Exergy analysis of biodiesel production process from vegetable oil using aspen plus

By

Muzammil Hussain

School of Chemical and Materials Engineering

National University of Sciences and Technology

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Exergy analysis of biodiesel production process from vegetable oil using aspen plus

Name: Muzammil Hussain

Reg.No: 00000318396

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Supervisor Name: Dr. Muhammad Nouman Aslam Khan

School of Chemical and Materials Engineering (SCME)

National University of Sciences and Technology (NUST)

H-12 Islamabad, Pakistan

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Declaration

I have clarified that my research work on "Exergy Analysis of biodiesel production process'' is my own doing work. This work is not doing any one before or nothing has published a research paper. The data has been used in this research paper are referred properly.

Signature of Student

Muzammil Hussain

00000318396

Dedication

This work is dedicated to my parents, all my teachers
and my friends for their endless support and encouragement
during research work

Acknowledgment

I would like to express my sincere gratitude to Dr. Muhammad Nouman Aslam Khan and Dr. Iftikhar Ahmad salarzai and Head of the Department of SCME Chemical for allowing me to undertake this work. I am grateful to my Co-Supervisor Associate Professor Dr. Iftikhar Ahmad salarzai Department of Chemical engineering at SCME for his continuous guidance advice effort and invertible suggestion throughout the research. I am also grateful to my supervisor Dr. Muhammad Nouman Aslam Khan and GEC members for providing me the logistic support and their valuable suggestion to carry out my research successfully. I would like to express thanks to my genius junior Muhammad Husnain Saghir and Abdul Sammad for their valuable assistance during my work.

Abstract

Biodiesel is a good alternative to fulfill the demand for fossil fuels because of its properties, such as lower carbon footprint, nontoxicity, and biodegradability. The biodiesel production process is a highly energy-intensive process in view of cost. So there is a need to improve it in cost-effective and low energy and material consumption way. The pursuit of energy-efficient design has led to exergy because it can determine the process's true thermodynamic potential and cause of energy degradation in the process. This work performed exergy analysis on a biodiesel production plant from vegetable oil in an integrated Aspen plus and Excel. Using the Aspen Plus property package EXERGYFL, the physical exergy of the plant was calculated, and an integrated environment of Aspen Plus. For better quality analysis process is divided into three sections; transesterification and ethanol recovery, water washing and Fame production, and glycerol recovery. Then exergy destruction, exergy efficiencies, and exergetic improvement potential of the plant and sections were calculated which is 525.02kW, 32.59% and 353.89kW.

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List of abbreviations

Exergy	e_x
Physical Exergy	exphysical
Chemical exergy	$e_{xchemical}$
Artificial Neural Network	ANN
Enthalpy	ΔH
Entropy	S
Exergy in	e_{xin}
Exergy out	e_{xout}
Reaction rate constant	K
Standard temperature	T
Reference temperature	T_o
Carbon monoxide	CO
Greek letter (juttnur modulus)	Ψ

Chapter1

1 Introduction

The depletion of fossil fuels and global warming due to continuous increase in population, urbanization, industrialization and cost slope raised led us towards an alternative source of energy. Biodiesel is one of the attractive bio based fuels and the best alternative because of its properties, such as lower carbon footprint, nontoxicity, and biodegradability [1]. Biodiesel is defined as; it is monoalkyl ester of long chain fatty acid obtained from renewable feedstock. It emits less amount of CO, SO2 and particulate solids.it has better lubricity and high flash point [1].biodiesel is produced by chemical reaction i.e. Transesterification of vegetable oil with short chain alcohol like methanol or ethanol using a suitable catalyst to from Fatty acid methyl ester and glycerol as by product. Ultrasonic mixing in reactor make the production rate faster [2].biodiesel is more sustainable fuel for transportation. Its production process complexity and nonlinearity leading towards modeling process for their design, optimization and process monitoring [3]. There are various methods to produced biodiesel the most suitable are take less sulfur content and economically suitable raw material. Worldwide biodiesels production in last two decades is shown in figure 1.

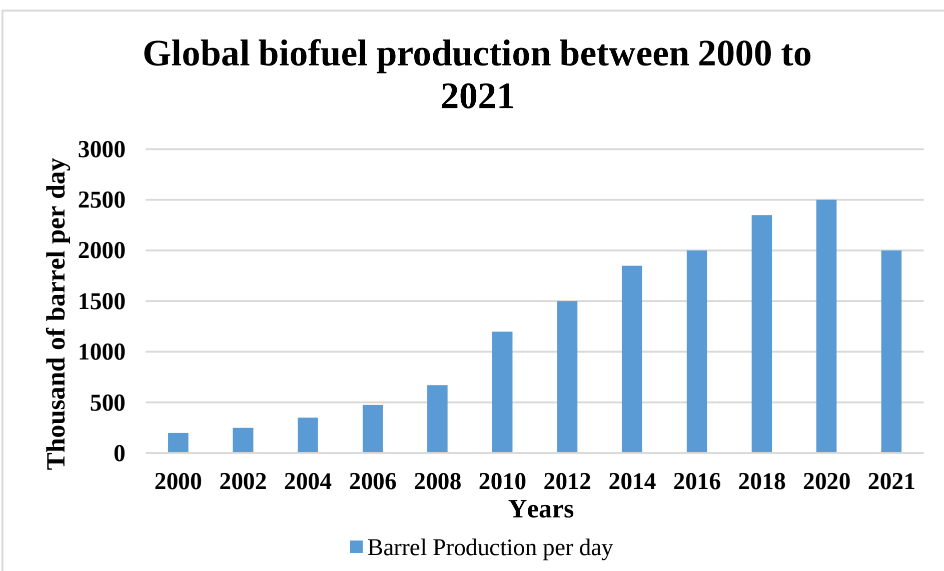


Figure 1 Global biofuel production between 2000 to 2021

Life cycle of biodiesel and simulation is made by Sergio Morais by three catalyzed method alkali based, acid based and supercritical Methanol Process in which alkali based catalyst show high efficiency than acid based catalyst but supercritical are higher efficient than both [4].

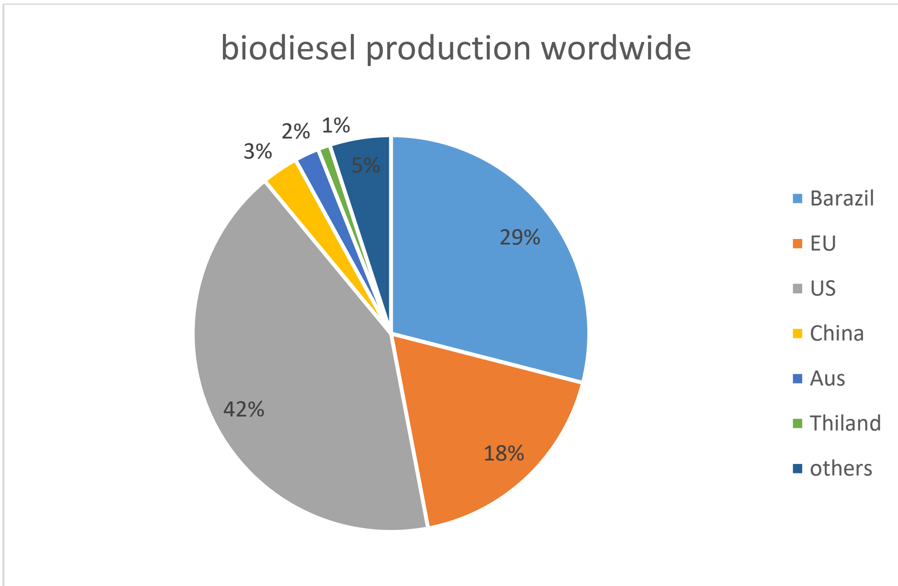


Figure 2 Biodiesel worldwide production in 2020

Biodiesel production total cost and capital cost is measured by using Aspen plus and Excel by Michael j Haa [5]. Biodiesel quality parameter are viscosity, density, heating value, iodine and cetane number.so according to Gustavo Apereyra-irujo the biodiesel obtained from sunflower oil is depend upon the its hybrid and weather condition which is different for different region [6]. Biodiesel is globally supplied to3.9 billion liters in 2005 to 18.1 billion in 2010, in continuous process 33 billion liter in 2016 and it will reach 41.4 billion liters 2025.biodiesel prices facing downward slope due to low petro oil prices. Many studies on sustainability of biodiesel life cycle assessment demonstrated that biodiesel show 80-20% less emission of greenhouse gases then petro oil. Curde oil extraction and refine is highly energy intensive which is found less in biodiesel. Biodiesel show less climatic harmful particles [7].

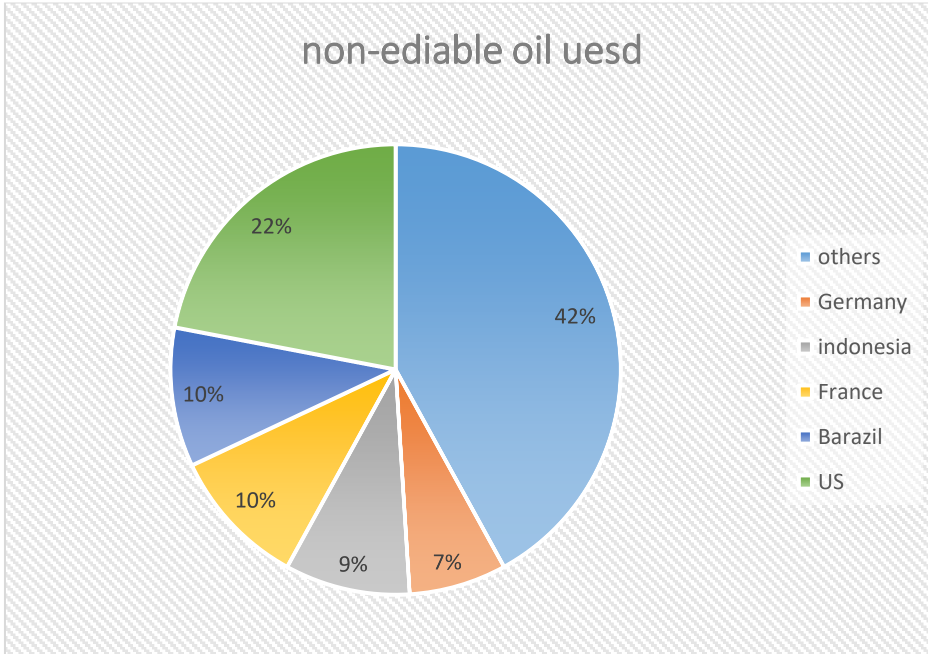


Figure 3 a review on non-edible used for biodiesel production

Pakistan is rich in agriculture which can produce lot of biomass like vegetable oil, animal waste and fats. Biofuels are considering best source of renewable energy to fulfill energy crises in countries like Pakistan. Waste cooking oil produce in industries can also be used for biodiesel production and resolve the waste management issue. Simulation results show that waste cooking biodiesel production cost is 0.66USD/L [8].

