SIMULATION AND PROCESS DESIGN OF BIODIESEL PRODUCTION

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Abstract

To meet the increasing demand for energy throughout the whole world, natural gas, along with fossil fuels, are widely used. But these fuels are non-renewable, and therefore, the price is very high, as a consequence of spiraling demand and diminishing supply. Biodiesel is increasingly being recognized worldwide as a renewable, alternative fuel, to reduce dependency on conservative fuels with limited reserve. Biodiesel is a combination of fatty acid methyl esters (FAMEs), and, is usually derived from animal and vegetable oils. In this project, production of biodiesel by transesterification of vegetable oil containing triolein, with methanol in presence of an acid catalyst (H_2SO_4) have been studied. Using Aspen HYSYS 2006 software, a continuous process was designed with a plant capacity of 6,600 tonnes per year, *i.e.*, 1000 kg per hour biodiesel production. For this project, firstly, the relation among various process parameters, which influence the production of biodiesel, have been studied and several graphical representations have been formulated showing the relation. This type of relation is crucial for proper understanding and operation of the whole plant. Secondly, after analyzing the process variables, HYSYS Optimizer has been used to optimize the profit and maximum annual profit was found to be 7.437 million dollars at optimum conditions.

Keywords: Biodiesel; triolein; alternative fuel; transesterification; simulation; optimization.

1   Introduction

Owing to the high rate of fuel consumption, increasing oil crisis and detrimental effect of fossil fuels on environment, the necessity and demand of using alternative fuels have been increasing worldwide. Biodiesel, a mixture of monoalkyl esters of fatty acids [Agarwal & Das, n.d.; Pinto, et al., 2005; Supple, et al., 1999], can be produced from renewable domestic resources [Syam, et al., 2013], and, is gaining acceptance as a substitute of petro-diesel since it has many biological benefits and possesses physical properties similar to diesel fuel [Dhar & K., 2009; Ehsan, et al., 2012; Emmanuel I. Bello, et al., 2013].

Biodiesel has improved cetane number, viscosity, oxidative stability, [Syam, et al., 2013] combustion efficiency, biodegradability (biodiesel is 90% more bio-degradable than diesel),

lower sulfur & aromatic content and toxicity than petroleum diesel [Gomez-Castroa, et al., 2013; Korbitz, 1999; Morais, et al., 2010; Okoronkwo & Leke, 2012]. It reduces emission of GHGs and most exhaust gases except NO_x [Leung, et al., 2010], for example, biodiesel reduces emission of CO_2 by 78% [West, et al., 2007], SO_2 by 99%, CO by 20%, hydrocarbons by 32%, soot by 50% and particulate matters by 39% [Korbitz, 1999].

A number of methods have been implemented for the production of biodiesel, such as− direct use and blending of raw oils, micro-emulsions, thermal cracking and transesterification [Okoronkwo & Leke, 2012]. Transesterification of animal fats or vegetable oils is the most commonly used method to convert these to biodiesel [Gaurav, et al., 2013; Leung, et al., 2010]. The quality of biodiesel is directly related to the quality of the raw oil [Supple, et al., 1999], which can be− vegetable oil (edible or non-edible); animal fat [Leung, et al., 2010]; non-edible plant biomass such as algae and seaweeds, and even animal biomass [Okoronkwo & Leke, 2012]. The costs of the biodiesel feedstocks are very high, and therefore, more than 95% of biodiesel production feedstocks comes from edible oils since vegetable oils are renewable in nature, produced in many regions on a large scale and environmentally friendly [Leung, et al., 2010].

The transesterification reaction can be accomplished by a number of different methods− alkali catalysis, acid catalysis, non-catalytic supercritical and ultrasound aided alcohol, using heterogeneous catalysts, enzyme catalysis etc. It has been found that, the one step acid-catalyzed process, which has been used in this project, is the most economically attractive one [Okoronkwo & Leke, 2012; West, et al., 2007]. In transesterification, an alcohol, methanol in this case, is used to separate the vegetable oil's molecules, and replace them with radicals from the alcohols used, by removing glycerol from the triglycerides in presence of a catalyst. In this reaction, the triglyceride, having a branched molecular structure attached to glycerol backbone, is transformed to a monoglyceride, containing a straight chain of smaller molecular structure [Emmanuel I. Bello, et al., 2013; Pinto, et al., 2005].

In this project, a simulation software, Aspen HYSYS 2006, which provides the thermodynamic and fluid properties for basic chemical compounds, has been used for simulation and process design of biodiesel production by homogeneous acid catalyzed transesterification [Kapilakarn & Peugtong, 2007].

2 Methodology

2.1 *Process Description*

The complete process involved the transesterification reaction to convert triolein to biodiesel, the recovery of unreacted methanol, neutralization and removal of acid catalyst, separation of by-product and finally biodiesel purification.

2.1.1 Biodiesel production

For the homogeneous acid catalyzed transesterification of triolein, first, methanol (CH_3OH) was mixed with sulfuric acid (H_2SO_4) and the mixed feed was pumped before combining with the recycle stream. This feed then entered Reactor-1 and reacted with triolein to form methyl ester, which is the main product of the process, and glycerol as by-product.

2.1.2 Downstream purification

Methanol recovery: The excess methanol was separated from the product stream of Reactor-1, in a distillation column as the distillate, to be used as the recycle stream.

Catalyst removal: The rest of the materials, *i.e.,* methyl ester, glycerol and unreacted triolein, entered another reactor where calcium oxide (CaO) was added, to neutralize the acid by formation of calcium sulfate ($CaSO_4$). The $CaSO_4$ precipitate was removed in a splitter.

Separation of glycerol: The by-product, *i.e.,* glycerol was separated in another splitter, along with the water produced in the second reaction. The separation was facilitated by the difference in weight between glycerol and methyl ester.

Biodiesel purification: The lighter fraction from the second splitter, containing the main product, *i.e.*, methyl ester and the unreacted triolein entered a second distillation column, where most of the biodiesel was separated as the distillate.

2.2 *Reactions Involved*

For this project, biodiesel has been produced from vegetable oil which involved two major reactions.

