR (%, 20 Y)	260	56

2.4 Sensitivity analysis

A sensitivity analysis was conducted to show the effect of the variables on the NPV of the biodiesel production plant from WSLO using an acid catalyst, and a biodiesel production plant from rapeseed oil using an alkali catalyst. The variables tested in this study are the price of methanol, WSLO, and rapeseed oil, and the selling price of biodiesel and glycerol based on a plant life of 20 years. The degree of variation of all these variables was between -50% and 50% of the original values. Figure 2 (a) and (b) show the change in the NPV as a function of the WSLO, rapeseed oil, and methanol purchase prices. Clearly, the variation in rapeseed oil is more sensitive than the variation in WSLO prices, due to the low price of the WSLO, which is mainly associated with the logistics cost. The NPV for the alkali process using rapeseed oil decreased by US $6.2 million with every 10% increase in the rapeseed oil price. However, the NPV for the WSLO process was less sensitive and decreased US $2.9 million with every 10% increase in the WSLO price.

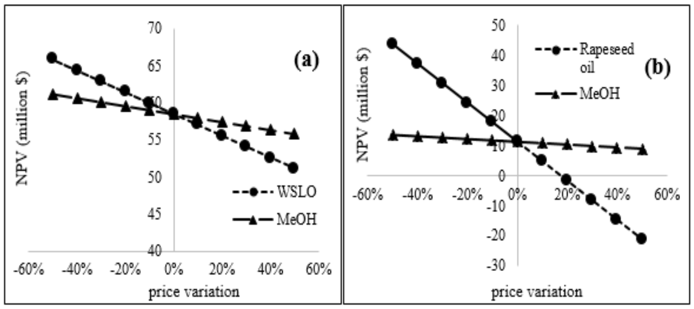


Figure 2: The change in the NPV as functions of the purchase prices of (a) WSLO and methanol (b) rapeseed oil and methanol

Furthermore, a 10% increase in the methanol price resulted in a reduction in NPV, as the price increased by US $0.54 million for the acid-Catalysed process and US $0.46 million for the alkali-Catalysed process. Thus, rapeseed oil price has the most significant effect on NPV in comparison to the variation in methanol price. As shown in Figure 2 (b), an increase in rapeseed oil price of 20% or more will cause the process to run at a deficit, but a 50% variation in WSLO price will not result in a loss. Clearly, Figure 3 shows the change in the NPV as functions of the biodiesel and glycerol selling prices for the acid- and alkali-Catalysed process. The NPV was sensitive to the biodiesel selling price, since biodiesel is the main product in the process and plays a significant role in its economics. The NPV increased US $7.4 million with every 10% increase in the biodiesel selling price. In addition, the effect of a 10% glycerol variation was US $0.03 million for the acid-Catalysed process and US $ 0.17 for the alkali-Catalysed. The effect of a glycerol price variation on NPV is more significant for the alkali process than the acid due to the higher amount of glycerol produced from the alkali process using rapeseed oil, which is mainly triglycerides.

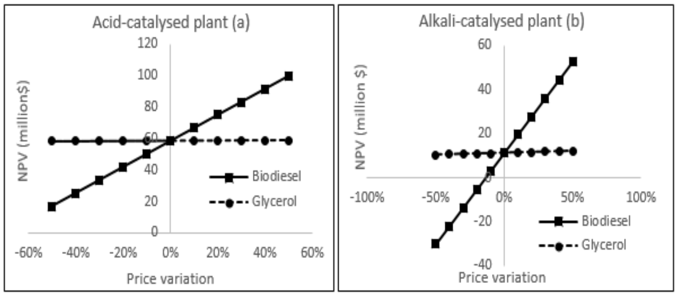


Figure 3: The change in the NPV as functions of the biodiesel and glycerol selling prices for (a) the acid-catalysed plant using WSLO, and (b) the alkali-catalysed plant using vegetable oil (rapeseed oil)

It can be clearly noticed that the biodiesel selling price has more influence on the NPV in comparison to the glycerol variation prices. Moreover, the sensitivity analysis as shown in Figure 2 and 3 gives an idea of the minimum selling price required to have a positive NPV for the process, which is known as the break-even price. The break-even price for producing biodiesel from the acid-Catalysed WSLO process was 600.3 US $/te, and 1,100 US $/te for the alkali-Catalysed rapeseed oil process.

2.5 Conclusions

The feedstock purchase price has the largest influence on the economics of the two processes. These results are in line with the literature, which shows that the cost of feedstock accounts for 70–95% of total biodiesel production costs [6]. This has caused increasing research interest in the use of cheap, non-edible feedstocks, such as waste shark liver oil, to improve production costs and make the process economically

Taken together, the economic analysis suggests that producing biodiesel from WSLO as a new techno-economically viable feedstock for biodiesel using an acid catalyst at a plant capacity of 12,000 te/y is more profitable and attractive than an alkali-catalysed process. It should be used as such, as long as it remains a “waste to wealth” product. However, the limited supply of WSLO in one location is the main downside of this process. It needs to be acknowledged that WSLO should be used as new feedstock for biodiesel, as long as it remains a “waste to wealth” product. It is not desirable that the process created a market for increased shark fishing.

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