1.1 Thesis outline:

Basic introduction concept, Theoretical work, reaction and properties and Exergy concept discuss in chapter 1. Literature review and basic exergy concept and formulation is done in chapter 2. The methodology option of physical exergy analysis with whole procedure is discuss in Chp3. Results are representing in chapter 4, conclusions are discussing in chapter 5. After that reference and bibtex are added.

1.2 Theoretical Background:

1.2.1 Biodiesel Production Process:

Process description:

The biodiesel production process involves a series of steps; including transesterification reaction and methanol recovery, water washing, Fame Purification, and Glycerol separations.

1.2.2 Transesterification reaction and Methanol recovery:

Transesterification is a major process for biodiesel production, followed by glycerin, methanol recovery, and fame production. Noah and Methanol (MeOH) are fed into a mixer where a meth-oxide reaction occurs. It is then fed into the reaction chamber (R1). Vegetable oil from other feed sections is heated up to the required temperature condition and then fed to the reaction chamber where the transesterification reaction occurs. The product from the reactor is sent to the separator (Sp1). An excess amount of methanol is collected upstream and recycled.

1.2.3 Water washing & Fame Purification:

Fatty acid methyl esters (FAME) are collected downstream of Sp1 and sent to the separator (Sp2) for further process purification. The glycerol, excess methanol, and catalyst are removed from fatty acid methyl ester by the water washing process in Sp2. Then, the top stream of the Sp2 mixture of oil and FAME is sent to Separator (Sp3) for further oil separation and to get pure FAME.

1.2.4 Glycerol separations:

The bottom stream from sp2 is sent towards the reactor (R2). Stream flow is neutralized using phosphoric acid in reactor (R2) and moved towards Separator (Sp4). Solid particles are removed by filtration in Separator (Sp4). Separator (Sp4) effluent is sent to Separator (Sp5) where water and glycerol are obtained as pure by-products [9].

A process flow diagram of biodiesel production from vegetable oil is shown in

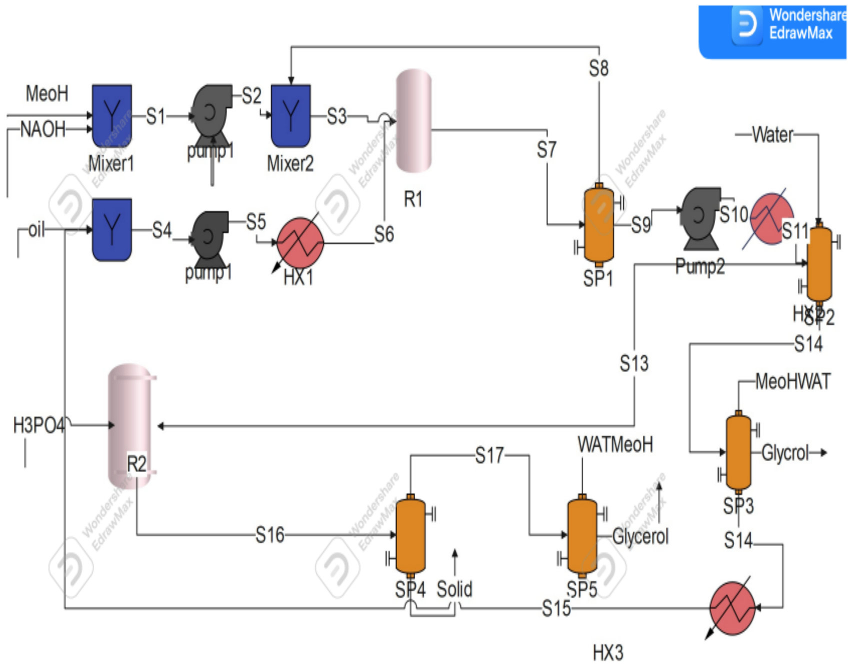


Figure 4 biodiesel production process block diagram

1.3 Chemical reaction:

Oil + alcohol → biodiesel + glycerin

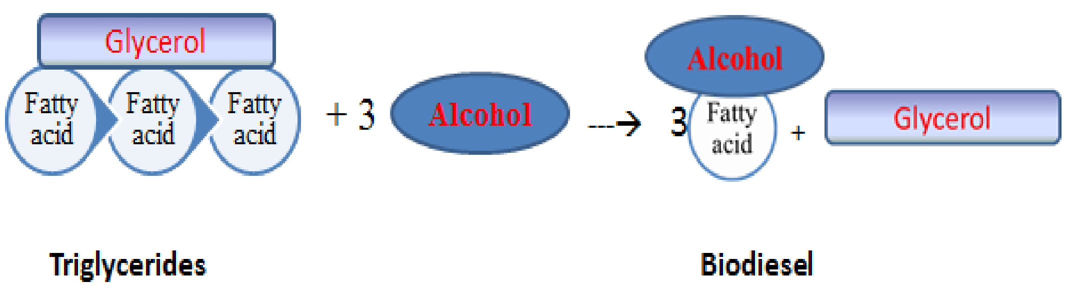


Figure 5 show actual reaction

Tranestrification:

Triglycerides + ROH ⇌ Diglycerides + RCOOR

Diglycerides + ROH ⇌ Monoglycerides +RCOOR

Monoglycerides +ROH ⇌ Glycerol + RCOOR

1.4 Thermodynamics and Reaction Kinetics:

Thermodynamics properties of biofuels reactant and product have significant role in determine the kinetics of reaction rate and phase separations. Thermodynamic properties of final product show flow, combustion and storage characteristics. Generally thermodynamic properties like boiling point, pour point, flash point and cloud point of biodiesels is higher than diesel

1.5 Advantage:

Biodiesel is renewable fuel, made from vegetable oil, animal dung and fat.

Less toxic as compared to Petro diesel.

It is environmental friendly emits less amount of Co, polycyclic aromatic hydrocarbons, particulate solids.

It emits less amount of carcinogenic substance.

No sulfur oxide emission

It can easily blend and directly can be used in diesel engine without modification.

Wastes cooking oil can also be used as raw material for biodiesels production.

1.6 Disadvantage:

Biodiesel is biodegradable so it cannot store more than six months.

It can dissolve the contamination present into tank so make the tank clean before storage.

It can degrade plastic and rubber so use Teflon tanks are used to eliminate this problem.

Uses:

Biodiesel used in Transport, chemical reaction, in making electricity and biogas can obtain from cow dung and other biomaterial.

Glycerol obtained as by product of biodiesel production can be used in pharmaceutical, cosmetic and as lubrication of molds [10].

1.7 Exergy Analysis:

Our Natural sources of biodiesel production are also limited and we need to generate sustainability in Production of biodiesel. Biodiesel production process is highly energy intensive due to high temperature and pressure requirement for better catalytic activity and product quality. Energy efficient process design is required to make it more economically suitable. Exergy analysis is the basic tool to find useful amount of energy during process and analysis the thermodynamic properties. It calculation depend upon 1st and 2nd law of thermodynamics analysis. According to 1st law of thermodynamic energy of a closed system is conserved, but according to 2nd law of thermodynamic energy is not conserved. It wastes during the process or destruction of Exergy is also produced. To optimize the thermodynamic values Exergy analysis is only the way to assess the energy analysis. Exergy analysis decides where to improve the existing process and where to change it. Exergy analysis determine the actual desire result, define the boundary condition by determine the environmental interaction with system. Determine the reversibility, irreversibility of system energy and measure process efficiency. Discuss process inlet and outlet and determine how to improve it. Exergy is defined as the maximum useful amount of work obtained from energy carriers under environmental conditions. It depends upon energy carrier and environmental states. It also directly links with economic because on industrial basis user have to pay for Exergy not for energy. Exergy is basically dived into four components like physical, chemical, potential, kinetic Exergy. The sum of physical, potential and kinetic Exergy is known as thermo-mechanical Exergy. Exergy is basic property. Exergy analysis of biodiesel production process is made on Aspen Plus. Process is optimizing by strong understanding. Biodiesel is produced from vegetable oil (Palm oil). According to 2nd law of thermodynamic the process occur spontaneously in one direction cannot be take place in other direction as well as energy is used to build it in restate form, like ice when melt cannot be transform it again by self. Entropy and Enthalpy are two major contributions in Exergy analysis of a process.

Entropy is defined as the physical quantity that represents the capacity of distribution of energy all over the energy level of constituent particle in a system. Enthalpy is measure of total heat present in thermodynamic system where pressure is constant [11].

