DESIGN OF A PLANT FOR THE PRODUCTION OF 100,000 TONNES PER ANNUM OF BIODIESEL FROM RAPESEED OIL

BY

SHITTU AMIDU

MAT NO. 2004/18538EH

SUBMITTED TO

DEPARTMENT OF CHEMICAL ENGINEERING, FEDERAL
UNIVERSITY OF TECHNOLOGY, MINNA,

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE, BACHELOR OF ENGINEERING (B.ENG) IN CHEMICAL ENGINEERING.

JANUARY, 2010

DECLARATION

I whole-heartedly declare that this design project is solely undertaken by me and has not been presented in this form for the award of degree elsewhere. Works of contributors have been greatly acknowledged.

Amidu Shittu

Signature

01|01|2010

Date

CERTIFICATION

This is to certify that this design was supervised, moderated, and approved by the following under listed persons: on behave of the Chemical Engineering Department, School of Engineering and Engineering Technology, Federal University of Technology, Minna, Nigeria.

04/01/2010

Engr. M.S Galadima
Project Supervisor

Signature and Date

Engr. J.O Okafor
H.O.D

Signature and Date

External Supervisor

Signature and Date

DEDICATION

I dedicated this project to Almighty ALLAH (S.W.T), with whom all things are possible. He is the Beginning and the End. His guidance, mercies, protection and love saw me through this project work. And to my loving and caring parent, my sisters and brothers. Their unrelenting support and fervent prayer towards my academic advancement are invaluable. All I am and all I have, was given to me by you all.

ACKNOWLEDGEMENT

My sincere and profound gratitude goes to Almighty Allah (S.W.T), most especially for granting me life and divine grace to accomplish my academic pursuit and also for granting me the opportunity to complete this work successfully.

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To my supportive classmate and colleagues, I say kudos for happy moments we shared together and the hard period we discussed over.

And finally to all that make my programme a success in one way or the other I pray for God's blessing continuously.

ABSTRACT

The design of a plant for the production of 100,000 tonnes of Biodiesel per annum from Rape seed oil was carried out using Transesterification reaction. The product from this plant is found to be compactable with all diesel combustion engines. The design covered the material and energy balance for the entire process. It also involves flow sheeting which shows the bulk flow of materials and various processes involved as well as the operating conditions, the sizing of all the equipment and its optimization. The Economic evaluation indicate a net profit of $1.199x10^7$ Naira per year from total annual sales of $1.69x10^7$ Naira per year. The rate of return and payback period was 16.415 % and 4.55 4year respectively, which shows the economic viability of this project.

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NOTATION

D	Diameter (m)
f	Frequency (Hz)
j	Stream Indices
m	Viscosity (kgm2 s_1)
N_j	Total mass flow of a stream j (kh/hr)
$n_{s,j}$	Mass flow rate of a component s in a given stream j (kg/hr)
r	Density (kgm_3)
Re_n	Net flow Reynolds number
Re_o	Oscillatory Reynolds number
Str	Strouhal number
s	Components Indices
v	Velocity (ms^{-1})
xo	Centre-to-peak amplitude
$x_{s,j}$	Mass compositions of components in a stream j
$y_{s,j}$	Molar compositions of components in a stream j
Z_j	Total molar flow of a stream j (kmol/hr)
$z_{s,j}$	Molar flow rate of a component s in a given stream j (kmol/hr)
y	Velocity ratio
FFA	Free Fatty Acids
TBHQ	t-butylhydroquinone

CHAPTER ONE

1.0 INTRODUCTION

Design is a creativity whereby ideas are generated and translated into processes and equipment for producing new materials or significantly upgrading the value of the existing once. In this case, the target of this project is to design a plant to produce biodiesel fuel. (Buraimoh, 2006)

The rising need for an alternative fuel that is not subjected to problems posed by the conventional fossil fuel is fast becoming inevitable. As such, a renewable non -toxic substitute is required to supplement or completely replace the conventional fuel, due to the increasing demand for these products.

Biodiesel fuel is a potential substitute for fossil diesel because of its huge benefits. It consists of methyl esters (biodiesel) of fatty acids produced by the transesterification reaction of natural oils with triglyceride composition with methanol using a homogenous catalyst such as sodium hydroxide. Glycerol, a useful raw material is also produced as a by-product from the process (Wang *et al.*, 2007).

Of the several methods available for producing biodiesel, transesterification of natural oils and fats is currently the method of choice. The purpose of the process is to lower the viscosity of the oil or fat. Transesterification is basically a sequential reaction. Triglycerides are first reduced to diglycerides, which are subsequently reduced to monoglycerides, which are finally reduced to fatty acid esters. The order of the reaction changes with the reaction conditions. The main factors affecting transesterification are the molar ratio of glycerides to alcohol, catalysts, reaction temperature and time, and free fatty acid and water content in oils and fats. Transesterification is extremely important for biodiesel (Ma et al, 1999).

In this project, Rapeseed oil is the focused source of natural oil needed in the transesterification process. Other source of triglycerides includes palm seed, sunflower seed, peanut, soya beans, castor seed etc. However, the most economical feasible of these seeds is the rapeseed since it is the preferred oil stock for biodiesel production in most part of the world. This is because, rape seed produce more oil per unit of land area compared to other natural seeds.

1.1 AIM AND OBJECTIVES OF THIS DESIGN PROJECT

The aim of this design project is to design a plant for the production of 100,000 tonnes per year of biodiesel fuel by the Transesterification of rapeseed oil with methanol aided by homogenous sodium hydroxide catalyst.

It is expected that this design project would achieve the following objectives to:

- Understand the important of the biodiesel fuel and the need for a potential substitute for fossil diesel oil.
- Highlight the characteristics, advantage, disadvantage, justification and limitation of the production of biodiesel fuel.
- Evaluate the process design and control, process flow diagram and equipment required for the production of biodiesel.
- Identify the idea of how to go about pilot plant, plant location and mechanical engineering design of the biodiesel fuel plant.

1.2 CHARACTERISTICS OF BIODIESEL FUEL

- It has a higher octane number and flash point than petroleum diesel
- Its viscosity is lower than diesel
- Its specific gravity is slightly higher than diesel
- It is biodegradable, non-toxic and free of sulphur and aromatics.

1.3 SIGNIFICANCE OF THE PROJECT

To increase energy self-sufficiency of non-oil producing countries and boost the availability of diesel fuel in oil producing nation through the following ways.

- Reduce pollution
- Create more employment opportunities.
- Provide a better alternative source of diesel fuel.
- Increase the demand for agricultural products.

1.4 DISADVANTAGES OF BIODIESEL FUEL

- High cost of production.
- Environmental impacts of increase fertilizer and pesticide usage to increase the oil seed production.
- It has a high viscosity than the conventional diesel and therefore becomes less useful at low temperature; hence, depressing agents and dissolving solvents may have to be added.

1.5 THE ECONOMIC COST AND EFFECTIVENESS OF BIODIESEL FUEL IN THE FUTURE.

In Malaysia and America, biodiesel fuel is more expensive than the conventional diesel but in European countries, biodiesel costs no more than diesel and can be up 5% cheaper as it is not subject to oil tax

Acceptance of biodiesel fuel is likely to increase over the year since it is non-toxic and has greater advantage than conventional diesel fuel. It is hope that in the near future more biodiesel plant will be set up in every country and hence, substitute consumption of conventional diesel from fossil fuel, through biodiesel is still not economically competitive nor is it seen to be the for-see-able future (DA Potts *et al,* 1999).

1.6 LIMITATION OF THE PROJECT

The cost of assembling the pilot scale set up for the manufacture of biodiesel is quite expensive. Rapeseed is not grown in this country hence it has to be imported from Europe for the course of this project. The feed prices are expensive ranging from £100/tonne for rapeseed oil to £200/tonne for sodium hydroxide.

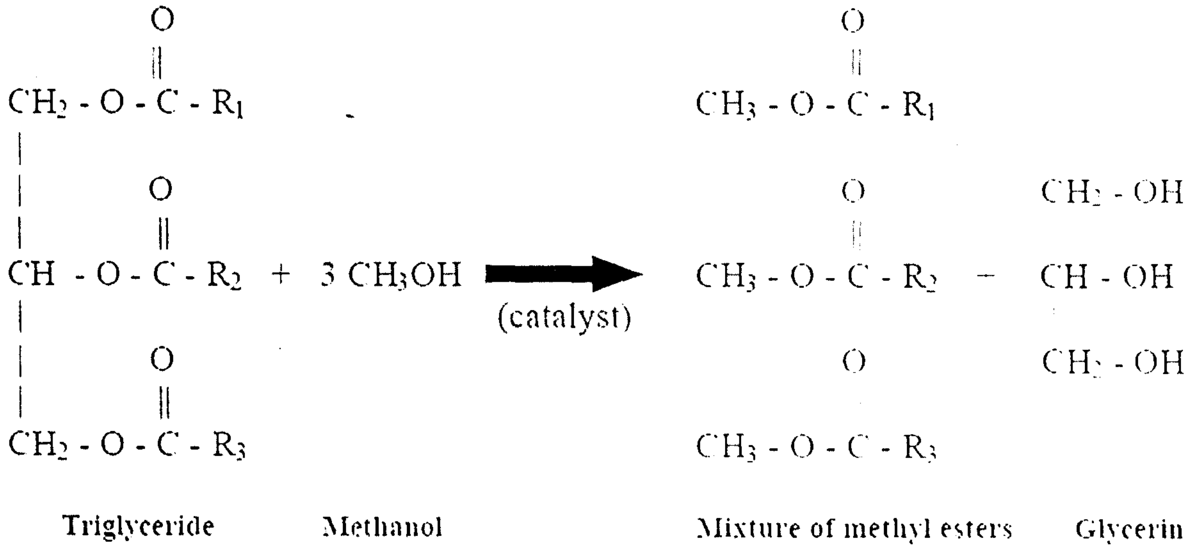
CHAPTER TWO

2.0 LITERATURE REVIEW

For comprehensive design of this project work literatures were reviewed to serve as a guide toward successful completion.

2.1 BIODIESEL

Biodiesel, defined as monoalkyl esters of vegetable oils or animal fats is a promising alternative fuel for use in compression-ignition (diesel) engines and is being produced in commercial quantity and used in various countries around the world, including the United States, Austria, The Czech Republic, France, Germany, Italy, Malaysia and Sweden(Gerhard Knothe,2001). It is produced by chemically reacting a fat or oil with an alcohol, in the presence of a catalyst. The product of the reaction is a mixture of methyl esters, which are known as biodiesel, and glycerol, which is a high value co-product. The process used is known as transesterification, and is shown in the equation below, where R_1, R_2, and R_3 are long hydrocarbon chains, sometimes called fatty acid chains.



$$\begin{array}{l} CH_2-O-\overset{\overset{O}{\|}}{C}-R_1 \\ CH-O-\overset{\overset{O}{\|}}{C}-R_2 \\ CH_2-O-\overset{\overset{O}{\|}}{C}-R_3 \end{array} + 3\,CH_3OH \xrightarrow[\text{(catalyst)}]{} \begin{array}{l} CH_3-O-\overset{\overset{O}{\|}}{C}-R_1 \\ CH_3-O-\overset{\overset{O}{\|}}{C}-R_2 \\ CH_3-O-\overset{\overset{O}{\|}}{C}-R_3 \end{array} - \begin{array}{l} CH_2-OH \\ CH-OH \\ CH_2-OH \end{array}$$

There are five chains that are common in most vegetable oils and animal fats (others are present in small amounts). The relative amounts of the five methyl esters determine the physical

properties of the fuel, including the cetane number (a combustion-related diesel fuel quality index), cold flow, and oxidative stability.(Van Gerpen and M. Canakci, 1997)

2.2 Characteristics and Specifications Biodiesel

As biodiesel is produced from a wide variety of vegetable oils of varying origin and quality, it was necessary to implement criteria for standardization of fuel quality for better engine performance. Austria was the pioneering country in the world to define and approve the standards for rapeseed oil methyl esters as diesel fuel (Meher et al. 2006). As standardization is a prerequisite for quality control, certain parameters are considered for the purpose, of which cetane number and fuel viscosity are important ones. The detailed physical attributes of biodiesel produced following the transesterification process given in Table1 and Table 2 depicts the vegetable oil specific parameters and the corresponding value of fatty acid methyl esters according to select countries.

2.3 Current Technologies in Biodiesel Production

Of the several methods available for producing biodiesel, transesterification of natural oils and fats is currently the method of choice. The purpose of the process is to lower the viscosity of the oil or fat. Transesterification is basically a sequential reaction. Triglycerides are first reduced to diglycerides, which are subsequently reduced to monoglycerides, which are finally reduced to fatty acid esters.

The order of the reaction changes with the reaction conditions. The main factors affecting transesterification are the molar ratio of glycerides to alcohol, catalysts, reaction temperature and time, and free fatty acid and water content in oils and fats. Transesterification is extremely important for biodiesel. Biodiesel as it is defined today is obtained by transesterifying triglycerides with methanol. Methanol is the preferred alcohol for obtaining biodiesel because it is the cheapest alcohol.

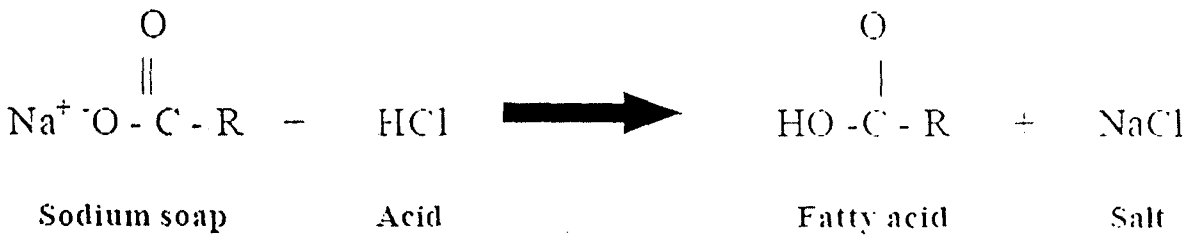
Base catalysts are more effective than acid catalysts and enzymes (Ma and Hanna, 1999). Methanol is made to react with triglycerides to produce methyl esters (biodiesel) and glycerol

2.3.1 TRANSESTERIFICATION

Transesterification is the general term used to describe the important class of organic reactions where an ester is transformed into another through the interchange of alkoxy when the original ester is reacted with an alcohol. Transesterification also known as alcoholysis of carboxylic esters, which is based on the chemical reaction of triglycerides with an alcohol in the presence of an alkaline catalyst to form a mixture of methyl esters, which are known as biodiesel and glycerine, which is a high value co-product. Transesterification is a reversible reaction. Thus, excess methanol is required to shift the equilibrium favourably. The transesterification process as shown in the equation below, where R_1, R_2, and R_3 are long chain hydrocarbon (Jon Van Gerpen, 2008).

2.3.1.1 Alkali-catalyzed Transesterification

Figure 1 shows a schematic diagram of the processes involved in biodiesel production from feedstocks containing low levels of free fatty acids (FFA). This includes soybean oil, canola (rapeseed) oil, and the higher grades of waste restaurant oils. Alcohol, catalyst, and oil are combined in a reactor and agitated for approximately one hour at 60°C. Smaller plants often use batch reactors (W.D. Stidham et al,2000) but most larger plants (> 4 million liters/yr) use continuous flow processes involving continuous stirred-tank reactors (CSTR) or plug flow reactors (G. Assman,1996). The reaction is sometimes done in two steps where approximately 80% of the alcohol and catalyst is added to the oil in a first stage CSTR. Then, the product stream from this reactor goes through a glycerol removal step before entering a second CSTR. The remaining 20% of the alcohol and catalyst are added in this second reactor. This system provides a very complete reaction with the potential of using less alcohol than single step systems.



$$\mathrm{Na^{+}\,{}^{-}O-\overset{O}{\overset{\|}{C}}-R} \; - \; \mathrm{HCl} \longrightarrow \mathrm{HO-\overset{O}{\overset{|}{C}}-R} \; + \; \mathrm{NaCl}$$

Following the reaction, the glycerol is removed from the methyl esters. Due to the low solubility of glycerol in the esters, this separation generally occurs quickly and may be accomplished with either a settling tank or a centrifuge. The excess methanol tends to act as a solubilizer and can slow the separation. However, this excess methanol is usually not removed from the reaction stream until after the glycerol and methyl esters are separated due to concern about reversing the transesterification reaction. Water may be added to the reaction mixture after the transesterification is complete to improve the separation of glycerol (T. Wimmer, 1995).

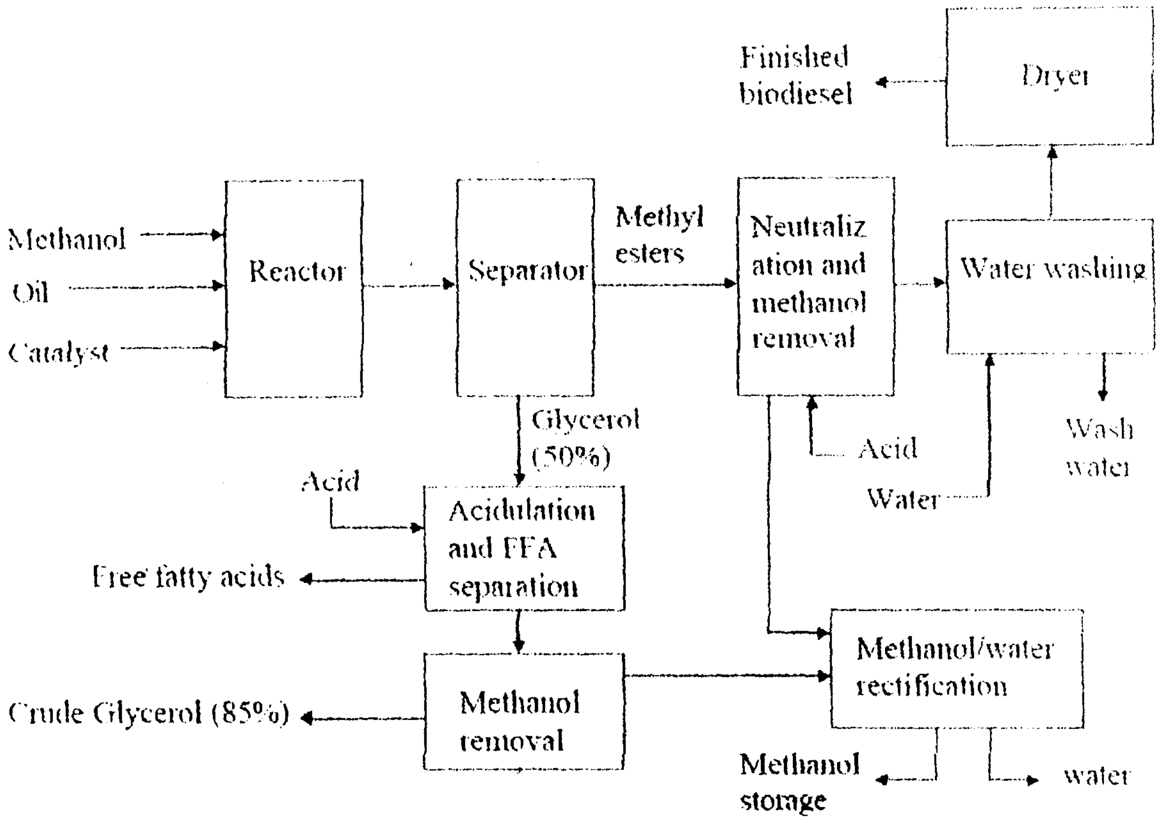
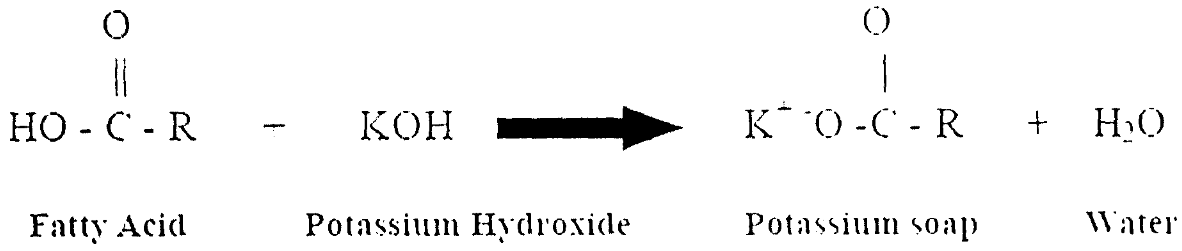


Figure1. Process Flow Schematic for Biodiesel Production

The methanol that is removed from the methyl ester and glycerol streams will tend to collect any water that may have entered the process. This water should be removed in a distillation column before the methanol is returned to the process. This step is more difficult if an alcohol such as ethanol or isopropanol is used that forms an azeotrope with water. Then, a molecular sieve is used to remove the water.

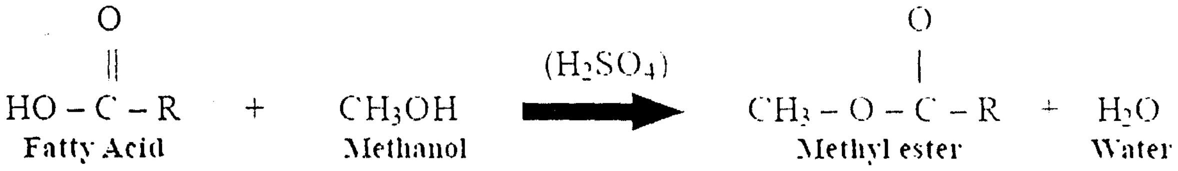
2.3.1.2 Acid Catalyzed Pretreatment

Special processes are required if the oil or fat contains significant amounts of FFAs. Used cooking oils typically contain 2-7 % FFAs and animal fats contain from 5-30 % FFAs. Some very low quality feedstocks, such as trap grease, can approach 100 % FFAs. When an alkali catalyst is added to these feedstocks, the free fatty acids react with the catalyst to form soap and water as shown in the reaction below:



$$\underset{\text{Fatty Acid}}{HO-\overset{\overset{\displaystyle O}{\|}}{C}-R} \quad - \quad \underset{\text{Potassium Hydroxide}}{KOH} \longrightarrow \underset{\text{Potassium soap}}{K^{+}\,{}^{-}O-\overset{\overset{\displaystyle O}{|}}{C}-R} \quad + \quad \underset{\text{Water}}{H_2O}$$

Up to about 5% FFAs, the reaction can still be catalyzed with an alkali catalyst but additional catalyst must be added to compensate for that lost to soap. The soap created during the reaction is either removed with the glycerol or is washed out during the water wash. When the FFA level is above 5%, the soap inhibits separation of the glycerol from the methyl esters and contributes to emulsion formation during the water wash. For these cases, an acid catalyst such as sulfuric acid can be used to esterify the FFAs to methyl esters as shown in the following reaction:



$$\underset{\text{Fatty Acid}}{HO-\overset{\overset{\displaystyle O}{\|}}{C}-R} \quad + \quad \underset{\text{Methanol}}{CH_3OH} \xrightarrow{(H_2SO_4)} \underset{\text{Methyl ester}}{CH_3-O-\overset{\overset{\displaystyle O}{|}}{C}-R} \quad + \quad \underset{\text{Water}}{H_2O}$$

As shown in Figure 2, this process can be used as a pretreatment to convert the FFAs to methyl esters and thereby reduce the FFA level. Then, the low FFA pretreated oil can be transesterified with an alkali catalyst to convert the triglycerides to methyl esters (G.I. Keim, 1945). As shown in the reaction, water is formed and, if it accumulates, it can stop the reaction well before completion.

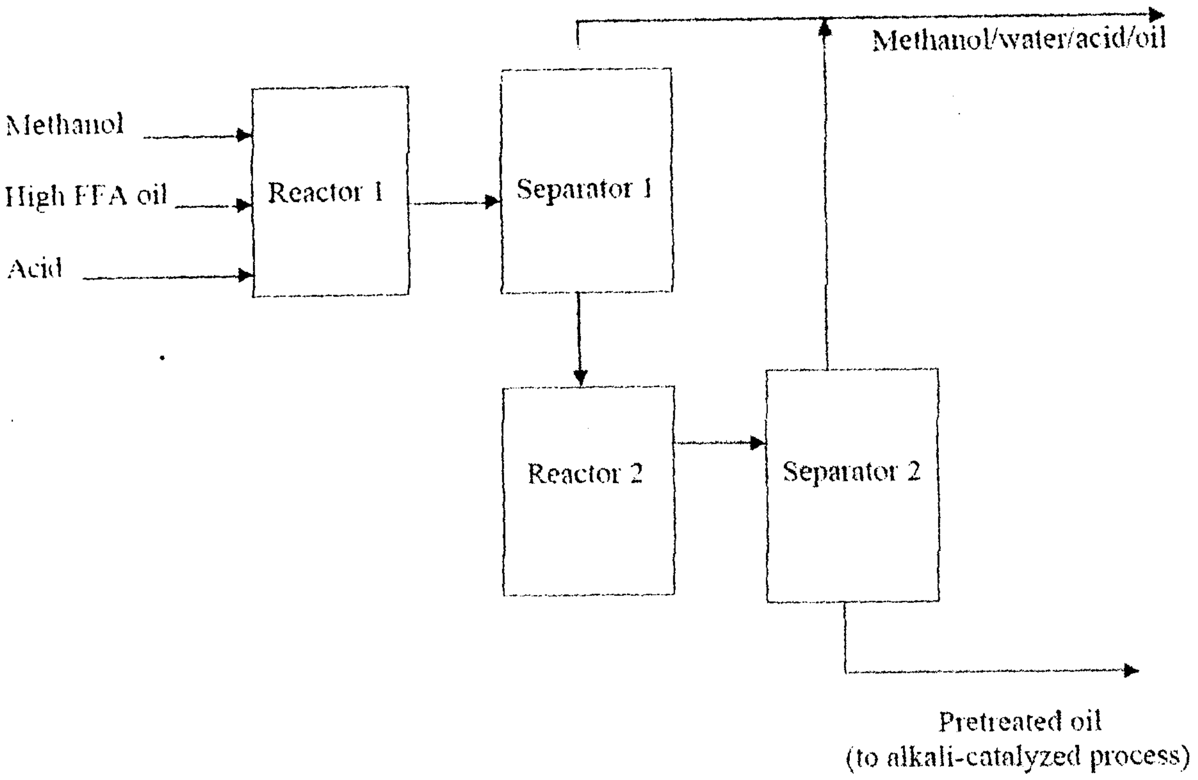


Figure 2: Pretreatment process for high free fatty acids feedstocks

Kawahara and Ono (Kawahara and Ono, 1979) propose allowing the alcohol to separate from the pretreated oil or fat following the reaction. Removal of this alcohol also removes the water formed by the esterification reaction and allows for a second step of esterification or proceeding directly to alkali-catalyzed transesterification.

Note that the methanol-water mixture will also contain some dissolved oil and FFAs that should be recovered and reprocessed.

2.4 Fuel Quality

The primary criterion for biodiesel quality is adherence to the appropriate standard. In the United States, this standard is ASTM D 6751-02 "Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels". Generally, the fuel quality of biodiesel can be influenced by several factors:

- The quality of the feedstock.
- The fatty acid composition of the parent vegetable oil or animal fat.
- The production process and the other materials used in this process.
- Post-production parameters.

Table 3 shows the property values required for a mixture of methyl esters to be considered biodiesel. When these limits are met, the biodiesel can be used in most modern engines without modifications while maintaining the engine's durability and reliability. Even in low level blends with conventional diesel fuel, the biodiesel blending stock is expected to meet the standard before being blended. While some properties in the standard, such as cetane number and density, reflect the properties of the chemical compounds that make up biodiesel, other properties provide indications of the quality of the production process. Generally, the parameters given in ASTM D6751 are defined by other ASTM standards. However, other test methods, such as those developed for the American Oil Chemists' Society, (AOCS) may also be suitable (or even more appropriate as they were developed for fats and oils and not for petroleum-derived materials addressed in the ASTM standards). This discussion will focus on the most important issues for assuring product quality for biodiesel as it is related to production as well as some post-production parameters.

Table 3. ASTM D 6751–02 Biodiesel Specifications

Property	*Method*	*Limits*	*Units*
Flash point, closed cup	*D 93*	*130 min*	*° C*
Water and sediment	*D 2709*	*0.050 max*	*% volume*
Kinematic viscosity, 40 ° C	*D 445*	*1.9 – 6.0*	mm^2/s
Sulfated ash	*D 874*	*0.020 max*	*wt. %*
Total Sulfur	*D 5453*	*0.05 max*	*wt. %*
Copper strip corrosion	*D 130*	*No. 3 max*	
Cetane number	*D 613*	*47 min*	
Cloud point	*D 2500*	*Report to customer*	*° C*
Carbon residue	*D 4530*	*0.05 max*	*wt. %*
Acid number	*D 664*	*0.8 max*	*mg KOH/g*
Free glycerin	*D 6584*	*0.02*	*wt. %*
Total glycerin	*D 6584*	*0.24*	*wt. %*
Phosphorus	*D 4951*	*10*	*ppm*
Vacuum distillation end point	*D 1160*	*360 °C max, at T-90*	
Storage stability	*To be determined*	*To be determined*	*To be determined*

Source: American Society for Testing and Materials, Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels, 2002

2.5 Production Process Factors

2.5.1 Completion of reaction

The most important issue during biodiesel production is the completeness of the transesterification reaction. The basic chemical process that occurs during the reaction is indicated by the following sequence of events:

$$\begin{tikzcd}
\textbf{Triglyceride} \arrow[r] & \textbf{Diglyceride} \arrow[r] \arrow[d] & \textbf{Monoglyceride} \arrow[r] \arrow[d] & \textbf{Glycerol} \arrow[d] \\
& \textbf{methyl ester} & \textbf{methyl ester} & \textbf{methyl ester}
\end{tikzcd}$$

The triglycerides are converted to diglycerides, which in turn are converted to monoglycerides, and then to glycerol. Each step produces a molecule of a methyl ester of a fatty acid. If the reaction is incomplete, then there will be triglycerides, diglycerides, and monoglycerides left in the reaction mixture. Each of these compounds still contains a glycerol molecule that has not been released. The glycerol portion of these compounds is referred to as *bound glycerol*.