2.2.1 Transesterification of oil

The oil (triolein) reacts with methanol and produces biodiesel (methyl oleate) and glycerol in the presence of an homogenous acid catalyst. Sulfuric acid has been used as the acid catalyst in this process. The reaction is given below –

$$C_{57}H_{104}O_6 + 3CH_3OH \rightarrow 3C_{19}H_{36}O_2 + C_3H_8O_3$$

| Triolein | Methanol | Methyl oleate | Glycerol |
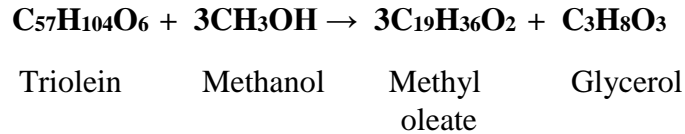
2.2.2 Acid neutralization

In the other reaction, calcium oxide reacts with sulfuric acid to form calcium sulfate and water. This is an important reaction as it reduces the amount of residual acid used as the catalyst. The reaction is given below –

$$CaO \quad + \quad H_2SO_4 \quad \rightarrow \quad CaSO_4 \quad + \quad H_2O$$

| Calcium Oxide | Sulfuric acid | Calcium Sulfate | Water |
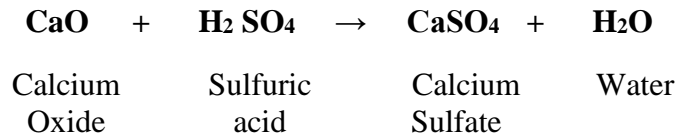
2.3 Process Simulation

Complete process simulation for biodiesel production was performed using Aspen HYSYS 2006, to evaluate technological viability and obtain material and energy balances. HYSYS was selected as a process simulator for both its simulation capabilities and its ability to incorporate calculations using the spreadsheet tool. Although, simulation result does not guarantee 100% correct results compared to the real process, simulation provides the opportunity to design and test the unit operations in a short period of time. The major steps involved in the simulation using were –

- Specifying the components involved in the process.
- Selection of a thermodynamic model.
- Drawing the graphical simulation process flowsheet using required unit operations.
- Specifying the operating and input conditions (flow-rate, temperature, pressure, composition etc.).

2.3.1   Specifying the components

The basic components required for this process were triolein, methanol, sulfuric acid, methyl oleate, glycerol, water, calcium oxide and calcium sulfate. HYSYS library contained information for most of these components. Calcium oxide, calcium sulfate and triolein were specified using the 'Hypo manager' tool. Since triolein is a crucial component of the process and is involved in operations requiring data for vapor-liquid equilibria, the property values were specified with great care.

2.3.2   Selection of thermodynamic model

As the property package for the simulation, non-random two liquid (NRTL) thermodynamic/activity model was selected because of the presence of polar compounds, such as, glycerol and methanol.

2.3.3   Specifying unit operations and conditions

The simulation was performed on the basis of 1000 kg/h biodiesel production. For this, stoichiometric amount of methanol (CH_3OH) and triolein ($C_{57}H_{104}O_6$) were provided, along with 110.3 kg/h sulfuric acid (H_2SO_4) as the catalyst, at 25°C and 1 atm. First, 108.1 kg/h methanol was mixed with the acid, then the mixed feed was pressurized to 2 atm with a pump. This pressurized feed and the recycle stream containing almost pure methanol (99.99%), from the top of Distillation column-1 were mixed before entering the Reactor-1. On the other hand, 1026 kg/h triolein was pressurized to 2 atm, and then, heated to 60°C before entering Reactor-1, where it reacted with the mixed feed to reactor. For the transesterification reaction, a general conversion reactor was selected where 97% conversion of the oil was achieved.

The liquid product stream from Reactor-1 containing glycerol ($C_3H_8O_3$), methyl oleate ($C_{19}H_{36}O_2$) and a little amount of unreacted methanol, oil and all of the acid, entered Distillation column-1. From the top of the distillation column, all of the unreacted methanol was recovered and sent back as the recycle stream. The bottom product containing glycerol, methyl oleate with unreacted oil and H_2SO_4 at 300.9°C was cooled to 200°C before entering Reactor-2, which was also a general conversion reactor for complete conversion of sulfuric acid. The acid reacted with

3 kgmole/hr CaO to produce $CaSO_4$, which along with glycerol, methyl oleate and oil entered into the first component splitter, Splitter-1.

From the bottom of this splitter, $CaSO_4$ was removed at 25°C as precipitate and the top product entered the second component splitter, Splitter-2, where 95% solution of glycerol was collected at the bottom as the heavy fraction. The top product containing oil and methyl oleate was passed to Distillation column-2, where all of the biodiesel was separated at 99.99% purity.

The methyl-ester purification column was operated under vacuum conditions, condenser pressure 10 kPa and reboiler pressure 15 kPa, to keep the temperature of the distillate and bottom stream at low levels, since biodiesel is subject to distillation at temperature greater than 250°C.