In this topic we analyze exergy for each single unit and all production process. Exergy analysis is based on 2nd law of thermodynamic in which overall energy use and its destruction is measured. Exergy Analysis identifies the location, magnitude and thermodynamic deficiencies in energy used for process. We use aspen plus to analyses the exergy efficiency of biodiesel production from vegetable oil. It increases exergy efficiency up to 99% by physical and chemical exergy analysis. Entropy is opposite form of exergy causes due to irreversibility that reduce the efficiency

Reversible process is ideal changes but these are not found in nature so there are some processes that are very closely related to it. Process of Exergy analysis is made by ecosystem efficiency of process, industrial, thermos-economic and environmental impact of process. Energy is conserved does not observed in real life. Exergy consumption is proportional to entropy created. Entropy is opposite of Exergy. Exergy calculate both Quality and Quantity of energy involved with transformation of system. In fact, Exergy efficiency measure the degree of perfection of the process and improve it thermodynamically.it decrease the fuel consumption and improve process also by economic point of veiw.as there are large quantity of utility streams are used in process and therefore large amount of energy is consumed so Exergy become a crucial factor for that. Exergy analysis become more understandable by using highly oriented software like Aspen Plus. [12]

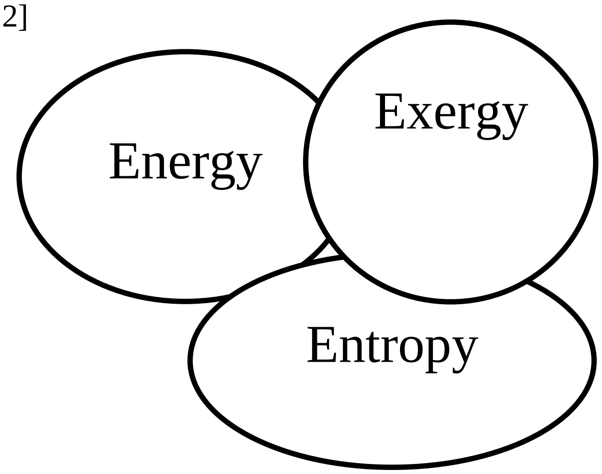


Figure 6: interaction of Entropy, energy and Exergy

Reference Environment: Reference environment is mostly considered as standard temperature and pressure. Any process will be in exergy balance when it became in equilibrium with its reference environment.

Exergy balances: according to first law of motion exergy will be equal as amount in and out through equipment but when practical perform it is less amount in outer side so, there is some exergy loss in this is due to irreversibility present in the system.

$$E_{xtotal} = E_{xK\cdot E} + E_{xP\cdot E} + E_{xphy} + E_{xchem}$$

Chapter 2

2 Literature review and objectives

This chapter is related to Physical Exergy Analysis of biodiesel Production by using Aspen Plus and Excel. This literature review is about to exergy analysis of biodiesel production process using aspen plus, excel and Matlab.

Arvind Kumar Madheshiya calculate the exergy and energy analysis of biodiesel produced from waste vegetable oil. A. Amelio study investigation on exergy analysis of biodiesel production using aspen plus. He clears that in exergy analysis reaction section has larges loss but in energy analysis separation process are important. He optimized the Exergy and energy concept using the same parameter but showing different results according to objective function.

Exergy analysis is previously known as considered as classical thermodynamics.it is also known as "available energy" or technical working capacities of a system. The exergy term alone used is enough instead of written as available energy, availability, potential work or useful energy. Some further predication and working of scientist.

Table 1 shows the exergy initiative work

Gibbs	Define the available work
Stodola	Derived expression for useful energy
Rant	Suggest the term exergy
Sazargut	New notation system
Kotas	Uniform the notation of exergy

A. Amelio describes that energy and exergy calculation has some difference in their calculations. He use Aspen plus V 7.3 to calculate exergy and energy values and demonstrated that exergy is much more beneficial than energy to calculate thermodynamic deficiency [13].Ali Gholami used exergy analysis of biodiesel production for three altering process of mechanical stirrer tank, ultra-cavitation and Hydrodynamic based cavitation process and compare three parameter for every process exergy destruction, exergy efficiency and waste emission. Ultra Cavitation process Leeds both in exergy efficiency of process. Hydrodynamic cavitation has more exergy efficiency and solves effect of phasing in reactor so use this instead of stirrer tank. HC eliminate waste stream, exergy destruction become half and increase exergy efficiency up to 6.2% [14].

Golmohammad khoobbakt analyses exergy flow by esterification and transesterification of waste cooking canola oil to reduce material and exergy consumption exergy analysis. Golmohammad used methanol: oil: catalyst and reaction temperature to achieve maximum exergy efficiency and minimize exergy destruction. He achieves 97%exergy efficiency & 4320Kj/kg of minimum exergy loss on methanol: oil ratio 8:1 and 1% concentration of catalyst at 55C [15].

Zoya A. Antonova analyzed exergy analysis in Belarus. He determines the physical and chemical exergy values of canola based oil.

Laura Talen's used Exergy flow analysis to determine waste exergy efficiency compare substitute and other type energy resources. Exergy losses shows 492MJ which can be reduce by using sulphuric acid and Koh as catalyst further improve the quality of waste cooking oil.

2.1 Exergy Analysis:

Exergy analysis use first and 2nd law of thermodynamic, to identify and quantify the exergy destruction and minimize its value and make it more energy efficient process. Many Process simulators are used like ChemCad, Matlab and Aspen (Hysys & Plus) are intensively used in process simulation. Chemical Exergy analysis is not performed in this simulator we use Excel or Forton for exergy analysis and then interface with any simulator.

Exergy: is defined as maximum amount work obtained by taking a stream from initial state to chemical and thermodynamic equilibrium with environment. (Naphtha)

$$\boldsymbol{e_{x_{total}} = e_{xchemical} + e_{xphysical}} \text{.................. } \mathbf{(1)}$$

Exergy analysis is used to design, evaluation and optimized the energy conversion system.

2.1.1 Physical Exergy:

Physical Exergy is defined as maxim work obtained in a physical process by taking stream from initial state to thermo-Mechanical state.

$$E_{phy} = m\,(h - h_o) - T_o(S - S_o) \text{ ………………………. (2)}$$

In this equation, m denotes mass, h enthalpy, and s entropy of stream, ho enthalpy, T_o temperature, and s_o is entropy of a stream at environment condition.

2.1.2 Chemical exergy:

Chemical exergy is the maximum work obtained when a substance is brought from the environmental state to the standard dead state with the environment. The chemical exergies are the sum of specific chemical exergy and molar fraction of different components.

$$E_{xchem} = m\left[\sum component, I\ x_{ie}xei\right] \ldots\ldots\ldots\ldots\ldots (3)$$

Specific chemical exergies of different elements can be taken from a thermodynamic table or calculated by their constituent element and component free energies of formation (g_f).

$$E_{xcomponent,i} = g_{f,i} + \sum n_{element,i}\ x_j e_{xj} \ldots\ldots\ldots\ldots (4)$$

Work exergy is defined as the actual amount of work taken by the thermodynamics process or amount of work is done by system when it comes into thermodynamic equilibrium with environment.

$$E_{xwork} = W \ldots\ldots\ldots\ldots (5)$$

According to the second thermodynamic law, heat is not entirely converted to work.it destruct into environment and other by product.

2.1.3 Heat exergy:

Heat exergy is defined as the amount of heat used to perform the thermodynamic process of work. Exergy of heat flow is only beneficial to work. The exergy of heat is calculated from the equation below.

$$E_{xheat} = Q\left(1 - \frac{T_o}{T}\right) \ldots\ldots\ldots\ldots\ldots (6)$$

All heat transfer across process boundaries towards the environment is heat destruction. Q denotes heat transfer, T_o be environment temperature and T is system temperature.

2.1.4 Exergy destruction:

Exergy destruction is a difference between the input and output exergies of the streams in a process. It represents the amount of destructed exergy in each unit of a process.

$$E_{xdestroyed} = \sum (E_{xin} - E_{xout}) \ldots\ldots\ldots(7)$$

This equation can be used for each unit to calculate irreversibility.

2.1.5 Exergy efficiency:

Exergy efficiency measures a system toward idealness (completely converted energies process). It gives a more accurate process evaluation than a conventional energy efficiency process. The following equation can evaluate it.

$$\Psi_{universal} = \frac{e_{out}}{e_{xin}} \ldots\ldots\ldots\ldots\ldots(8)$$

2.1.6 Exergy improvement potential:

Technology and economic constraint are used to improve exergy efficiency and minimize the irreversibility of a process. Exergy improvement is evaluated to find Exergy magnitude and compare improvement possibility by the following equation [[16]].

$$P = (1 - \psi)(E_{xin} - E_{xout}) \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

2.2 **Objective**:

- Physical and chemical Exergy analysis of biodiesel production process on Aspen Plus.
- Developing interface between Aspen Plus and Matlab to perform Multi objective Optimization of the model and to do chemical exergy analysis.
- Calculation of exergy destruction, exergy efficiencies and Improvement of energy utilization by exergy analysis of different unit in process and overall process by Aspen Plus.

Chapter 3

3 Methodology

The methodology adopted for exergy analysis of the biodiesel production process is as follows:

1. Biodiesel production process is divided into three sections: Transesterification reaction and Methanol recovery, Water washing & Fame Purification, and Glycerol separation.
2. EXERGYFL property set of Aspen Plus is used for the calculation of the physical exergy of the plant. Chemical exergies are calculated using the interface of Aspen Plus and Matlab.
3. Input and Output streams of three sections are identified. Exergy destruction and exergy efficiency equations are developed for each section based on equations and the values of exergy destruction and efficiency are calculated.

   Using the values of exergy destruction and efficiency, exergetic improvement potential values are calculated

I. Take the reference value of pressure and temperature from the user

II. Get the values of Gibbs free energy formation from the database provider

III. Split the chemical component into elements along with a stoichiometric coefficient.

IV. Get the values of chemical exergy of elements from a database and calculate standard molar chemical exergies of chemical compounds.

V. Get the composition of each material stream by doing flash calculations at the reference temperature and pressure and calculating the molar chemical exergy of a stream [17].