2.5.2 Free Glycerol

Free glycerol refers to the amount of glycerol that is left in the finished biodiesel. Glycerol is essentially insoluble in biodiesel so almost all of the glycerol is easily removed by settling or centrifugation. Free glycerol may remain either as suspended droplets or as the very small amount that is dissolved in the biodiesel. Alcohols can act as cosolvents to increase the solubility of glycerol in the biodiesel. Most of this glycerol should be removed during the water washing process. Water-washed fuel is generally very low in free glycerol, especially if hot water is used for washing. Distilled biodiesel tends to have a greater problem with free glycerol due to glycerol carry-over during distillation. Fuel with excessive free glycerol will usually have a problem with glycerol settling out in storage tanks, creating a very viscous mixture that can plug fuel filters and cause combustion problems in the engine.

2.5.3 Residual Alcohol and Residual Catalyst

Since methanol (and ethanol) and the alkaline catalysts are more soluble in the polar glycerol phase, most will be removed when the glycerol is separated from the biodiesel. However, the biodiesel typically contains 2-4 % methanol after the separation, which may constitute as much as 40% of the excess methanol from the reaction. Most processors will recover this methanol using a vacuum stripping process. Any methanol remaining after this stripping process should be removed by the water washing process. Therefore, the residual alcohol level in the biodiesel should be very low. A specific value for the allowable alcohol level is specified in European biodiesel standards (0.2 % in EN 14214), but is not included in the ASTM standard. Tests have shown that as little as 1% methanol in the biodiesel can lower the flashpoint of the biodiesel from 170 °C to less than 40 °C. Therefore, by including a flashpoint specification of 130°C, the ASTM standard limits the amount of alcohol to a very low level (<0.1 %). Residual alcohol left in the biodiesel will generally be too small to negatively impact the fuel's performance. However, lowering the flashpoint presents a potential safety hazard as the fuel may need to be treated more like gasoline, which also has a low flashpoint, than diesel fuel.

Most of the residual catalyst is removed with the glycerol. Like the alcohol, remaining catalyst should be removed during the water washing. Although a value for residual catalyst is not included in the ASTM standard, it will be limited by the specification on sulfated ash.

Excessive ash in the fuel can lead to engine deposits and high abrasive wear levels. The European standard EN 14214 places limits on calcium and magnesium as well as the alkali metals sodium and potassium.

2.6 Post-production Factors

2.6.1 Water and Sediment

Water and sediment contamination are basically housekeeping issues for biodiesel. Water can be present in two forms, either as dissolved water or as suspended water droplets. While biodiesel is generally considered to be insoluble in water, it actually takes up considerably more water than diesel fuel. Biodiesel can contain as much as 1500 ppm of dissolved water while diesel fuel usually only takes up about 50 ppm (Van Gerpen, 1997). The standards for diesel fuel (ASTM D

975) and biodiesel (ASTM D 6751) both limit the amount of water to 500 ppm. For petroleum-based diesel fuel, this actually allows a small amount of suspended water. However, biodiesel must be kept dry. This is a challenge because many diesel storage tanks have water on the bottom due to condensation. Suspended water is a problem in fuel injection equipment because it contributes to the corrosion of the closely fitting parts in the fuel injection system.

Water can also contribute to microbial growth in the fuel. This problem can occur in both biodiesel and conventional diesel fuel and can result in acidic fuel and sludges that will plug fuel filters.

Sediment may consist of suspended rust and dirt particles or it may originate from the fuel as insoluble compounds formed during fuel oxidation. Some biodiesel users have noted that switching from petroleum-based diesel fuel to biodiesel causes an increase in sediment that comes from deposits on the walls of fuel tanks that had previously contained diesel fuel. Because its solvent properties are different from diesel fuel, biodiesel may loosen these sediments and cause fuel filter plugging during the transition period.

2.6.2 Storage Stability

Storage stability refers to the ability of the fuel to resist chemical changes during long term storage. These changes usually consist of oxidation due to contact with oxygen from the air. The fatty acid composition of the biodiesel fuel is an important factor in determining stability towards air. Generally, the polyunsaturated fatty acids (C18:2, linoleic acid; C18:3 linolenic acid) are most susceptible to oxidation. The changes can be catalyzed by the presence of certain metals (including those making up the storage container) and light. If water is present, hydrolysis can also occur. The chemical changes in the fuel associated with oxidation usually produce hydroperoxides that can, in turn, produce short chain fatty acids, aldehydes, and ketones. Under the right conditions, the hydroperoxides can also polymerize. Therefore, oxidation is usually denoted by an increase in the acid value and viscosity of the fuel. Often these changes are accompanied by a darkening of the biodiesel color from yellow to brown and the development of a "paint" smell. When water is present, the esters can hydrolyze to long chain free fatty acids which also cause the acid value to increase.

There is currently no generally accepted method for measuring the stability of biodiesel. The techniques generally used for petroleum-based fuels, such as ASTM D 2274, have been shown to be incompatible with biodiesel. Other procedures, such as the Oil Stability Index or the Rancimat apparatus, which are widely used in the fats and oils industry, seem to be more appropriate for use with biodiesel. However, the engine industry has no experience with these tests and acceptable values are not known. Also, the validity of accelerated testing methods has not been established or correlated to actual engine problems. If biodiesel's acid number, viscosity, or sediment content increase to the point where they exceed biodiesel's ASTM limits, the fuel should not be used as a transportation fuel.

Additives such as BHT and TBHQ (t-butylhydroquinone) are common in the food industry and have been found to enhance the storage stability of biodiesel. Biodiesel produced from soybean oil naturally contain some antioxidants (tocopherols, i.e., vitamin E), providing some protection against oxidation (some tocopherol is lost during refining of the oil prior to biodiesel production). Any fuel that will be stored for more than 6 months, whether it is diesel fuel or biodiesel, should be treated with an antioxidant additive.

2.7 Quality Control

All biodiesel production facilities should be equipped with a laboratory so that the quality of the final biodiesel product can be monitored. It is also important to monitor the quality of the feedstocks.

One strategy used by many producers is to draw a sample of the oil (or alcohol) from each delivery and use that sample to produce biodiesel in the laboratory. This test can be fairly rapid (1 or 2 hours) and can indicate whether serious problems are likely in the plant. Measuring feedstock quality can usually be limited to acid value and water content.

To monitor the completeness of the reaction according to the total glycerol level specified in ASTM D 6751 requires the use of a gas chromatograph and a skilled operator. Large producers will find that having this equipment on-site is necessary. Commercial laboratories (i.e.Magellan Midstream Partners) are available that can analyze the samples but the cost is $80-$150/test and

the time required may be several days. Smaller producers will need to use a more robust production process involving extra methanol and probably multiple reaction steps. Then the product quality can be monitored through periodic testing by an outside laboratory.

Other possibilities for monitoring the transesterification reaction and assessing fuel quality are methods based on spectroscopy (such as near- infrared spectroscopy) or physical properties (such as viscometry). These methods, although they are not (yet?) ASTM methods, are usually faster and easier to use than gas chromatography. However, some of them require extensive calibration. They also cannot accurately quantify glycerol at the low levels called for in the ASTM standard. To circumvent this, comparison to a reaction and product known to meet ASTM standards is needed.

2.8 RAPESEED

Rapeseed (Brassica napus), also known as rape, oilseed rape, rapa, rapaseed and (in the case of one particular group of cultivars) canola, is a bright yellow flowering member of the family Brassicaceae (mustard or cabbage family). The name derives from the Latin for turnip, rāpum or rāpa, and is first recorded in English at the end of the 14th century.

In agriculture, canola is certain varieties of oilseed rape, or the oil produced from those varieties. It's a trademarked hybrid of rape initially bred in Canada. Rape Seed Oil was produced in the 19th century as a source of a lubricant for steam engines, and the oil has a bitter taste due to high levels of acids. Canola has been bred to reduce the amount of acid, yielding palatable oil. Rapeseed is grown for the production of animal feed, vegetable oil for human consumption, and biodiesel; leading producers include the European Union, Canada, the United States, Australia, China and India. In India, it is grown on 13 % of cropped land. According to the United States Department of Agriculture, rapeseed was the third leading source of vegetable oil in the world in 2000, after soybean and oil palm, and also the world's second leading source of protein meal, although only one-fifth of the production of the leading soybean meal. World production is growing rapidly, with FAO reporting that 36 million tonnes of rapeseed was produced in the 2003-4 season, and 46 million tonnes in 2004-5. In Europe, rapeseed is primarily cultivated for

animal feed (owing to its very high lipid and medium protein content), and is a leading option for Europeans to avoid importation of GMO product. (Wikimpedia,2009/Rapeseed.)

Natural rapeseed oil contains 50 % erucic acid. Wild type seeds also contain high levels of glucosinolates (mustard oil glucosindes), chemical compounds that significantly lowered the nutritional value of rape seed press cakes for animal feed. The rapeseed is the valuable, harvested component of the crop. The crop is also grown as a winter-cover crop. It provides good coverage of the soil in winter, and limits nitrogen run-off. The plant is ploughed back in the soil or used as bedding. On some ecological or organic operations, livestock such as sheep or cattle are allowed to graze on the plants.

Processing of rapeseed for oil production provides rapeseed animal meal as a by-product. The by-product is a high-protein animal feed, competitive with soya. The feed is mostly employed for cattle feeding, but also for pigs and chickens (though less valuable for these). The meal has a very low content of the glucosinolates responsible for metabolism disruption in cattle and pigs. Rapeseed "oil cake" is also used as a fertilizer in China, and may be used for ornamentals. Rapeseed leaves and stems are also edible. Some varieties of rapeseed are used for vegetable oil production. Rapeseed is a heavy nectar producer, and honeybees produce a light colored, but peppery honey from it. It must be extracted immediately after processing is finished, as it will quickly granulate in the honeycomb and will be impossible to extract. The honey is usually blended with milder honeys, if used for table use, or sold as bakery grade. Rapeseed growers contract with beekeepers for the pollination of the crop.

Rapeseed oil is used in the manufacture of biodiesel for powering motor vehicles. Biodiesel may be used in pure form in newer engines without engine damage, and is frequently combined with fossil-fuel diesel in ratios varying from 2 % to 20 % biodiesel. Formerly, owing to the costs of growing, crushing, and refining rapeseed biodiesel, rapeseed derived biodiesel cost more to produce than standard diesel fuel. Prices of rapeseed oil are at very high levels presently owing to increased demand on rapeseed oil for this purpose. Rapeseed oil is the preferred oil stock for

CHAPTER ONE

1.0 INTRODUCTION

Design is a creativity whereby ideas are generated and translated into processes and equipment for producing new materials or significantly upgrading the value of the existing once. In this case, the target of this project is to design a plant to produce biodiesel fuel. (Buraimoh, 2006)

The rising need for an alternative fuel that is not subjected to problems posed by the conventional fossil fuel is fast becoming inevitable. As such, a renewable non -toxic substitute is required to supplement or completely replace the conventional fuel, due to the increasing demand for these products.

Biodiesel fuel is a potential substitute for fossil diesel because of its huge benefits. It consists of methyl esters (biodiesel) of fatty acids produced by the transesterification reaction of natural oils with triglyceride composition with methanol using a homogenous catalyst such as sodium hydroxide. Glycerol, a useful raw material is also produced as a by-product from the process (Wang *et al.*, 2007).

Of the several methods available for producing biodiesel, transesterification of natural oils and fats is currently the method of choice. The purpose of the process is to lower the viscosity of the oil or fat. Transesterification is basically a sequential reaction. Triglycerides are first reduced to diglycerides, which are subsequently reduced to monoglycerides, which are finally reduced to fatty acid esters. The order of the reaction changes with the reaction conditions. The main factors affecting transesterification are the molar ratio of glycerides to alcohol, catalysts, reaction temperature and time, and free fatty acid and water content in oils and fats. Transesterification is extremely important for biodiesel (Ma et al, 1999).

In this project, Rapeseed oil is the focused source of natural oil needed in the transesterification process. Other source of triglycerides includes palm seed, sunflower seed, peanut, soya beans, castor seed etc. However, the most economical feasible of these seeds is the rapeseed since it is the preferred oil stock for biodiesel production in most part of the world. This is because, rape seed produce more oil per unit of land area compared to other natural seeds.

1.1 AIM AND OBJECTIVES OF THIS DESIGN PROJECT

The aim of this design project is to design a plant for the production of 100,000 tonnes per year of biodiesel fuel by the Transesterification of rapeseed oil with methanol aided by homogenous sodium hydroxide catalyst.

It is expected that this design project would achieve the following objectives to:

- Understand the important of the biodiesel fuel and the need for a potential substitute for fossil diesel oil.
- Highlight the characteristics, advantage, disadvantage, justification and limitation of the production of biodiesel fuel.
- Evaluate the process design and control, process flow diagram and equipment required for the production of biodiesel.
- Identify the idea of how to go about pilot plant, plant location and mechanical engineering design of the biodiesel fuel plant.

1.2 CHARACTERISTICS OF BIODIESEL FUEL

- It has a higher octane number and flash point than petroleum diesel
- Its viscosity is lower than diesel
- Its specific gravity is slightly higher than diesel
- It is biodegradable, non-toxic and free of sulphur and aromatics.

1.3 SIGNIFICANCE OF THE PROJECT

To increase energy self-sufficiency of non-oil producing countries and boost the availability of diesel fuel in oil producing nation through the following ways.

- Reduce pollution
- Create more employment opportunities.
- Provide a better alternative source of diesel fuel.
- Increase the demand for agricultural products.

1.4 DISADVANTAGES OF BIODIESEL FUEL

- High cost of production.
- Environmental impacts of increase fertilizer and pesticide usage to increase the oil seed production.
- It has a high viscosity than the conventional diesel and therefore becomes less useful at low temperature; hence, depressing agents and dissolving solvents may have to be added.

1.5 THE ECONOMIC COST AND EFFECTIVENESS OF BIODIESEL FUEL IN THE FUTURE.

In Malaysia and America, biodiesel fuel is more expensive than the conventional diesel but in European countries, biodiesel costs no more than diesel and can be up 5% cheaper as it is not subject to oil tax

Acceptance of biodiesel fuel is likely to increase over the year since it is non-toxic and has greater advantage than conventional diesel fuel. It is hope that in the near future more biodiesel plant will be set up in every country and hence, substitute consumption of conventional diesel from fossil fuel, through biodiesel is still not economically competitive nor is it seen to be the for-see-able future (DA Potts *et al,* 1999).

1.6 LIMITATION OF THE PROJECT

The cost of assembling the pilot scale set up for the manufacture of biodiesel is quite expensive. Rapeseed is not grown in this country hence it has to be imported from Europe for the course of this project. The feed prices are expensive ranging from £100/tonne for rapeseed oil to £200/tonne for sodium hydroxide.

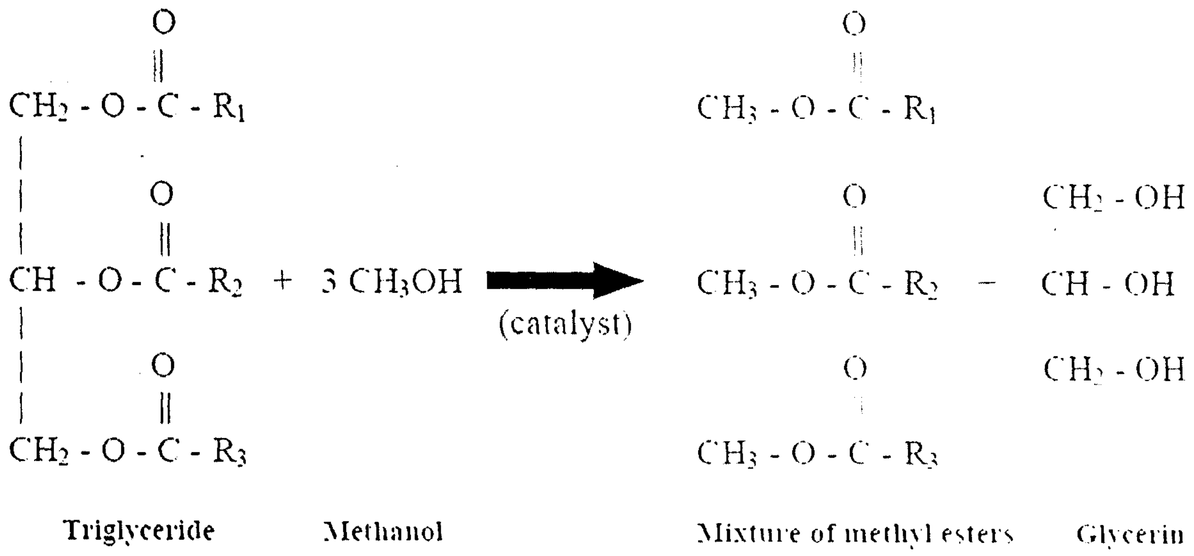
CHAPTER TWO

2.0 LITERATURE REVIEW

For comprehensive design of this project work literatures were reviewed to serve as a guide toward successful completion.

2.1 BIODIESEL

Biodiesel, defined as monoalkyl esters of vegetable oils or animal fats is a promising alternative fuel for use in compression-ignition (diesel) engines and is being produced in commercial quantity and used in various countries around the world, including the United States, Austria, The Czech Republic, France, Germany, Italy, Malaysia and Sweden(Gerhard Knothe,2001). It is produced by chemically reacting a fat or oil with an alcohol, in the presence of a catalyst. The product of the reaction is a mixture of methyl esters, which are known as biodiesel, and glycerol, which is a high value co-product. The process used is known as transesterification, and is shown in the equation below, where R_1, R_2, and R_3 are long hydrocarbon chains, sometimes called fatty acid chains.



$$\begin{array}{l} CH_2-O-\overset{O}{\overset{\|}{C}}-R_1 \\ | \\ CH-O-\overset{O}{\overset{\|}{C}}-R_2 \\ | \\ CH_2-O-\overset{O}{\overset{\|}{C}}-R_3 \end{array} + 3\,CH_3OH \xrightarrow[\text{(catalyst)}]{} \begin{array}{l} CH_3-O-\overset{O}{\overset{\|}{C}}-R_1 \\ CH_3-O-\overset{O}{\overset{\|}{C}}-R_2 \\ CH_3-O-\overset{O}{\overset{\|}{C}}-R_3 \end{array} - \begin{array}{l} CH_2-OH \\ CH-OH \\ CH_2-OH \end{array}$$

There are five chains that are common in most vegetable oils and animal fats (others are present in small amounts). The relative amounts of the five methyl esters determine the physical

properties of the fuel, including the cetane number (a combustion-related diesel fuel quality index), cold flow, and oxidative stability.(Van Gerpen and M. Canakci,1997)

2.2 Characteristics and Specifications Biodiesel

As biodiesel is produced from a wide variety of vegetable oils of varying origin and quality, it was necessary to implement criteria for standardization of fuel quality for better engine performance. Austria was the pioneering country in the world to define and approve the standards for rapeseed oil methyl esters as diesel fuel (Meher et al. 2006). As standardization is a prerequisite for quality control, certain parameters are considered for the purpose, of which cetane number and fuel viscosity are important ones. The detailed physical attributes of biodiesel produced following the transesterification process given in Table1 and Table 2 depicts the vegetable oil specific parameters and the corresponding value of fatty acid methyl esters according to select countries.

2.3 Current Technologies in Biodiesel Production

Of the several methods available for producing biodiesel, transesterification of natural oils and fats is currently the method of choice. The purpose of the process is to lower the viscosity of the oil or fat. Transesterification is basically a sequential reaction. Triglycerides are first reduced to diglycerides, which are subsequently reduced to monoglycerides, which are finally reduced to fatty acid esters.

The order of the reaction changes with the reaction conditions. The main factors affecting transesterification are the molar ratio of glycerides to alcohol, catalysts, reaction temperature and time, and free fatty acid and water content in oils and fats. Transesterification is extremely important for biodiesel. Biodiesel as it is defined today is obtained by transesterifying triglycerides with methanol. Methanol is the preferred alcohol for obtaining biodiesel because it is the cheapest alcohol.

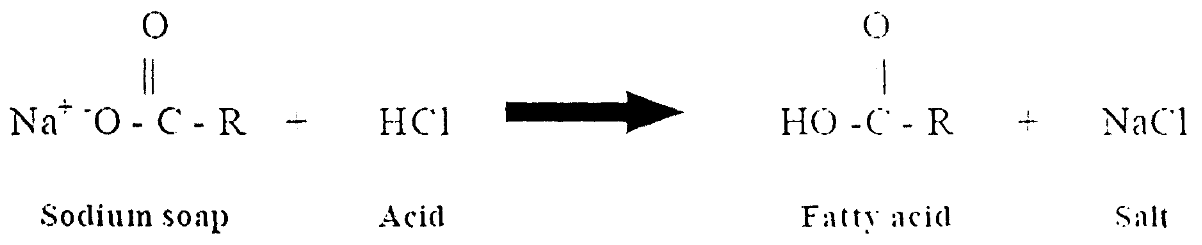
Base catalysts are more effective than acid catalysts and enzymes (Ma and Hanna, 1999). Methanol is made to react with triglycerides to produce methyl esters (biodiesel) and glycerol

2.3.1 TRANSESTERIFICATION

Transesterification is the general term used to describe the important class of organic reactions where an ester is transformed into another through the interchange of alkoxy when the original ester is reacted with an alcohol. Transesterification also known as alcoholysis of carboxylic esters, which is based on the chemical reaction of triglycerides with an alcohol in the presence of an alkaline catalyst to form a mixture of methyl esters, which are known as biodiesel and glycerine, which is a high value co-product. Transesterification is a reversible reaction. Thus, excess methanol is required to shift the equilibrium favourably. The transesterification process as shown in the equation below, where R_1, R_2, and R_3 are long chain hydrocarbon (Jon Van Gerpen, 2008).

2.3.1.1 Alkali-catalyzed Transesterification

Figure 1 shows a schematic diagram of the processes involved in biodiesel production from feedstocks containing low levels of free fatty acids (FFA). This includes soybean oil, canola (rapeseed) oil, and the higher grades of waste restaurant oils. Alcohol, catalyst, and oil are combined in a reactor and agitated for approximately one hour at 60°C. Smaller plants often use batch reactors (W.D. Stidham et al,2000) but most larger plants (> 4 million liters/yr) use continuous flow processes involving continuous stirred-tank reactors (CSTR) or plug flow reactors (G. Assman,1996). The reaction is sometimes done in two steps where approximately 80% of the alcohol and catalyst is added to the oil in a first stage CSTR. Then, the product stream from this reactor goes through a glycerol removal step before entering a second CSTR. The remaining 20% of the alcohol and catalyst are added in this second reactor. This system provides a very complete reaction with the potential of using less alcohol than single step systems.



$$Na^{+}\,{}^{-}O-\overset{\overset{O}{\|}}{C}-R + HCl \longrightarrow HO-\overset{\overset{O}{|}}{C}-R + NaCl$$

Following the reaction, the glycerol is removed from the methyl esters. Due to the low solubility of glycerol in the esters, this separation generally occurs quickly and may be accomplished with either a settling tank or a centrifuge. The excess methanol tends to act as a solubilizer and can slow the separation. However, this excess methanol is usually not removed from the reaction stream until after the glycerol and methyl esters are separated due to concern about reversing the transesterification reaction. Water may be added to the reaction mixture after the transesterification is complete to improve the separation of glycerol (T. Wimmer,1995).

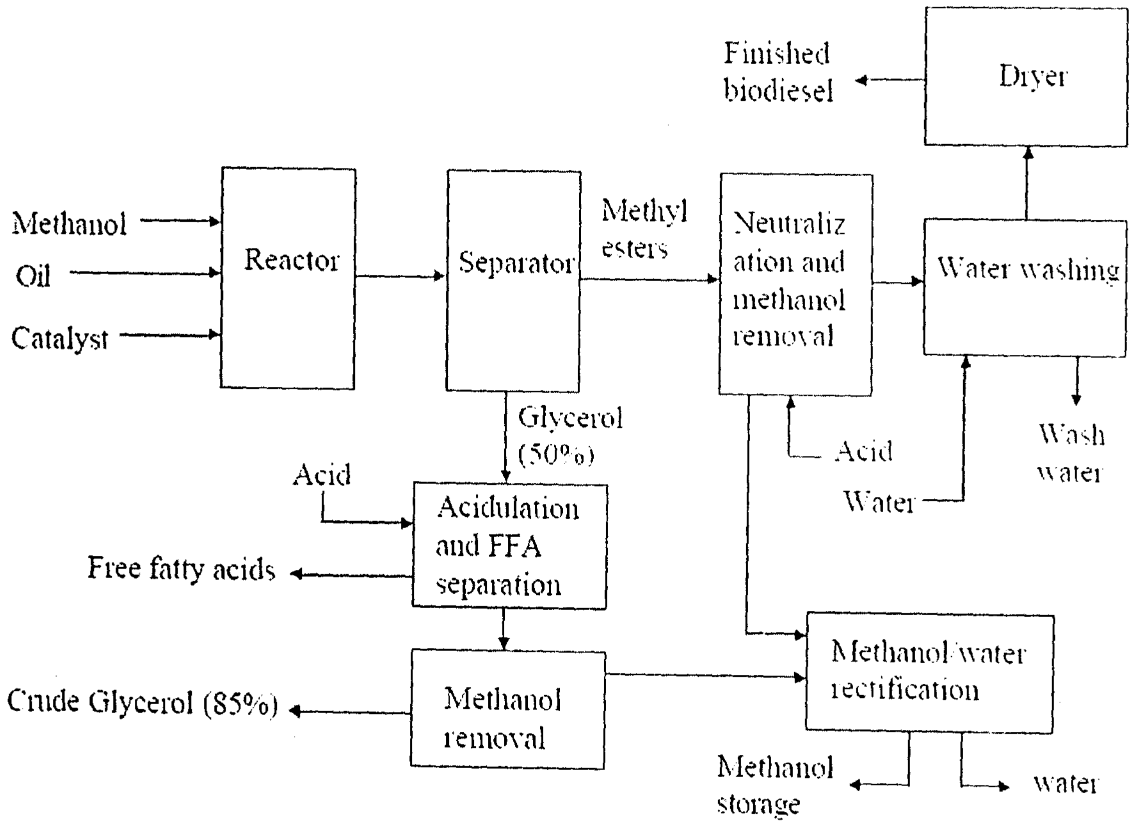
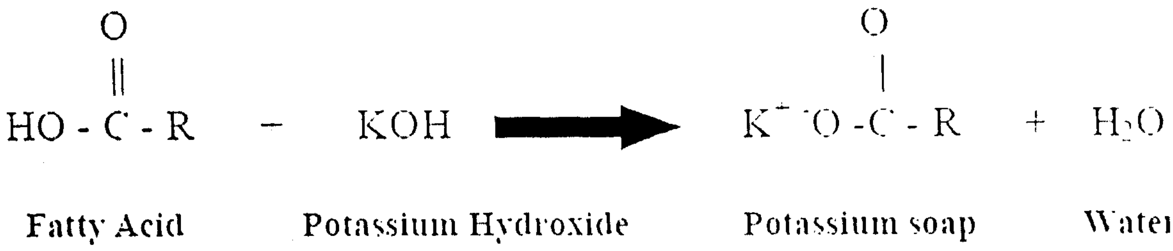


Figure1. Process Flow Schematic for Biodiesel Production

The methanol that is removed from the methyl ester and glycerol streams will tend to collect any water that may have entered the process. This water should be removed in a distillation column before the methanol is returned to the process. This step is more difficult if an alcohol such as ethanol or isopropanol is used that forms an azeotrope with water. Then, a molecular sieve is used to remove the water.