2.4 Process block diagram
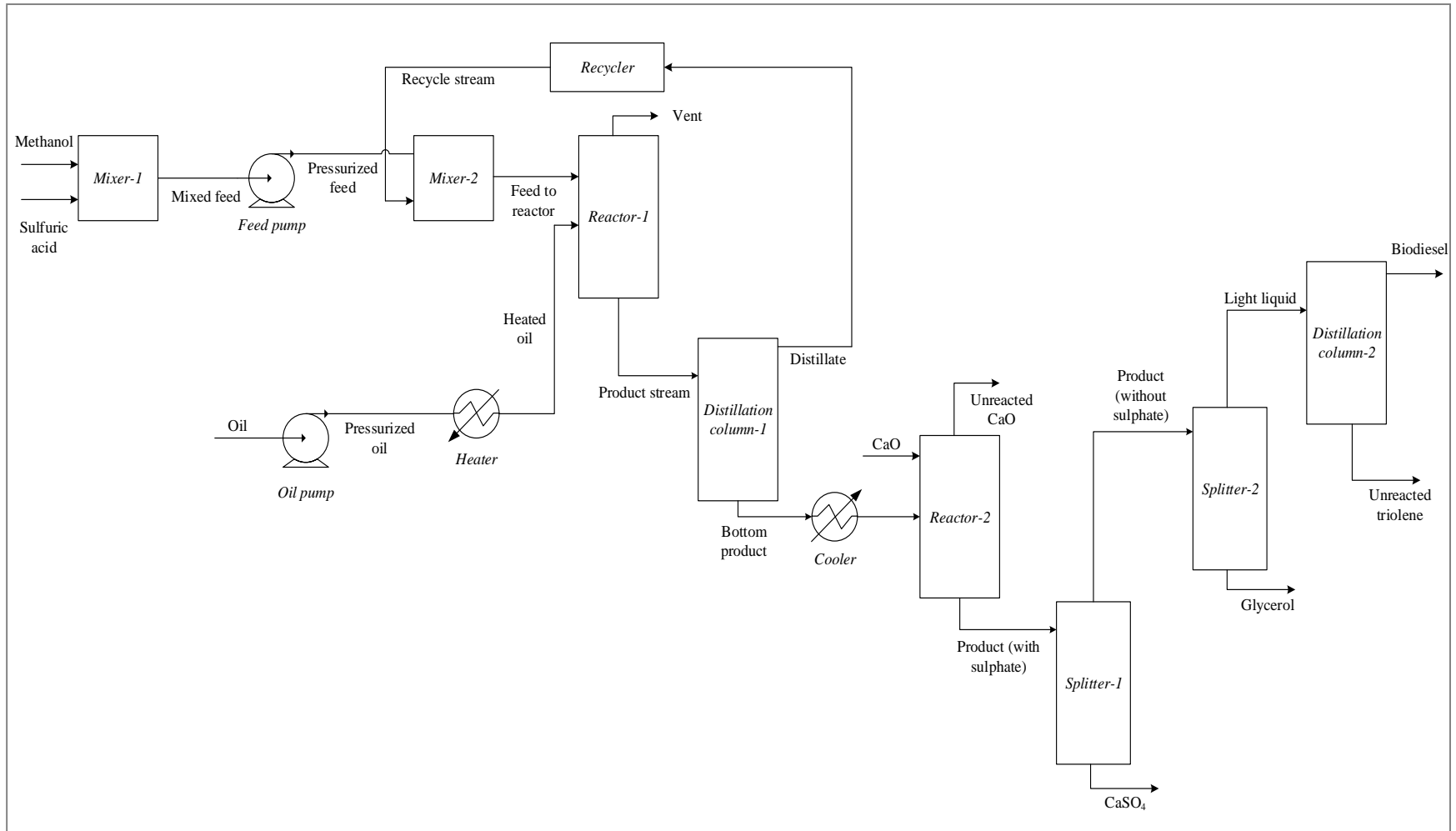
Figure 01: Process block diagram of biodiesel production
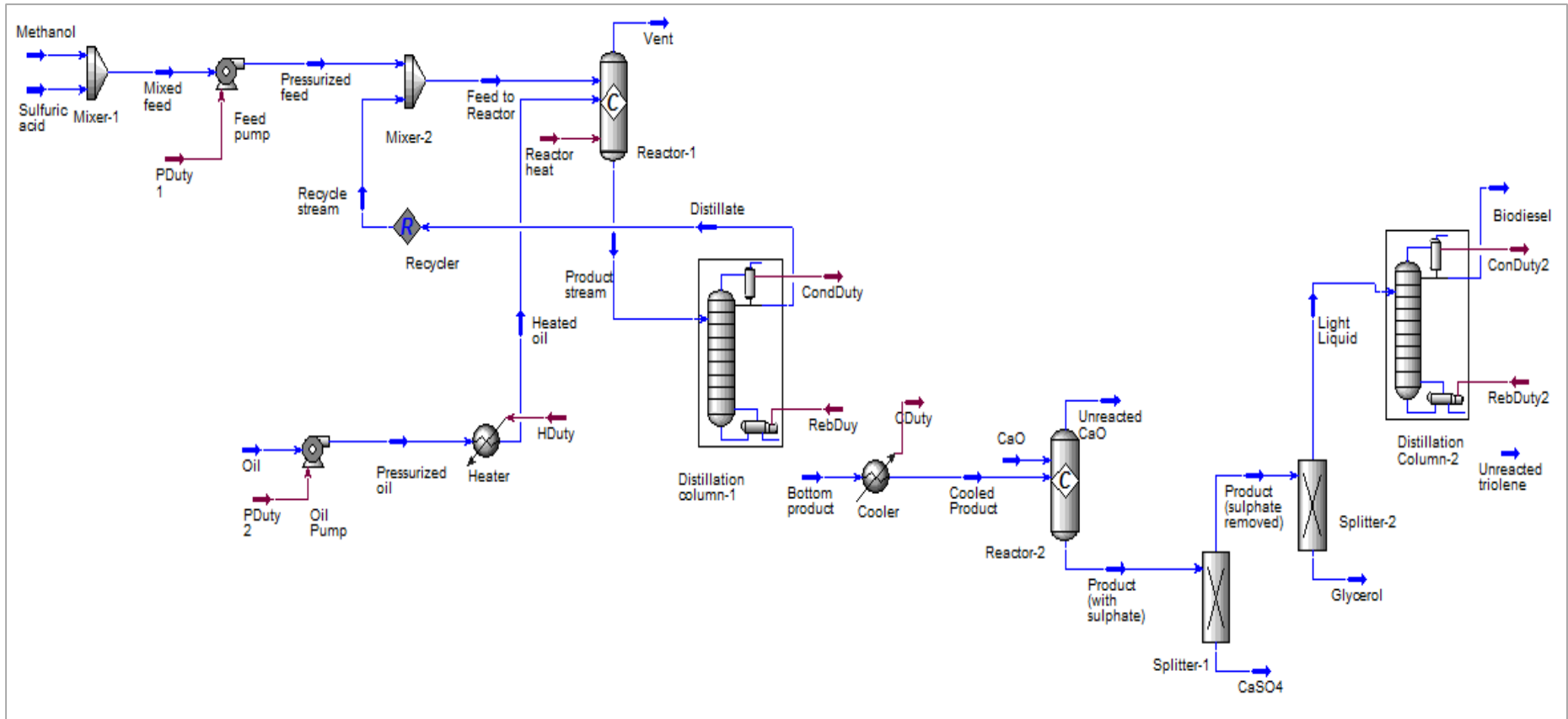
2.5   *Process flow diagram*

Figure 02: Process flow diagram of biodiesel production

3   Optimization

Optimization is a process or methodology, by which, a design, system, or a decision is made fully perfect, functional, or as effective as possible. It is a mathematical procedure, done to find the maximum of one or more desired function or functions and the minimum of the undesired ones.