This work is related to physical exergy analysis of biodiesel production process from vegetable oil. This model is related to work of Iftikhar Ahmad uncertainty analysis. This is steady state model and used for mass and energy balance. Main process flow diagram as shown in fig 1.

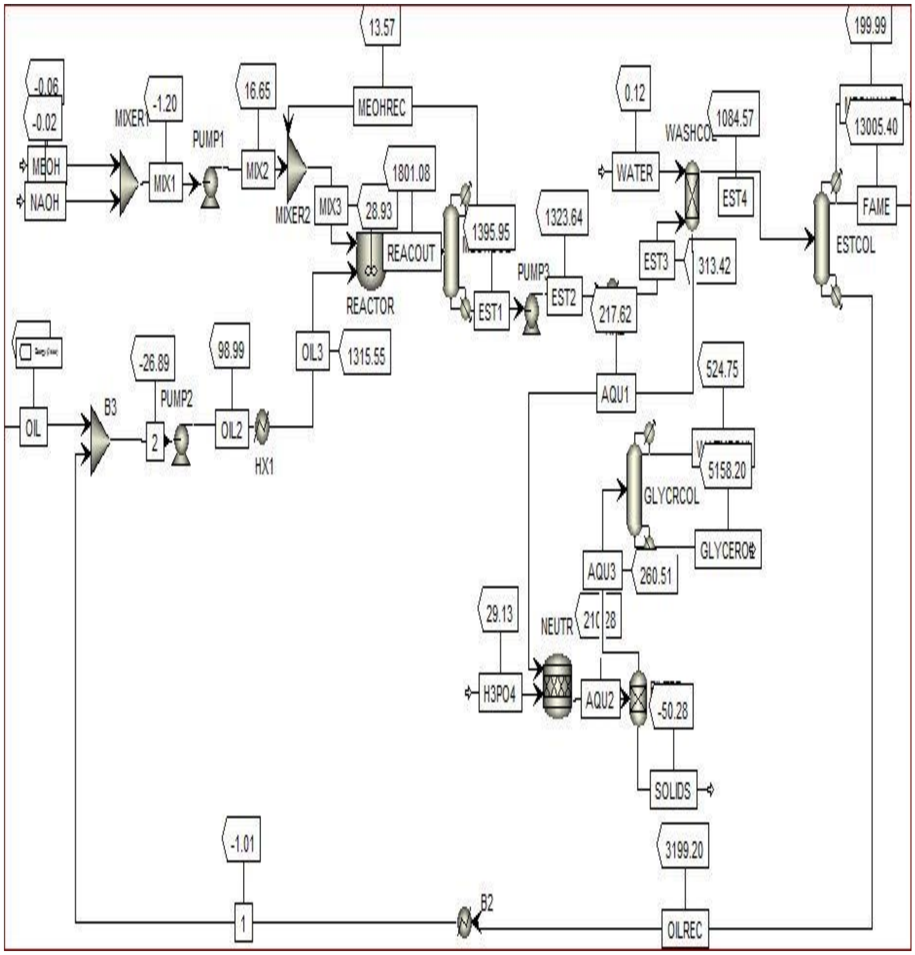


Figure 7 Process flow diagram of biodiesel production in aspen plus

NAOH and MEOH is used and mixed to form alkloxed in mixture 1 then pump is used to push the material in 2nd mixer. Work duty of pump is calculating in KW. Then send the material in reactor. Palm oil is used and pump it and heat it according to require temperature. We calculate heat exergy of heater by the formulation and then send it to reactor for transesterification reaction. Transesterification reaction is carried out at 60 c for 1 hr.

Exergy Analysis of every equipment of model**:**

Table 2.shows exergy destruction equation

Sr no	Equipment	Exergy equation
1	Mixer1	$e_{xdus} = e_{xnaoh} + e_{xmeoh} - e_{xmix1}$
		$e_{xefficency} = \frac{e_{xmix1}}{e_{xnaoh} + e_{xmeoh}}$
		$e_{xIP} = (1 - (e_{xdus} * e_{xefficency}))$
4	Pump1	$e_{xdus} = e_{xmix1} + w_p - e_{xmix2}$
		$e_{xefficency} = \frac{e_{xmix2}}{e_{xmix1} + W_p}$
		$e_{xIP} = (1 - (e_{xdus} * e_{xeficency})$
7	Mix2	$e_{xdus} = e_{xmeohrec} + e_{xmix2} - e_{xmix3}$
8	Mix3	$e_{xdus} = e_{xoil} + e_{x1} - e_{x2}$
9	Pump 2	$e_{xdus} = e_{x2} + W_{p2} - e_{xoil2}$
10	Hx1	$e_{xdus} = e_{oil2} + e_{xheat} - e_{xoil3}$

11	**Reactor**	$e_{xdus} = e_{xmix3} + e_{xoil3} - e_{xreactout}$
12	**Meohcol**	$e_{xdus} = (e_{xreactout} + e_{xreboiler}) - (e_{xmeohwat} + e_{xEst1})$
13	**Pump3**	$e_{xdus} = e_{xEst1} + W_{p3} - e_{xEst2}$
14	**HX2**	$e_{xdus} = e_{xEst2} - (e_{xEst3} - e_{xheat})$
15	**Washcol**	$e_{xdus} = e_{xEst3} + e_{xwater} - e_{xEst4} + e_{xAqu1}$
16	**Estcol**	$e_{xdus} = e_{xrebioler} + e_{xEst4} - (e_{xmeohwat} + e_{xFame} + e_{xoilRec} + e_{xcondsor}$
17	**Neuter**	$e_{xdus} = e_{xH3po4} + e_{xAqu1} - e_{xAqu2}$
18	**Filter**	$e_{xdus} = e_{xAqu2} - (e_{xsolid} + e_{xAqu3})$
19	**Glycerol**	

After that exergy were calculated by section wise. I divide it into three section because three major process are occurring like Transesterification and Methanol recovery(I), Water washing and FAME purification(II) and Glycerol purification(III). The section wise exergy calculation is based on equation below in Table 1& 2. We identify all input and output streams and utility streams given to each section and then we made calculation of exergy destruction and efficiency of all section. At the end we calculate overall plant exergy destruction, efficiency and improvement potential by follow the same procedures.

3.1 Exergy analysis of each section:

Table 3 show exergy destruction equations

Process Section	Exergy destruction equation
I	$(e_{x1} + e_{xoil} + e_{xmeoh+}e_{xnaoh} + e_{xwork} + e_{xaqu3} + e_{xreboiler}) - (e_{xEst1} + e_{xcondensor})$
II	$(e_{xEst1} + e_{xheatexergy} + e_{xwater} + e_{xreboiler} + e_{xheatmix3}) - (e_{xFAME} + e_{xMeohWat} + e_{x1} + e_{xAqu1} + e_{xcond})$
III	$e_{xAqu1} + e_{xH3PO4} + e_{xreboiler}) - (e_{xsolid} + e_{xglycerol} + e_{xWatmeoh} + e_{xcondonsor}$

Table 4 show exergy efficiency equations

Process Section	Exergy Efficiency equation
φ_I	$\frac{e_{xEst1} + e_{xcondosor}}{e_{x1} + e_{xoil} + e_{xmeoh} + e_{xNAOH} + e_{xwork} + e_{xAqu1} + e_{Est1heat} + e_{xrebo}}$
φ_{II}	$\frac{e_{xFAME} + e_{xmeohwat} + e_{x1} + e_{xAqu1} + e\_xcondosor}{e_{xEst1} + e_{xheat} + e_{xwater} + e_{xreboiler} + e_{xheater}}$
φ_{III}	$\frac{e_{xsoild} + e_{xglyceol} + e_{xwatmeoh} + e_{xcondoser}}{e_{xAqu1} + e_{xH3Po4} + e_{xreboiler}}$

Work of pump 2 is calculated form results which are in KW. Heat Exergy of Heater is defined by the formula of

Ex=Q (1-T_o/T)

Here Q is heat duty, T_o is reference temperature and T is internal stream or system temperature

Stream exergies are calculated with reference temperature

3.2 **Exergy destruction internally in stream**:

Internal exergy loss in a stream is also known as exergy destruction is due to entropy generation and thermodynamic imperfection in a process operation.

There are three type of exergy loss in a system without involving reference environment. Non-homogeneity, dissipative effect and chemical reaction.

Non homogeneities develop due to mixing of two or more components have different temperature and internal concentration. Dissipative effect is produce in stirrer tank. Entropy generated in a chemical reactor is directly proportional to chemical reaction progression.

3.3 Improvement ways of Exergy of a process:

- Driving force in a reaction should be uniform.
- If our reaction is exothermic we should increase the temperature and if our reaction is endothermic then we should decrease the temperature so that reaction or process performed in equilibrium conditions.
- Mostly try to use plug flow reactor
- Try to perform the reaction in Quasi-equilibrium conditions.

3.4 Exergy improvement of process**:**

There is some instrument that is used in a process of biodiesels and how we can improve their physical exergies.