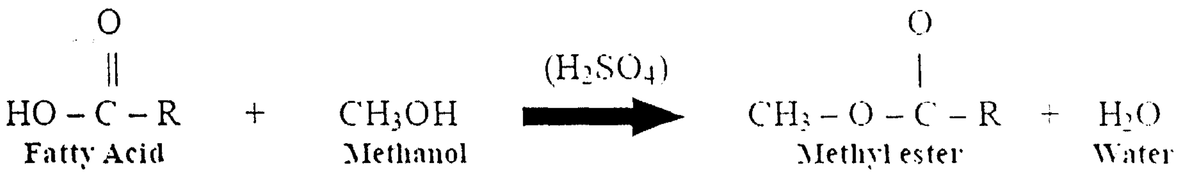
2.3.1.2 Acid Catalyzed Pretreatment

Special processes are required if the oil or fat contains significant amounts of FFAs. Used cooking oils typically contain 2-7 % FFAs and animal fats contain from 5-30 % FFAs. Some very low quality feedstocks, such as trap grease, can approach 100 % FFAs. When an alkali catalyst is added to these feedstocks, the free fatty acids react with the catalyst to form soap and water as shown in the reaction below:



$$\underset{\text{Fatty Acid}}{HO-\overset{\overset{O}{\|}}{C}-R} \quad - \quad \underset{\text{Potassium Hydroxide}}{KOH} \longrightarrow \underset{\text{Potassium soap}}{K^{+}\,{}^{-}O-\overset{\overset{O}{|}}{C}-R} \quad + \quad \underset{\text{Water}}{H_2O}$$

Up to about 5% FFAs, the reaction can still be catalyzed with an alkali catalyst but additional catalyst must be added to compensate for that lost to soap. The soap created during the reaction is either removed with the glycerol or is washed out during the water wash. When the FFA level is above 5%, the soap inhibits separation of the glycerol from the methyl esters and contributes to emulsion formation during the water wash. For these cases, an acid catalyst such as sulfuric acid can be used to esterify the FFAs to methyl esters as shown in the following reaction:



$$\underset{\text{Fatty Acid}}{HO-\overset{\overset{O}{\|}}{C}-R} \quad + \quad \underset{\text{Methanol}}{CH_3OH} \xrightarrow{(H_2SO_4)} \underset{\text{Methyl ester}}{CH_3-O-\overset{\overset{O}{|}}{C}-R} \quad + \quad \underset{\text{Water}}{H_2O}$$

As shown in Figure 2, this process can be used as a pretreatment to convert the FFAs to methyl esters and thereby reduce the FFA level. Then, the low FFA pretreated oil can be transesterified with an alkali catalyst to convert the triglycerides to methyl esters (G.I. Keim, 1945). As shown in the reaction, water is formed and, if it accumulates, it can stop the reaction well before completion.

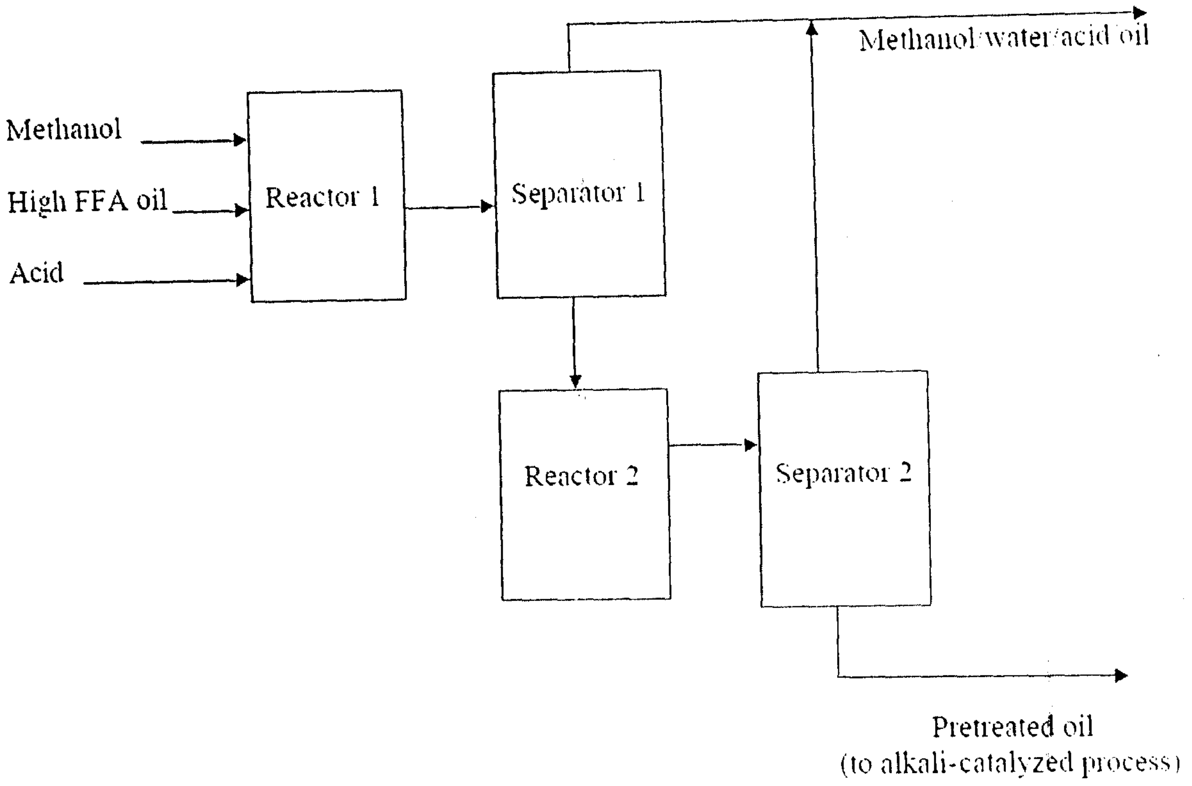


Figure 2: Pretreatment process for high free fatty acids feedstocks

Kawahara and Ono (Kawahara and Ono, 1979) propose allowing the alcohol to separate from the pretreated oil or fat following the reaction. Removal of this alcohol also removes the water formed by the esterification reaction and allows for a second step of esterification or proceeding directly to alkali-catalyzed transesterification.

Note that the methanol-water mixture will also contain some dissolved oil and FFAs that should be recovered and reprocessed.

2.4 Fuel Quality

The primary criterion for biodiesel quality is adherence to the appropriate standard. In the United States, this standard is ASTM D 6751-02 "Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels". Generally, the fuel quality of biodiesel can be influenced by several factors:

- The quality of the feedstock.
- The fatty acid composition of the parent vegetable oil or animal fat.
- The production process and the other materials used in this process.
- Post-production parameters.

Table 3 shows the property values required for a mixture of methyl esters to be considered biodiesel. When these limits are met, the biodiesel can be used in most modern engines without modifications while maintaining the engine's durability and reliability. Even in low level blends with conventional diesel fuel, the biodiesel blending stock is expected to meet the standard before being blended. While some properties in the standard, such as cetane number and density, reflect the properties of the chemical compounds that make up biodiesel, other properties provide indications of the quality of the production process. Generally, the parameters given in ASTM D6751 are defined by other ASTM standards. However, other test methods, such as those developed for the American Oil Chemists' Society, (AOCS) may also be suitable (or even more appropriate as they were developed for fats and oils and not for petroleum-derived materials addressed in the ASTM standards). This discussion will focus on the most important issues for assuring product quality for biodiesel as it is related to production as well as some post-production parameters.

Table 3. ASTM D 6751–02 Biodiesel Specifications

Property	*Method*	*Limits*	*Units*
Flash point, closed cup	*D 93*	*130 min*	*°C*
Water and sediment	*D 2709*	*0.050 max*	*% volume*
Kinematic viscosity, 40 °C	*D 445*	*1.9 – 6.0*	mm^2/s
Sulfated ash	*D 874*	*0.020 max*	*wt. %*
Total Sulfur	*D 5453*	*0.05 max*	*wt. %*
Copper strip corrosion	*D 130*	*No. 3 max*	
Cetane number	*D 613*	*47 min*	
Cloud point	*D 2500*	*Report to customer*	*°C*
Carbon residue	*D 4530*	*0.05 max*	*wt. %*
Acid number	*D 664*	*0.8 max*	*mg KOH/g*
Free glycerin	*D 6584*	*0.02*	*wt. %*
Total glycerin	*D 6584*	*0.24*	*wt. %*
Phosphorus	*D 4951*	*10*	*ppm*
Vacuum distillation end point	*D 1160*	*360 °C max, at T-90*	
Storage stability	*To be determined*	*To be determined*	*To be determined*

Source: American Society for Testing and Materials, Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels, 2002

2.5 Production Process Factors

2.5.1 Completion of reaction

The most important issue during biodiesel production is the completeness of the transesterification reaction. The basic chemical process that occurs during the reaction is indicated by the following sequence of events:

$$\begin{tikzcd}
\text{Triglyceride} \arrow[r] & \text{Diglyceride} \arrow[r] \arrow[d] & \text{Monoglyceride} \arrow[r] \arrow[d] & \text{Glycerol} \arrow[d] \\
& \text{methyl ester} & \text{methyl ester} & \text{methyl ester}
\end{tikzcd}$$

The triglycerides are converted to diglycerides, which in turn are converted to monoglycerides, and then to glycerol. Each step produces a molecule of a methyl ester of a fatty acid. If the reaction is incomplete, then there will be triglycerides, diglycerides, and monoglycerides left in the reaction mixture. Each of these compounds still contains a glycerol molecule that has not been released. The glycerol portion of these compounds is referred to as *bound glycerol.*

2.5.2 Free Glycerol

Free glycerol refers to the amount of glycerol that is left in the finished biodiesel. Glycerol is essentially insoluble in biodiesel so almost all of the glycerol is easily removed by settling or centrifugation. Free glycerol may remain either as suspended droplets or as the very small amount that is dissolved in the biodiesel. Alcohols can act as cosolvents to increase the solubility of glycerol in the biodiesel. Most of this glycerol should be removed during the water washing process. Water-washed fuel is generally very low in free glycerol, especially if hot water is used for washing. Distilled biodiesel tends to have a greater problem with free glycerol due to glycerol carry-over during distillation. Fuel with excessive free glycerol will usually have a problem with glycerol settling out in storage tanks, creating a very viscous mixture that can plug fuel filters and cause combustion problems in the engine.

2.5.3 Residual Alcohol and Residual Catalyst

Since methanol (and ethanol) and the alkaline catalysts are more soluble in the polar glycerol phase, most will be removed when the glycerol is separated from the biodiesel. However, the biodiesel typically contains 2-4 % methanol after the separation, which may constitute as much as 40% of the excess methanol from the reaction. Most processors will recover this methanol using a vacuum stripping process. Any methanol remaining after this stripping process should be removed by the water washing process. Therefore, the residual alcohol level in the biodiesel should be very low. A specific value for the allowable alcohol level is specified in European biodiesel standards (0.2 % in EN 14214), but is not included in the ASTM standard. Tests have shown that as little as 1% methanol in the biodiesel can lower the flashpoint of the biodiesel from 170 °C to less than 40 °C. Therefore, by including a flashpoint specification of 130°C, the ASTM standard limits the amount of alcohol to a very low level (<0.1 %). Residual alcohol left in the biodiesel will generally be too small to negatively impact the fuel's performance. However, lowering the flashpoint presents a potential safety hazard as the fuel may need to be treated more like gasoline, which also has a low flashpoint, than diesel fuel.

Most of the residual catalyst is removed with the glycerol. Like the alcohol, remaining catalyst should be removed during the water washing. Although a value for residual catalyst is not included in the ASTM standard, it will be limited by the specification on sulfated ash.

Excessive ash in the fuel can lead to engine deposits and high abrasive wear levels. The European standard EN 14214 places limits on calcium and magnesium as well as the alkali metals sodium and potassium.

2.6 Post-production Factors

2.6.1 Water and Sediment

Water and sediment contamination are basically housekeeping issues for biodiesel. Water can be present in two forms, either as dissolved water or as suspended water droplets. While biodiesel is generally considered to be insoluble in water, it actually takes up considerably more water than diesel fuel. Biodiesel can contain as much as 1500 ppm of dissolved water while diesel fuel usually only takes up about 50 ppm (Van Gerpen, 1997). The standards for diesel fuel (ASTM D

975) and biodiesel (ASTM D 6751) both limit the amount of water to 500 ppm. For petroleum-based diesel fuel, this actually allows a small amount of suspended water. However, biodiesel must be kept dry. This is a challenge because many diesel storage tanks have water on the bottom due to condensation. Suspended water is a problem in fuel injection equipment because it contributes to the corrosion of the closely fitting parts in the fuel injection system.

Water can also contribute to microbial growth in the fuel. This problem can occur in both biodiesel and conventional diesel fuel and can result in acidic fuel and sludges that will plug fuel filters.

Sediment may consist of suspended rust and dirt particles or it may originate from the fuel as insoluble compounds formed during fuel oxidation. Some biodiesel users have noted that switching from petroleum-based diesel fuel to biodiesel causes an increase in sediment that comes from deposits on the walls of fuel tanks that had previously contained diesel fuel. Because its solvent properties are different from diesel fuel, biodiesel may loosen these sediments and cause fuel filter plugging during the transition period.

2.6.2 Storage Stability

Storage stability refers to the ability of the fuel to resist chemical changes during long term storage. These changes usually consist of oxidation due to contact with oxygen from the air. The fatty acid composition of the biodiesel fuel is an important factor in determining stability towards air. Generally, the polyunsaturated fatty acids (C18:2, linoleic acid; C18:3 linolenic acid) are most susceptible to oxidation. The changes can be catalyzed by the presence of certain metals (including those making up the storage container) and light. If water is present, hydrolysis can also occur. The chemical changes in the fuel associated with oxidation usually produce hydroperoxides that can, in turn, produce short chain fatty acids, aldehydes, and ketones. Under the right conditions, the hydroperoxides can also polymerize. Therefore, oxidation is usually denoted by an increase in the acid value and viscosity of the fuel. Often these changes are accompanied by a darkening of the biodiesel color from yellow to brown and the development of a “paint” smell. When water is present, the esters can hydrolyze to long chain free fatty acids which also cause the acid value to increase.

There is currently no generally accepted method for measuring the stability of biodiesel. The techniques generally used for petroleum-based fuels, such as ASTM D 2274, have been shown to be incompatible with biodiesel. Other procedures, such as the Oil Stability Index or the Rancimat apparatus, which are widely used in the fats and oils industry, seem to be more appropriate for use with biodiesel. However, the engine industry has no experience with these tests and acceptable values are not known. Also, the validity of accelerated testing methods has not been established or correlated to actual engine problems. If biodiesel's acid number, viscosity, or sediment content increase to the point where they exceed biodiesel's ASTM limits, the fuel should not be used as a transportation fuel.

Additives such as BHT and TBHQ (t-butylhydroquinone) are common in the food industry and have been found to enhance the storage stability of biodiesel. Biodiesel produced from soybean oil naturally contain some antioxidants (tocopherols, i.e., vitamin E), providing some protection against oxidation (some tocopherol is lost during refining of the oil prior to biodiesel production). Any fuel that will be stored for more than 6 months, whether it is diesel fuel or biodiesel, should be treated with an antioxidant additive.

2.7 Quality Control

All biodiesel production facilities should be equipped with a laboratory so that the quality of the final biodiesel product can be monitored. It is also important to monitor the quality of the feedstocks.

One strategy used by many producers is to draw a sample of the oil (or alcohol) from each delivery and use that sample to produce biodiesel in the laboratory. This test can be fairly rapid (1 or 2 hours) and can indicate whether serious problems are likely in the plant. Measuring feedstock quality can usually be limited to acid value and water content.

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2.8 RAPESEED

Rapeseed (Brassica napus), also known as rape, oilseed rape, rapa, rapaseed and (in the case of one particular group of cultivars) canola, is a bright yellow flowering member of the family Brassicaceae (mustard or cabbage family). The name derives from the Latin for turnip, rāpum or rāpa, and is first recorded in English at the end of the 14th century.

In agriculture, canola is certain varieties of oilseed rape, or the oil produced from those varieties. It's a trademarked hybrid of rape initially bred in Canada. Rape Seed Oil was produced in the 19th century as a source of a lubricant for steam engines, and the oil has a bitter taste due to high levels of acids. Canola has been bred to reduce the amount of acid, yielding palatable oil. Rapeseed is grown for the production of animal feed, vegetable oil for human consumption, and biodiesel; leading producers include the European Union, Canada, the United States, Australia, China and India. In India, it is grown on 13 % of cropped land. According to the United States Department of Agriculture, rapeseed was the third leading source of vegetable oil in the world in 2000, after soybean and oil palm, and also the world's second leading source of protein meal, although only one-fifth of the production of the leading soybean meal. World production is growing rapidly, with FAO reporting that 36 million tonnes of rapeseed was produced in the 2003-4 season, and 46 million tonnes in 2004-5. In Europe, rapeseed is primarily cultivated for

animal feed (owing to its very high lipid and medium protein content), and is a leading option for Europeans to avoid importation of GMO product. (Wikimpedia,2009/Rapeseed.)

Natural rapeseed oil contains 50 % erucic acid. Wild type seeds also contain high levels of glucosinolates (mustard oil glucosindes), chemical compounds that significantly lowered the nutritional value of rape seed press cakes for animal feed. The rapeseed is the valuable, harvested component of the crop. The crop is also grown as a winter-cover crop. It provides good coverage of the soil in winter, and limits nitrogen run-off. The plant is ploughed back in the soil or used as bedding. On some ecological or organic operations, livestock such as sheep or cattle are allowed to graze on the plants.

Processing of rapeseed for oil production provides rapeseed animal meal as a by-product. The by-product is a high-protein animal feed, competitive with soya. The feed is mostly employed for cattle feeding, but also for pigs and chickens (though less valuable for these). The meal has a very low content of the glucosinolates responsible for metabolism disruption in cattle and pigs. Rapeseed "oil cake" is also used as a fertilizer in China, and may be used for ornamentals. Rapeseed leaves and stems are also edible. Some varieties of rapeseed are used for vegetable oil production. Rapeseed is a heavy nectar producer, and honeybees produce a light colored, but peppery honey from it. It must be extracted immediately after processing is finished, as it will quickly granulate in the honeycomb and will be impossible to extract. The honey is usually blended with milder honeys, if used for table use, or sold as bakery grade. Rapeseed growers contract with beekeepers for the pollination of the crop.

Rapeseed oil is used in the manufacture of biodiesel for powering motor vehicles. Biodiesel may be used in pure form in newer engines without engine damage, and is frequently combined with fossil-fuel diesel in ratios varying from 2 % to 20 % biodiesel. Formerly, owing to the costs of growing, crushing, and refining rapeseed biodiesel, rapeseed derived biodiesel cost more to produce than standard diesel fuel. Prices of rapeseed oil are at very high levels presently owing to increased demand on rapeseed oil for this purpose. Rapeseed oil is the preferred oil stock for

CHAPTER ONE

1.0 INTRODUCTION

Design is a creativity whereby ideas are generated and translated into processes and equipment for producing new materials or significantly upgrading the value of the existing once. In this case, the target of this project is to design a plant to produce biodiesel fuel. (Buraimoh, 2006)

The rising need for an alternative fuel that is not subjected to problems posed by the conventional fossil fuel is fast becoming inevitable. As such, a renewable non -toxic substitute is required to supplement or completely replace the conventional fuel, due to the increasing demand for these products.

Biodiesel fuel is a potential substitute for fossil diesel because of its huge benefits. It consists of methyl esters (biodiesel) of fatty acids produced by the transesterification reaction of natural oils with triglyceride composition with methanol using a homogenous catalyst such as sodium hydroxide. Glycerol, a useful raw material is also produced as a by-product from the process (Wang *et al.*, 2007).

Of the several methods available for producing biodiesel, transesterification of natural oils and fats is currently the method of choice. The purpose of the process is to lower the viscosity of the oil or fat. Transesterification is basically a sequential reaction. Triglycerides are first reduced to diglycerides, which are subsequently reduced to monoglycerides, which are finally reduced to fatty acid esters. The order of the reaction changes with the reaction conditions. The main factors affecting transesterification are the molar ratio of glycerides to alcohol, catalysts, reaction temperature and time, and free fatty acid and water content in oils and fats. Transesterification is extremely important for biodiesel (Ma et al, 1999).

In this project, Rapeseed oil is the focused source of natural oil needed in the transesterification process. Other source of triglycerides includes palm seed, sunflower seed, peanut, soya beans, castor seed etc. However, the most economical feasible of these seeds is the rapeseed since it is the preferred oil stock for biodiesel production in most part of the world. This is because, rape seed produce more oil per unit of land area compared to other natural seeds.

1.1 AIM AND OBJECTIVES OF THIS DESIGN PROJECT

The aim of this design project is to design a plant for the production of 100,000 tonnes per year of biodiesel fuel by the Transesterification of rapeseed oil with methanol aided by homogenous sodium hydroxide catalyst.

It is expected that this design project would achieve the following objectives to:

- Understand the important of the biodiesel fuel and the need for a potential substitute for fossil diesel oil.
- Highlight the characteristics, advantage, disadvantage, justification and limitation of the production of biodiesel fuel.
- Evaluate the process design and control, process flow diagram and equipment required for the production of biodiesel.
- Identify the idea of how to go about pilot plant, plant location and mechanical engineering design of the biodiesel fuel plant.

1.2 CHARACTERISTICS OF BIODIESEL FUEL

- It has a higher octane number and flash point than petroleum diesel
- Its viscosity is lower than diesel
- Its specific gravity is slightly higher than diesel
- It is biodegradable, non-toxic and free of sulphur and aromatics.

1.3 SIGNIFICANCE OF THE PROJECT

To increase energy self-sufficiency of non-oil producing countries and boost the availability of diesel fuel in oil producing nation through the following ways.

- Reduce pollution
- Create more employment opportunities.
- Provide a better alternative source of diesel fuel.
- Increase the demand for agricultural products.

1.4 DISADVANTAGES OF BIODIESEL FUEL

- High cost of production.
- Environmental impacts of increase fertilizer and pesticide usage to increase the oil seed production.
- It has a high viscosity than the conventional diesel and therefore becomes less useful at low temperature; hence, depressing agents and dissolving solvents may have to be added.

1.5 THE ECONOMIC COST AND EFFECTIVENESS OF BIODIESEL FUEL IN THE FUTURE.

In Malaysia and America, biodiesel fuel is more expensive than the conventional diesel but in European countries, biodiesel costs no more than diesel and can be up 5% cheaper as it is not subject to oil tax

Acceptance of biodiesel fuel is likely to increase over the year since it is non-toxic and has greater advantage than conventional diesel fuel. It is hope that in the near future more biodiesel plant will be set up in every country and hence, substitute consumption of conventional diesel from fossil fuel, through biodiesel is still not economically competitive nor is it seen to be the for-see-able future (DA Potts *et al,* 1999).

1.6 LIMITATION OF THE PROJECT

The cost of assembling the pilot scale set up for the manufacture of biodiesel is quite expensive. Rapeseed is not grown in this country hence it has to be imported from Europe for the course of this project. The feed prices are expensive ranging from £100/tonne for rapeseed oil to £200/tonne for sodium hydroxide.

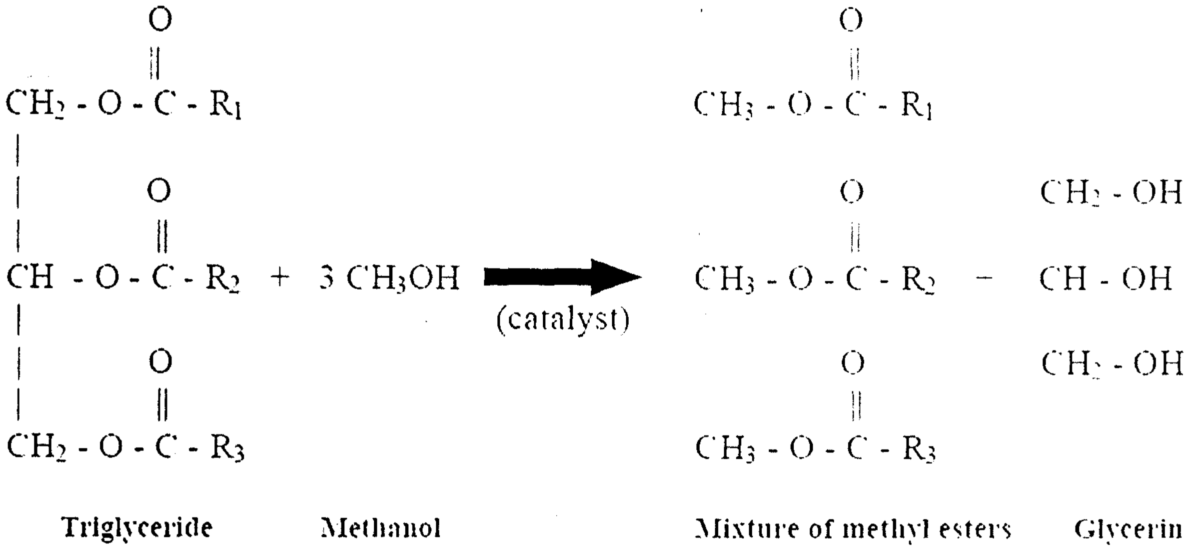
CHAPTER TWO

2.0 LITERATURE REVIEW

For comprehensive design of this project work literatures were reviewed to serve as a guide toward successful completion.

2.1 BIODIESEL

Biodiesel, defined as monoalkyl esters of vegetable oils or animal fats is a promising alternative fuel for use in compression-ignition (diesel) engines and is being produced in commercial quantity and used in various countries around the world, including the United States, Austria, The Czech Republic, France, Germany, Italy, Malaysia and Sweden(Gerhard Knothe,2001). It is produced by chemically reacting a fat or oil with an alcohol, in the presence of a catalyst. The product of the reaction is a mixture of methyl esters, which are known as biodiesel, and glycerol, which is a high value co-product. The process used is known as transesterification, and is shown in the equation below, where R_1, R_2, and R_3 are long hydrocarbon chains, sometimes called fatty acid chains.



There are five chains that are common in most vegetable oils and animal fats (others are present in small amounts). The relative amounts of the five methyl esters determine the physical

properties of the fuel, including the cetane number (a combustion-related diesel fuel quality index), cold flow, and oxidative stability.(Van Gerpen and M. Canakci,1997)

2.2 Characteristics and Specifications Biodiesel

As biodiesel is produced from a wide variety of vegetable oils of varying origin and quality, it was necessary to implement criteria for standardization of fuel quality for better engine performance. Austria was the pioneering country in the world to define and approve the standards for rapeseed oil methyl esters as diesel fuel (Meher et al. 2006). As standardization is a prerequisite for quality control, certain parameters are considered for the purpose, of which cetane number and fuel viscosity arc important ones. The detailed physical attributes of biodiesel produced following the transesterification process given in Table1 and Table 2 depicts the vegetable oil specific parameters and the corresponding value of fatty acid methyl esters according to select countries.

2.3 Current Technologies in Biodiesel Production

Of the several methods available for producing biodiesel, transesterification of natural oils and fats is currently the method of choice. The purpose of the process is to lower the viscosity of the oil or fat. Transesterification is basically a sequential reaction. Triglycerides are first reduced to diglycerides, which are subsequently reduced to monoglycerides, which are finally reduced to fatty acid esters.

The order of the reaction changes with the reaction conditions. The main factors affecting transesterification are the molar ratio of glycerides to alcohol, catalysts, reaction temperature and time, and free fatty acid and water content in oils and fats. Transesterification is extremely important for biodiesel. Biodiesel as it is defined today is obtained by transesterifying triglycerides with methanol. Methanol is the preferred alcohol for obtaining biodiesel because it is the cheapest alcohol.

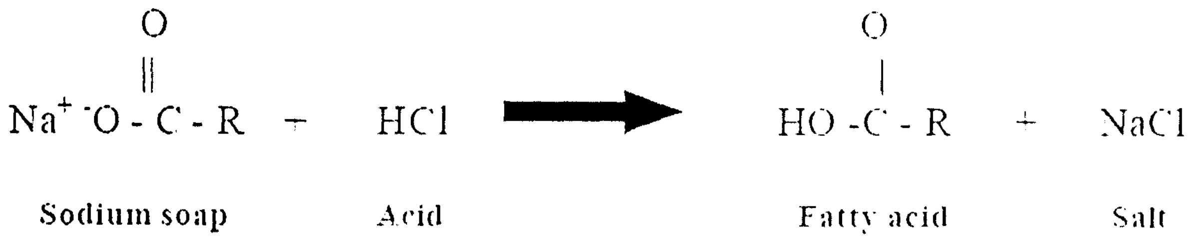
Base catalysts are more effective than acid catalysts and enzymes (Ma and Hanna, 1999). Methanol is made to react with triglycerides to produce methyl esters (biodiesel) and glycerol

2.3.1 TRANSESTERIFICATION

Transesterification is the general term used to describe the important class of organic reactions where an ester is transformed into another through the interchange of alkoxy when the original ester is reacted with an alcohol. Transesterification also known as alcoholysis of carboxylic esters, which is based on the chemical reaction of triglycerides with an alcohol in the presence of an alkaline catalyst to form a mixture of methyl esters, which are known as biodiesel and glycerine, which is a high value co-product. Transesterification is a reversible reaction. Thus, excess methanol is required to shift the equilibrium favourably. The transesterification process as shown in the equation below, where R_1, R_2, and R_3 are long chain hydrocarbon (Jon Van Gerpen, 2008).