In this simulation, optimization was done using HYSYS optimizer tool to find the optimum parameters for optimum production and the maximum profit that can be achieved in that optimum production.

3.1   Assumptions

To determine the profit that can be gained if Biodiesel is produced according to this process, several assumptions were made.

- The simulation was based on a plant capacity of 6,600 tonnes of biodiesel production per year considering 330 days of operation per year with operating hour set at 20 hours per day.
- The oil used was assumed to be waste cooking oil with 30% triolein content.
- Electricity was used as heating and cooling medium. Cost of heating and cooling was assumed to be equivalent to the cost of electrical energy consumed.

Table 01: The selling prices of biodiesel and glycerol and cost of raw materials & electricity have been tabulated below–

Item	Cost/ Price	Item	Cost/ Price
Methanol	$180/tonne[1]	Biodiesel	$6/gallon (or $1585/m^3) [2]
Oil	$200/tonne[1]	Glycerol	$1200/tonne[1]
Sulfuric acid	$60/tonne[1]		
CaO	$40/tonne.[1]	Electricity	$0.12/kWh [3]

[1] (West, et al., 2008)

[2] http://farmdocdaily.illinois.edu/2013/09/recent-trends-in-biodiesel.html

[3] http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_06_a

3.2   *Profit function*

In this simulation process, to perform the optimization, an optimization function was used. This is a function for calculating profit that showed a relation between the selling prices with the costs of reactant materials and the electricity bill for using the energy to run the process, ultimately giving the profit obtained. To calculate profit, HYSYS spreadsheet tool was used. The equation is given below –

$$\text{Profit} = V_B S_B + M_G S_G - M_M S_M - M_S S_S - M_C S_C - M_O S_O - \frac{C_E \times (Q_{FP} + Q_{OP} + Q_C + Q_H + Q_{CD_1} + Q_{RD_1} + Q_{CD_2} + Q_{RD_2} + Q_R)}{3600}$$

Table 02: Variables in profit function

Variable	Identity	Variable	Identity
S_B	Selling price of Biodiesel ($/m^3)	M_O	Mass flow rate of waste cooking oil used (kg/h)
V_B	Rate of Biodiesel production (m^3)	Q_{FP}	Energy required to pressurize the mixed feed in Feed pump (kJ/h)
S_G	Selling price of Glycerol ($/kg)	Q_{OP}	Energy required to pressurize the feed oil in Oil pump (kJ/h)
M_G	Mass flow rate of Glycerol produced (kg/h)	Q_C	Energy required to cool the bottom product from Distillation column-1 in Cooler (kJ/h)
S_M	Cost of Methanol ($/kg)	Q_H	Energy required to heat the pressurized oil from oil pump in Heater-1 (kJ/h)
M_M	Mass flow rate of Methanol used (kg/h)	Q_{CD1}	Condenser duty in Distillation column-1 (kJ/h)
S_S	Cost of Sulfuric acid ($/kg)	Q_{RD1}	Reboiler duty in Distillation column-1 (kJ/h)
M_S	Mass flow rate of Sulfuric acid used (kg/h)	Q_{CD2}	Condenser duty in Distillation column-2 (kJ/h)
S_C	Cost of CaO ($/kg)	Q_{RD2}	Reboiler duty in Distillation column-2 (kJ/h)
M_C	Mass flow rate of CaO (kg/h)	Q_R	Energy required in Reactor-1 (kJ/h)
S_O	Cost of waste cooking oil ($/kg)	C_E	Cost of electricity per kWh ($/kWh)

3.3   Primary variables

The primary variables that were varied to determine the optimum condition using HYSYS optimizer tool, has been given below –

- The percentage of conversion of triolein in Reactor-1;

- The pressure of the feed containing fresh methanol, sulfutic acid & recycled methanol before entering Reactor-1;

- The pressure of the oil before heating;

- The temperature to which triolein (oil) was heated before entering Reactor-1;

- Pressure of mixed feed before combining with recycle stream in Mixer-2;

- The reflux ratio in Distillation column-1;

- The fractional recovery of biodiesel in Distillation column-2.

- The temperature at which $CaSO_4$ was removed from Splitter-1;

3.4   Method of optimization

The optimization process involved several steps.

- Variables included in the profit function were either imported from the simulation or entered manually.

- Profit and annual profit were determined using the profit function.

- The primary variables were added and their ranges were selected, with the help of the graphs that were plotted to understand the flexibility of the variables.

- Using HYSYS optimizer tool, optimum conditions for maximum profit was attained.

The various steps of optimization, *i.e.*, profit calculation and selection of primary variables were recorded and have been shown in Figure 03 and Figure 04.

Figure 03: View of optimizer spreadsheet before optimization

Figure 04: Selection of primary variables for optimization

4 Optimized Workbook

The major streams of the complete process were,

- The input streams, *i.e.*, methanol, oil and sulfuric acid streams.

- The product stream from Reactor-1 after conversion of triolein to biodiesel.

- The distillate from Distillation column-1 that formed the recycle stream.

- The product obtained after neutralization and removal acid catalyst.

- The product after removal of glycerol.

- The final products to be sold, *i.e.*, the biodiesel and glycerol streams.

The final conditions the major streams and their compositions have been shown below.

Name	Vapour Fraction	Temperature	Pressure	Molar Flow	Mass Flow	Liquid Volume Flow	Heat Flow
Methanol	0.0000	25.00	101.3	3.373	108.1	0.1358	-8.076e+005
Oil	0.0000	25.00	101.3	1.159	1026	1.121	-1.952e+006
Sulfuric acid	0.0000	25.00	101.3	1.124	110.3	5.958e-002	-8.984e+005
Product stream	0.0000	70.00	101.3	6.915	1285	1.366	-4.359e+006
Distillate	0.0000	64.48	101.3	1.261	40.40	5.077e-002	-2.960e+005
Product (sulpha	0.0000	176.1	101.3	4.819	1138	1.260	-2.967e+006
Light Liquid	0.0000	193.9	101.3	3.403	1029	1.173	-2.125e+006
Glycerol	0.0000	25.00	101.3	1.416	108.3	8.698e-002	-8.420e+005
Biodiesel	0.0000	257.5	10.00	3.368	998.7	1.139	-1.912e+006