Table 5 shows how to improve exergy analysis of equipment

Equipment	Effects	Improvement
Reactor	Minimum conversion	Recycle the waste, mixing reactant uniformly
Heat Exchanger	Temperature differ	Use minimum driving force,
	Pressure drop	Minimized the number of baffled in a process.
	Less heat transfer	Flow velocity should be optimized
Cold utility	Refrigeration	Minimum use the sub ambient system.
Pump	Hydraulic function	Hydraulic should be optimized

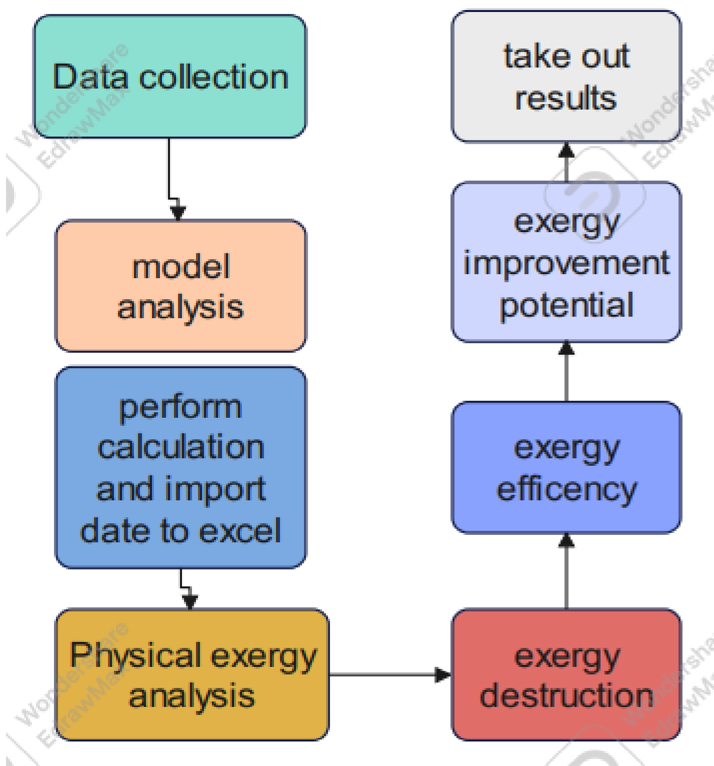


Figure 8 flow chart of process

Overall Plant Exergy: Overall exergy of process destruction is calculated by the formula of exergy destruction.

$$E_{xdustruction} = E_{in} - E_{xout}$$

3.5 Overall Plant Exergy destruction can be calculated by the formula:

$e_{xdustruct(overall)} = (e_{x1} + e_{x2} + e_{xAqu1} + e_{xAqu2} + e_{xAqu3} + e_{xEst1} + e_{xEst2} + e_{xEst3} + e_{xEst4} + e_{xH3PO4} + e_{xMEOH} + e_{xMEOHREC} + e_{xMEOHWAT} + e_{xmix1} + e_{xmix2} + e_{mix3} + e_{xNAOH} + e_{xoil} + e_{xwater} + e_{xHX3} + +e_{xESTCOL} + e_{xpump3} + e_{xMEOHCOL} + e_{xHX1} + e_{xpump2} + e_{xpump3}) - (e_{x1} + e_{x2} + e_{xAqu1} + e_{xAqu2} + e_{xAqu3} + e_{xEst1} + e_{xEst2} + e_{xEst3} + e_{xEst4} + e_{xFAME} + e_{xglycerol} + e_{xMEOHREC} + e_{xMEOHWAT} + e_{xmix1} + e_{xmix2} + e_{mix3} + e_{xoil2} + e_{xoil3} + e_{xoilREC} + e_{xREACTOUT} + e_{xsolid} + e_{xWATMEOH})$……………………. (10)

By using this equation, we can calculate the exergy destruction of overall plant and then using formula to calculate exergy efficiency and improvement potential. These values calculation is results are given in chapter 4.

Chapter 4

4 Results and Discussion

Exergy Analysis is beneficial in evaluation of a process or design and show the real potential of work, exergy deficiencies and how to improve it. Exergy loss express true loss produced in process and it give a direction towards ideal state. Exergy can be calculated for any process, it section and overall plant. Exergy analysis can have optimized and change the maximum output.

Exergy efficiency give us the true exergy destruction value of equipment.

Exergy efficiency = E_{xout}/E_{xin}

Physical exergy calculation was done on aspen plus. All calculation procedure of model physical exergy flow rate is given in figures and after that data was imported to excel and then further calculation is made.

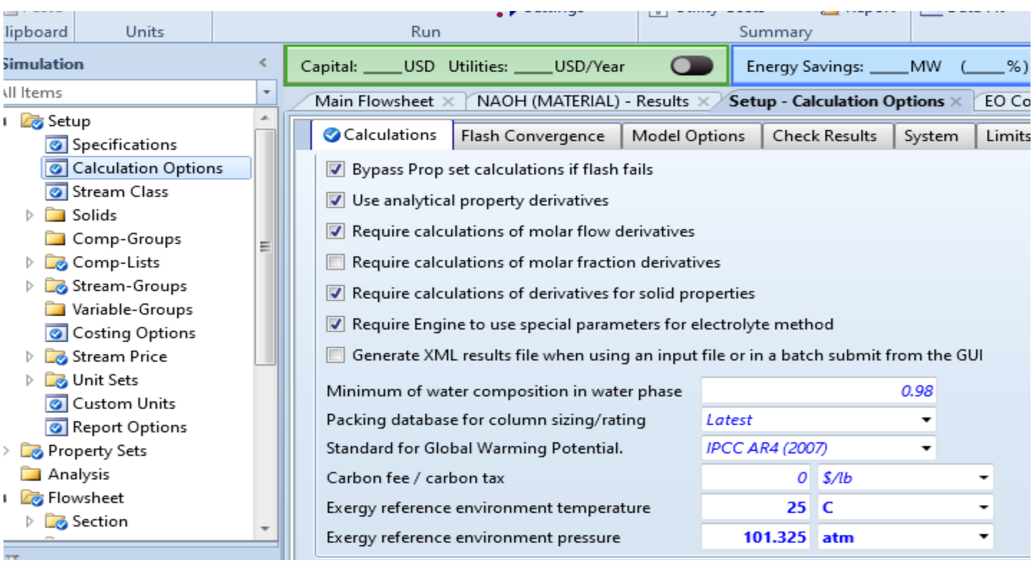


Figure 9 select exergy reference environment temperature and pressure

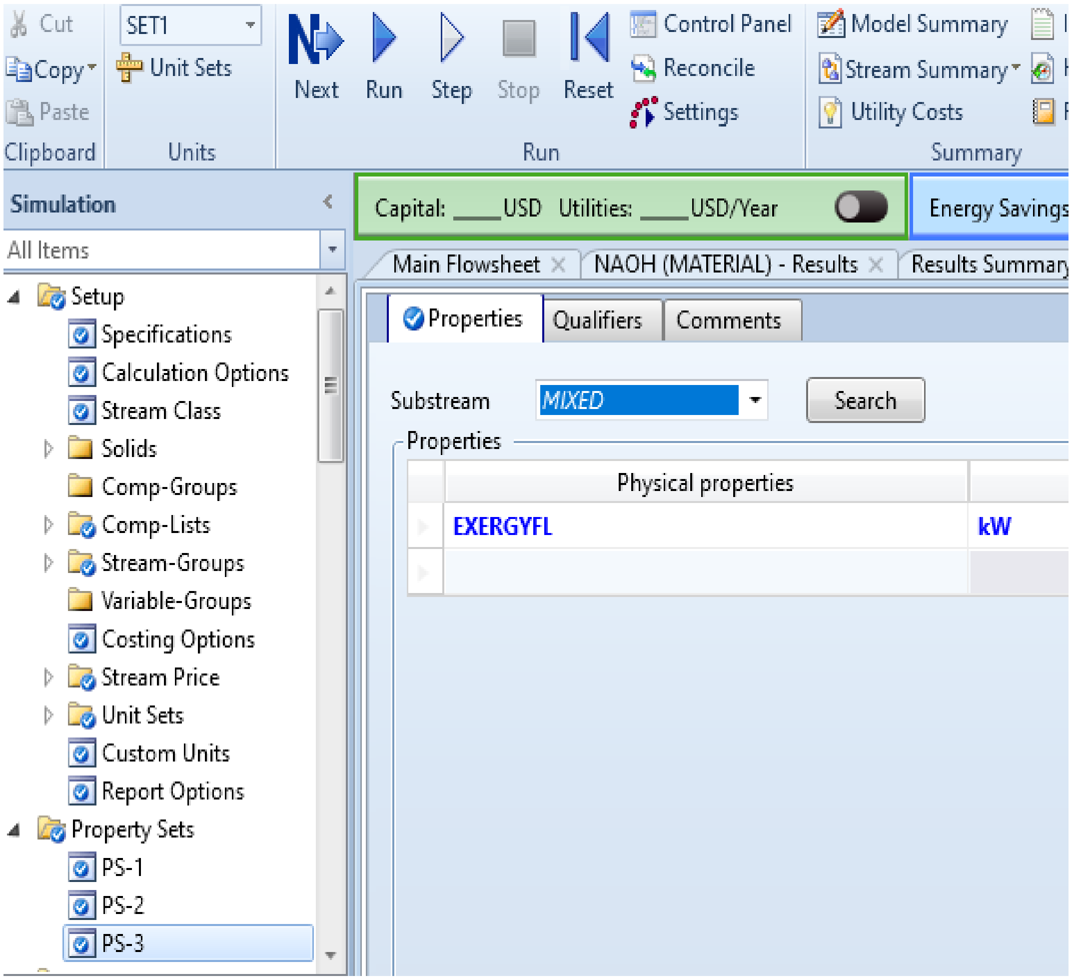


Figure 10 –select exergy calculation types from property set folder

Add unit of exergy as in above case it is kW. After selection of unit, if required then we can display values of temperature, pressure and volume flow rate from bar and added them to related property set and display.