2.3.1.1 Alkali-catalyzed Transesterification

Figure 1 shows a schematic diagram of the processes involved in biodiesel production from feedstocks containing low levels of free fatty acids (FFA). This includes soybean oil, canola (rapeseed) oil, and the higher grades of waste restaurant oils. Alcohol, catalyst, and oil are combined in a reactor and agitated for approximately one hour at 60°C. Smaller plants often use batch reactors (W.D. Stidham et al,2000) but most larger plants (> 4 million liters/yr) use continuous flow processes involving continuous stirred-tank reactors (CSTR) or plug flow reactors (G. Assman,1996). The reaction is sometimes done in two steps where approximately 80% of the alcohol and catalyst is added to the oil in a first stage CSTR. Then, the product stream from this reactor goes through a glycerol removal step before entering a second CSTR. The remaining 20% of the alcohol and catalyst are added in this second reactor. This system provides a very complete reaction with the potential of using less alcohol than single step systems.



$$Na^{+}\,{}^{-}O-\overset{\overset{\displaystyle O}{\|}}{C}-R \;+\; HCl \longrightarrow HO-\overset{\overset{\displaystyle O}{|}}{C}-R \;+\; NaCl$$

Following the reaction, the glycerol is removed from the methyl esters. Due to the low solubility of glycerol in the esters, this separation generally occurs quickly and may be accomplished with either a settling tank or a centrifuge. The excess methanol tends to act as a solubilizer and can slow the separation. However, this excess methanol is usually not removed from the reaction stream until after the glycerol and methyl esters are separated due to concern about reversing the transesterification reaction. Water may be added to the reaction mixture after the transesterification is complete to improve the separation of glycerol (T. Wimmer,1995).

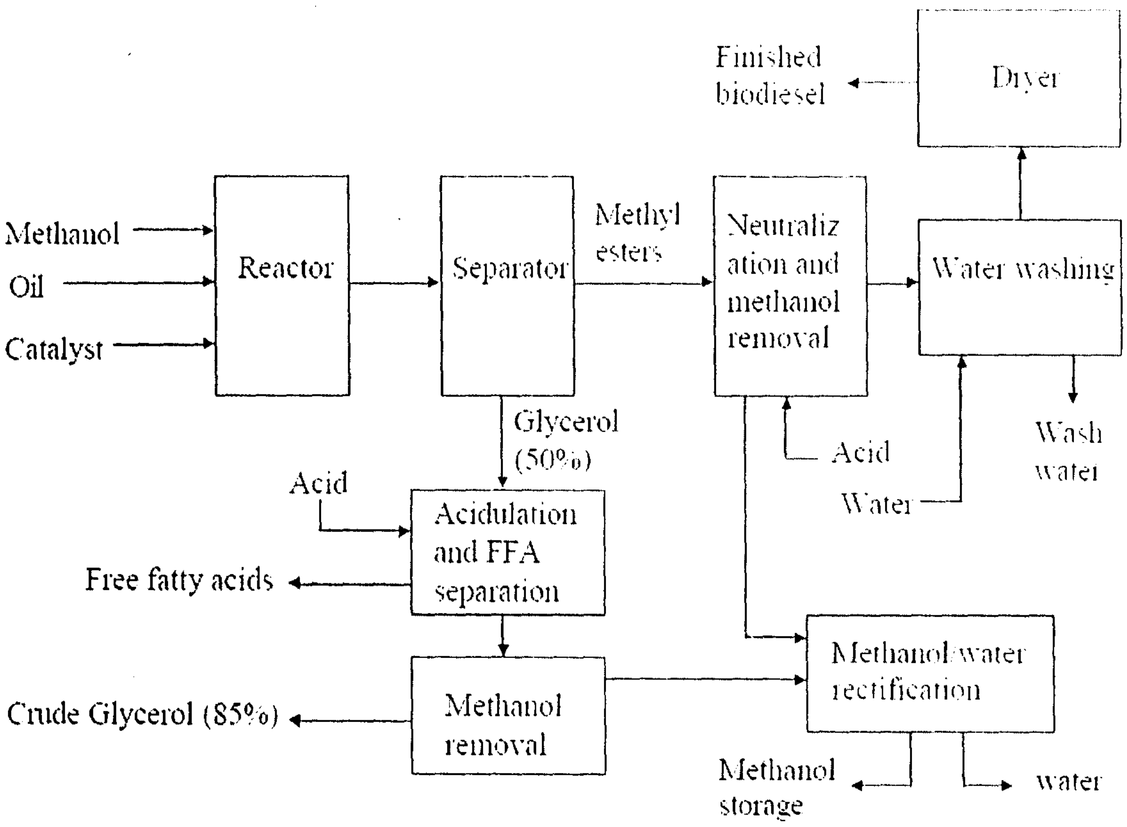
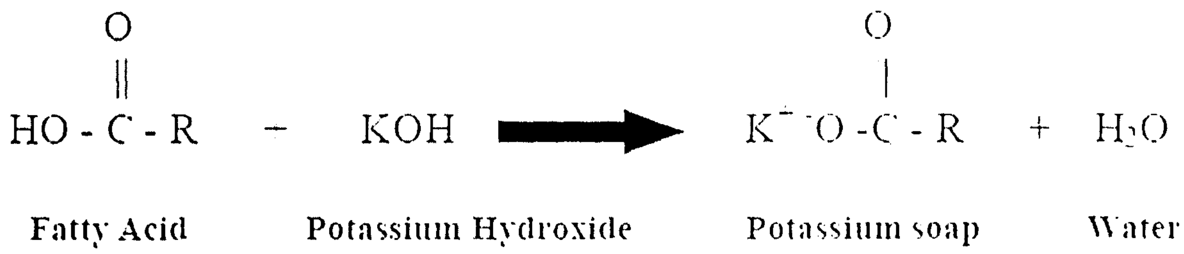


Figure1. Process Flow Schematic for Biodiesel Production

The methanol that is removed from the methyl ester and glycerol streams will tend to collect any water that may have entered the process. This water should be removed in a distillation column before the methanol is returned to the process. This step is more difficult if an alcohol such as ethanol or isopropanol is used that forms an azeotrope with water. Then, a molecular sieve is used to remove the water.

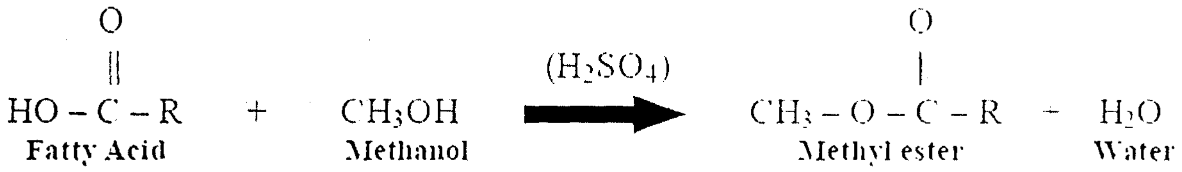
2.3.1.2 Acid Catalyzed Pretreatment

Special processes are required if the oil or fat contains significant amounts of FFAs. Used cooking oils typically contain 2-7 % FFAs and animal fats contain from 5-30 % FFAs. Some very low quality feedstocks, such as trap grease, can approach 100 % FFAs. When an alkali catalyst is added to these feedstocks, the free fatty acids react with the catalyst to form soap and water as shown in the reaction below:



$$\underset{\text{Fatty Acid}}{HO-\overset{\overset{O}{\|}}{C}-R} + \underset{\text{Potassium Hydroxide}}{KOH} \longrightarrow \underset{\text{Potassium soap}}{K^{+}\,{}^{-}O-\overset{\overset{O}{|}}{C}-R} + \underset{\text{Water}}{H_2O}$$

Up to about 5% FFAs, the reaction can still be catalyzed with an alkali catalyst but additional catalyst must be added to compensate for that lost to soap. The soap created during the reaction is either removed with the glycerol or is washed out during the water wash. When the FFA level is above 5%, the soap inhibits separation of the glycerol from the methyl esters and contributes to emulsion formation during the water wash. For these cases, an acid catalyst such as sulfuric acid can be used to esterify the FFAs to methyl esters as shown in the following reaction:



$$\underset{\text{Fatty Acid}}{HO-\overset{\overset{O}{\|}}{C}-R} + \underset{\text{Methanol}}{CH_3OH} \xrightarrow{(H_2SO_4)} \underset{\text{Methyl ester}}{CH_3-O-\overset{\overset{O}{|}}{C}-R} + \underset{\text{Water}}{H_2O}$$

As shown in Figure 2, this process can be used as a pretreatment to convert the FFAs to methyl esters and thereby reduce the FFA level. Then, the low FFA pretreated oil can be transesterified with an alkali catalyst to convert the triglycerides to methyl esters (G.I. Keim, 1945). As shown in the reaction, water is formed and, if it accumulates, it can stop the reaction well before completion.

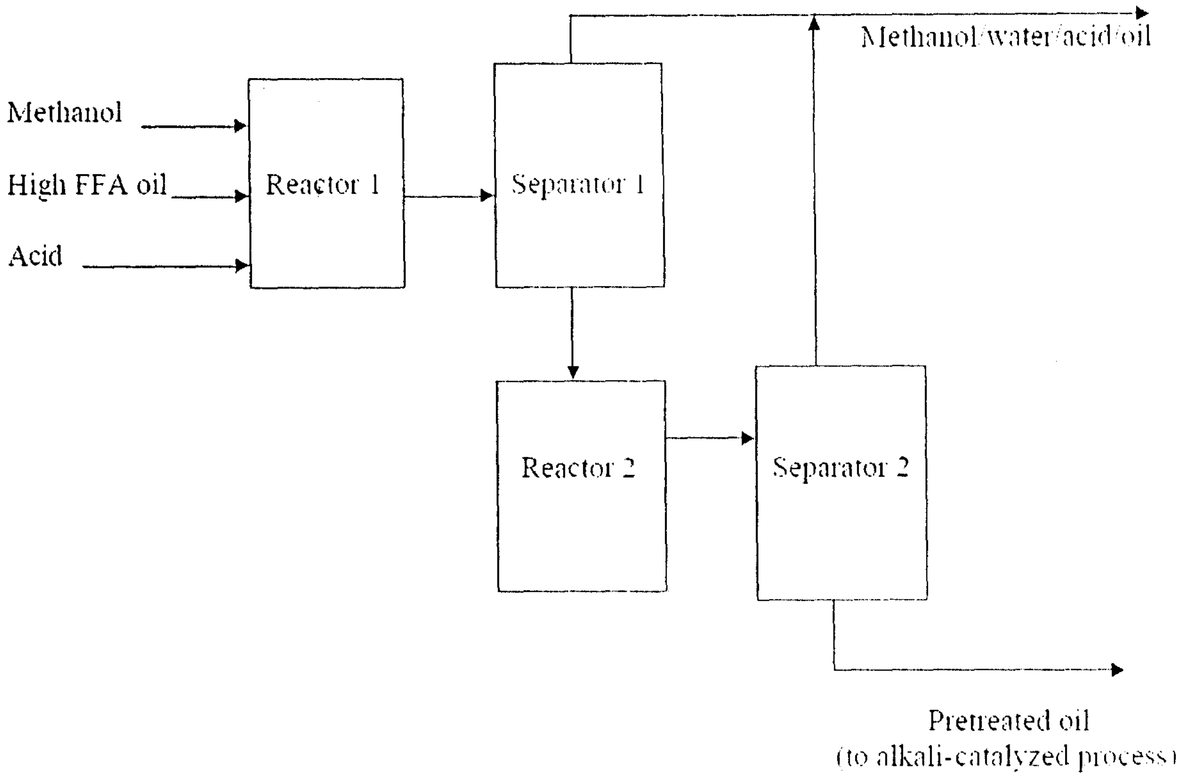


Figure 2: Pretreatment process for high free fatty acids feedstocks

Kawahara and Ono (Kawahara and Ono, 1979) propose allowing the alcohol to separate from the pretreated oil or fat following the reaction. Removal of this alcohol also removes the water formed by the esterification reaction and allows for a second step of esterification or proceeding directly to alkali-catalyzed transesterification.

Note that the methanol-water mixture will also contain some dissolved oil and FFAs that should be recovered and reprocessed.

2.4 Fuel Quality

The primary criterion for biodiesel quality is adherence to the appropriate standard. In the United States, this standard is ASTM D 6751-02 "Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels". Generally, the fuel quality of biodiesel can be influenced by several factors:

- The quality of the feedstock.
- The fatty acid composition of the parent vegetable oil or animal fat.
- The production process and the other materials used in this process.
- Post-production parameters.

Table 3 shows the property values required for a mixture of methyl esters to be considered biodiesel. When these limits are met, the biodiesel can be used in most modern engines without modifications while maintaining the engine's durability and reliability. Even in low level blends with conventional diesel fuel, the biodiesel blending stock is expected to meet the standard before being blended. While some properties in the standard, such as cetane number and density, reflect the properties of the chemical compounds that make up biodiesel, other properties provide indications of the quality of the production process. Generally, the parameters given in ASTM D6751 are defined by other ASTM standards. However, other test methods, such as those developed for the American Oil Chemists' Society, (AOCS) may also be suitable (or even more appropriate as they were developed for fats and oils and not for petroleum-derived materials addressed in the ASTM standards). This discussion will focus on the most important issues for assuring product quality for biodiesel as it is related to production as well as some post-production parameters.

Table 3. ASTM D 6751–02 Biodiesel Specifications

Property	Method	Limits	Units
Flash point, closed cup	D 93	130 min	°C
Water and sediment	D 2709	0.050 max	% volume
Kinematic viscosity, 40 °C	D 445	1.9 – 6.0	mm^2/s
Sulfated ash	D 874	0.020 max	wt. %
Total Sulfur	D 5453	0.05 max	wt. %
Copper strip corrosion	D 130	No. 3 max	
Cetane number	D 613	47 min	
Cloud point	D 2500	Report to customer	°C
Carbon residue	D 4530	0.05 max	wt. %
Acid number	D 664	0.8 max	mg KOH/g
Free glycerin	D 6584	0.02	wt. %
Total glycerin	D 6584	0.24	wt. %
Phosphorus	D 4951	10	ppm
Vacuum distillation end point	D 1160	360 °C max. at T-90	
Storage stability	To be determined	To be determined	To be determined

Source: American Society for Testing and Materials, Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels, 2002

2.5 Production Process Factors

2.5.1 Completion of reaction

The most important issue during biodiesel production is the completeness of the transesterification reaction. The basic chemical process that occurs during the reaction is indicated by the following sequence of events:

$$\begin{tikzcd}
\text{Triglyceride} \arrow[r] & \text{Diglyceride} \arrow[r] \arrow[d] & \text{Monoglyceride} \arrow[r] \arrow[d] & \text{Glycerol} \arrow[d] \\
 & \text{methyl ester} & \text{methyl ester} & \text{methyl ester}
\end{tikzcd}$$

The triglycerides are converted to diglycerides, which in turn are converted to monoglycerides, and then to glycerol. Each step produces a molecule of a methyl ester of a fatty acid. If the reaction is incomplete, then there will be triglycerides, diglycerides, and monoglycerides left in the reaction mixture. Each of these compounds still contains a glycerol molecule that has not been released. The glycerol portion of these compounds is referred to as *bound glycerol.*

2.5.2 Free Glycerol

Free glycerol refers to the amount of glycerol that is left in the finished biodiesel. Glycerol is essentially insoluble in biodiesel so almost all of the glycerol is easily removed by settling or centrifugation. Free glycerol may remain either as suspended droplets or as the very small amount that is dissolved in the biodiesel. Alcohols can act as cosolvents to increase the solubility of glycerol in the biodiesel. Most of this glycerol should be removed during the water washing process. Water-washed fuel is generally very low in free glycerol, especially if hot water is used for washing. Distilled biodiesel tends to have a greater problem with free glycerol due to glycerol carry-over during distillation. Fuel with excessive free glycerol will usually have a problem with glycerol settling out in storage tanks, creating a very viscous mixture that can plug fuel filters and cause combustion problems in the engine.

2.5.3 Residual Alcohol and Residual Catalyst

Since methanol (and ethanol) and the alkaline catalysts are more soluble in the polar glycerol phase, most will be removed when the glycerol is separated from the biodiesel. However, the biodiesel typically contains 2-4 % methanol after the separation, which may constitute as much as 40% of the excess methanol from the reaction. Most processors will recover this methanol using a vacuum stripping process. Any methanol remaining after this stripping process should be removed by the water washing process. Therefore, the residual alcohol level in the biodiesel should be very low. A specific value for the allowable alcohol level is specified in European biodiesel standards (0.2 % in EN 14214), but is not included in the ASTM standard. Tests have shown that as little as 1% methanol in the biodiesel can lower the flashpoint of the biodiesel from 170 °C to less than 40 °C. Therefore, by including a flashpoint specification of 130°C, the ASTM standard limits the amount of alcohol to a very low level (<0.1 %). Residual alcohol left in the biodiesel will generally be too small to negatively impact the fuel's performance. However, lowering the flashpoint presents a potential safety hazard as the fuel may need to be treated more like gasoline, which also has a low flashpoint, than diesel fuel.

Most of the residual catalyst is removed with the glycerol. Like the alcohol, remaining catalyst should be removed during the water washing. Although a value for residual catalyst is not included in the ASTM standard, it will be limited by the specification on sulfated ash.

Excessive ash in the fuel can lead to engine deposits and high abrasive wear levels. The European standard EN 14214 places limits on calcium and magnesium as well as the alkali metals sodium and potassium.

2.6 Post-production Factors

2.6.1 Water and Sediment

Water and sediment contamination are basically housekeeping issues for biodiesel. Water can be present in two forms, either as dissolved water or as suspended water droplets. While biodiesel is generally considered to be insoluble in water, it actually takes up considerably more water than diesel fuel. Biodiesel can contain as much as 1500 ppm of dissolved water while diesel fuel usually only takes up about 50 ppm (Van Gerpen, 1997). The standards for diesel fuel (ASTM D

975) and biodiesel (ASTM D 6751) both limit the amount of water to 500 ppm. For petroleum-based diesel fuel, this actually allows a small amount of suspended water. However, biodiesel must be kept dry. This is a challenge because many diesel storage tanks have water on the bottom due to condensation. Suspended water is a problem in fuel injection equipment because it contributes to the corrosion of the closely fitting parts in the fuel injection system.

Water can also contribute to microbial growth in the fuel. This problem can occur in both biodiesel and conventional diesel fuel and can result in acidic fuel and sludges that will plug fuel filters.

Sediment may consist of suspended rust and dirt particles or it may originate from the fuel as insoluble compounds formed during fuel oxidation. Some biodiesel users have noted that switching from petroleum-based diesel fuel to biodiesel causes an increase in sediment that comes from deposits on the walls of fuel tanks that had previously contained diesel fuel. Because its solvent properties are different from diesel fuel, biodiesel may loosen these sediments and cause fuel filter plugging during the transition period.

2.6.2 Storage Stability

Storage stability refers to the ability of the fuel to resist chemical changes during long term storage. These changes usually consist of oxidation due to contact with oxygen from the air. The fatty acid composition of the biodiesel fuel is an important factor in determining stability towards air. Generally, the polyunsaturated fatty acids (C18:2, linoleic acid; C18:3 linolenic acid) are most susceptible to oxidation. The changes can be catalyzed by the presence of certain metals (including those making up the storage container) and light. If water is present, hydrolysis can also occur. The chemical changes in the fuel associated with oxidation usually produce hydroperoxides that can, in turn, produce short chain fatty acids, aldehydes, and ketones. Under the right conditions, the hydroperoxides can also polymerize. Therefore, oxidation is usually denoted by an increase in the acid value and viscosity of the fuel. Often these changes are accompanied by a darkening of the biodiesel color from yellow to brown and the development of a "paint" smell. When water is present, the esters can hydrolyze to long chain free fatty acids which also cause the acid value to increase.

There is currently no generally accepted method for measuring the stability of biodiesel. The techniques generally used for petroleum-based fuels, such as ASTM D 2274, have been shown to be incompatible with biodiesel. Other procedures, such as the Oil Stability Index or the Rancimat apparatus, which are widely used in the fats and oils industry, seem to be more appropriate for use with biodiesel. However, the engine industry has no experience with these tests and acceptable values are not known. Also, the validity of accelerated testing methods has not been established or correlated to actual engine problems. If biodiesel's acid number, viscosity, or sediment content increase to the point where they exceed biodiesel's ASTM limits, the fuel should not be used as a transportation fuel.

Additives such as BHT and TBHQ (t-butylhydroquinone) are common in the food industry and have been found to enhance the storage stability of biodiesel. Biodiesel produced from soybean oil naturally contain some antioxidants (tocopherols, i.e., vitamin E), providing some protection against oxidation (some tocopherol is lost during refining of the oil prior to biodiesel production). Any fuel that will be stored for more than 6 months, whether it is diesel fuel or biodiesel, should be treated with an antioxidant additive.

2.7 Quality Control

All biodiesel production facilities should be equipped with a laboratory so that the quality of the final biodiesel product can be monitored. It is also important to monitor the quality of the feedstocks.

One strategy used by many producers is to draw a sample of the oil (or alcohol) from each delivery and use that sample to produce biodiesel in the laboratory. This test can be fairly rapid (1 or 2 hours) and can indicate whether serious problems are likely in the plant. Measuring feedstock quality can usually be limited to acid value and water content.

To monitor the completeness of the reaction according to the total glycerol level specified in ASTM D 6751 requires the use of a gas chromatograph and a skilled operator. Large producers will find that having this equipment on-site is necessary. Commercial laboratories (i.e.Magellan Midstream Partners) are available that can analyze the samples but the cost is $80-$150/test and

the time required may be several days. Smaller producers will need to use a more robust production process involving extra methanol and probably multiple reaction steps. Then the product quality can be monitored through periodic testing by an outside laboratory.

Other possibilities for monitoring the transesterification reaction and assessing fuel quality are methods based on spectroscopy (such as near- infrared spectroscopy) or physical properties (such as viscometry). These methods, although they are not (yet?) ASTM methods, are usually faster and easier to use than gas chromatography. However, some of them require extensive calibration. They also cannot accurately quantify glycerol at the low levels called for in the ASTM standard. To circumvent this, comparison to a reaction and product known to meet ASTM standards is needed.

2.8 RAPESEED

Rapeseed (Brassica napus), also known as rape, oilseed rape, rapa, rapaseed and (in the case of one particular group of cultivars) canola, is a bright yellow flowering member of the family Brassicaceae (mustard or cabbage family). The name derives from the Latin for turnip, rāpum or rāpa, and is first recorded in English at the end of the 14th century.

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Natural rapeseed oil contains 50 % erucic acid. Wild type seeds also contain high levels of glucosinolates (mustard oil glucosindes), chemical compounds that significantly lowered the nutritional value of rape seed press cakes for animal feed. The rapeseed is the valuable, harvested component of the crop. The crop is also grown as a winter-cover crop. It provides good coverage of the soil in winter, and limits nitrogen run-off. The plant is ploughed back in the soil or used as bedding. On some ecological or organic operations, livestock such as sheep or cattle are allowed to graze on the plants.

Processing of rapeseed for oil production provides rapeseed animal meal as a by-product. The by-product is a high-protein animal feed, competitive with soya. The feed is mostly employed for cattle feeding, but also for pigs and chickens (though less valuable for these). The meal has a very low content of the glucosinolates responsible for metabolism disruption in cattle and pigs. Rapeseed "oil cake" is also used as a fertilizer in China, and may be used for ornamentals. Rapeseed leaves and stems are also edible. Some varieties of rapeseed are used for vegetable oil production. Rapeseed is a heavy nectar producer, and honeybees produce a light colored, but peppery honey from it. It must be extracted immediately after processing is finished, as it will quickly granulate in the honeycomb and will be impossible to extract. The honey is usually blended with milder honeys, if used for table use, or sold as bakery grade. Rapeseed growers contract with beekeepers for the pollination of the crop.

Rapeseed oil is used in the manufacture of biodiesel for powering motor vehicles. Biodiesel may be used in pure form in newer engines without engine damage, and is frequently combined with fossil-fuel diesel in ratios varying from 2 % to 20 % biodiesel. Formerly, owing to the costs of growing, crushing, and refining rapeseed biodiesel, rapeseed derived biodiesel cost more to produce than standard diesel fuel. Prices of rapeseed oil are at very high levels presently owing to increased demand on rapeseed oil for this purpose. Rapeseed oil is the preferred oil stock for

biodiesel production in most of Europe, partly because rapeseed produces more oil per unit of land area compared to other oil sources, such as soy beans (DA Potts et-al., 1999).

2.9 METHANOL

Methanol is the most common alcohol used for the conversion of fats and oils to biodiesel. Methanol is flammable, as such proper handling is required for safety. Methanol and oil do not mix well, and poor contact between the oil and methanol reactants means the reaction rate will be slow. Vigorous mixing at the beginning of the reaction improves reaction rates. Towards the end of the reaction, reduced mixing helps the separation of glycerine, and the reaction would proceed faster in the top layer, which contains oil and methanol. At ambient temperature (21 ^{0}C or 70 ^{0}F), the reaction takes four to eight hours to complete. The reaction is usually conducted below the boiling point of methanol (60 ^{0}C or 140 ^{0}F). At this temperature, the reaction time may vary between 20 minutes to 1.5 hours. A higher temperature will decrease reaction time, but this requires the use of a pressure vessel because the boiling point of methanol is 65 ^{0}C or 148 ^{0}F. The reactor is either sealed or equipped with a condenser to minimize alcohol evaporation during the conversion process. Higher oil conversion rates can be achieved if the production system is set up as a two-step process with two reactors. In such cases, glycerine formed in the first reactor is removed, and the reaction is completed in the second reactor.

$$y_{s,10} = \begin{array}{|r|}\hline 0.02 \\ \hline 0.015 \\ \hline 4.901\cdot 10^{-3} \\ \hline 9.605\cdot 10^{-3} \\ \hline 0.951 \\ \hline 0 \\ \hline \end{array} \qquad \begin{pmatrix} \text{Rapeseed\_oil} \\ \textit{Methanol} \\ \text{NaOH} \\ \text{Glycerol} \\ \textit{Biodiesel} \\ \text{Water} \end{pmatrix}$$

$$\sum_{s=0}^{5} y_{s,10} = 1$$

SUMMARY OF MATERIAL BALANCE FOR UNIT SIX (COLUMN II)

INPUT

$$Input_6 := \sum_{j=8}^{8} N_j$$

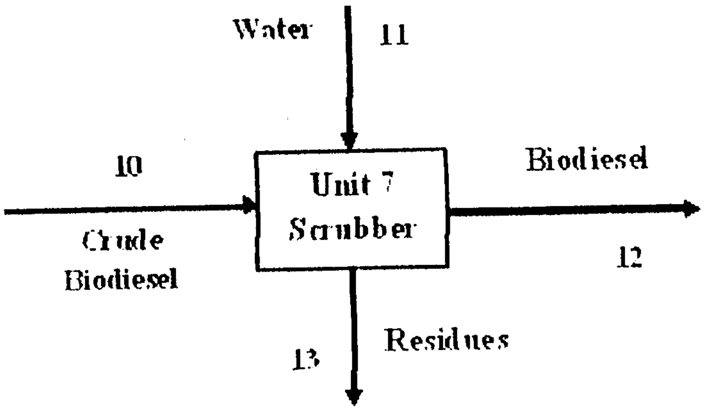
OUTPUT

$$Output_6 := \sum_{j=9}^{10} N_j$$

$$\begin{pmatrix} \text{Rapeseed\_oil} \\ \text{Methanol} \\ \text{NaOH} \\ \text{Glycerol} \\ \text{Biodiesel} \\ \text{Water} \end{pmatrix} \qquad \sum_{j=8}^{8} n_{s,j} = \begin{array}{|r|}\hline 259.66 \\ \hline 21.588 \\ \hline 8.808 \\ \hline 3.975\cdot 10^{3} \\ \hline 1.28\cdot 10^{4} \\ \hline 0 \\ \hline \end{array} \cdot \frac{kg}{hr} \qquad \sum_{j=9}^{10} n_{s,j} = \begin{array}{|r|}\hline 259.66 \\ \hline 21.588 \\ \hline 8.808 \\ \hline 3.975\cdot 10^{3} \\ \hline 1.28\cdot 10^{4} \\ \hline 0 \\ \hline \end{array} \cdot \frac{kg}{hr}$$

Total = $Input_6 = 1.706\times 10^{4}\cdot\frac{kg}{hr}$ $Output_6 = 1.706\times 10^{4}\cdot\frac{kg}{hr}$

UNIT SEVEN: Scrubber



Stream 11: Water

Water for washing is fed into the Scrubber/settling tank to eliminate base catalyst residues and to separate out the final Biodiesel.