Figure 05: Final condition of major streams

Name	Methanol	Oil	Sulfuric acid	Product stream	Distillate	Light Liquid	Product (sulpha	Glycerol	Biodiesel
Comp Mole Frac (Methanol)	1.0000	0.0000	0.0000	0.1823	1.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Glycerol)	0.0000	0.0000	0.0000	0.1625	0.0000	0.0000	0.2318	0.7891	0.0000
Comp Mole Frac (H2O)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0619	0.2109	0.0000
Comp Mole Frac (H2SO4)	0.0000	0.0000	1.0000	0.1626	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (M-Oleate)	0.0000	0.0000	0.0000	0.4876	0.0000	0.9898	0.6990	0.0000	1.0000
Comp Mole Frac (Calcium oxide*)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CaSO4*)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (triolene*)	0.0000	1.0000	0.0000	0.0050	0.0000	0.0102	0.0072	0.0000	0.0000

Figure 06: Final composition of major streams

5 Results & discussions

The simulation was done for a production of 1000 kg biodiesel per hour. Several graphs were plotted to observe the relationships among the different variables involved in the whole process.

## 5.1 Results from simulation

For production of 1000 kg biodiesel per hour, with 97% conversion of input triolein to biodiesel, it was found that 3420 kg/h oil, containing 30% triolein, and 108.1 kg/h methanol are required. The process has been designed for recovery of unreacted methanol with 99.99% purity and complete recovery of produced biodiesel with also 99.99% purity. As a byproduct, 95% glycerol solution was obtained. The process also resulted in the production of 153.1 kg/h calcium sulfate.

The process might be improved by recycling the unreacted oil from the final stage of purification and can be made more energy efficient if heat produced in the transesterification reaction and during cooling of bottom product from Distillation column-1 were used to preheat the oil and methanol.

5.2 Case study

Case study 1: Effect of mass flow rate of sulfuric acid on the mass flow rate of $CaSO_4$

From graph 01, it can be seen that, the mass flow rate of $CaSO_4$ increases with mass flow rate of H_2SO_4 until the provided amount of CaO is exhausted. At this stage, the amount of $CaSO_4$ produced becomes constant. In this simulation, 3 kmol/h CaO has been given as input, for which stoichiometric amount of H_2SO_4 is 294.24 kg. From graph 01, the amount of $CaSO_4$ became constant at 408.4 kg/h for flow rate of H_2SO_4 greater than 294.24 kg/h.
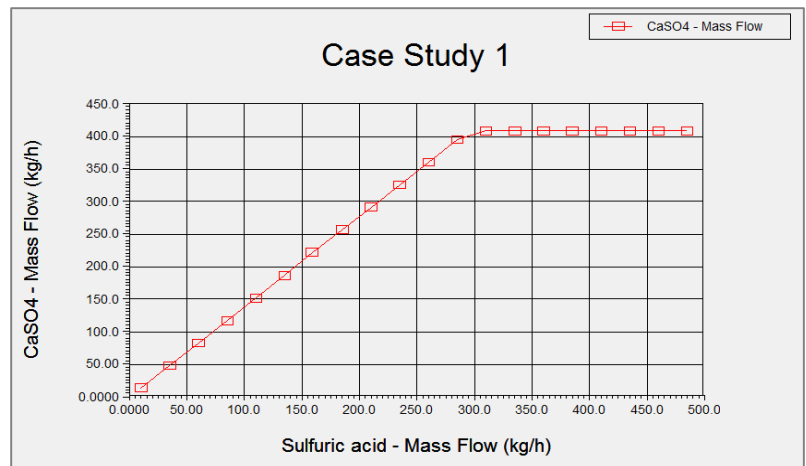
Graph 01: Effect of mass flow rate of sulfuric acid on the mass flow rate of $CaSO_4$

Case study 2: Effect of temperature of oil on heat produced in transesterification process

From graph 02, heat produced in the transesterification reaction starts fluctuating when the temperature of the oil is greater than 80°C. As a result, the rate at which heat has to be removed from the reactor changes, which complicates the overall process. In this simulation, oil was heated to 60°C before entering the reactor, for which rate of heat produced remained constant at 1.65×10^8 kJ/h.
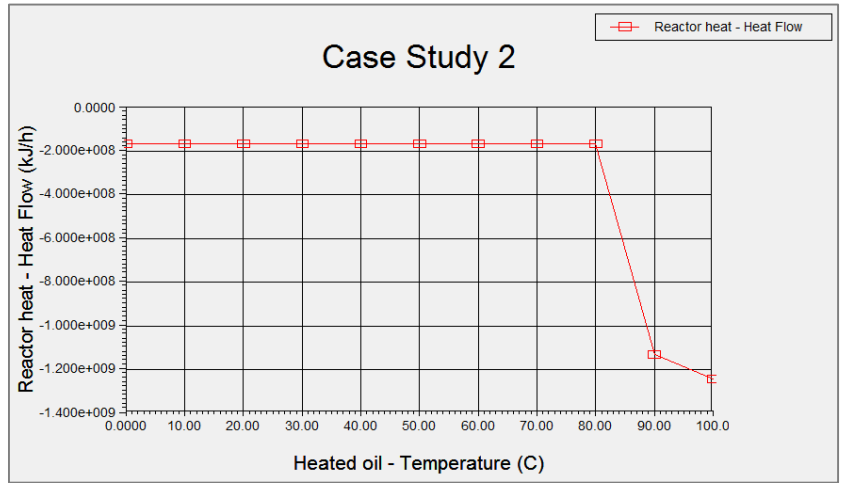
Graph 02: Effect of temperature of heated oil on heat flow of Reactor-1

Case Study 3: Effect of temperature of the liquid stream from Reactor-1 on the heat flow rate of the bottom product of the Distillation Column-1