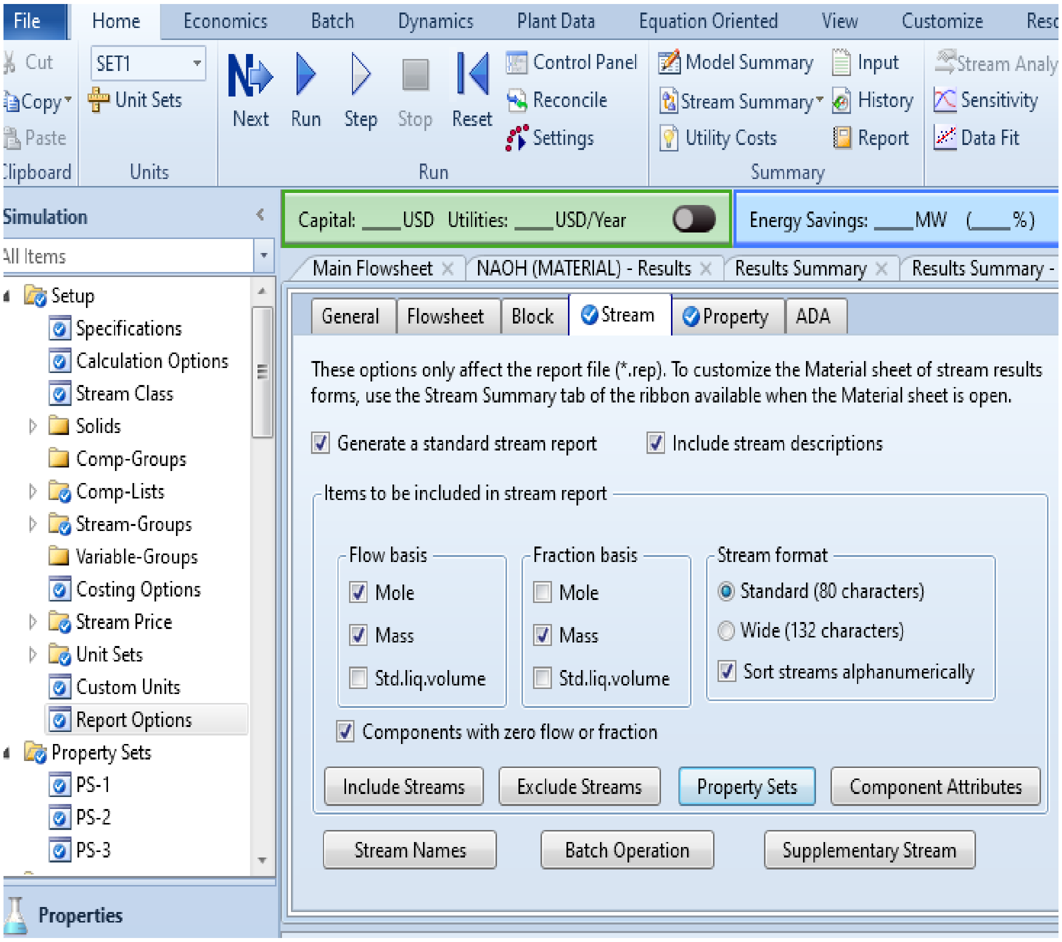
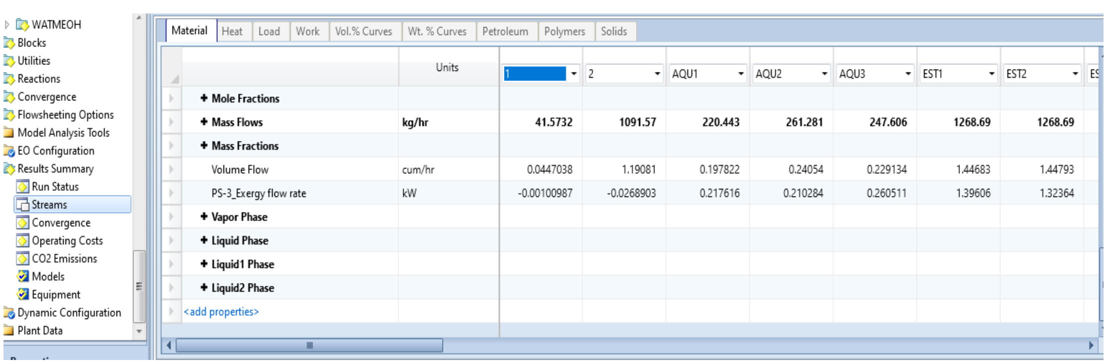


Figure 11 addition of properties set of exergy

After addition of property set run the model and check the stream results.



	Units	1	2	AQU1	AQU2	AQU3	EST1	EST2
+ Mole Fractions								
+ Mass Flows	kg/hr	41.5732	1091.57	220.443	261.281	247.606	1268.69	1268.69
+ Mass Fractions								
Volume Flow	cum/hr	0.0447038	1.19081	0.197822	0.24054	0.229134	1.44683	1.44793
PS-3_Exergy flow rate	kW	-0.00100987	-0.0268903	0.217616	0.210284	0.260511	1.39606	1.32364
+ Vapor Phase								
+ Liquid Phase								
+ Liquid1 Phase								
+ Liquid2 Phase								
<add properties>								

Figure 12 Exergy values display chart

4.1 Physical exergy calculations:

Table 6 shows physical exergies of all streams of biodiesel production process from vegetable oil

Stream Name	Mass flow rate(kg/hr)	Temperature C	Pressure(Bar)	Physical Exergy(KW)	Stream Name	Mass flow rate(kg/hr)	Temperature C	Pressure(Bar)	Physical Exergy(KW)
1	41.5732	25	0.2	-0.00100982	MEOHWAT	4.84932	148.3	0.1	0.199984
2	1091.57	24.8924	0.2	-0.0268903	MIX1	177.117	33.3985	1	-0.0011959
AQU1	220.443	60.933	1	0.217616	MIX2	177.117	33.6777	4	0.0166477
AQU2	261.281	50	1.1	0.210285	MIX3	177.117	32.1983	0.2	0.0289263
AQU3	247.606	50	1.1	0.260511	NAOH	299.875	25	1	-1.67E-05
EST1	1268.69	59.2095	0.2	1.39635	OIL	50	25	1	-0.00042187

EST2	1268.69	60.1193	1.1	1.32368	OIL2	1050	25.4232	4	0.0989888
EST3	12.68.69	60	1.1	1.31342	OIL3	1091.57	60	4	1.31555
EST4	1098.25	57.8379	1	1.08457	OILREC	41.5732	338.067	0.2	3.19905
FAME	1051.82	148.3	0.1	13.0054	REACOUT	1391.45	60	4	1.80108
GLYCEROL	114.173	262.198	0.5	5.15821	SOLIDS	13.6753	50	1.1	-0.0502826
H3PO4	40.8384	20	1.1	0.0291328	WATER	50	25	1.1	0.000121129
MEOH	127.117	25	1	-5.93E-05	WATMEOH	133.433	70.9371	0.4	0.524749
MEOHREC	122.117	28.8059	0.2						

I subdivide this biodiesel production process into three main section i.e. Transesterification and Methanol recovery, Water washing and FAME Purification and Glycerol separation. We calculate physical exergy as shown in table by using aspen properties and then calculate exergy destruction, exergy efficiency and improvement potential for all equipment in process, sections and for overall plant.

4.2 Exergy destruction:

The overall exergy destruction of all plants is 543.93kW. The transesterification and methanol recovery process have exergy destruction is 36.41kW, water washing and Fame production have an exergy destruction value of 282kW and glycerol recovery have exergy destruction values are 206.065kW. Exergy destruction peak value takes place in ESTCOL where FAME is produced and removes some impurities, water content, t, and methanol are recovered. Its value is 272.6083886kW which is 96% of overall exergy destruction of water washing and Fame Production. The basic reason of more exergy destruction in this unit is due to major separation process occur.

Table 7 shows exergy destruction of biodiesel production process of all sections and equipment's

Exergy Destruction of biodiesel production process of different sections and equipment		
Section	Equipment	Exergy Destruction(kW)
Transesterification & Methanol Recovery	Mixer 1	1.12E-03
	Pump 1	0.040850462
	Mixer2	0.0013037
	Mixer3	0.02545861
	Pump 2	0.299262505
	Heater1(HX1)	16.3385056
	Reactor	-0.4566037
	MEOHCOl	20.15124256
production Water washing & FAME	Pump-3	0.195095124
	HX2	0.034528072
	Washcol	0.011355129
	ESTCOL	272.6083886
	Total Exergy destruction	282.45
Glycerol Recovery	NEUTR	0.0364638
	FILTER	5.66E-05
	GLYCRCOL	206.0289138
	B2	9.726976087
	Total exergy destruction	206.065

Graphical values of exergy destruction are shown below in which reactor show negative value because chemical reaction is required so chemical exergy is not included so it need to further research.

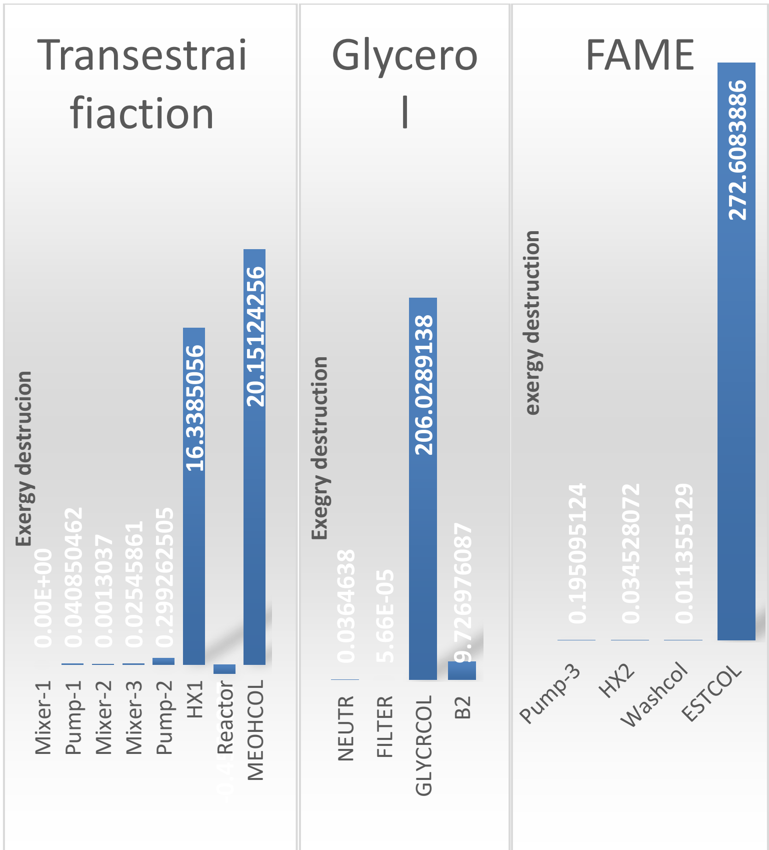


Figure 13 shows graphical values of exergy destruction of all section of biodiesel process