Water feed into the Scrubber is given as:

$$n_{5,11} := 0.40 N_{10}$$

$$n_{5,11} = 5.199\times 10^{3}\cdot\frac{kg}{hr}$$

Total mass flow of stream 11 is given as:

$$N_{11} := \sum_{s=0}^{5} n_{s,11}$$

$$N_{11} = 5.199\times 10^{3}\cdot\frac{kg}{hr}$$

Mass compositions of stream 11 is:

$$x_{s,11} := \frac{n_{s,11}}{N_{11}} \qquad x_{s,11} = \begin{array}{|c|}\hline 0\\\hline 0\\\hline 0\\\hline 0\\\hline 0\\\hline 1\\\hline\end{array} \quad \begin{pmatrix}\text{Rapeseed\_oil}\\ \text{Methanol}\\ \text{NaOH}\\ \text{Glycerol}\\ \text{Biodiesel}\\ \text{Water}\end{pmatrix}$$

$$\sum_{s=0}^{5} x_{s,11} = 1$$

Molar compositions of stream 11 is:

$$z_{s,11} := \frac{n_{s,11}}{M_{w_s}}$$

$$z_{s,11} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 288.527 \end{bmatrix} \cdot \frac{\text{kmol}}{\text{hr}}$$

Total molar flow of stream 11 is:

$$Z_{11} := \sum_{s=0}^{5} z_{s,11}$$

$$Z_{11} = 288.527 \cdot \frac{\text{kmol}}{\text{hr}}$$

Molar compositions of stream 11 is:

$$y_{s,11} := \frac{z_{s,11}}{Z_{11}} \qquad y_{s,11} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \quad \begin{pmatrix} \text{Rapeseed\_oil} \\ \text{Methanol} \\ \text{NaOH} \\ \text{Glycerol} \\ \text{Biodiesel} \\ \text{Water} \end{pmatrix}$$

$$\sum_{s=0}^{5} y_{s,11} = 1$$

Stream 12: Biodiesel

Mass flow of final Biodiesel product in stream 12 is given as:

$$n_{4,12} := 0.999 n_{4,10}$$

$$n_{4,12} = 1.266 \times 10^{4} \cdot \frac{kg}{hr}$$

Glycerol present in the final Biodiesel product obtained is calculated as:

$$n_{3,12} := 0.50 n_{3,10}$$

$$n_{3,12} = 19.874 \frac{kg}{hr}$$

Total mass flow of stream 12 is given as:

$$N_{12} := \sum_{s=0}^{5} n_{s,12}$$

$$N_{12} = 1.268 \times 10^{4} \cdot \frac{kg}{hr}$$

Mass compositions of stream 12 is:

$$x_{s,12} := \frac{n_{s,12}}{N_{12}}$$

$$x_{s,12} = \begin{array}{|r|}\hline 0\\ \hline 0\\ \hline 0\\ \hline 1.568\cdot 10^{-3}\\ \hline 0.998\\ \hline 0\\ \hline \end{array} \qquad x_{s,12}\cdot 100 = \begin{array}{|r|}\hline 0\\ \hline 0\\ \hline 0\\ \hline 0.157\\ \hline 99.843\\ \hline 0\\ \hline \end{array} \qquad \begin{pmatrix} \text{Rapeseed\_oil}\\ \text{Methanol}\\ \text{NaOH}\\ \text{Glycerol}\\ \text{Biodiesel}\\ \text{Water} \end{pmatrix}$$

$$\sum_{s=0}^{5} x_{s,12} = 1$$

Molar compositions of stream 12 is:

$$z_{s,12} := \frac{n_{s,12}}{M_{w_s}}$$

$$z_{s,12} = \begin{array}{|r|}\hline 0\\ \hline 0\\ \hline 0\\ \hline 0.216\\ \hline 42.684\\ \hline 0\\ \hline \end{array} \cdot \frac{\text{kmol}}{\text{hr}}$$

Total molar flow of stream 12 is:

$$Z_{12} := \sum_{s=0}^{5} z_{s,12}$$

$$Z_{12} = 42.899 \frac{\text{kmol}}{\text{hr}}$$

Molar compositions of stream 12 is:

$$y_{s,12} := \frac{z_{s,12}}{Z_{12}}$$

$$y_{s,12} = \begin{array}{|r|}\hline 0 \\ \hline 0 \\ \hline 0 \\ \hline 5.03\cdot10^{-3} \\ \hline 0.995 \\ \hline 0 \\ \hline \end{array} \quad \begin{pmatrix}\text{Rapeseed\_oil}\\ \text{Methanol}\\ \text{NaOH}\\ \text{Glycerol}\\ \text{Biodiesel}\\ \text{Water}\end{pmatrix}$$

$$\sum_{s=0}^{5} y_{s,12} = 1$$

Stream 13: Residues

Mass flow of components present as residue in stream 13 is given as:

$$n_{s,13} := n_{s,10} + n_{s,11} - n_{s,12}$$

$$n_{s,13} = \begin{array}{|r|}\hline 259.66 \\ \hline 21.588 \\ \hline 8.808 \\ \hline 19.874 \\ \hline 12.668 \\ \hline 5.199\cdot10^{3} \\ \hline \end{array} \cdot \frac{kg}{hr} \quad \begin{pmatrix}\text{Rapeseed\_oil}\\ \text{Methanol}\\ \text{NaOH}\\ \text{Glycerol}\\ \text{Biodiesel}\\ \text{Water}\end{pmatrix}$$

Total mass flow of stream 13 is given as:

$$N_{13} := \sum_{s=0}^{5} n_{s,13}$$

$$N_{13} = 5.522 \times 10^{3} \cdot \frac{kg}{hr}$$

Mass compositions of stream 13 is:

$$x_{s,13} := \frac{n_{s,13}}{N_{13}}$$

$x_{s,13} =$

0.047	Rapeseed_oil
$3.91 \cdot 10^{-3}$	Methanol
$1.595 \cdot 10^{-3}$	NaOH
$3.599 \cdot 10^{-3}$	Glycerol
$2.294 \cdot 10^{-3}$	Biodiesel
0.942	Water

$$\sum_{s=0}^{5} x_{s,13} = 1$$

Molar compositions of stream 13 is:

$$z_{s,13} := \frac{n_{s,13}}{M_{w_s}}$$

$z_{s,13} =$

$\frac{kmol}{hr}$
0.881
0.674
0.22
0.216
0.043
288.527

Total molar flow of stream 13 is:

$$Z_{13} := \sum_{s=0}^{5} z_{s,13}$$

$$Z_{13} = 290.56 \frac{\mathrm{kmol}}{\mathrm{hr}}$$

Molar compositions of stream 13 is:

$$y_{s,13} := \frac{Z_{s,13}}{Z_{13}}$$

$y_{s,13} =$

$y_{s,13}$	
$3.031 \cdot 10^{-3}$	Rapeseed_oil
$2.319 \cdot 10^{-3}$	Methanol
$7.578 \cdot 10^{-4}$	NaOH
$7.427 \cdot 10^{-4}$	Glycerol
$1.47 \cdot 10^{-4}$	Biodiesel
0.993	Water

$$\sum_{s=0}^{5} y_{s,13} = 1$$

SUMMARY OF MATERIAL BALANCE FOR UNIT SEVEN (SCRUBBER)

	INPUT	OUTPUT
	$\mathrm{Input}_7 := \sum_{j=10}^{11} N_j$	$\mathrm{Output}_7 := \sum_{j=12}^{13} N_j$
	$\sum_{j=10}^{11} n_{s,j} =$ $\frac{\mathrm{kg}}{\mathrm{hr}}$	$\sum_{j=12}^{13} n_{s,j} =$ $\frac{\mathrm{kg}}{\mathrm{hr}}$
Rapeseed_oil	259.66	259.66
Methanol	21.588	21.588
NaOH	8.808	8.808
Glycerol	39.748	39.748
Biodiesel	$1.267 \cdot 10^{4}$	$1.267 \cdot 10^{4}$
Water	$5.199 \cdot 10^{3}$	$5.199 \cdot 10^{3}$
Total =	$\mathrm{Input}_7 = 1.82 \times 10^{4} \cdot \frac{\mathrm{kg}}{\mathrm{hr}}$	$\mathrm{Output}_7 = 1.82 \times 10^{4} \cdot \frac{\mathrm{kg}}{\mathrm{hr}}$

Product Quality:

According to (Gerpen et al., 2004), Biodiesel product quality allows for about 0.24% total Glycerol. Hence the Biodiesel so gotten from this process meets the required product quality standard.

Total mass flow of stream 10 (Final Biodiesel obtained from the process) is:

$$N_{12} := \sum_{s=0}^{5} n_{s,12}$$

$$N_{12} = 1.268\times 10^{4}\cdot\frac{kg}{hr}$$

$$N_{12} = 1\times 10^{5}\cdot\frac{tonne}{annum}$$

Scale up factor:

Biodiesel Target production is 100,000 tonnes/annum.

That is,

$$Target_{production} := 100000\frac{tonne}{annum}$$

But Calculated value of Biodiesel produced from the chosen Basis is:

$$Calculated_{value} := N_{12}$$

$$Calculated_{value} = 1\times 10^{5}\cdot\frac{tonne}{annum}$$

Therefore, the Scale up factor is calculated as follows:

$$SF := \frac{Target_{production}}{Calculated_{value}}$$

SF=1

CHAPTER FOUR

4.1 ENERGY BALANCES AND THERMODYNAMICS PROPERTIES

The thermodynamics properties used in this work was gotten from standard texts

4.1.1 HEAT CAPACITY COEFFICIENTS OF THE COMPONENTS

The heat capacity coefficient of the components involved in this project are as outlined below. Denoting the matrix of the heat capacity coefficients by c, we have

THERMODYNAMICS PROPERTIES

$$c := \begin{pmatrix} 0.0000 & -0.266860 & 3.514010^{-3} & -2.318710^{-6} \\ 0:0000 & 0.66020 & 1.107210^{-3} & 2.6925610^{-7} \\ 3.14015 & 0.63178 & 1.5533510^{-3} & -1.7553110^{-6} \\ 0.0000 & 9.1531610^{-2} & 2.4132210^{-3} & -1.1441310^{-6} \\ 1.0934710^{-7} & -0.152999 & 3.4338410^{-3} & -1.7137410^{-6} \\ -5.7296 & 1.91450 & -3.9574010^{-4} & 8.7620610^{-7} \end{pmatrix} \qquad \begin{pmatrix} \text{Rapeseed\_oil} \\ \text{Methanol} \\ \text{NaOH} \\ \text{Glycerol} \\ \text{Biodiesel} \\ \text{Water} \end{pmatrix}$$

4.1.2 HEAT OF FORMATION OF THE COMPONENTS

The heat of formation of the components involved in this project are as outlined below:

Denoting the matrix of the heat capacity coefficients by h_f, we have

$$h_f := \begin{pmatrix} -1.743 \times 10^2 \\ -4.811 \times 10^1 \\ 0.0000 \\ -1.399 \cdot 10^2 \\ -1.496 \cdot 10^2 \\ -5.76 \cdot 10^1 \end{pmatrix} \cdot \frac{\text{kcal}}{\text{mol}} \qquad \begin{pmatrix} \text{Rapeseed\_oil} \\ \text{Methanol} \\ \text{NaOH} \\ \text{Glycerol} \\ \text{Biodiesel} \\ \text{Water} \end{pmatrix}$$

$k := 1 .. 4$ $\qquad s := 0 .. 5$ $\qquad H_{s,i} := 0 \frac{J}{hr}$ $\qquad kJ \equiv 1000\,\text{joule}$ $\qquad cal = 4.187J$

The equation to be used for the energy balance is given as:

$$\Delta H = n \cdot \int_{T_r}^{T_s} c_p \, dT$$

where

H = Enthalpy

C_p = Heat capacity

T = Temperature

n = Amount

T_r = Reference temperature

T_s = System temperature

If a reaction is involved, the equation becomes

$$\Delta H = n \cdot \int_{T_r}^{T_s} c_p \, dT + h_f$$

where h_f = heat of formation

It should be noted that C_p is given in terms of heat capacity coefficients as

$$C_p = a + b \cdot T + c \cdot T^2 + d \cdot T^3$$

where a, b, c and d are heat capacity coefficients (constants).

So, the energy balance equation will then become

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3\right) dT$$

4.2.1 ENERGY BALANCES CALCULATIONS

Energy Balances:

Evaluation of Species Enthalpies: the reference state is the elements at 25^{0}C.

$T_r := 298$ K $\qquad T_0 := (25 + 273.16) \qquad T := T_0$

$$h(s,0) = z_{s,0} \cdot \left[\left[\frac{c_{s,0}}{1} \cdot \left(T - T_r\right) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^{\,2}\right) \dots + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^{\,4}\right) \right] \right] \cdot \frac{J}{mol}$$

UNIT 1: Oil Heater

Enthalpy of stream 0:

$T_r := 298$ K $\qquad T_0 := (25 + 273.16)$ K $\qquad T := T_0$

$$H_{s,0} := z_{s,0} \cdot \left[\frac{c_{s,0}}{1} \cdot \left(T - T_r\right) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^{\,2}\right) \dots + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^{\,4}\right) \right] \cdot \frac{J}{mol}$$

$$H_{s,0} = \cdot \frac{kJ}{hr}$$

$$\Delta H_0 := \sum_s H_{s,0}$$

$$\Delta H_0 = \cdot \frac{kJ}{hr}$$

Total enthalpy into the Heater:

$$\Delta H_{in1} := \Delta H_0$$

$$\Delta H_{in1} = \cdot \frac{kJ}{hr}$$

Enthalpy of stream 1:

$T_r := 298 \quad K$ $\qquad$ $T_1 := (60 + 273.16) \quad K$ $\qquad$ $T := T_1$

$$H_{s,1} := z_{s,1} \cdot \left[\begin{array}{l} \frac{c_{s,0}}{1} \cdot (T - T_r) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^{\,2}\right) \ldots \\ + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^{\,4}\right) \end{array} \right] \cdot \frac{J}{mol}$$

$$H_{s,1} = \cdot \frac{kJ}{hr}$$

$$\Delta H_1 := \sum_s H_{s,1}$$

$$\Delta H_1 = \cdot \frac{kJ}{hr}$$

Total enthalpy out of the Heater:

$$\Delta H_{out1} := \Delta H_1$$

$$\Delta H_{out1} = \cdot \frac{kJ}{hr}$$

Heat load: $\Delta H := \Delta H_{out1} - \Delta H_{in1}$

$$\Delta H = \cdot \frac{kJ}{hr}$$

i.e. Heat supplied to the Heater = 297600 kJ/hr

UNIT 2: Mixer 1

Enthalpy of stream 2:

$T_r := 298 \quad K$ $\qquad T_2 := (25 + 273.16) \quad K$ $\qquad T := T_2$

$$H_{s,2} := n_{s,2} \cdot \left[\begin{bmatrix} \frac{c_{s,0}}{1} \cdot (T - T_r) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^2\right) \ldots \\ + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^3\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^4\right) \end{bmatrix} \right] \cdot \frac{J}{mol}$$

$$H_{s,2} = \cdot \frac{kJ}{hr}$$

$$\Delta H_2 := \sum_s H_{s,2}$$

$$\Delta H_2 = \cdot \frac{kJ}{hr}$$

Enthalpy of stream 3:

$T_r := 298\ \ K$ $\qquad T_3 := (25 + 273.16)\ \ K$ $\qquad T := T_3$

$$H_{s,3} := n_{s,3}\cdot\left[\left[\frac{c_{s,0}}{1}\cdot\left(T - T_r\right) + \frac{c_{s,1}}{2}\cdot\left(T^2 - T_r^{\,2}\right) \dots + \frac{c_{s,2}}{3}\cdot\left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4}\cdot\left(T^4 - T_r^{\,4}\right)\right]\right]\cdot\frac{J}{mol}$$

$$H_{s,3} = \cdot\frac{kJ}{hr}$$

$$\Delta H_3 := \sum_s H_{s,3}$$

$$\Delta H_3 = \cdot\frac{kJ}{hr}$$

Total enthalpy into Mixer 1:

$$\Delta H_{in2} := \Delta H_2 + \Delta H_3$$

$$\Delta H_{in2} = \cdot\frac{kJ}{hr}$$

Enthalpy of stream 4:

$T_r := 298\ \ K$ $\qquad T_4 := (30 + 273.16)\ \ K$ $\qquad T := T_4$

$$H_{s,4} := n_{s,4}\cdot\left[\left[\frac{c_{s,0}}{1}\cdot\left(T - T_r\right) + \frac{c_{s,1}}{2}\cdot\left(T^2 - T_r^{\,2}\right) \dots + \frac{c_{s,2}}{3}\cdot\left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4}\cdot\left(T^4 - T_r^{\,4}\right)\right]\right]\cdot\frac{J}{mol}$$

$H_{s,4} = \cdot\frac{kJ}{hr}$

$\Delta H_4 := \sum_s H_{s,4}$

$\Delta H_4 = \cdot\frac{kJ}{hr}$

Total enthalpy out of Mixer 1:

$\Delta H_{out2} := \Delta H_4$

$\Delta H_{out2} = \cdot\frac{kJ}{hr}$

Heat load: $\Delta H := \Delta H_{out2} - \Delta H_{in2}$

$\Delta H = \cdot\frac{kJ}{hr}$

UNIT 3: Mixer 2

Total enthalpy into Mixer 2:

$\Delta H_{in3} := \Delta H_1 + \Delta H_4$

$\Delta H_{in3} = \cdot\frac{kJ}{hr}$

Enthalpy of stream 5:

$T_r := 298 \quad K$ $\qquad T_5 := (50 + 273.16) \quad K$ $\qquad T := T_5$

$$H_{s,5} := \nu_{s,5} \cdot \left[\left[\begin{array}{l} \frac{c_{s,0}}{1}\cdot\left(T - T_r\right) + \frac{c_{s,1}}{2}\cdot\left(T^2 - T_r^2\right) \dots \\ + \frac{c_{s,2}}{3}\cdot\left(T^3 - T_r^3\right) + \frac{c_{s,3}}{4}\cdot\left(T^4 - T_r^4\right) \end{array}\right]\right]\cdot\frac{J}{mol}$$

$H_{s,5} = \cdot\frac{kJ}{hr}$

$$\Delta H_5 := \sum_s H_{s,5}$$

$\Delta H_5 = \cdot\frac{kJ}{hr}$

Total enthalpy out of Mixer 2:

$\Delta H_{out3} := \Delta H_5$

$\Delta H_{out3} = \cdot\frac{kJ}{hr}$

Heat load: $\qquad \Delta H := \Delta H_{out3} - \Delta H_{in3}$

$\Delta H = \cdot\frac{kJ}{hr}$

UNIT 4: Transesterification Reactor

Enthalpy of stream 5:

$T_r := 298\ \ \mathrm{K}$ $\qquad T_5 := (50 + 273.16)\ \ \mathrm{K}$ $\qquad T := T_5$

$$H_{s,5} := {}'_{s,5} \cdot \left[\left[\frac{c_{s,0}}{1} \cdot (T - T_r) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^{\,2}\right) \cdots \atop + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^{\,4}\right) \right] \cdot \frac{\mathrm{J}}{\mathrm{mol}} + h_{f_s} \right]$$

$$H_{s,5} = \cdot \frac{\mathrm{kJ}}{\mathrm{hr}}$$

$$\Delta H_5 := \sum_s H_{s,5}$$

$$\Delta H_5 = \cdot \frac{\mathrm{kJ}}{\mathrm{hr}}$$

Total enthalpy into the Reactor:

$$\Delta H_{in4} := \Delta H_5$$

$$\Delta H_{in4} = \cdot \frac{\mathrm{kJ}}{\mathrm{hr}}$$

Enthalpy of stream 6:

$T_r := 298\ \ \mathrm{K}$ $\qquad T_6 := (60 + 273.16)\ \ \mathrm{K}$ $\qquad T := T_6$

$$H_{s,6} := \nu_{s,6}\cdot\left[\left[\frac{c_{s,0}}{1}\cdot(T - T_r) + \frac{c_{s,1}}{2}\cdot\left(T^2 - T_r^2\right)\ldots + \frac{c_{s,2}}{3}\cdot\left(T^3 - T_r^3\right) + \frac{c_{s,3}}{4}\cdot\left(T^4 - T_r^4\right)\right]\cdot\frac{J}{mol} + h_{f_s}\right]$$

$$H_{s,6} = \cdot\frac{kJ}{hr}$$

$$\Delta H_6 := \sum_s H_{s,6}$$

$$\Delta H_6 = \cdot\frac{kJ}{hr}$$

Total enthalpy out of the Reactor:

$$\Delta H_{out4} := \Delta H_6$$

$$\Delta H_{out4} = \cdot\frac{kJ}{hr}$$

Heat load: $\Delta H := \Delta H_{out4} - \Delta H_{in4}$

$$\Delta H = \cdot\frac{kJ}{hr}$$

UNIT 5: Distillation Column I

Enthalpy of stream 6:

$T_r := 298$ K $\quad T_6 := (60 + 273.16)$ K $\quad T := T_6$

$$H_{s,6} := z_{s,6} \cdot \left[\left[\frac{c_{s,0}}{1} \cdot \left(T - T_r\right) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^2\right) \ldots \atop + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^3\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^4\right) \right]\right] \cdot \frac{J}{mol}$$

$$H_{s,6} = \cdot \frac{kJ}{hr}$$

$$\Delta H_6 := \sum_s H_{s,6}$$

$$\Delta H_6 = \cdot \frac{kJ}{hr}$$

Total enthalpy into Column I:

$$\Delta H_{in5} := \Delta H_6$$

$$\Delta H_{in5} = \cdot \frac{kJ}{hr}$$

Enthalpy of stream 7:

$T_r := 298 \quad K$ $\qquad T_7 := (45 + 273.16) \quad K$ $\qquad T := T_7$

$$H_{s,7} := z_{s,7} \cdot \left[\left[\frac{c_{s,0}}{1} \cdot \left(T - T_r\right) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^2\right) \ldots \atop + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^3\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^4\right) \right]\right] \cdot \frac{J}{mol}$$

$$H_{s,7} = \cdot \frac{kJ}{hr}$$

$$\Delta H_7 := \sum_{s} H_{s,7}$$

$$\Delta H_7 = \cdot \frac{kJ}{hr}$$

Enthalpy of stream 8:

$T_r := 298 \quad K$ $\qquad$ $T_7 := (75 + 273.16)$

$$H_{s,8} := n_{s,8} \cdot \left[\left[\frac{c_{s,0}}{1} \cdot \left(T - T_r\right) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^{\,2}\right) \ldots \\ + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^{\,4}\right) \right] \right] \cdot \frac{J}{mol}$$

$$H_{s,8} = \cdot \frac{kJ}{hr}$$

$$\Delta H_8 := \sum_{s} H_{s,8}$$

$$\Delta H_8 = \cdot \frac{kJ}{hr}$$

Total enthalpy out of Column I:

$\Delta H_{out5} := \Delta H_{7} + \Delta H_{8}$

$\Delta H_{out5} = \cdot\frac{kJ}{hr}$

Heat load: $\Delta H := \Delta H_{out5} - \Delta H_{in5}$

$\Delta H = \cdot\frac{kJ}{hr}$

UNIT 6: Distillation Column II

Total enthalpy into Column II:

$\Delta H_{in6} := \Delta H_{8}$

$\Delta H_{in6} = \cdot\frac{kJ}{hr}$

Enthalpy of stream 9:

$T_r := 298\ \ K$ $\qquad T_9 := (45 + 273.16)\ \ K$ $\qquad T := T_9$

$$H_{s,9} := F_{s,9} \cdot \left[\left[\begin{aligned}&\frac{c_{s,0}}{1}\cdot\left(T - T_r\right) + \frac{c_{s,1}}{2}\cdot\left(T^2 - T_r^{\,2}\right) \ldots \\ &+ \frac{c_{s,2}}{3}\cdot\left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4}\cdot\left(T^4 - T_r^{\,4}\right)\end{aligned}\right]\right]\cdot\frac{J}{mol}$$

$H_{s,9} = \cdot\frac{kJ}{hr}$

$$\Delta H_{9} := \sum_{s} H_{s,9}$$

$$\Delta H_{9} = \cdot\frac{kJ}{hr}$$

Enthalpy of stream 10:

$T_r := 298 \quad K$ $\qquad T_{10} := (90 + 273.16)\ K$ $\qquad T := T_{10}$

$$H_{s,10} := F_{s,10}\cdot\left[\left[\frac{c_{s,0}}{1}\cdot\left(T - T_r\right) + \frac{c_{s,1}}{2}\cdot\left(T^2 - T_r^{\,2}\right) \ldots + \frac{c_{s,2}}{3}\cdot\left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4}\cdot\left(T^4 - T_r^{\,4}\right)\right]\right]\cdot\frac{J}{mol}$$

$$H_{s,10} = \cdot\frac{kJ}{hr}$$

$$\Delta H_{10} := \sum_{s} H_{s,10}$$

$$\Delta H_{10} = \cdot\frac{kJ}{hr}$$

Total enthalpy out of Column II:

$$\Delta H_{out6} := \Delta H_{9} + \Delta H_{10}$$

$$\Delta H_{out6} = \cdot\frac{kJ}{hr}$$

Heat load: $\qquad \Delta H := \Delta H_{out6} - \Delta H_{in6}$

$$\Delta H = \cdot \frac{kJ}{hr}$$

UNIT 7: Scrubber

Enthalpy of stream 11:

$T_r := 298\ K$ $\quad T_{11} := (25 + 273.16)\ K$ $\quad T := T_{11}$

$$H_{s,11} := /_{s,11} \cdot \left[\left[\frac{c_{s,0}}{1} \cdot (T - T_r) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^{\,2}\right) \dots + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^{\,4}\right) \right]\right] \cdot \frac{J}{mol}$$

$$H_{s,11} = \cdot \frac{kJ}{hr}$$

$$\Delta H_{11} := \sum_{s} H_{s,11}$$

$$\Delta H_{11} = \cdot \frac{kJ}{hr}$$

Total enthalpy into the Scrubber:

$$\Delta H_{in7} := \Delta H_{10} + \Delta H_{11}$$

$$\Delta H_{in7} = \cdot \frac{kJ}{hr}$$

Enthalpy of stream 12:

$T_r := 298 \quad K$ $\qquad T_{12} := 70 + 273.16 \quad K$ $\qquad T := T_{12}$

$$H_{s,12} := z_{s,12} \cdot \left[\left[\frac{c_{s,0}}{1} \cdot \left(T - T_r\right) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^{\,2}\right) \ldots \atop + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^{\,4}\right) \right] \right] \cdot \frac{J}{mol}$$

$H_{s,12} = \cdot \frac{kJ}{hr}$

$$\Delta H_{12} := \sum_{s} H_{s,12}$$

$\Delta H_{12} = \cdot \frac{kJ}{hr}$

Enthalpy of stream 13:

$T_r := 298 \quad K$ $\qquad T_{13} := (70 + 273.16) \quad K$ $\qquad T := T_{13}$

$$H_{s,13} := z_{s,13} \cdot \left[\left[\frac{c_{s,0}}{1} \cdot \left(T - T_r\right) + \frac{c_{s,1}}{2} \cdot \left(T^2 - T_r^{\,2}\right) \ldots \atop + \frac{c_{s,2}}{3} \cdot \left(T^3 - T_r^{\,3}\right) + \frac{c_{s,3}}{4} \cdot \left(T^4 - T_r^{\,4}\right) \right] \right] \cdot \frac{J}{mol}$$

$H_{s,13} = \cdot \frac{kJ}{hr}$

$$\Delta H_{13} := \sum_{s} H_{s,13}$$

$$\Delta H_{13} = \cdot \frac{kJ}{hr}$$

Total enthalpy out of Scrubber:

$$\Delta H_{out7} := \Delta H_{12} + \Delta H_{13}$$

$$\Delta H_{out7} = \cdot \frac{kJ}{hr}$$

Heat load: $\Delta H := \Delta H_{out7} - \Delta H_{in7}$

$$\Delta H = \cdot \frac{kJ}{hr}$$

CHAPTER FIVE

5.0 Process Description

From figure 3 which depicts a simplified block flow diagram (BFD) for the typical biodiesel production process from the Trans-esterification of Rapeseed oil by methanol. In the first step, methanol and catalyst (NaOH) are mixed with the aim to create the active methoxide ions. Then, the oil and the methanol-catalyst solution are transferred to the main reactor where the transesterification reaction occurs. Once the reaction has finished, two distinct phases are formed with the less dense (top) phase containing the ester products and unreacted oil as well as some residual methanol, glycerol, and catalyst. The denser (bottom) layer is mainly composed of glycerin and methanol, but ester residues as well as most of the catalyst, water, and soap can also be found in this layer.

In general, a vacuum distillation step is used for methanol recycle prior to glycerin purification. Next, the remaining base catalyst in the crude glycerin is commonly neutralized with low cost mineral acids, such as phosphoric acid. This operation also converts the soaps back to Free Fatty Acids (FFAs). After neutralization, three distinct phases form: a low density (top) layer containing FFAs, a dense (bottom) liquid layer composed of glycerin, water and alcohol, and a third layer made of salt precipitates. These three phases are then separated with the non glycerin layers being treated as waste. Glycerin is further purified by distillation to remove water and alcohol. This procedure yields 90–95 % pure glycerin, which can be sold at market price.

Crude biodiesel is initially purified by thoroughly washing the ester phase with water or by neutralization with a polyprotic mineral acid to eliminate base catalyst residues. Next, in a settling tank, an aqueous phase, salt precipitates, and biodiesel are separated. Another water washing step follows to further remove polar compounds that might still be present in the biodiesel product. Finally, the biodiesel is vacuum distillated at moderate-to-high temperatures (around 190–2701 °C) to comply with ASTM specifications (99.6 % or purer).

In general, base catalyzed processes are carried out at low temperatures and pressures (60–65 °C and 1.4–4.1 bars) with low catalyst concentrations (0.5–2 wt %) by weight of lipid feedstock. Conversions of greater than or equal to 95 % can be expected after 1hr. alcohol to oil molar ratio of 6:1.