From graph 03, heat flow of bottom product of the Distillation column-1 remains constant at 3.361×10^6 kJ/h with increasing temperature of the liquid stream from the Reactor-1 until it becomes greater than 175°C. At this stage, it becomes impossible to achieve required recovery of methanol in Distillation column-1. In this simulation, the liquid stream from Reactor-1 was drawn at 25°C, for which the vapor stream mass flow rate became zero and it was possible to recover all unreacted methanol in the distillation column.
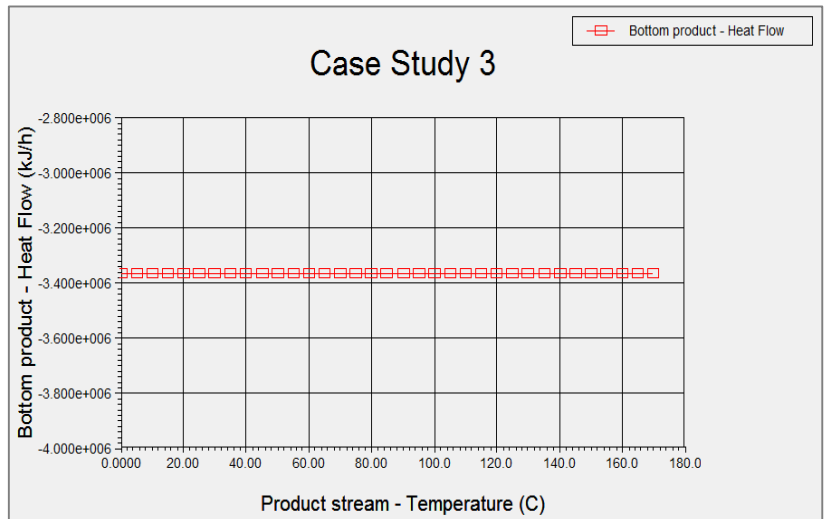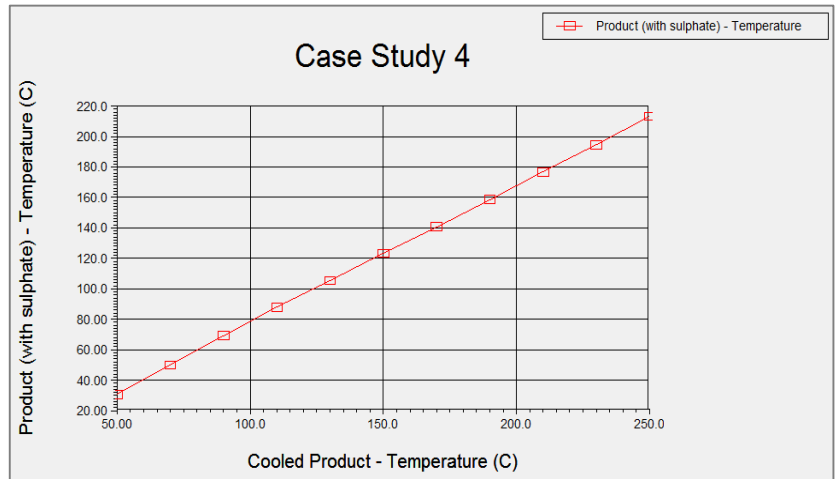

Graph 03: Effect of temperature of the liquid stream from Reactor-1 on the heat flow rate of the bottom product of the Distillation Column-1

Case Study 4: Effect of the temperature of the cooler outlet on the temperature of the liquid outlet of the Reactor-2

From graph 04, it is obvious that with increasing cooler outlet temperature, the liquid outlet temperature of Reactor-2 increases linearly. In this simulation, bottom product from Distillation column-1 was cooled to 200°C for which the temperature of the liquid stream from Reactor-2 was at 167.8°C.
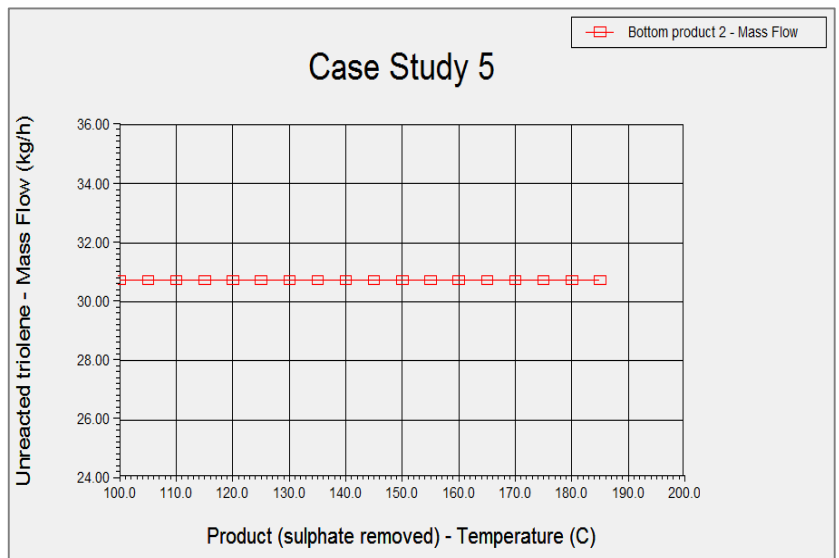

Graph 04: Effect of the temperature of the Cooler outlet on the temperature of the liquid outlet of the Reactor-2

Effect of the temperature of the stream after removal of acid on the mass flow rate of the bottom product of the Distillation column-2

From graph 05, mass flow of bottom product of Distillation column-2 remains constant at 30.75kg/h with increasing temperature of the inlet stream to Splitter-2 until it becomes greater than 185°C. At this stage, it becomes impossible to separate $CaSO_4$ from the products of Reactor-2. In this simulation, the $CaSO_4$ was separated at 25°C from Splitter-1 and the remaining stream from the splitter was obtained at 176.1°C.

