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Brief Report
Design and Integration for Biodiesel Production from Vegetable Oil via Transesterification Reaction

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Introduction

Biodiesel is Fatty Acid Methyl Esters (FAME) which is used as a renewable fuel in diesel engines. Extraction of lipid from various flora sources, including Sunflower, Palm, Canola or animal oils, with a Trans-Esterification reaction between alcohol and Triglyceride (TG), leads to production of Biodiesel and Glycerin.

The production cost of biodiesel is so important that is now considered as the greatest obstacle during scale-up process.

In this research, a model-type of biodiesel production unit (using vegetable oil source), was designed by Aspen HYSYS V7.2 software, then a great deal of the attempt was employed to optimize the overall yield against the processing parameters including: mass and energy consumption load, as well as some technical discussion regarding associated apparatuses.

Materials and Methods

Process Design

The simulation was carried out using Aspen HYSYS V7.2 employing Triolein (as TG), Oleic acid (as Free Fatty Acid (FFA)), and Oleat as biodiesel. Avoiding side-stream reactions as well as trans-esterification, the FFA content was taken to a mere 0.05% (%mass). Feed stream was considered as product of NaOH-catalyzed bi-reactor system operating at 60˚C and 1 atm with the overall conversion of 70% using two series reactors.

The ratio of TG to Alcohol is 1:3, however, owing to establish an appropriate reactor performance; this ratio was applied as 1:6 practically. The design was mainly intended to produce 480 m^3d^{-1} biodiesel with mass concentration of 99.65%.

Methanol was used in this investigation due to low cost, accessibility and handling considerations.

NRTL was taken as the Equation of State (EOS) for the process and should be used PRSV equation in the decanter.

Thermal Integration

Energy consumption was taken into account as basis of optimization in this study. Table 2 demonstrates the thermal characteristics of all streams consist of source and down-streams, while outlet stream like glycerol streams were neglected to be considered. HR-1, HR-2, HD1-1, HD2-1 and HD3-1 represent cooling water leaving reactors and condensers respectively which input cooling water temperature to utility was 25˚C. C_p also indicates the thermal capacity of each line which can be calculated by multiplying mass flow rate in specific heat capacity.

In order to calculate interval temperature, as the next step, the inlet and outlet temperatures of hot flow must be diffracted from the half of minimum approach temperature of exchangers; and the inlet and outlet cold temperatures should be summed with the half of minimum of approach temperature of exchangers. Interval enthalpy can also be calculated using following equation:

$$\Delta H_{\text{interval}} = \Delta T_{\text{interval}} [C_{p\ \text{Cold}} - C_{p\ \text{Hot}}]$$

Minimum approach temperature (ΔT_{min}) was also taken as 10°C in the following calculations. Results are shown in Table 3.

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Results and Discussion

Mass Integration

Feed stream after reaching 60˚C and 1 atm entered into first reactor. Feed streams reacted in Reac.1, and effluent after cooling to 25˚C flowed to Sep.1. Unreacted oil sent to Reac.1 and effluent of this reactor after cooling to 25 ˚C entered into Sep. 2. Products of Reac.2 including glycerin, methanol, biodiesel and oil were conveyed to Sep.2 (25˚C) for separation of ester and glycerin. The light phase (Ester) was directed to a recycle distillation column (Dist.1) with R=1.5 and 6 trays to obtain extra-pure methanol from biodiesel. Second effluents from Sep.1 and Sep.2 including large quantities of methanol and glycerin were conveyed to second distillation tower (Dist.2) with 5 tray and R=1.5 in order to purify methanol recovery and obtain glycerin purity up to 99.63%. Due to declining expenditure, methanol recycled back to the beginning of process as a feed; while glycerin was sent out to downstream as by-product.

Effluent exited from Dist.2 flowed to Sep.3 to improve purity and remove any residual catalysts (NaOH) via HCl reaction. HCl and catalyst entered with identical molar flow and reacted with 95% conversion.

The cold and hot energy required for the whole processes were calculated: 18860 kW and 17330 kW respectively.

Heat Integration

According to Table 3 network required hot and cold energy were found to be zero and 17146.6 kW respectively; where the number “zero” indicates hot streams are able to provide energy needed of cold stream. Care should be taken that the exchanger approach temperature should not be less than the minimum selected approach temperature (ΔT_{min}).

Applying the new system in the process, cold and hot energy reduced to 17018 kW and 16670 kW respectively.

According to Figure 2, HEX-8 outlet stream temperature reached 291.8 ˚C after heat transfer. On the other hand, required temperature and heat of distillation tower’s re-boiler were 187.6 ˚C and 1858 kW respectively; therefore this could be used as energy source for the second distillation tower’s re-boilers. The output stream of the 3rd distillation tower virtual exchanger (SHD 3-out) was also important; this stream temperature was 565 ℃ that could be used to provide energy in the 1st distillation column re-boiler.

Finally cold energy and hot energy reduced by 19.6% and 38% reaching 15160 kW and 10990 kW respectively. Input and output streams of the process data and the main process flow diagram of the biodiesel process production are shown in table 4 and fig.3.

Conclusions

Using stream recycle and mass integration methanol, unreacted oil and feed oil consumption reduced up to 60.6%, 70% and 9% respectively. Consequently, due to energy integration by exchanger network, cold and hot energy was reduced by 19.6% and 38% respectively. This integration increases the number of exchangers and pumps power due to the integration target, because the mass and heat integration targets are just reducing the mass and heat consumption. As can be seen from table 5, the number/capacity of used facilities increased in some cases as a result of application of integration method; this item can be optimized depending on economic and operating data and changing the final target to reduce overall cost, for this purpose can be used other methods such as genetic algorithms.

Keywords: Biodiesel process design, Integration and simulation, Heat exchangers network, Pinch technology, Vegetable oil