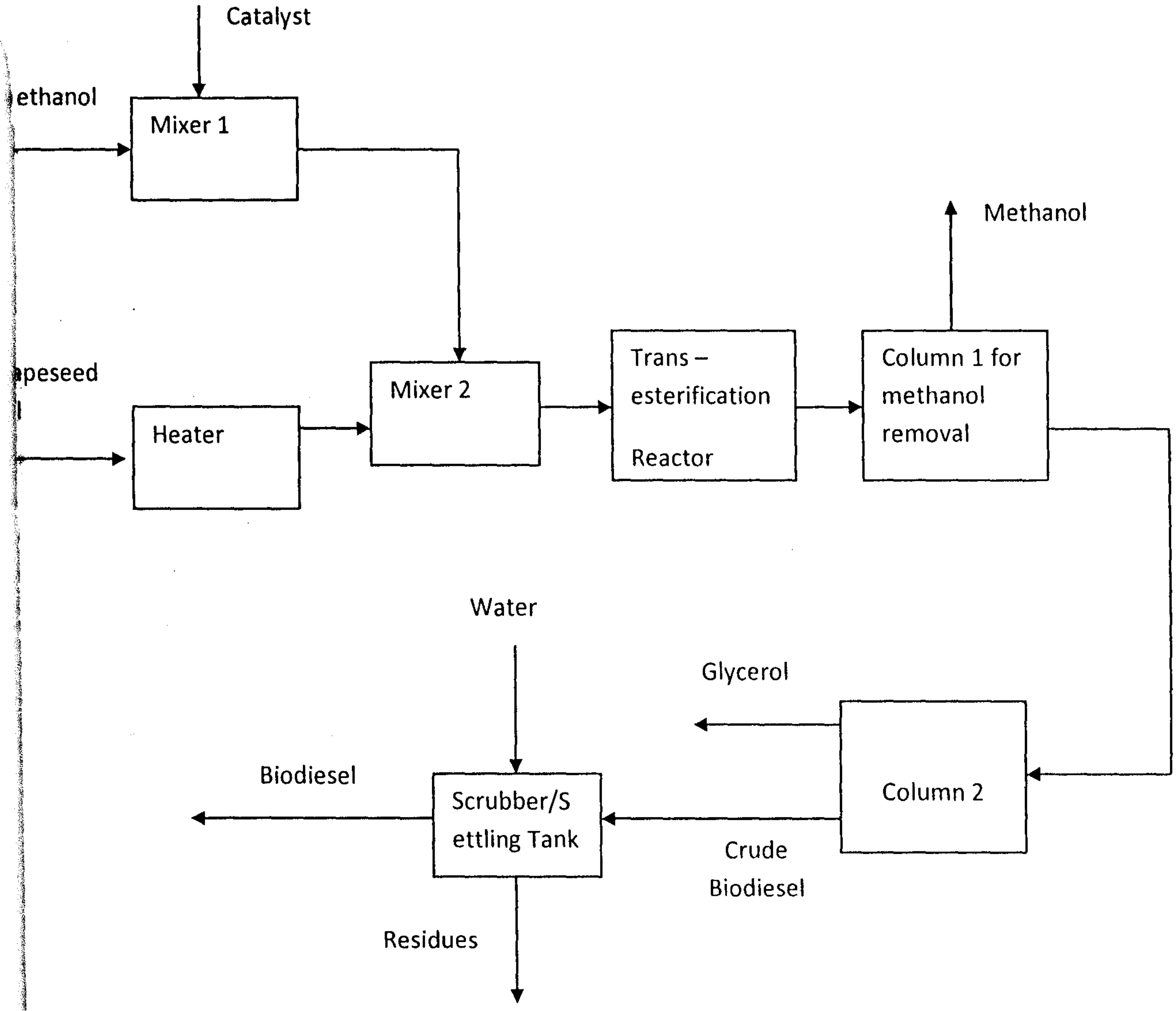


Figure 3: Block Process Diagram for Biodiesel Production using Rapeseed Oil

CHAPTER SIX

6.0 EQUIPMENT SIZING AND DESIGN

6.1 SIZING OF OIL HEATER

6.1.1 Design of Oil Pump

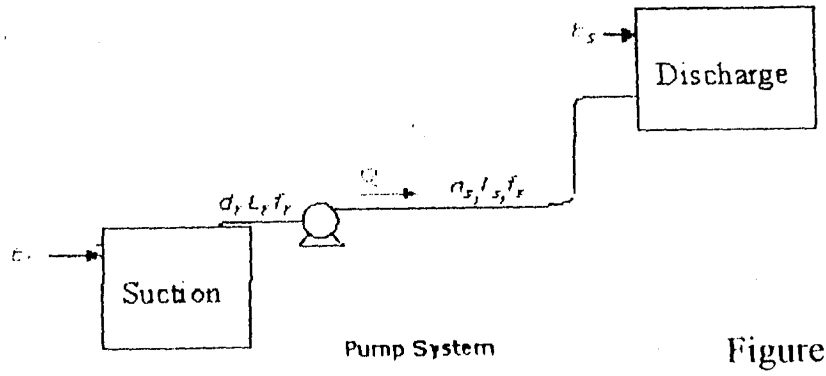


Figure4: A Pump System

Parameters

Mass flow rate of oil to the pump:

$$F_o := 1.298\times 10^4 \frac{kg}{hr}$$

Density of oil

$$\rho_o := 880 \frac{kg}{m^3}$$

Volumetric flow rate of the oil

$$Q := \frac{F_o}{\rho_o}$$

$$Q = 14.75 \frac{m^3}{hr}$$

Flowrate: $Q := 2500 \frac{gal}{min}$

Fluid specific weight:: $\gamma := 84.13 \frac{lbf}{ft^3}$

	Suction:	Discharge
Elevation:	$E_r := 1.5 \cdot m$	$E_s := 5 \cdot m$
Pipe diameter:	$d_r := 0.203 m$	$d_s := 0.254 m$
Pipe length:	$L_r := 5 \cdot m$	$L_s := 10 \cdot m$
Pipe friction factor:	$f_r := 0.02$	$f_s := 0.01$

Results

The solution is found by first writing the energy equation

$$\frac{V_r^2}{2 \cdot g} + \frac{P_r}{\gamma} + E_r + E_p = \frac{V_s^2}{2 \cdot g} + \frac{P_s}{\gamma} + E_s + h_L$$

Where: V_r, V_s = velocity

P_r, P_s = pressure

E_r, E_s = elevation

= fluid density

E_p = pump energy

h_L = head loss

Now, solve this equation for pump energy

$$E_p = \left(\frac{V_s^2}{2 \cdot g} - \frac{V_r^2}{2 \cdot g} \right) + \left(\frac{P_s}{\gamma} - \frac{P_r}{\gamma} \right) + \left(E_s - E_r \right) + h_L$$

assuming that the velocity and pressure head are negligible.

$$E_p = \left(E_S - E_T\right) + h_L$$

The head loss in this equation can be found using the Darcy-Weisbach equation.

$$h_L = f \cdot \frac{L}{d} \cdot \left(\frac{Q}{\pi \cdot \frac{d^2}{4}} \right)^2 \cdot \frac{1}{2 \cdot g}$$

rewriting as a *function*

$$h_L(f, L, d, Q) := f \cdot \frac{L}{d} \cdot \left(\frac{Q}{\pi \cdot \frac{d^2}{4}} \right)^2 \cdot \frac{1}{2 \cdot g}$$

Now, by substitution of the Darcy-Weisbach equation into the energy equation the pump head is calculated as:

$$E_p := \left(E_S - E_T\right) + h_L\left(f_T, L_T, d_T, Q\right) + h_L\left(f_S, L_S, d_S, Q\right)$$

$$E_p = 4.291\,m$$

The horsepower required is the product of the fluid specific weight, flowrate, and pump en

$$HP := \gamma \cdot Q \cdot E_p$$

$$HP = 11.995\,hp$$

The hydraulic grade line is calculated by first defining a number N of points to evaluate at

Number of points: $N := 20($

defining a *range* of distances x along the pipeline from zero to total combined length of pipe from the source to the storage reservoir

$$x := 0 \cdot L_T, \left(\frac{L_T + L_S}{N}\right) .. \left(L_T + L_S\right)$$

and then using an *if statement* to control calculation of the hydraulic grade line as the calculations proceed through the range of distances.

$$\mathrm{hgl}(x) := \mathrm{if}\left(x < L_T, E_T - h_L\left(f_T, x, d_T, Q\right), E_T - h_L\left(f_T, L_T, d_T, Q\right) \cdots + E_p - h_L\left(f_S, x - L_T, d_S, Q\right)\right)$$

Now, the hydraulic grade line can be *graphed*.

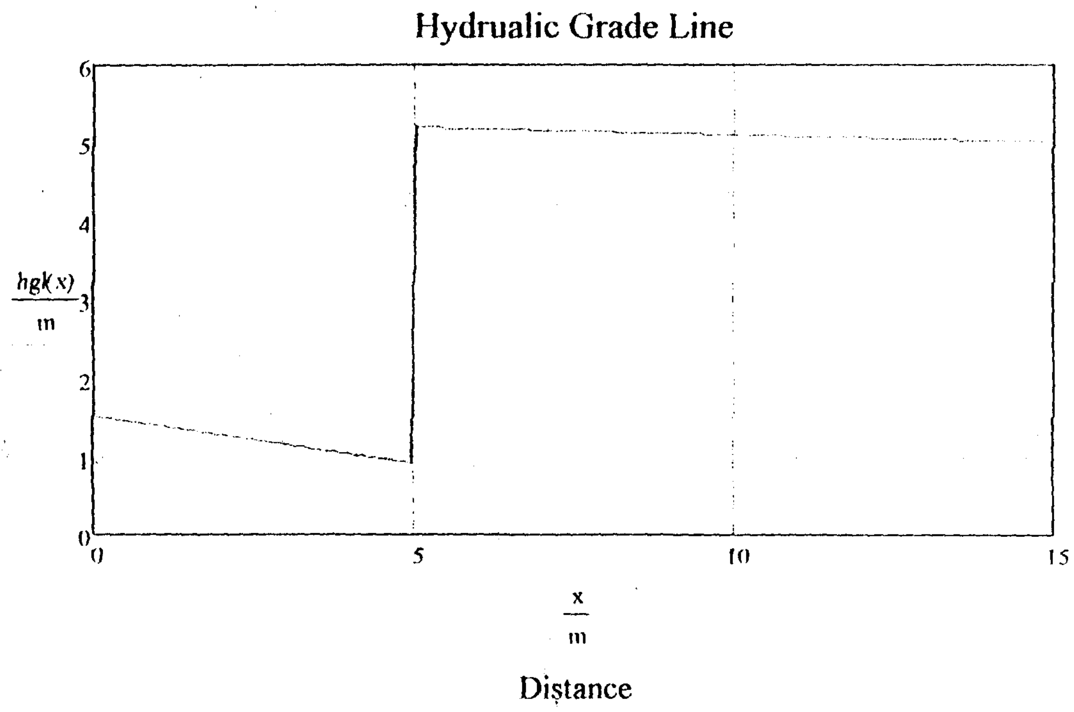


Figure 5 Hydrualic Grade Line

Total flow rate of component to the heater

$$F_h := 1.298\times 10^4 \frac{kg}{hr}$$

$$F_h = 1.138\times 10^8 \cdot \frac{kg}{yr}$$

Average density of component to the heating vessel

$$\rho_{avg} := 880\frac{kg}{m^3}$$

$$\rho_{avg} = 880\frac{kg}{m^3}$$

Volumetric flow rate of the heater

$$V_h := \frac{F_h}{\rho_{avg}}$$

$$V_h = 14.75\frac{m^3}{hr}$$

Retention time, τ:

$$\tau := 1 \cdot hr$$

Volume of the Heater required for the retention time:

$$V := V_h \cdot \tau$$

$$V = 1.475\times 10^4 L$$

The total volume of the Heater can be calculated as thus:

$$V_{total} := V$$

$$V_{total} = 1.475 \times 10^4 L$$

Allowing for 30% safety allowance:

$$V_{total} := \left(V_{total} \cdot 0.3\right) + V_{total} \qquad V_{total} = 1.918 \times 10^4 L$$

The optimum proportions for a cylindrical container is a classical example of the optimization of a simple function.

The surface area, A, of a closed cylinder is:

$$A = \pi \times D \times L + 2\frac{\pi}{4}D^2$$

Where D = Heater diameter

L = Heater length (or height)

This will be the objective function which is to be minimized; simplified:

$$f(D \times L) = D \times L + \frac{D^2}{2}$$

For a given volume, V, the diameter and length are related by:

$$V = \frac{\pi}{4}D^2 \times L$$

$$L = 4\frac{V}{\pi D^2}$$

and the objective function becomes

$$f(D) = 4\frac{V}{\pi D} + \frac{D^2}{2}$$

Setting the differential of this function zero will give the optimum value for D

$$-4\frac{V}{\pi D^{2}} + D = 0$$

$$D := \sqrt[3]{4\frac{V_{total}}{\pi}}$$

$D = 2.901\,m$ $\qquad$ $D = 9.518\,ft$

From literature, Cerebro, 2003 ratio of vessel diameter to its height (D/H) is:

$$Ratio = \frac{D}{H} = 0.83$$

$$Ratio := 0.83$$

$$H := \frac{D}{Ratio}$$

$H = 3.495\,m$ $\qquad$ $H = 11.467\,ft$

6.2 Mixer I Design

6.2.1 Feed Rate to Mixer I

The mass flowrate of the feed to the Mixer

$$F := 8.475\times 10^{3}\,\frac{kg}{hr}$$

$number\_of\_mixer := 3$ Each mixer capable of handling 1/6 of the design flow.

$$F := \frac{F}{number\_of\_mixer}$$

$F = 0.785\frac{kg}{s}$ $\qquad$ $F = 0.785\frac{kg}{s}$

The density of the feed to the mixer

$$\rho := 1538 \frac{kg}{m^3}$$

$$flowrate := \frac{F}{\rho}$$

$Mixing\_time := 6 \cdot hr$ This is somewhat the same as that in the guidelines given in the text, 48 hrs which is within the guidelines.

$G := 900 \, sec^{-1}$ velocity gradient, units are m/(sec*m)

impeller type : turbine, 6 flat blades, vaned disc: $K_T := 6.3$ The drawing of a vaned disk impeller is shown below

As part of your design proposal for this facility provide the following:

1. Water power input in kW
2. tank dimensions
3. JWI mixer model number
4. rotational speed of the impeller in rpm.

6.2.2 Mixer I Design Calculation:

appropriate definitions and constants:

$rps := 2 \cdot \pi \cdot \frac{rad}{sec}$ $rpm := 2 \cdot \pi \cdot \frac{rad}{min}$ $\rho := 1538 \frac{kg}{m^3}$ $\mu := 1.027 \cdot 10^{-3} \cdot \frac{newton \cdot sec}{m^2}$

$$Dilution\_time = \frac{volume}{flowrate}$$

The available mixer model from Hysys Model (Hyprotech, 1999) is shown below:

$$G = \sqrt{\frac{P}{\mu \cdot volume}}$$

AVAILABLE MIXER MODELS

Model	Rotational speed, rpm	power, kW
JTQ50	30, 45	.37
JTQ75	45, 70	.56
JTQ100	45, 110	.75
JTQ150	45, 110	1.12
JTQ200	70, 110	1.50
JTQ300	110, 175	2.24
JTQ500	175	3.74

$$P = K_T \cdot n^3 \cdot D_{imp}^5 \cdot \rho$$

impeller diameter should be between 0.2 and 0.5 the diameter of the tank

6.2.3 Mixer Volume

$volume := Mixing\_time \cdot flowrate$

Allowing for 30% safety allowance:

$$V := \frac{volume}{0.9}$$

$$V = 1.225 \times 10^4 L$$

$volume = 1.102 \times 10^4 L$ total volume, the volume of each tank's value. The depth and diameter of each tank are calculated below:

6.2.4 Mixer Diameter

$$\frac{\pi \cdot D^2}{4} \cdot D = \frac{volume}{2}$$

$$D := 2^{\frac{1}{3}} \cdot \left(\frac{volume}{\pi}\right)^{\frac{1}{3}}$$

$D = 1.914m$

The optimum proportions for a cylindrical container. A classical example of the optimization o

a simple function.

The surface are, A, of a closed cylinder is:

$$A = \pi \times D \times L + 2\frac{\pi}{4}D^2$$

Where D = vessel diameter

L = vessel length (or height)

This will be the objective function which is to be minimized; simplified:

$$f(D \times L) = D \times L + \frac{D^2}{2}$$

For a given volume, V, the diameter and length are related by:

$$V = \frac{\pi}{4} D^2 \times L$$

and

$$L = 4 \frac{V}{\pi D^2}$$

and the objective function becomes

$$f(D) = 4 \frac{V}{\pi D} + \frac{D^2}{2}$$

Setting the differential of this function zero will give the optimum value for D

$$-4 \frac{V}{\pi D^2} + D = 0$$

$$D := \sqrt[3]{4 \frac{V}{\pi}}$$

$$D = \sqrt[3]{4 \frac{119.632}{3.142}}$$

$$D = 2.498\text{m}$$

Accoding to, (Cerebro, 2003) ratio of tank diameter to tank height (D/H) is:

$$\text{Ratio} = \frac{H}{D} = 0.8$$

$$Ratio := 0.8$$

$$H := \frac{D}{Ratio}$$

$$H = 3.01\,m$$

6.2.5 Mixer Stirrer Power Requirement

$$G = \sqrt{\frac{P}{\mu\cdot\left(\frac{volume}{2}\right)}}$$

$$P := G^2\cdot\mu\cdot\frac{volume}{2}$$

$P = 4.584\times 10^3\,W$ power required to meet required velocity gradient, 70 sec $^{-1}$

6.2.6 Mixer Efficiency

Assumption:

Assume that any mixer used is only 80 % efficient at transferring power into tank. Therefore

required mixer should have power rating of at least :

$eff := .8$

$P_{mixer} := \frac{P}{eff}$ $\qquad$ $P_{mixer} = 5.73\,kW$

6.2.7 Mixer Impeller Diameter

At this point we have to use some judgement. We have rules of thumb regarding the

relationship of the size of the mixing impeller to the size of the tank. We have a G value to be

met and we have the rotational speed of the impeller which is somewhat fixed by the available

mixers, pg. 209 3rd edition (Mc Cabe et-al, 1979). Using a maximum rotational speed of 175

rpm, a six blade, vaned disk impeller K_T = 6.30 (see drawing) we can compute the diameter

of the impeller. Looking at the table the smallest unit that will work is the JTQ300 which has a

nameplate power level of 2.24 kW

$n := 175\,\mathrm{rpm}$ $\qquad P_{actual} := 2.24\,\mathrm{kW}\cdot .8$

Compute the impeller diameter resulting from using a JTQ300 rated at 2.24 kW

$$D_{imp} := \left[\frac{\dfrac{P_{actual}}{\mathrm{watt}}}{K_T\cdot\left(\dfrac{\frac{n}{60}}{\mathrm{rpm}}\right)^3\cdot\dfrac{\rho}{\frac{\mathrm{kg}}{\mathrm{m}^3}}}\right]^{\frac{1}{5}}\cdot \mathrm{m}$$

$D_{imp} = 0.375\mathrm{m}$ This is the impeller diameter that results if we use a JTQ300 mixing unit

This results in an impeller to tank ratio of $\frac{D_{imp}}{D} = 0.15$ **which is just inside the rule of thumb of 0.03 to 0.5.**

The tank has baffles attached to its periphery to break up bulk movement and promote mixing.

The rule of thumb is that the baffles should extend into the tank a distance of [0.1*diameter]

$$G := \sqrt{\frac{P_{actual}}{\mu\cdot\frac{\mathrm{volume}}{2}}} \qquad G = 562.72\frac{1}{\mathrm{sec}}$$

We can use a slightly smaller impeller to bring G down to 800 sec^{-1} if we care to

$G\cdot \mathrm{Mixing\_time} = 1.215\times 10^7$

Reynolds and Richards also check the Reynolds number, which should be > 10,000 to assure turbulent mixing conditions.

$N_{Re} := \frac{D_{imp}^{2} \cdot n \cdot \rho}{\mu}$ $\qquad N_{Re} = 3.867 \times 10^{6}$ turbulent mixing conditions

6.3 Mixer II Design

6.3.1 Feed Rate to Mixer II

The mass flowrate of the feed to the Mixer

$$F := 2.146 \times 10^{4} \frac{kg}{hr}$$

$number\_of\_mixer := 3$ Each mixer capable of handling 1/6 of the design flow.

$$F := \frac{F}{number\_of\_mixer}$$

$F = 1.987 \frac{kg}{s}$ $\qquad F = 1.987 \frac{kg}{s}$

The density of the feed to the mixer

$$\rho := 1538 \frac{kg}{m^{3}}$$

$$flowrate := \frac{F}{\rho}$$

$Mixing\_time := 6 \cdot hr$ This is somewhat the same as that in the guidelines given in the text, 48 hrs which is within the guidelines.

$G := 900 sec^{-1}$ velocity gradient, units are m/(sec*m) impeller type : turbine, 6 flat blades, vaned disc: $K_T := 6.3$ The drawing of a vaned disk impeller is shown below

As part of your design proposal for this facility provide the following:

1. Water power input in kW
2. tank dimensions
3. JWI mixer model number
4. rotational speed of the impeller in rpm.

6.3.2 Mixer II Design Calculation:

appropriate definitions and constants:

$$rps := 2\cdot\pi\cdot\frac{rad}{sec} \qquad rpm := 2\cdot\pi\cdot\frac{rad}{min} \qquad \rho := 1538\frac{kg}{m^3} \qquad \mu := 1.027\cdot10^{-3}\cdot\frac{newton\cdot sec}{m^2}$$

$$Dilution\_time = \frac{volume}{flowrate}$$

The available mixer model from Hysys Model (Hyprotech, 1999) is shown below:

$$G = \sqrt{\frac{P}{\mu\cdot volume}}$$

$$P = K_T\cdot n^3\cdot D_{imp}{}^5\cdot\rho$$

AVAILABLE MIXER MODELS

Model	Rotational speed, rpm	power, kW
JTQ50	30, 45	.37
JTQ75	45, 70	.56
JTQ100	45, 110	.75
JTQ150	45, 110	1.12
JTQ200	70, 110	1.50
JTQ300	110, 175	2.24
JTQ500	175	3.74

impeller diameter should be between 0.2 and 0.5 the diameter of the tank

6.3.3 Mixer Volume

$$volume := Mixing\_time\cdot flowrate$$

Allowing for 30 % safety allowance:

$$V := \frac{volume}{0.9}$$

$$V = 3.101 \times 10^4 L$$

$volume = 2.791 \times 10^4 L$ total volume, the volume of each tank's value. The depth and diameter of each tank are calculated below:

6.3.4 Mixer Diameter

$$\frac{\pi \cdot D^2}{4} \cdot D = \frac{volume}{2}$$

$$D := 2^{\frac{1}{3}} \cdot \left(\frac{volume}{\pi}\right)^{\frac{1}{3}}$$

$$D = 2.609m$$

The optimum proportions for a cylindrical container. A classical example of the optimization o a simple function.

The surface are, A, of a closed cylinder is:

$$A = \pi \times D \times L + 2\frac{\pi}{4}D^2$$

Where D = vessel diameter

L = vessel length (or height)

This will be the objective function which is to be minimized; simplified:

$$f(D \times L) = D \times L + \frac{D^2}{2}$$

For a given volume, V, the diameter and length are related by:

$$V = \frac{\pi}{4} D^2 \times L$$

and

$$L = 4 \frac{V}{\pi D^2}$$

and the objective function becomes

$$f(D) = 4 \frac{v}{\pi D} + \frac{D^2}{2}$$

Setting the differential of this function zero will give the optimum value for D

$$-4 \frac{V}{\pi D^2} + D = 0$$

$$D := \sqrt[3]{4 \frac{V}{\pi}}$$

$$D = \sqrt[3]{4 \frac{119.63}{3.142}}$$

$$D = 3.405m$$

According to (Cerebro, 2003) ratio of tank diameter to tank height (D/H) is:

$$Ratio = \frac{H}{D} = 0.8$$

$$Ratio := 0.8$$

$$H := \frac{D}{Ratio}$$

$$H = 3.01m$$

6.3.5 Mixer Stirrer Power Requirement

$$G = \sqrt{\frac{P}{\mu \cdot \left(\frac{volume}{2} \right)}}$$

$$P := G^2 \cdot \mu \cdot \frac{volume}{2}$$

$P = 1.161 \times 10^4\ W$ power required to meet required velocity gradient, 70 sec $^{-1}$

6.3.6 Mixer Efficiency

Assumption:

Assume that any mixer used is only 80 % efficient at transferring power into tank. Therefore required mixer should have power rating of at least :

$eff := .8($

$P_{mixer} := \frac{P}{eff}$ $\qquad$ $P_{mixer} = 14.509 kW$

6.3.7 Mixer Impeller Diameter

At this point we have to use some judgement. We have rules of thumb regarding the relationship of the size of the mixing impeller to the size of the tank. We have a G value to be met and we have the rotational speed of the impeller which is somewhat fixed by the available mixers, pg. 209 3^rd^ edition (Mc Cabe et-al, 1979). Using a maximum rotational speed of 175 rpm, a six blade, vaned disk impeller $K_T = 6.30$ (see drawing) we can compute the diameter of the impeller. Looking at the table the smallest unit that will work is the JTQ300 which has a nameplate power level of 2.24 kW

$n := 175 \cdot rpm$ $\qquad$ $P_{actual} := 2.24 kW \cdot .8$

Compute the impeller diameter resulting from using a JTQ300 rated at 2.24 kW

$$D_{imp} := \left[\frac{\frac{P_{actual}}{watt}}{K_T \cdot \left(\frac{\frac{n}{60}}{rpm}\right)^3 \cdot \frac{\rho}{\frac{kg}{m^3}}}\right]^{\frac{1}{5}} \cdot m$$

$D_{imp} = 0.375m$ This is the impeller diameter that results if we use a JTQ300 mixing unit

This results in an impeller to tank ratio of $\frac{D_{imp}}{D} = 0.11$ **which is just inside the rule of thumb of 0.03 to 0.5.**

The tank has baffles attached to its periphery to break up bulk movement and promote mixing. The rule of thumb is that the baffles should extend into the tank a distance of [0.1*diameter]

$$G := \sqrt{\frac{P_{actual}}{\mu \cdot \frac{volume}{2}}} \qquad G = 353.628\frac{1}{sec}$$

We can use a slightly smaller impeller to bring G down to 800 sec^{-1} if we care to

$$G \cdot Mixing\_time = 7.638 \times 10^6$$

Reynolds and Richards also check the Reynolds number, which should be > 10,000 to assure turbulent mixing conditions.

$$N_{Re} := \frac{D_{imp}^{\;2} \cdot n \cdot \rho}{\mu} \qquad N_{Re} = 3.867 \times 10^6$$ turbulent mixing conditions

6.4 SIZING OF TRANS ESTERIFICATION REACTOR

Total flow rate of component to the reactor

$$F_r := 2.146 \times 10^4 \, \frac{kg}{hr}$$

$$F_r = 1.881 \times 10^8 \cdot \frac{kg}{yr}$$

Average density of component to the reactor vessel

$\rho_{oil} := 880 \frac{kg}{m^3}$ $\qquad$ $M_{w\_oil} := 294.81 \frac{g}{mol}$

$\rho_{methanol} := 795.72 \frac{kg}{m^3}$ $\qquad$ $M_{w\_methanol} := 32.04 \frac{g}{mol}$

$\rho_{NaOH} := 1782.31 \frac{kg}{m^3}$ $\qquad$ $M_{w\_NaOH} := 40.00 \frac{g}{mol}$

$$\rho_{avg} := \frac{\left(\rho_{oil} \cdot M_{w\_oil} + \rho_{methanol} \cdot M_{w\_methanol} + \rho_{NaOH} \cdot M_{w\_NaOH}\right)}{M_{w\_oil} + M_{w\_methanol} + M_{w\_NaOH}}$$

$$\rho_{avg} = 971.024 \frac{kg}{m^3}$$

Volumetric flow rate of the reactor

$$V_r := \frac{F_r}{\rho_{avg}}$$

$$V_r = 22.1 \cdot \frac{m^3}{hr}$$

Residence time, τ:

$$\tau := 1 \cdot hr$$

Volume of the Reactor required for the residence time:

$$V := V_r \cdot \tau$$

$$V = 2.21 \times 10^4 L$$

The total volume of the reactor can be calculated as thus:

$$V_{total} := V$$

$$V_{total} = 2.21 \times 10^4 L$$

Allowing for 30% safety allowance:

$$V_{total} := (V_{total} \cdot 0.3) + V_{total} \qquad V_{total} = 2.873 \times 10^4 L$$

The optimum proportions for a cylindrical container is a classical example of the optimization of a simple function.