Graph 05: Effect of the temperature of the inlet to Splitter-2 on the mass flow rate of the bottom product of the Distillation column-2

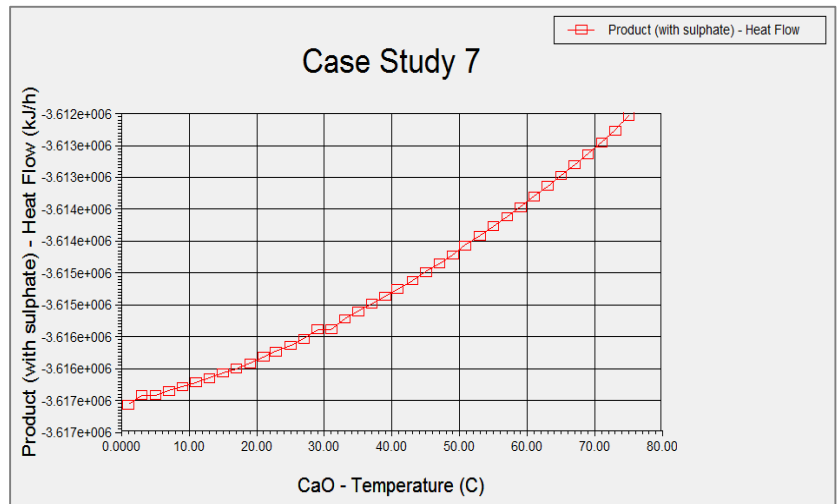Effect of the temperature of oil on the mass flow rate of biodiesel in the liquid product of the Reactor-

From graph 06, mass flow rate of biodiesel in the liquid product from Reactor-1, *i.e.*, biodiesel production, decreases with temperature of the oil fed to the reactor above 80°C. In the simulation, the heated oil temperature was kept at 60°C.
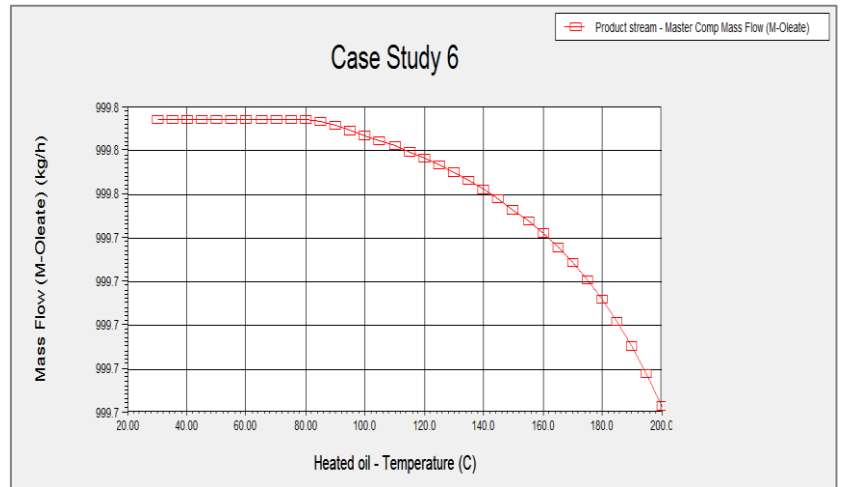
Graph 06: Effect of the temperature of heated oil on the mass flow rate of the liquid product of the Reactor-1

Case study 7: Effect of the temperature of CaO on the heat flow rate of the liquid product of the Reactor-2

From graph 07, the change in heat flow of the liquid product from Reactor-2 with increasing temperature of CaO, shows fluctuation when the temperature is below 18°C or greater than 44°C. Therefore, the temperature of CaO should be in between these two values. In this simulation, the temperature of CaO was set at 25°C, for which heat flow of the liquid product from Reactor-2 was 3.616×10^6 kJ/h.
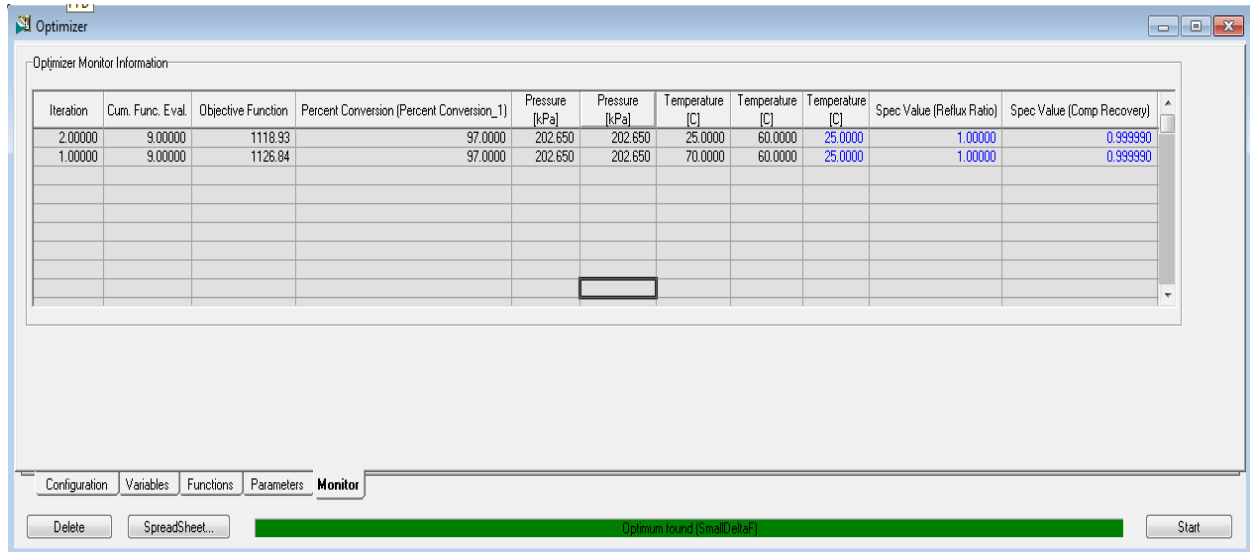

Graph 07: Effect of the temperature of CaO on the heat flow rate of the liquid product of the Reactor-2

5.2   Optimization

At the initial process condition, the profit was determined using HYSYS spreadsheet tool to be $1119/hr (Figure 09) and the annual profit was $7,385,000 (Figure 03). Optimum condition for maximum profit was obtained using HYSYS optimizer tool.

During the optimization process, only two iterations were needed to find the optimum situation, in which the profit reached its maximum value, $1127/hr.