4.3 Exergy Efficiency:

The exergy efficiency of overall present in model of biodiesel is 32.59%. Transesterification and methanol recovery has exergy efficiency 69.45%. water washing and Fame production have exergy efficiency of 24.062% and glycerol recovery has 25. 60%.The maximum Exergy efficiency is of reactor which is 133.96% in part 1 and minimum exergy efficiency of heater which is 7.45%

Table 8 Shows exergy efficiency of biodiesel production process of all sections and equipment's

Exergy Destruction of biodiesel production process of different sections and equipment		
Section	Equipment	Exergy Destruction(kW)
Transesterification & Methanol Recovery	Mixer 1	1.12E-03
	Pump 1	0.040850462
	Mixer2	0.0013037
	Mixer3	0.02545861
	Pump 2	0.299262505
	Heater1(HX1)	16.3385056
	Reactor	-0.4566037
	MEOHCOl	20.15124256
production Water washing & FAME	Pump-3	0.195095124
	HX2	0.034528072
	Washcol	0.011355129
	ESTCOL	272.6083886
	Total Exergy destruction	282.45
Glycerol Recovery	NEUTR	0.0364638
	FILTER	5.66E-05
	GLYCRCOL	206.0289138
	B2	9.726976087
	Total exergy destruction	206.065

Graphical values of exergy efficiency of every section are shown below

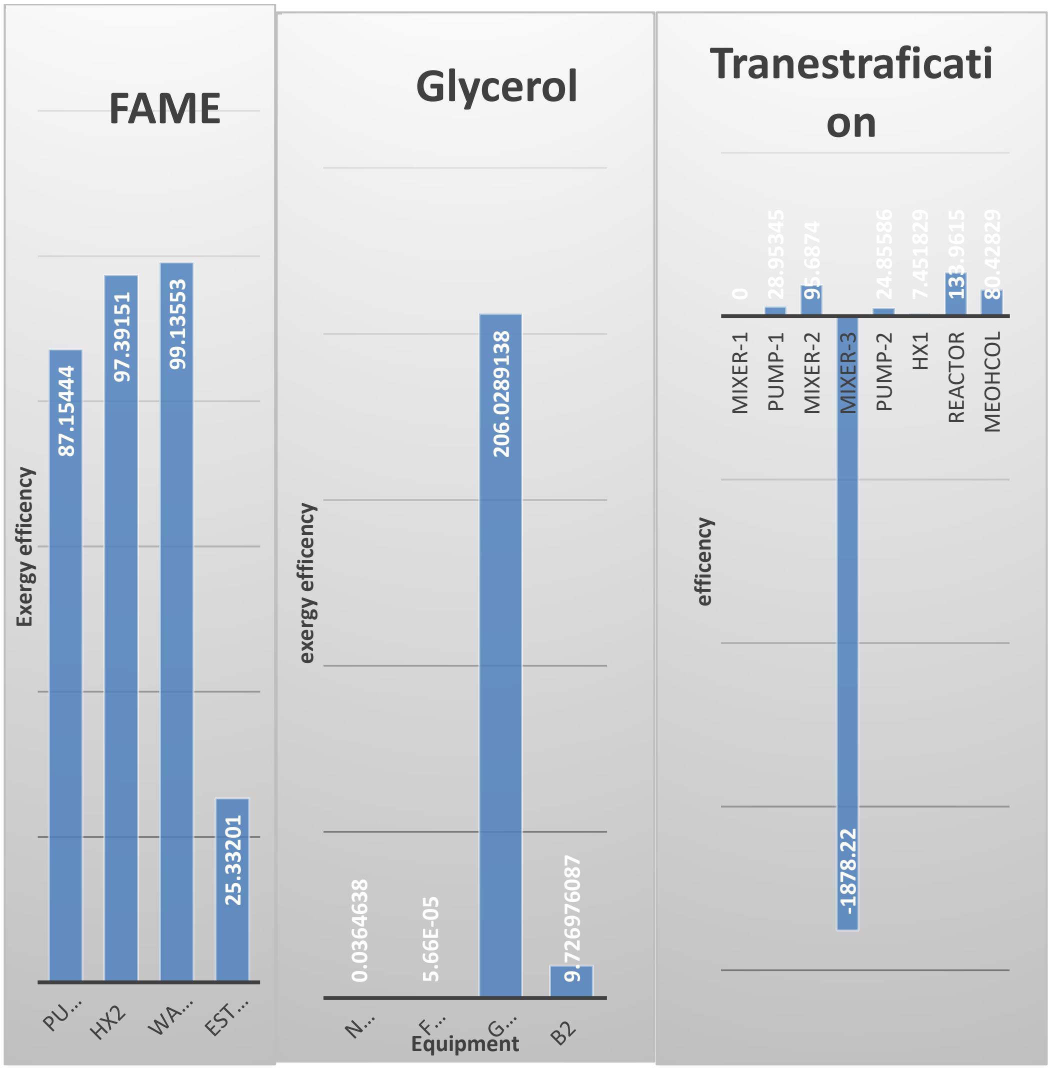


Figure 14 show exergy efficiency values for all section of biodiesel production process

4.4 **Exergy Improvement potential**:

The exergetic improvement potential of plant overall is 378kW. The transesterification and methanol recovery have exergy improvement potential is 11.2234kW, water washing and Fame production has 214.48 and glycerol recovery has 153.29kW. In section two ESTCOL has exergy destruction of 203.5512kW and glycerol has Exergy improvement potential of 153. 2371kW.Maximum exergy improvement potential is in ESTCOL which is 203.5512kW and This is 94%

Table 9 shows exergetic improvement potential of biodiesel production process of all sections and equipment's

Exergy improvement potential of biodiesel production process of different sections and equipment		
Section	Equipment	Exergy improvement potential (KW)
Transesterification & Methanol Recovery	Mixer 1	0
	Pump 1	0.029023
	Mixer2	5.62E-05
	Mixer3	0.503628
	Pump 2	0.224878
	Heater1(HX1)	15.12099
	Reactor	0.155069
	MEOHCOl	3.943942
	Total Exergy destruction	11.12
production Water washing & FAME	Pump-3	0.025061
	HX2	0.000901
	Washcol	9.82E-05
	ESTCOL	203.5512
	Total Exergy destruction	214.48
Glycerol Recovery	NEUTR	0.005389
	FILTER	1.52E-08
	GLYCRCOL	153.2371
	B2	9.727986
	Total exergy destruction	153.29
Overall plant Exergy improvement potential	All three sections	378.89

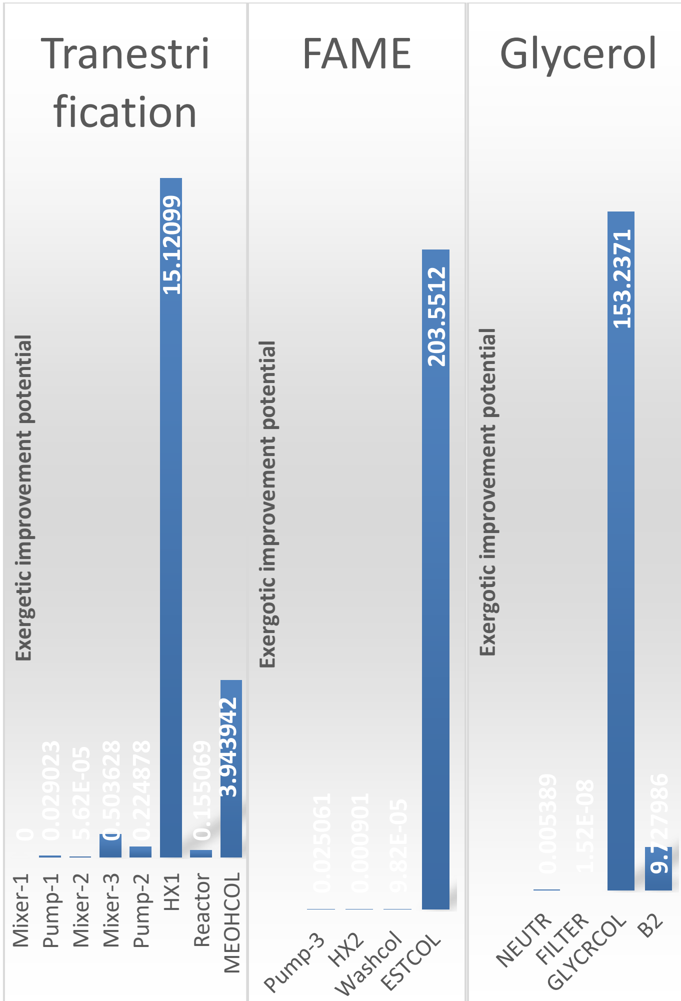


Figure 15 show exergy improvement value of all section of biodiesel production process

We identify the input and output of every section and develop equations that are used to calculate the values of all sections and overall plant.

Overall Exergy calculated in different sections in different section is given below.

4.5 Section Wise calculations:

4.5.1 Transesterification and Methanol recovery:

Exergy destruction values of section 1 is 36.42 kW, exergy efficiency is 69.45% and exergy improvement potential is11.12 kW.