The surface area, A, of a closed cylinder is:

$$A = \pi \times D \times L + 2\frac{\pi}{4}D^2$$

Where D = Reactor diameter

L = Reactor length (or height)

This will be the objective function which is to be minimized; simplified:

$$f(D \times L) = D \times L + \frac{D^2}{2}$$

For a given volume, V, the diameter and length are related by:

$$V = \frac{\pi}{4}D^2 \times L$$

$$L = 4\frac{V}{\pi D^2}$$

and the objective function becomes

$$f(D) = 4\frac{v}{\pi D} + \frac{D^2}{2}$$

Setting the differential of this function zero will give the optimum value for D

$$-4\frac{V}{\pi D^2} + D = 0$$

$$D := \sqrt[3]{4\frac{V_{total}}{\pi}}$$

$D = 3.32\text{m}$ $\qquad\qquad$ $D = 10.891\text{ft}$

From literature, Cerebro, 2003 ratio of reactor diameter to reactor height (D/H) is:

$$\text{Ratio} = \frac{D}{H} = 0.83$$

$$\text{Ratio} := 0.83$$

$$H := \frac{D}{\text{Ratio}}$$

$H = 4\cdot\text{m}$ $\qquad\qquad$ $H = 13.122\text{ft}$

6.5 Column I Design

This equipment design calculation program calculates the diameter of a sieve-tray tower to satisfy an approach to flooding criterium, and estimates the tray efficiency.

Enter data related to the gas and liquid streams

Enter liquid flow rate, mL, in kg/s

$mL := 0.0139\text{kg}\cdot\text{sec}^{-1}$

Enter gas flow rate, mG, in kg/s

$mG := 0.0174 kg \cdot sec^{-1}$

Enter liquid density, in kg/m3

$\rho L := 791 \cdot kg \cdot m^{-3}$

Enter gas density, kg/m3

$\rho G := 1.18 kg \cdot m^{-3}$

Enter gas viscosity, Pa-s

$\mu G := 1.05 \cdot 10^{-5} \cdot Pa \cdot sec$

Enter temperature, T, in K

$T := 353 \cdot K$

Enter total pressure, P, in Pa

$P := 101300 Pa$

Enter liquid surface tension, in dyne/cm

$\sigma := 21 \cdot \frac{dyne}{cm}$

Molar gas constant

$R := 8.314510 \frac{joule}{mole \cdot K}$

Gas Flowrate

$QG := \frac{mG}{\rho G}$

Liquid Flowrate

$qL := \frac{mL}{\rho L}$

Enter foaming factor, dimensionless

$FF := 0.9$

Calculate flow parameter, X

$$X := \frac{mL}{mG} \cdot \sqrt{\frac{\rho G}{\rho L}}$$ $X = 0.031$

Specify the ratio of downcomer area to total area, AdAt

$$AdAt := \begin{cases} 0.1 & \text{if } X \le 0.1 \\ 0.2 & \text{if } X \ge 1 \\ 0.1 + \dfrac{X - 0.1}{9} & \text{otherwise} \end{cases}$$ $AdAt = 0.1$

If X is smaller than 0.1, use X = 0.1 in equation (4-31)

$$X := \begin{cases} X & \text{if } X \ge 0.1 \\ 0.1 & \text{otherwise} \end{cases}$$

$X = 0.1$

Calculate the ratio of hole to active area, Ah/Aa

$$AhAa := 0.907 \left(\frac{do}{p} \right)^2$$ $AhAa = 0.128$

Calculate FHA

$$FHA := \begin{cases} 5 \cdot AhAa + 0.5 & \text{if } AhAa < 0.1 \\ 1 & \text{otherwise} \end{cases}$$

$FHA = 1$

Calculate FST

$$FST := \left(\frac{\sigma}{20 \cdot \frac{dyne}{cm}} \right)^{0.2}$$

$FST = 1.01$

$C1 := FST \cdot FHA \cdot FF$

$C1 = 0.909$

Enter parameters

$\alpha 1 := 0.0744 m^{-1}$ $\alpha 2 := 0.0117$

$\beta 1 := 0.0304 m^{-1}$ $\beta 2 := 0.01$

Iterate to find diameter and tray spacing

$\alpha(t) := \alpha 1 \cdot t + \alpha 2$

$\beta(t) := \beta 1 \cdot t + \beta 2$

$CF(t) := \alpha(t) \cdot \log\left(X^{-1}\right) + \beta(t)$ $C(t) := C1 \cdot CF(t) \cdot \frac{m}{sec}$

$$vGF(t) := C(t) \cdot \sqrt{\frac{\rho L - \rho G}{\rho G}}$$

Initial Estimates of Tray Spacing and Diameter

$D := 2 \cdot m$ $t := 0.5 \cdot m$

Given

$$D = \sqrt{\frac{4 \cdot QG}{f \cdot vGF(t) \cdot (1 - AdAt) \cdot \pi}}$$

Use is made here of the step function F(x) to define the recommended values of tray spacing.

$$\begin{aligned} t = {} & 0.5 \cdot m \cdot \Phi(1 \cdot m - D) + 0.6 m \cdot (\Phi(3 \cdot m - D) - \Phi(1 \cdot m - D)) \ldots \\ & + 0.75 m \cdot (\Phi(4 \cdot m - D) - \Phi(3 \cdot m - D)) \ldots \\ & + 0.9 \cdot m \cdot (\Phi(20 \cdot m - D) - \Phi(4 \cdot m - D)) \end{aligned}$$

$\begin{pmatrix} D \\ t \end{pmatrix} := \text{Find}(D, t)$

$D = 0.118\text{m}$ $t = 0.5\text{m}$

Calculate some further details of the tray design

$At := \dfrac{\pi \cdot D^2}{4}$

total area

$At = 0.011\text{m}^2$

downcomer area

$Ad := AdAt \cdot At$

$Ad = 1.101 \times 10^{-3}\,\text{m}^2$

active area

$Aa := At - 2 \cdot Ad$

$Aa = 8.806 \times 10^{-3}\,\text{m}^2$

hole area

$Ah := AhAa \cdot Aa$

$Ah = 1.123 \times 10^{-3}\,\text{m}^2$

first estimate

$\theta 1 := 1.2 \cdot \text{rad}$

Given

$$AdAt = \frac{\theta 1 - \sin(\theta 1)}{2 \cdot \pi}$$

$\theta 1 := \mathrm{Find}(\theta 1)$ $\qquad \theta 1 = 1.627$

weir length

$$Lw := D \cdot \sin\left(\frac{\theta 1}{2}\right)$$

$Lw = 0.086\mathrm{m}$

distance from tower center to weir

$$rw := \frac{D}{2} \cdot \left(\cos\left(\frac{\theta 1}{2}\right)\right)$$

$rw = 0.041\mathrm{m}$

Estimate the gas-pressure drop through the tray

Dry tray head loss, hd

Calculate orifice gas velocity, vo

$$vo := \frac{QG}{Ah}$$

$vo = 13.129\frac{\mathrm{m}}{\mathrm{s}}$

Calculate orifice coefficient, Co,

$$Co := 0.85032 - 0.04231\frac{do}{l} + 0.0017954\left(\frac{do}{l}\right)^2$$

$Co = 0.764$

$$hd := 0.0051\left(cm \cdot m \cdot \frac{sec^2}{kg}\right)\cdot\left(\frac{vo}{Co}\right)^2 \cdot \rho G \cdot \frac{\rho W}{\rho L}\cdot\left(1 - AhAa^2\right)$$

$$hd = 0.021m$$

Equivalent head of clear liquid, hl

Calculate gas velocity based on active area, va

$$va := \frac{QG}{Aa}$$

$$va = 1.675\frac{m}{s}$$

Calculate capacity parameter, Ks

$$qL = 1.757\times 10^{-5}\frac{m^3}{s}$$

$$Ks := va\cdot\sqrt{\frac{\rho G}{\rho L - \rho G}}$$

$$Ks = 0.065\frac{m}{s}$$

Calculate froth density ϕe

$$\phi e := \exp\left[-12.55\left(\frac{Ks}{1\cdot m\cdot sec^{-1}}\right)^{0.91}\right]$$

$$\phi e = 0.354$$

$$CL1 := 50.12cm\cdot sec^{\frac{2}{3}}\cdot m^{\frac{-4}{3}}$$

$$CL2 := 43.89\,cm\cdot sec^{\frac{2}{3}}\cdot m^{\frac{-4}{3}}$$

$$CL := CL1 + CL2\cdot \exp\left(-1.378\,cm^{-1}\cdot hw\right)$$

$$hl := \phi e\cdot\left[hw + CL\cdot\left(\frac{qL}{Lw\cdot\phi e}\right)^{\frac{2}{3}}\right]$$

$hl = 0.019m$

Head loss due to surface tension, hs

$$h\sigma := \frac{6\cdot\sigma}{g\cdot\rho L\cdot do}$$

$h\sigma = 3.61\times 10^{-3}\,m$

Total head loss, ht

$ht := hd + hl + h\sigma$

ht=0.044 m

Convert head loss to pressure drop, DP

$\Delta P := ht\cdot\rho L\cdot g$

= 340.93 Pa

Check tray design for excessive weeping; calculate orifice Froude number, Fro

If Fro > 0.5 there is no weeping problem.

$$Fro := \sqrt{\frac{\rho G vo^2}{\rho L\cdot g\cdot hl}}$$

$Fro = 1.177$

Calculate fractional entrainment, E

$$\kappa := 0.5\cdot\left(1 - \tanh\left(1.3\cdot\ln\left(\frac{hl}{do}\right) - 0.15\right)\right)$$

$$\kappa = 0.031$$

$$h2\phi := \frac{hl}{\phi e} + 7.79\left[1 + 6.9\cdot\left(\frac{do}{hl}\right)^{1.85}\right]\cdot\frac{Ks^2}{\phi e\cdot g\cdot Ah Aa}$$

$$h2\phi = 0.163m$$

$$E := 0.00335\left(\frac{h2\phi}{t}\right)^{1.1}\cdot\left(\frac{\rho L}{\rho G}\right)^{0.5}\cdot\left(\frac{hl}{h2\phi}\right)^{\kappa}$$

$$E = 0.024$$

Calculate point efficiency, EOG

$$ReFe := \frac{\rho G\cdot vo\cdot hl}{\mu G\cdot \phi e}$$

$$ReFe = 7.89\times 10^{4}$$

$$cG := \frac{\rho G}{MG}$$

$$cG = 0.035\frac{kg}{m^3}$$

$$cL := \frac{\rho L}{ML}$$

$$cL = 24.719\frac{kg}{m^3}$$

$a1 := 0.413$　　$a2 := 0.607$　　$a3 := -0.319$

$$\mathrm{EOG} := 1 - \exp\left[\frac{-0.0029}{1 + mc\cdot\frac{cG}{cL}\cdot\sqrt{DG\cdot\frac{1-\phi e}{DL\cdot AhAa}}}\cdot \mathrm{ReFe}^{a1}\cdot\left(\frac{hl}{do}\right)^{a2}\cdot AhAa^{a3}\right]$$

$\mathrm{EOG} = 0.72$

Calculate Murphree tray efficiency, EMG

Check the degree of vapor mixing; calculate PeG.

If PeG > 50, or if t Ð h2f < 0, vapor is unmixed.

$t - h2\phi = 0.337\mathrm{m}$

$\mathrm{DEG} := 0.01\cdot\frac{m^2}{sec}$

$$\mathrm{PeG} := \frac{4\cdot QG\cdot rw^2}{DEG\cdot Aa\cdot(t - h2\phi)}$$

$\mathrm{PeG} = 3.287$

Calculate PeL

$\mathrm{DEL} := 0.1\cdot\sqrt{g\cdot h2\phi^3}$

$\mathrm{DEL} = 0.021\frac{m^2}{s}$

$$\mathrm{PeL} := \frac{4\cdot qL\cdot rw^2}{Aa\cdot hl\cdot DEL}$$

$\mathrm{PeL} = 0.034$

$$N := \frac{PeL + 2}{2}$$

$N = 1.017$

$$\lambda := mc\cdot\frac{mG}{mL}\cdot\frac{ML}{MG}$$

$\lambda = 0.492$

For mixed vapor

$$\mathrm{EMGmixed} := \frac{\left(1 + \frac{\lambda\cdot EOG}{N}\right)^N - 1}{\lambda}$$

EMGmixed= 0.722

For unmixed vapor

$$EMGunmixed := EMGmixed\left(1 - 0.0335\lambda^{1.07272}\cdot EOG^{2.51844}\cdot PeL^{0.17524}\right)$$

EMGunmixed= 0.719

$$EMG := \begin{cases} EMGmixed & \text{if } 0 < PeG < 50 \\ EMGunmixed & \text{otherwise} \end{cases}$$

EMG = 0.722

Correct efficiency for entrainment

$$EMGE := EMG\left(1 - 0.8\cdot EOG\lambda^{1.543}\cdot\frac{E}{me}\right)$$

EMGE= 0.714

$N := 10$

Column efficiency:

Col_eff:= 80 %

$$Actual\_Number\_of\_Trays := \frac{N}{Col\_Eff}$$

Col_Eff = 0.8

Actual_Number_of_Trays = 12.5

Column Height

Column height = [Number of actual trays] x [Tray spacing] + Additional elevation of the liquid holdup in the base of the column.

Tray_Spacing := 0.5 m

Additional elevation of the liquid holdup in the base of the column (Z_A)

$Z_A := 0.5 \ m$

Column Height (H)

$Column\_Height := \left[\left[(Actual\_Number\_of\_Trays)\cdot Tray\_Spacing\right] + Z_A\right]$

$Column\_Height = 6.75m$

$Column\_volume1 := At\cdot Column\_Height$

$Column\_volume1 \quad = 74.301 \ L$

6.6 Column II Design:

This equipment design calculation program calculates the diameter of a sieve-tray tower to satisfy an approach to flooding criterium, and estimates the tray efficiency.

Enter data related to the gas and liquid streams

Enter liquid flow rate, mL, in kg/s

$mL := 0.043325kg\cdot sec^{-1}$

Enter gas flow rate, mG, in kg/s

$mG := 0.054157kg\cdot sec^{-1}$

Enter liquid density, in kg/m^3

$\rho L := 791\cdot kg\cdot m^{-3}$

Enter gas density, kg/m^3

$\rho G := 1.18 kg\cdot m^{-3}$

Enter gas viscosity, Pa-s

$\mu G := 1.05\cdot 10^{-5}\cdot Pa\cdot sec$

Enter temperature, T, in K

$T := 353 \cdot K$

Enter total pressure, P, in Pa

$P := 101300 Pa$

Enter liquid surface tension, in dyne/cm

$\sigma := 21 \cdot \frac{dyne}{cm}$

Molar gas constant

$R := 8.314510 \frac{joule}{mole \cdot K}$

Gas Flowrate

$QG := \frac{mG}{\rho G}$

Liquid Flowrate

$qL := \frac{mL}{\rho L}$

Enter foaming factor, dimensionless

$FF := 0.9$

Enter water density at T, kg/m3

$\rho W := 970 \, kg \cdot m^{-3}$

$g = 9.807 \frac{m}{s^2}$

Enter local slope of equilibrium curve

$me := 0.42$

Enter molecular weights of gas and liquid

$ML := 32$ $MG := 34.2$

Enter diffusivities of gas and liquid

$DG := 0.158\frac{cm^2}{sec}$ $DL := 2.07\cdot 10^{-5}\cdot\frac{cm^2}{sec}$

Enter data related to the tray design

Enter hole diameter and pitch

$do := 4.5\cdot mm$ $p := 12\cdot mm$

Enter plate thickness

$l := 2\cdot mm$

Enter weir height

$hw := 5\cdot cm$

Enter fractional approach to flooding

$f := 0.8$

Calculate flow parameter, X

$X := \frac{mL}{mG}\cdot\sqrt{\frac{\rho G}{\rho L}}$ $X = 0.031$

Specify the ratio of downcomer area to total area, AdAt

$$AdAt := \begin{cases} 0.1 & \text{if } X \le 0.1 \\ 0.2 & \text{if } X \ge 1 \\ 0.1 + \frac{X - 0.1}{9} & \text{otherwise} \end{cases}$$

$AdAt = 0.1$

If X is smaller than 0.1, use X = 0.1

$$X := \begin{cases} X & \text{if } X \ge 0.1 \\ 0.1 & \text{otherwise} \end{cases}$$

$X = 0.1$

Calculate the ratio of hole to active area, Ah/Aa

$$AhAa := 0.907\left(\frac{do}{p}\right)^2 \qquad AhAa = 0.128$$

Calculate FHA

$$FHA := \begin{cases} 5 \cdot AhAa + 0.5 & \text{if } AhAa < 0.1 \\ 1 & \text{otherwise} \end{cases}$$

$FHA = 1$

Calculate FST

$$FST := \left(\frac{\sigma}{20 \cdot \frac{dyne}{cm}}\right)^{0.2}$$

$FST = 1.01$

$C1 := FST \cdot FHA \cdot FF$

$C1 = 0.909$

Enter parameters

$\alpha1 := 0.0744 m^{-1}$ $\qquad$ $\alpha2 := 0.0117$

$\beta1 := 0.0304 m^{-1}$

$$\beta 2 := 0.01$$

Iterate to find diameter and tray spacing

$$\alpha(t) := \alpha 1 \cdot t + \alpha 2$$

$$\beta(t) := \beta 1 \cdot t + \beta 2$$

$$CF(t) := \alpha(t) \cdot \log\left(X^{-1}\right) + \beta(t) \qquad C(t) := C1 \cdot CF(t) \cdot \frac{m}{sec}$$

$$vGF(t) := C(t) \cdot \sqrt{\frac{\rho L - \rho G}{\rho G}}$$

Initial Estimates of Tray Spacing and Diameter

$$D := 2 \cdot m \qquad t := 0.5 \cdot m$$

Given

$$D = \sqrt{\frac{4 \cdot QG}{f \cdot vGF(t) \cdot (1 - AdAt) \cdot \pi}}$$

Use is made here of the step function F(x) to define the recommended values of tray spacing.

$$\begin{aligned} t = {} & 0.5 \cdot m \cdot \Phi(1 \cdot m - D) + 0.6 m \cdot (\Phi(3 \cdot m - D) - \Phi(1 \cdot m - D)) \ldots \\ & + 0.75 m \cdot (\Phi(4 \cdot m - D) - \Phi(3 \cdot m - D)) \ldots \\ & + 0.9 \cdot m \cdot (\Phi(20 \cdot m - D) - \Phi(4 \cdot m - D)) \end{aligned}$$

$$\begin{pmatrix} D \\ t \end{pmatrix} := \mathrm{Find}(D, t)$$

$$D = 0.209 m \qquad t = 0.5 m$$

Calculate some further details of the tray design

$$At := \frac{\pi \cdot D^2}{4}$$

total area

$At = 0.034m^2$

downcomer area

$Ad := AdAt \cdot At$ $\quad Ad = 3.426\times 10^{-3} m^2$

active area

$Aa := At - 2\cdot Ad$

$Aa = 0.027m^2$

hole area

$Ah := AhAa \cdot Aa$

$Ah = 3.496\times 10^{-3} m^2$

first estimate

$01 := 1.2\cdot rad$

Given

$$AdAt = \frac{01 - \sin(01)}{2\cdot\pi}$$

$01 := Find(01)$ $\quad 01 = 1.627$

weir length

$$Lw := D\cdot \sin\left(\frac{01}{2}\right)$$

$Lw = 0.152m$

distance from tower center to weir

$$rw := \frac{D}{2}\cdot\left(\cos\left(\frac{01}{2}\right)\right)$$

$rw = 0.072m$

Estimate the gas-pressure drop through the tray

Dry tray head loss, hd

Calculate orifice gas velocity, vo

$$vo := \frac{QG}{Ah}$$

$vo = 13.129\frac{m}{s}$

Calculate orifice coefficient, Co,

$$Co := 0.85032 - 0.04231\frac{do}{l} + 0.0017954\left(\frac{do}{l}\right)^2$$

$Co = 0.764$

$$hd := 0.0051\left(cm\cdot m\cdot\frac{sec^2}{kg}\right)\cdot\left(\frac{vo}{Co}\right)^2\cdot\rho G\frac{\rho W}{\rho L}\cdot\left(1 - AhAa^2\right)$$

$hd = 0.021m$

Equivalent head of clear liquid, hl

Calculate gas velocity based on active area, va

$$va := \frac{QG}{Aa}$$

$va = 1.675\frac{m}{s}$

Calculate capacity parameter, Ks

$$qL = 5.477\times 10^{-5}\,\frac{m^{3}}{s}$$

$$Ks := va\cdot\sqrt{\frac{\rho G}{\rho L-\rho G}}$$

$$Ks = 0.065\frac{m}{s}$$

Calculate froth density ϕe

$$\phi e := \exp\left[-12.55\left(\frac{Ks}{1\cdot m\cdot sec^{-1}}\right)^{0.91}\right]$$

$$\phi e = 0.354$$

$$CL1 := 50.12\,cm\cdot sec^{\frac{2}{3}}\cdot m^{\frac{-4}{3}}$$

$$CL2 := 43.89\,cm\cdot sec^{\frac{2}{3}}\cdot m^{\frac{-4}{3}}$$

$$CL := CL1 + CL2\cdot\exp\left(-1.378\,cm^{-1}\cdot hw\right)$$

$$hl := \phi e\cdot\left[hw + CL\cdot\left(\frac{qL}{Lw\cdot\phi e}\right)^{\frac{2}{3}}\right]$$

$$hl = 0.019m$$

Head loss due to surface tension, hs

$$h\sigma := \frac{6\cdot\sigma}{g\cdot\rho L\cdot do}$$

$h\sigma = 3.61 \times 10^{-3}\,m$

Total head loss, ht

$ht := hd + hl + h\sigma$

$ht = 0.045m$

Convert head loss to pressure drop, DP

$\Delta P := ht \cdot \rho L \cdot g$

$\Delta P = 345.343Pa$

Check tray design for excessive weeping; calculate orifice Froude number, Fro

If Fro > 0.5 there is no weeping problem.

$$Fro := \sqrt{\frac{\rho G \cdot vo^2}{\rho L \cdot g \cdot hl}}$$

$Fro = 1.16$

Calculate fractional entrainment, E

$$\kappa := 0.5 \cdot \left(1 - \tanh\left(1.3 \cdot \ln\left(\frac{hl}{do}\right) - 0.15\right)\right)$$

$\kappa = 0.029$

$$h2\phi := \frac{hl}{\phi c} + 7.79\left[1 + 6.9 \cdot \left(\frac{do}{hl}\right)^{1.85}\right] \cdot \frac{Ks^2}{\phi c \cdot g \cdot AhAa}$$

$h2\phi = 0.163m$

$$E := 0.00335\left(\frac{h2\phi}{t}\right)^{1.1}\cdot\left(\frac{\rho L}{\rho G}\right)^{0.5}\cdot\left(\frac{hl}{h2\phi}\right)^{\kappa}$$

$E = 0.024$

Calculate point efficiency, EOG

$$ReFe := \frac{\rho G\cdot vo\cdot hl}{\mu G\cdot \phi e}$$

$ReFe = 8.127\times 10^{4}$

$$cG := \frac{\rho G}{MG}$$

$cG = 0.035\frac{kg}{m^{3}}$

$$cL := \frac{\rho L}{ML}$$

$cL = 24.719\frac{kg}{m^{3}}$

$a1 := 0.413$ $a2 := 0.607$ $a3 := -0.319$

$$EOG := 1 - \exp\left[\frac{-0.0029}{1 + me\cdot\frac{cG}{cL}\cdot\sqrt{DG\cdot\frac{1-\phi e}{DL\cdot AhAa}}}\cdot ReFe^{a1}\cdot\left(\frac{hl}{do}\right)^{a2}\cdot AhAa^{a3}\right]$$

$EOG = 0.731$

Calculate Murphree tray efficiency, EMG

Check the degree of vapor mixing; calculate PeG.

If PeG > 50, or if t Ð h2f < 0, vapor is unmixed.

$$t - h2\phi = 0.337\mathrm{m} \qquad DEG := 0.01\cdot\frac{\mathrm{m}^2}{\mathrm{sec}}$$

$$PeG := \frac{4\cdot QG\cdot rw^2}{DEG\cdot Aa\cdot(t - h2\phi)} \qquad PeG = 10.221$$

Calculate PeL

$$DEL := 0.1\cdot\sqrt{g\cdot h2\phi^3} \qquad DEL = 0.021\frac{\mathrm{m}^2}{\mathrm{s}}$$

$$PeL := \frac{4\cdot qL\cdot rw^2}{Aa\cdot hl\cdot DEL} \qquad PeL = 0.103$$

$$N := \frac{PeL + 2}{2} \qquad N = 1.051$$

$$\lambda := mc\cdot\frac{mG}{mL}\cdot\frac{ML}{MG} \qquad \lambda = 0.491$$

For mixed vapor

$$EMGmixed := \frac{\left(1 + \frac{\lambda\cdot EOG}{N}\right)^N - 1}{\lambda} \qquad EMGmixed = 0.737$$

For unmixed vapor

$$EMGunmixed := EMGmixed\left(1 - 0.0335\lambda^{1.07272}\cdot EOG^{2.51844}\cdot PeL^{0.17524}\right)$$

$$EMGunmixed = 0.733$$

$$EMG := \left| \begin{array}{l} EMGmixed \text{ if } 0 < PeG < 50 \\ EMGunmixed \text{ otherwise} \end{array} \right.$$

$EMG = 0.737$

Correct efficiency for entrainment

$$EMGE := EMG\left(1 - 0.8 \cdot EOG\lambda^{1.543} \cdot \frac{E}{me}\right)$$

$EMGE = 0.729$

$N := 10$

Column efficiency:

$Col\_Eff := 80\ \%$

$$Actual\_Number\_of\_Trays := \frac{N}{Col\_Eff}$$

$Col\_Eff = 0.8$

$Actual\_Number\_of\_Trays = 12.5$

Column Height

Column height = [Number of actual trays] x [Tray spacing] + Additional elevation of the liquid holdup in the base of the column.

$Tray\_Spacing := 0.5\ m$

Additional elevation of the liquid holdup in the base of the column (Z_A)

$Z_A := 0.5\ m$

Column Height (H)

$$Column\_Height := \left[\left[(Actual\_Number\_of\_Trays) \cdot Tray\_Spacing \right] + Z_A \right]$$

$$Column\_Height = 6.75m$$

$$Column\_volume2 := At \cdot Column\_Height$$

$$Column\_volume2 = 231.259L$$

6.7 SCRUBBER SIZING

Total flow rate of component to the Scrubber

$$F_s := 6.912 \times 10^4 \frac{kg}{hr}$$

$$F_s = 6.059 \times 10^8 \cdot \frac{kg}{yr}$$

Average density of component to the Scrubber vessel

$$\rho_{glycerol} := 1260.78 \frac{kg}{m^3} \qquad M_{w\_glycerol} := 92.10 \frac{g}{mol}$$

$$\rho_{biodiesel} := 876.88 \frac{kg}{m^3} \qquad M_{w\_biodiesel} := 296.50 \frac{g}{mol}$$

$$\rho_{water} := 997.99 \frac{kg}{m^3} \qquad M_{w\_water} := 18.02 \frac{g}{mol}$$

$$\rho_{avg} := \frac{\left(\begin{array}{l} \rho_{oil} \cdot M_{w\_oil} + \rho_{methanol} \cdot M_{w\_methanol} + \rho_{NaOH} \cdot M_{w\_NaOH} \cdots \\ + \rho_{glycerol} \cdot M_{w\_glycerol} + \rho_{biodiesel} \cdot M_{w\_biodiesel} + \rho_{water} \cdot M_{w\_water} \end{array} \right)}{\begin{array}{l} M_{w\_oil} + M_{w\_methanol} + M_{w\_NaOH} + M_{w\_glycerol} + M_{w\_biodiesel} \cdots \\ + M_{w\_water} \end{array}}$$

$\rho_{avg} = 970.066 \frac{kg}{m^3}$

Volumetric flow rate of the Scrubber

$$V_s := \frac{F_s}{\rho_{avg}}$$

$$V_s = 71.253 \frac{m^3}{hr}$$

Retention time, τ:

$$\tau := 1 \cdot hr$$

Volume of the Scrubber required for the retention time:

$$V := V_s \cdot \tau$$

$$V = 7.125 \times 10^4 L$$

The total volume of the Scrubber can be calculated as thus:

$$V_{total} := V$$

$$V_{total} = 7.125 \times 10^4 L$$

Allowing for 30% safety allowance:

$$V_{total} := (V_{total} \cdot 0.3) + V_{total} \qquad V_{total} = 9.263 \times 10^4 L$$

The optimum proportions for a cylindrical container is a classical example of the optimization of a simple function.

The surface area, A, of a closed cylinder is:

$$A = \pi \times D \times L + 2\frac{\pi}{4}D^2$$

Where D = Scrubber diameter

L = Scrubber length (or height)

This will be the objective function which is to be minimized; simplified:

$$f(D \times L) = D \times L + \frac{D^2}{2}$$

For a given volume, V, the diameter and length are related by:

$$V = \frac{\pi}{4}D^2 \times L$$

$$L = 4\frac{V}{\pi D^2}$$

and the objective function becomes

$$f(D) = 4\frac{V}{\pi D} + \frac{D^2}{2}$$

Setting the differential of this function zero will give the optimum value for D

$$-4\frac{V}{\pi D^2} + D = 0$$

$$D := \sqrt[3]{4\frac{V_{total}}{\pi}}$$

D= 4.904 m D= 16.089 ft

According to (Cerebro, 2003) ratio of Scrubber diameter to its height (D/H) is:

$$\text{Ratio} = \frac{D}{H} = 0.83$$

$$\text{Ratio} := 0.83$$

$$H := \frac{D}{\text{Ratio}}$$

$H = 19.385\text{ft}$

$H = 5.908\text{m}$

CHAPTER SEVEN

7.0 EQUIPMENT OPTIMIZATION

In optimizing any equipment, the first step is to clearly define the objective. That is, the criterion to be used to judge the performance of the system. In engineering design, the

objective of optimizing any reactor or equipment must be an economical one. This is because

for any chemical plant set up, the primary objective is to maximize profits.