Iteration	Cum. Func. Eval.	Objective Function	Percent Conversion (Percent Conversion_1)	Pressure [kPa]	Pressure [kPa]	Temperature [C]	Temperature [C]	Temperature [C]	Spec Value (Reflux Ratio)	Spec Value (Comp Recovery)
2.00000	9.00000	1118.93	97.0000	202.650	202.650	25.0000	60.0000	25.0000	1.00000	0.999990
1.00000	9.00000	1126.84	97.0000	202.650	202.650	70.0000	60.0000	25.0000	1.00000	0.999990

Figure 07: View of optimizer monitor

Optimized value of primary variables

After optimization, the significant change seen was in the increase in temperature of the product stream from the Reactor-1. This change has been shown in Figure 08.
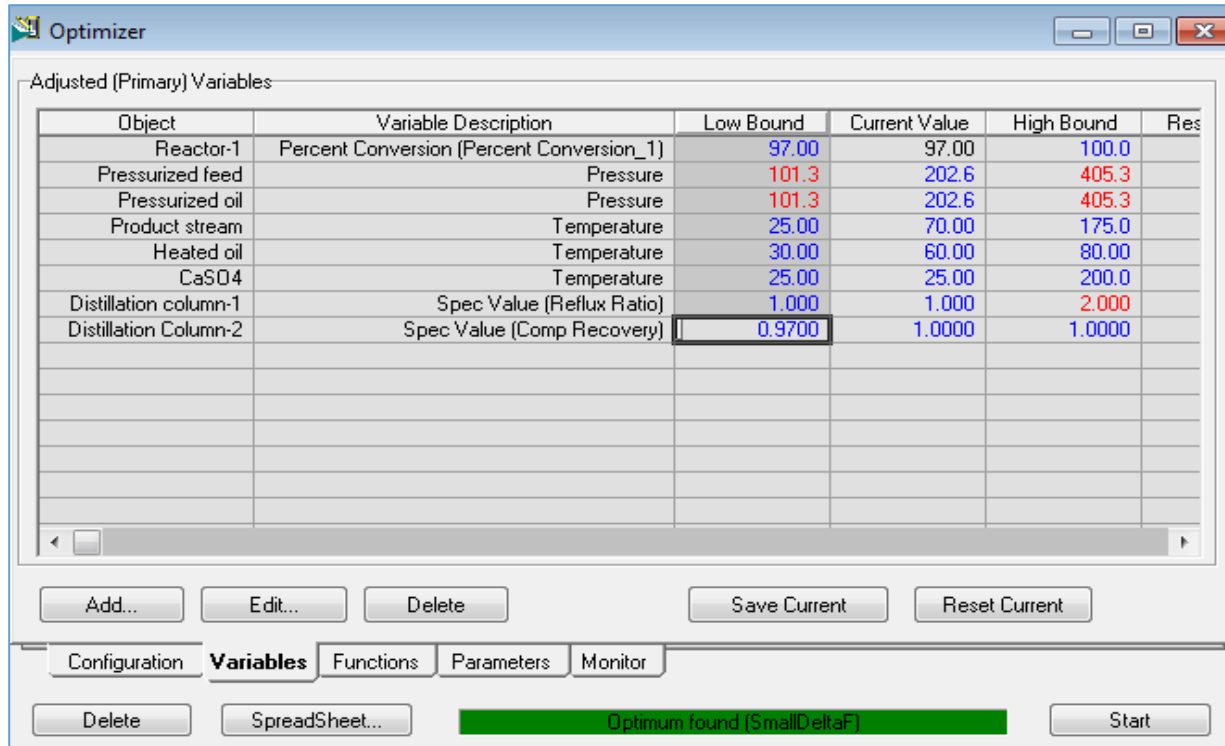
Figure 08: View of primary variables after optimization

Optimized value of profit

After optimization, the temperature of the product stream from Reactor-1 changed. Consequently, there were changes in reactor heat, *i.e.*, heat generated in Reactor-1 and condenser and reboiler duty of Distillation column-1. The maximized profit was found to be $1127 per hour which resulted in an annual profit of $7,437,000. The spreadsheet after optimization has been shown in Figure 09.
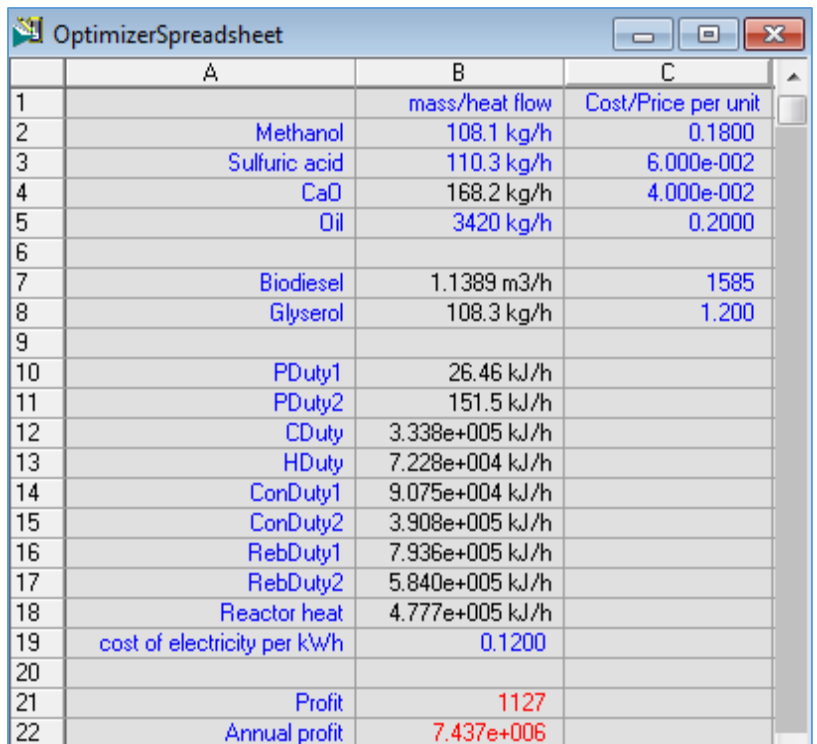

Figure 09: View of optimized spreadsheet

Conclusion

For dealing with the worldwide energy crisis, biodiesel is a promising alternative to non-renewable energy sources. In this project, a plant, to produce biodiesel using transesterification of triolein in presence of homogeneous acid catalyst was designed, and also analyzed to assess economic viability. The feasibility of a plant includes both technological and economic aspects, and therefore, various factors, such as, altering reactor specifications, changing reactor temperatures and greater reactivity of raw materials in presence of the acid catalyst as well as accessibility of the raw materials and catalyst and their provision cost, variations in the design conditions of distillation towers, the required extent of purification of the final product etc. have major influence on the quality, and consequently, on the price of the final products. While determining profit, it was found that raw materials consumed in the process accounts for a major portion of the manufacturing cost, and, further modification of the process may yield better economic outcome.

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