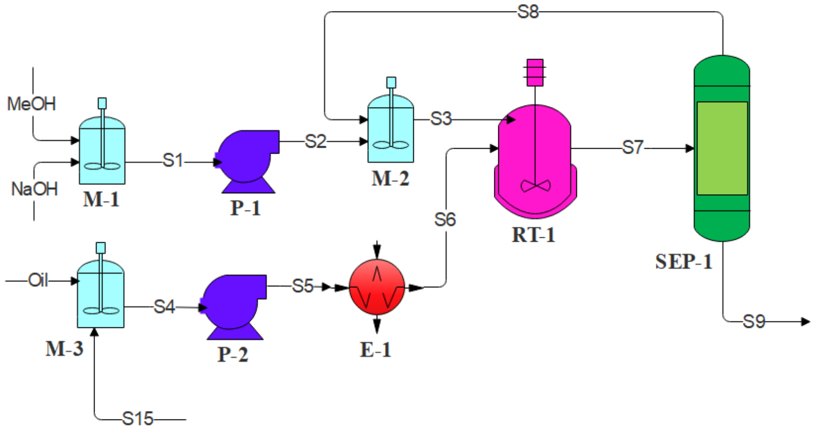


Figure 16 shows the Transesterification and methanol recovery section

4.5.2 Water washing and FAME Purification:

- Exergy destruction values of this section were 282.45 kW, Exergy efficiency 24.06% and Exergy improvement potential is 214.48kW.

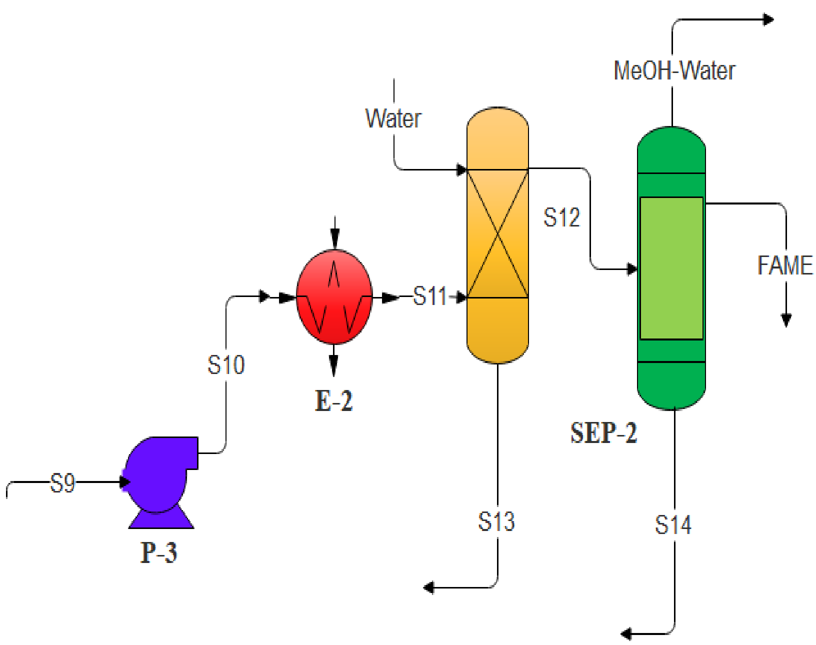


Figure 17 *shows water washing and Fame Production section.*

4.5.3 Glycerol purifications:

Exergy destruction in this section was 206.065kW, exergy efficiency is 25.06% and Exergy improvement potential is 153.29kW

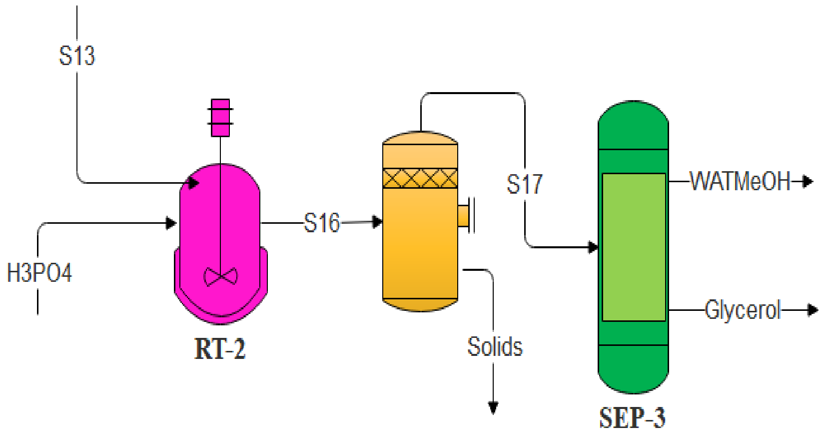


Figure 18 show the exergy Glycerol purification section

4.5.4 Overall plant:

The plant overall Exergy destruction values was 525.02 kW, exergy efficiency 32.59% and exergy improvement potential was 353.89kW.

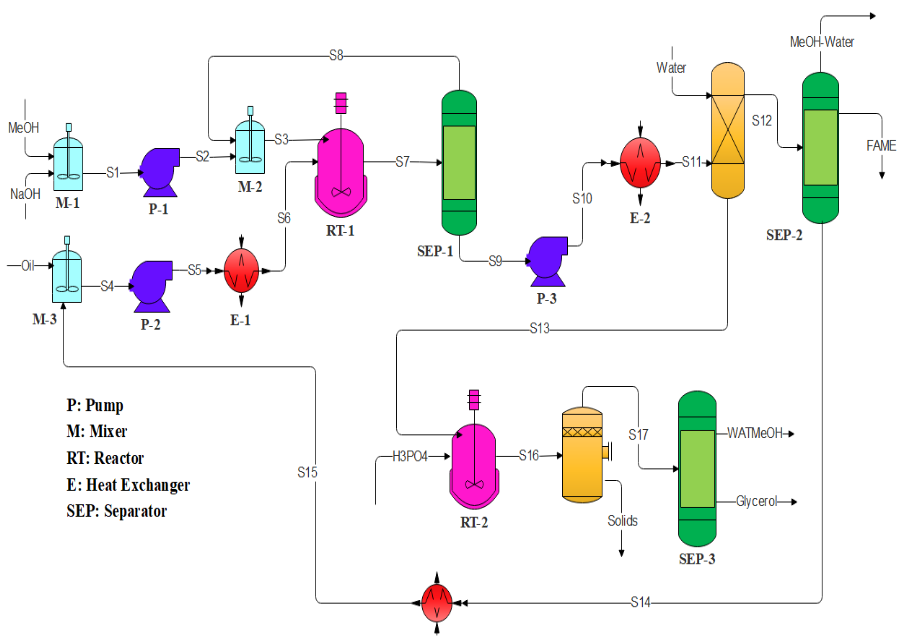


Figure 19 show the overall exergy calculation section

4.6 Excel sheet calculation figure:

Calculation of the values of exergy destruction, efficiency and improvement potential of every equipment, section and overall plant. We also calculate heat exergy of different equipment and identify work value of pumps.

Physical Exergy															
kW		EXERGY DESTRUCTION	EFFICENCY	EFFICENCY	IP			Heat exergy			Reboiler		condensor		Work
-0.00100982	Mixer-1	1.12E-03	1.57E+01			Work		-7.60E-05							0.058694
-0.0268903	Pump-1	0.040850462	0.289534471	28.95344709	0.029023	0.058694		0.087728162	0.045574		over all efficency				
0.217616	Mixer-2	0.0013037	0.956873966	95.68739663	5.62E-05			778.89	253.8665	0.325936	32.59357				
0.210285	Mixer-3	0.02545861	-18.78220844	-1878.22084	0.503628				overall ex	525.02					0.425142
0.260511	Pump-2	0.299262505	0.248558633	24.85586331	0.224878	0.425142			improvem	353.8963					
1.39635	HX1	16.3385056	0.074518288	7.451828802	15.12099			21.9438335	0.8	17.55507					
1.32368	Reator	-0.4566037	1.33961454	133.961454	0.155069										
1.31342	MEOHCOL	20.15124256	0.804282938	80.42829384	3.943942						118.02	101.16	-122.1	81.39992	0.122425
1.08457	Pump-3	0.195095124	0.87154443	87.15444302	0.025061	0.122425									
13.0054	HX2	0.034528072	0.973915091	97.39150911	0.000901			-0.097072289		0.024268					
5.15821	Washcol	0.011355129	0.99135533	99.13553305	9.82E-05										
0.0291328	ESTCOL	272.6083886	0.253320139	25.33201395	203.5512						373.3431	364.0095	-304.325	76.08125	
-5.93E-05	NEUTR	0.0364638	0.85222299	85.22229895	0.005389										
0.0135823	FILTER	5.66E-05	0.999730841	99.97308415	1.52E-08										
0.199984	GLYCRCOL	206.0289138	0.256234792	25.62347924	153.2371						283.8436	276.7475	-261.185	65.29613	
-0.0011959	B2	9.726976087	-0.000103827	-0.01038272	9.727986			-9.7903744	6.526916						
0.0166477	PART 1	36.41472196	0.694535529	69.45355292	11.1234										
0.0289263	PART 2	282.4539179	0.240627813	24.06278131	214.4876										
-1.67E-05	PART3	206.0654342	0.256065994	25.60659938	153.2991										
-0.00042187															

Figure 20 show the excel sheet of calculation

Conclusions

This work represents a physical and chemical exergy analysis of the biodiesel production process on Aspen Plus simulation v10 of each unit and section. The overall functional exergies efficiencies and exergy destructions are 32.59% and 525.36 kW. Estcol unit shows the highest exergy destruction values in water washing and fame Production which is 96% due to some major separation occurring. Mixer physical exergies are neglected due to minim values. Transesterification and methanol recovery section heater show minimum exergy efficiency which is 7.45%. Chemical Exergies are neglected in the overall process except in reactors where transesterification reaction is occurring.

Future Recommendations

Chemical exergy is an important factor to calculate in biodiesel production process due to chemical reaction take place

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