7.1 EQUIPMENT OPTIMIZATION

The optimization of the Fluidized bed reactor, where the major chemical process takes

place in the designed plant is carried out as shown below.

7.1.2 OPTIMIZATION OF THE TRANS ESTERIFICATION REACTOR USING THE PRINCIPLE OF MINIMIZING THE LENGTH AND DIAMETER

The reactor can be optimized using the fact that, in order to minimize cost of construction of the

reactor vessel, the length and diameter of the must be kept at minimum.

The reactor is taken to be cylindrical in shape.

That is, the total surface area of the reactor is given as

$$A_r = 2 \cdot \pi \cdot r^2 + 2 \cdot \pi \cdot r \cdot H$$

And $r = \frac{D}{2}$

where r = "radius of the reactor"

D = "diameter of the reactor"

H = "height of the reactor"

π = "pie, a constant"

So, the formula becomes

$$A_r = 2\cdot\pi\cdot r^2 + 2\cdot\pi\cdot r\cdot H$$

$$A_r = 2\cdot\pi\cdot\left(\frac{D}{2}\right)^2 + 2\pi\cdot\frac{D}{2}\cdot H$$

$$A_r = 2\cdot\pi\cdot\frac{D^2}{4} + 2\cdot\pi\cdot\frac{D}{2}\cdot H$$

$$A_r = \pi\cdot\frac{D^2}{2} + \pi\cdot D\cdot H$$

One can now say that the area of the reactor is a function of the diameter and length of the reactor. That is, mathematically,

$$A_r = f(D,H)$$

where $A_r = \pi\cdot\frac{D^2}{2} + \pi\cdot D\cdot H$ is the objective function and D = minimum and H = minimum are the constraints that are to be minimized.

so that the equation of A_r becomes

$$f(D,H) = \pi\cdot\frac{D^2}{2} + \pi\cdot D\cdot H$$

Noting that the volume of the reactor is given as

$$V_r = \pi \cdot r^2 \cdot H$$

with $r = \frac{D}{2}$

$$V_r = \pi \cdot \left(\frac{D}{2}\right)^2 \cdot H$$

$$V_r = \pi \cdot \frac{D^2}{4} \cdot H$$

Making H the subject of the formula in the above equation,

$$H = \frac{4 \cdot V_r}{\pi \cdot D^2}$$

substituting the expression of H into the equation of total area of the reactor which is a function

of distance, D, and height ,H, it is obtained that

$$f(D,H) = \pi \cdot \frac{D^2}{2} + \pi \cdot D \cdot \frac{4 \cdot V_r}{\pi \cdot D^2}$$

Simplifying,

$$f(D,H) = \pi \cdot \frac{D^2}{2} + \pi \cdot \frac{4 \cdot V_r}{\pi \cdot D}$$

Now, it can be observed that the term of H has disappeared. That is to say that the total surface area is now a function of only the diameter, D. As such, the expression can be rewritten as

$$f(D) = \pi \cdot \frac{D^2}{2} + \pi \cdot \frac{4 \cdot V_r}{\pi \cdot D}$$

Since the aim here is to optimize, it may either be maximizing or minimizing. In this case, the aim is to maximize buy to minimize the dimension of the tank so that the size can be less, consequently, the profit can be much.

Differentiating the above equation,

$$\frac{d}{dD}f(D) = \pi \cdot D - \frac{4}{D^2} \cdot V_r$$

To optimize, the differential will be equated to zero, that is,

$$\frac{d}{dD}f(D) = \pi \cdot D - \frac{4}{D^2} \cdot V_r = 0$$

Taking the last two expressions,

$$\pi \cdot D - \frac{4}{D^2} \cdot V_r = 0$$

Simplifying and making D the subject of the formula

$$\pi \cdot D = \frac{4}{D^2} \cdot V_r$$

$$D^2 \cdot D = \frac{4 \cdot V_r}{\pi}$$

$$D^3 = \frac{4 \cdot V_r}{\pi}$$

$$D = \sqrt[3]{\frac{4 \cdot V_r}{\pi}}$$

The above expression is now the optimized diameter of the reactor.

Using the relatioship between the height of the reactor and the diameter given as

$$H = \frac{4 \cdot V_r}{\pi \cdot D^2}$$

Substituting for D in this expression yields

$$H = \frac{4 \cdot V_r}{\pi \cdot \left(\sqrt[3]{\frac{4 \cdot V_r}{\pi}}\right)^2}$$

Simplifying,

$$H = \frac{V_r^{\frac{1}{3}}}{\pi^{\frac{1}{3}}} \cdot \sqrt[3]{2^2}$$

Numerically, with

$$V_r := 45m^3$$

$$D := \sqrt[3]{\frac{4 \cdot V_r}{\pi}}$$ D= 3.855 m

$$H := \frac{V_r^{\frac{1}{3}}}{\pi^{\frac{1}{3}}} \cdot \sqrt[3]{2^2}$$ H= 3.855 m

Thus, it, therefore, means that the optimum diameter and height of the reactor are the same and have the same value of H= 3.855 m and D= 3.855 m·

Taking cost as the objective function, which is always the primary objective of any Set-up, the optimum dimension is almost given as $H = 2 \cdot D$

CHAPTER EIGHT

8.0 SAFETY AND QUALITY CONTROL

Safety is one of the major criteria for the selection of the best alternative along with economic viability; this is due to the value placed on the operating personnel and equipment in designing a plant.Operating conditions and equipments in operation are usually dangerous and could lead to a serious injury or major damage to the plant as well as disability to the personnel or even loss of life.

The plant should be sited far away from the public to avoid environmental pollution to the host community. For this design, the hazards and some of the actions that could lead to these hazards are identified and safety measures are then recommended to fit into the plant design.

The following may be considered in Safety and loss prevention of a process design:

1. Identification and assessment of the hazards.
2. Control of the hazards: for example, by containment of flammable and toxic materials.
3. Control of the process. Prevention of hazardous deviations in process variables (pressure, temperature, flow) by provision of automatic control systems, interlocks, alarms, trips; together with good operating practices and management.
4. Limitation of the loss. The damage and injury caused if an incident occurs: pressure relief, plant layout, provision of fire-fighting equipment.

8.1 SAFETY

Any organization has a legal and moral obligation to safeguard the health and welfare of its employees and the general public. Safety is also good business; the good management practices needed to ensure safe operation will also ensure efficient operation; there is need for loss prevention. The term "loss prevention" is an insurance term, the loss being the financial loss caused by an accident. This loss will not only be the cost of replacing damaged plant and third party claims, but also the loss of earnings from lost production and lost sales opportunity.

All manufacturing processes are to some extent hazardous, but in chemical processes there are additional, special, hazards associated with the chemicals used and the process conditions. The designer must be aware of these hazards, and ensure, through the application of sound engineering practice, that the risks are reduced to acceptable levels.

8.1.1 HAZARDS IN BIODIESEL PLANT

A hazard is generally defined as the presence of a material or condition that has the potential of causing loss or harm (Odigure, 1998). Prevention reduces the likelihood of the hazard occurring, whereas protection lessens the chance of the consequences from happening.

Material and equipment inventory were carried out in order to identify the hazards present in the plant.

8.1.1.1 INVENTORY

The types of the inventories present in the process plant are material and equipment inventories.

8.1.1.2 EQUIPMENT INVENTORY

In this case, the followings are the major equipment present:

i. Trans-esterification reactor.
ii. Distillation columns.
iii. Heater
iv. Scrubber

8.2 Plant Safety

8.2.1 Introduction

The responsibility for the safe operation of any chemical process facility, including a biodiesel plant, begins with the CEO of the company and extends to every employee and visitor on the plant site. Safety is a result of training, operating, maintaining, and preparing to prevent unplanned and dangerous events in the plant. It is a way of thinking and acting during routine activities and in response to extraordinary situations.

There are numerous regulatory requirements associated with training and housekeeping to monitor and improve safety in the workplace. Regulations and procedures dictated by OSHA, EPA, and other agencies apply to biodiesel plants of any size. Some of these requirements are covered in other modules. In addition, every plant should have one person with the designated responsibility for overseeing the training and inspections in the workplace.

Given this introduction, this section will focus on some of the key elements of a plant safety program, safe design, and safe operation. The emphasis is on elements of safety associated with the operation of a chemical process facility. This section is intended to be a reminder for what must be known and taught, more than detailed instruction in all of the elements of plant safety.

8.2.2 Basic Definitions

- **Safety**: The prevention of accidents by the use of appropriate technologies to identify the hazards of a chemical plant and to eliminate them before the accident occurs.
- **Hazard:** Anything with the potential for producing an accident.
- **Risk:** The probability of a hazard resulting in an accident.
-

8.2.3 Keys to a Successful Safety Program

1. Safety Knowledge – Every person associated with the plant must know what the materials used in the plant are and what their hazards are. The people must be trained in the correct and safe operation of the processing equipment, and know how to respond in an emergency situation.
2. Safety Experience – Training is more than a lecture, a video module, or reading a manual. Personnel must have hands-on training in proper operation of equipment and develop an understanding of how to recognize and correct dangerous situations. The use of process simulators is needed, as is training with actual safety equipment.
3. Technical Competence – The ability to use training in proper operation and proper safety precautions must be demonstrated and documented on a regular basis.
4. Safety Management Support – Safety must be modeled and monitored throughout the management chain.
5. Commitment – Demonstrated commitment to safety in the workplace and beyond must begin with the CEO and permeate all employees. Breaches of safe procedures must be clear dismissal grounds and enforced.

8.2.4 Types of Chemical Plant Accidents

A biodiesel facility is first and foremost a chemical process facility. As such, the plant is subject to the same dangers as any other chemical process plant. Table 13 lists categories of accidents that are uniquely associated with chemical plants. Note that the likelihood of an event and its potential impacts are not closely related.

Table 4.0: Types of Chemical Plant Accidents

	Probability	**Potential Fatalities**	**Potential $ Loss**
Fire	High	Low	Moderate
Explosion	Moderate	Moderate	High
Toxic Release	Low	High	Low

In a biodiesel plant, the greatest risk is associated with methanol. It presents a fire and explosion hazard as well as being toxic through oral ingestions of skin contact.

In order to better understand how accidents occur in a chemical plant, it is useful to examine the causes for loss with respect to the source of the loss event. These causes are listed in order of frequency below:

Causes for Loss in a Chemical Plant Accident (in order)

1. Mechanical Failure
2. Operational Error
3. Unknown – Miscellaneous
4. Process Upset
5. Natural Hazard
6. Design Error
7. Arson – Sabota

Since the most common cause for loss is mechanical failure, it is useful to examine the specific equipment items responsible for the failures. These items are listed in order below:

Hardware Associated with Losses

- Piping Systems
- Miscellaneous of Unknown
- Storage Tanks
- Reactor Piping Systems
- Process Holding Tanks
- Heat Exchangers
- Process Towers
- Compressors
- Pumps
- Gages

8.2.5 Accident Sequence

It is rare that there is a single causal event that leads to a loss accident. Indeed, one of the most important ways to prevent accidents is to examine carefully the chain of events that result in an accident and that bring the accident sequence to an end. These lessons learned provide the basis for anticipating potential accident situations and planning interventions that halt the accident process before a loss occurs. The accident sequence can be described as follows:

•Initiation – event that begins the accident

•Propagation – event(s) that sustain or expand the accident

•Termination – event(s) that stop the accident or diminish it is size

The propagation steps in an accident sequence are generally associated with potential hazards that exist – accidents ready to happen. In many cases these steps are the results of intentional acts with unintended consequences. For example, turning off alarms and sensors during servicing makes the service personnel vulnerable to accidents that would have been prevented if the alarms were operational. The chemical process industry has a special category of hazards present because the industry is based on the utilization and transformation of chemical raw materials into new chemical products. These hazards are linked to the physical and chemical reactivity properties of the various chemicals present. The categories of chemical process hazards may be present in a chemical facility are listed as thus:

Categories of Chemical Process Hazards

- Explosion
- Gases – toxic, flammable, compressed
- Flammable Liquids
- Flammable Solids
- Oxidizers and Organic Peroxides
- Poisons, Pesticides, Carcinogens
- Radioactive
- Corrosives

8.2.6 Identifying Hazards

The most fundamental tasks in developing a safety program for a chemical process facility are summarized in the sequence shown below.

•What are the hazards? – Identification

•What can go wrong and how? – Scenario Building

•What are the chances? – Risk

•What are the consequences? - Results

There are a number of formalized procedural tools for hazard identification. Any given facility may choose to use one or more of these tools. The tools include:

• Process Hazards Checklist – Use a standard checklist that covers possible hazardous conditions in the operation. When a hazard is noted, the action step is to remove the hazard, or to mitigate its effect.

• Hazard Survey – Use an individual or a team to inspect a specific process or operational area, looking for hazardous conditions. Again, the action step is to eliminate or mitigate the hazard.

- Hazard and Operability Studies HAZOP – This is a formalized approach that examines every piece of equipment in a process on the basis of its function. The questions of cause and effect for each operation are framed in terms of the item not functioning, under functioning and over functioning (NOT, LESS, MORE, etc.). The effect of each condition is estimated, along with the likelihood of the cause being present. This process helps identify likely, significant faults for correction.
- Safety Review – An independent, experienced team reviews operations and safety procedures in use at a facility. The review includes simulated incidents and monitors the response to the incidents.

8.2.7 Toxic Hazards

In the chemical process industry there is the hazard of exposure to chemicals that are toxic.

Toxicity is defined as the ability of a chemical substance to cause physical harm to a living organism. The harm may range from a temporary irritation to permanent loss of function, to death. The toxic effect may be the result of a long term, cumulative effect (chronic toxicity) or a rapid response to the presence of the toxicant (acute toxicity).

In either case, a key factor in the response is the amount of material presented in the exposure (dose) and the degree of toxicity exhibited by the material. The dose is typically measured in terms of amount per kg of body weight. The degrees of toxicity based upon the dosage required to cause death in 50 percent of the exposed subjects is shown below:

Degree of Toxicity LD50 (dose per kg body weight)

< 1.0 mg	Dangerously toxic
1.0 – 50 mg	Seriously toxic
50 – 500 mg	Highly toxic
0.5 – 5 gm	Moderately toxic
5 – 15 gm	Slightly toxic
> 15 gm	Extremely low toxicity

When working with and around various chemicals, there are a number of paths for toxic materials to enter the body. These routes include:

•Ingestion – mouth or stomach

•Inhalation – mouth or nose

•Injection – skin cuts

•Dermal absorption

The toxic hazards can be eliminated from the body by excretion (kidneys, liver, lungs, other), detoxification through internal biotransformation, or by storage, typically in fatty tissue or bones. Methanol is the primary issue for toxic exposure in a biodiesel plant. Because of the risks from chronic exposure, there are limits to allowable exposures to most chemicals. These limits are based on a combination of time and concentration. These limits are termed "threshold limit values" and are described below.

8.2.8 Threshold Limit Values

- TLV-TWA: Time weighted average, 8 hr Day
- TLV-STEL: Time weighted average, short-term exposure, < 15 min
- TLV-C: Ceiling limit, do not exceed at all

A required source of information on the hazards associated with chemicals in use in the workplace is the Material Safety Data Sheet. There must be copies of the MSDS for every chemical in use in each area of the chemical plant and associated laboratories available in a public, easily located place. The hazard properties and recommended methods of handling each compound are included in the MSDS. All employees must be familiar with the chemicals that they are working with and must follow the recommendations for their handling, use and disposal.

8.2.9 Designing for Safety

There are a number of safety enhancement strategies –that can be applied during the design phase for any chemical plant. They include:

•Substitution – Less hazardous chemicals and equipment

•Attenuation – Less hazardous operating conditions = "less"

•Isolation – Isolate equipment from sources of hazard or from risk of harm to personnel

•Process intensification – smaller/higher throughput; smaller inventory

Similarly, there are safety enhancement strategies to be applied during the operating phase of a chemical plant:

•Enclosures

•Local Ventilation

•Dilution Ventilation

•Wet Methods and Cleaning

•Good Housekeeping

•Personal Protection

8.2.10 in Summary, safety is:

- **PREPARED**
- **PREPLANNED**
- **PREVENTION**
- **PREEMINENT**

8.3 STRATEGIES FOR SAFER PROCESS DESIGN

There are four major strategies for safer process design:

1. Minimizing the size of process equipment.
2. Substituting a less hazardous substance or process step.
3. Moderate storage or processing conditions.
4. Simplifying process and plant design.

8.4 SAFETY DECISIONS VIA RISK MAPPING

Risk is defined as a combination of the likelihood of occurrence and severity of impact from unexpected loss incidents (Odigure,1998). Risk represents potential expenditure or liabilities, but is not generally included in a budget or financial forecast. A probability exists that an expenditure or liability will actually be incurred within each period. Thus, the expense will be zero if the incident does not occur. Since decisions are generally made on an economic basis, it follows that risks must also be converted to monetary values (Odigure, 1998). Risk avoidance can result in increased productivity that translates directly to the corporate bottom line.

Developing an understanding of risk requires addressing three questions:

1. What is the hazard?
2. What are the possible undesired outcomes?
3. How likely are these to occur?

Having adequate knowledge about the hazards and the safe limits of certain key parameters such as the ignition temperature and explosion concentration is very important in risk mapping.

8.5 QUALITY CONTROL

Quality simply means "fitness for use". But, according to the International Standard Organisation (ISO), quality is defined as the totality of the characteristics of an entity that bear on its ability to satisfy stated and intended needs. It is more costly to exceed a specification than to meet it. Therefore, there is the need to get quality goal or target for effective quality control.

Maintaining product quality in accordance with acceptable standard has been a major role for industrial instrumentation since its inception decades ago. With the ever-increasing interest in speeding up production, one becomes aware of the fact that rejectable as well as acceptable products can be produced at high rates.

8.5.1 QUALITY ASSURANCE

Quality assurance is defined by ISO as all the planned and systematic activities implemented within the quality system and demonstration is needed to provide adequate confidence on entity will fulfil requirement for quality.

8.5.1.1 PRINCIPLES OF QUALITY ASSURANCE

The principles of quality assurance include the following:

i. Management involvements and objective (management) involvement is very essential to ensure quality.
ii. Programming and planning.
iii. Application of quality control principles.
iv. Design and specification control.
v. Purchasing control and vendor appraisal.
vi. Production control.
vii. Marketing and service quality functions.
viii. Proper documentation.
ix. Non-conformance control.
x. Remedial action.
xi. Defect and failure analysis.

8.5.1.2 QUALITY MANAGEMENT

Quality management involves all activities of the overall management functions that determine the quality policy, objective and responsibilities and implement then by means, such as quality planning control assurance and improvement within the quality system. Responsibility of quality lies at all level of all. To successfully implement quality management, the organisation structure, procedure process and resources are requisite.

CHAPTER NINE

9.0 PROCESS CONTROL AND INSTRUMENTATION

It is intended that most of the equipment in the Biodiesel plant could be operated automatically with automatic control, with the indicating instruments located in a central control room. Actually, this is the general practice of this kind that is proposed not to be labour intensive. With the exception of the trans-esterification (reactor), the plant operates at atmospheric pressure and therefore the instrumentation and control will be based upon temperature, flow and level measurements. Measurements of these parameters will be made using, for instance, thermocouples for the temperatures, orifice plates for the flow and float type indicators for the level measurements. Regulation by pneumatic control is recommended due to the flammability of the process fluids. The description of typical instrumentation and control systems of the plant equipments are as given below.

9.1 Chemical Plant Controls

To produce quality products from a biodiesel production plant it is necessary to be able to control the production process. While a tremendously important control variable is the properties of the feedstock to the process, this section will only discuss the control of chemical plants within the unit operation of the processes, such as those discussed in the previous section. Two general types of processes can be used in the production of biodiesel, either batch or continuous. For batch processes the process control variables will be temperature, pressure, and levels.

Temperature and pressure control are critical within the reaction and separation sections of the plants. Level control dictates charging to the reactor, operation of separation devices, and product storage. For continuous processes the process control variables include temperature, pressure, level, and flow rate.

It is important to note that process variables, which are monitored and controlled, are not the same as the product specifications. Specifications are properties that are required of the final product such as those given in ASTM D 6751 for biodiesel. Control variables are those process variables that are monitored and adjusted to meet the desired specifications. As such, specifications are generally measured off-line in an analytical laboratory, while the process variables are process conditions that are measured in real time. The process variables are related to the specifications through some type of process model. The process model will typically be provided by the process licensor with subsequent refinement from plant operation experience.

Some manufacturing plants will develop their own statistical or empirical models. It should be noted that the process models are typically feedstock dependent.

In discussing process variable measurement instruments, the performance of the instruments can be characterized by their accuracy and/or precision. Accuracy is the ability of an instrument to measure the correct or "true" value of a process variable. In contrast, precision is the ability of an instrument to reproduce a process váriable value within a certain interval. As such, it is possible to have either "accurate and imprecise" or "inaccurate and precise" instruments. For day-to-day operation the ability of a measurement instrument to be precise is generally more important than the need to be accurate. However, when the measurement instrument needs to be replaced, accuracy becomes an important issue.

When considering an instrumental control system for a chemical plant there are a number of factors that should be considered; cost, precision, reliability, and operator interface. It is desirable to have the lowest cost monitoring system that will allow appropriate control of the process. Precision is important to assure that there is reproducibility of measurements. Reliability insures that the system is not prone to failures. Finally, it is desirable to have a monitoring and control system that provides an easy interface with the plant operators.

The most common process variable monitored in a chemical plant is the temperature. The temperature at a specific point is generally measured using thermocouples, which are electrical devices.

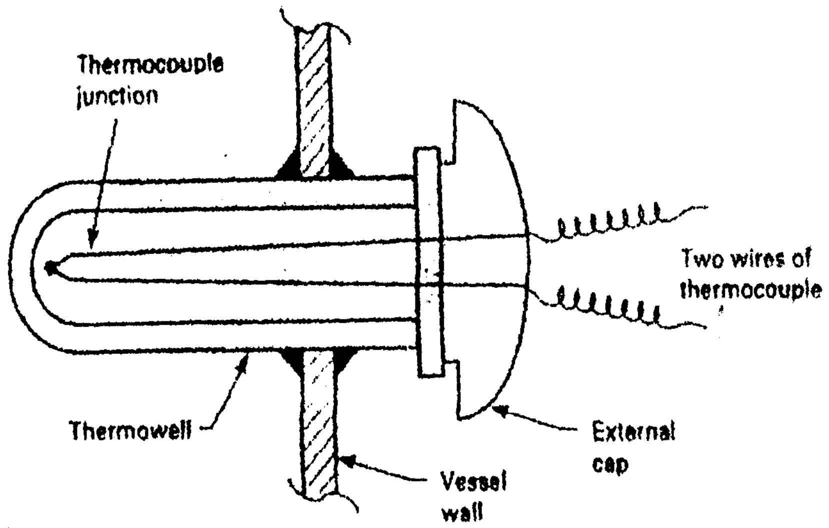


Figure 6.0: Thermocouples

Thermocouples are made of two different metallic wires. These wires are connected at a junction. An electrical current is established when the junction is heated. The electrical current is proportional to the temperature at the junction. For this reason, the thermocouple must be calibrated to correlate temperature to current. Thermocouples are categorized by the metals used in their junctions, with different metal junction combinations being more appropriate for different temperature ranges.

Individual thermocouples are typically not calibrated by the supplier. Instead, manufacturers will typically test a representative portion of the thermocouples they produce. Due to the manufacturing procedure, thermocouples are usually precise (or completely don't work) but can be inaccurate. The thermocouple is typically enclosed within a thermowell. The thermocouple must be fully inserted into the thermowell with the thermowell extended appropriately into the process to obtain a correct reading. If the temperature of a process liquid is being measured it is generally adequate for the thermowell to extend about 2-3 inches into the liquid. Due to inferior heat transfer, the thermowell should extend about 6 inches into a process vapor.

Thermocouples are typically used in processes for both monitoring and controlling the process. When a thermocouple is used as part of a process control loop, the electrical current output from the thermocouple is compared with the current expected for the set point temperature. Deviation of the actual temperature from the set point temperature will cause a change in the output to a heater or cooler that is included in the control loop.

Pressure values can be measured using several different types of devices such as liquid column, elastic element, and electrical sensing. The most common form of a liquid column device is a manometer in which the liquid height can be observed visually and correlated to the pressure through the density of the liquid. Liquid column devices are rarely used in chemical processes.

Elastic element devices measure pressure by determining deformation of an elastic material. This elastic material is usually metallic. One type of elastic element device uses bellows elements.

The displacement of the bellows can be correlated to the pressure value. The most common pressure measurement instruments used in chemical processes are electrical sensing devices, which are known as strain gauges. Strain gauges are predicated on the fact that the electrical resistance of conducting solids changes with length and diameter of the solid. The dimensional change of the solid induced by a pressure causes an increase in the electrical resistance of the conducting solid. An elastic element or electrical sensing device used to measure pressure is called a pressure transducer. The pressure tap for a transducer should be located in the vapor phase of a process. A transducer located in the liquid phase will detect a different pressure at different depths in the liquid.

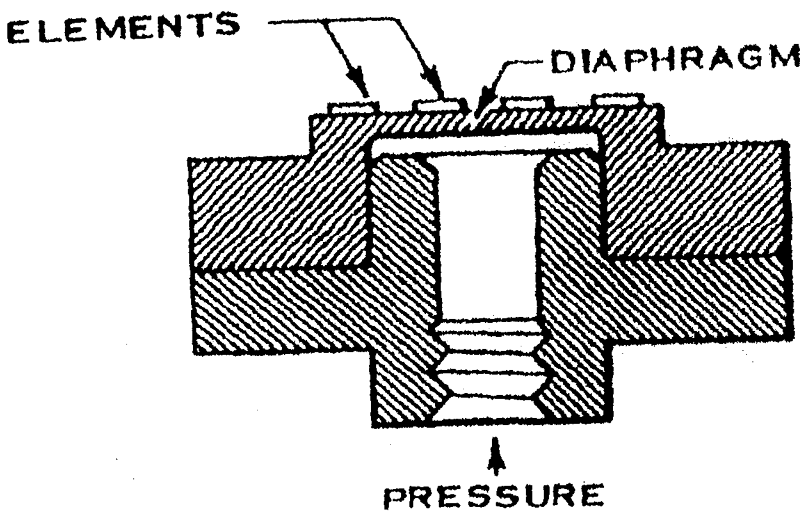


Figure 7.0: Pressure Transducer

To use a pressure transducer for process control or in continuous monitoring, the transducer must produce an electrical signal. For the elastic element device, the direct pressure reading due to displacement must somehow be converted to an electrical signal. An advantage of the electrical sensing approach is that these devices directly provide an electrical signal. As with thermocouples, pressure transducers can be used for process control by comparing the measured pressure to a desired set point pressure.

Level measurement can be used to yield mass balance information across the process or loading in a batch reactor. Historically, level measurement devices have typically been displacer-based meters or differential pressure meters. The displacer-based meter is based on buoyancy. The displacer is immersed in a displacer chamber that is located as a side chamber. The displacer is restrained by an elastic element whose motion is proportional to the buoyant force, so the level can be determined by the vertical location of the displacer. Differential pressure meters, which are the most common level indicating devices, measure the difference in pressure between two pressure taps in a vessel.

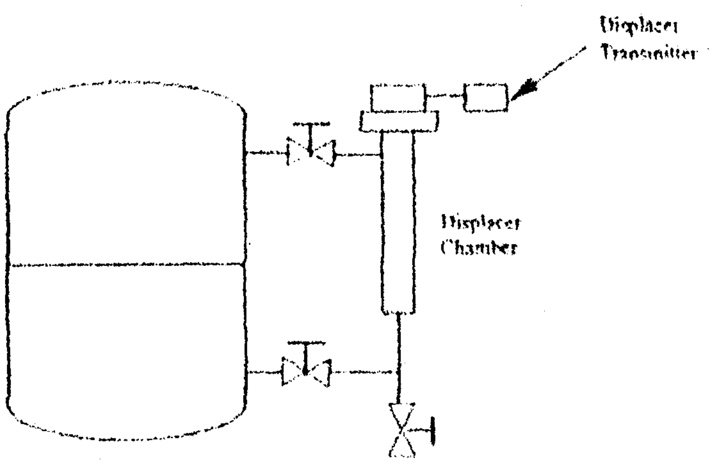


Figure 8.0: Differential Pressure Meters

It is important to note that both of these level measurement indicators are liquid density dependent, so that changes in liquid densities can affect their readings. This effect can be particularly important if several liquid phases are present in the device. For example, the height of liquid in a gauge glass connected to a vessel is not a direct measurement of the liquid level! Recently, level measurement devices have been developed that use signal reflectance from an ultrasonic transducer or radio frequency, which measures the change in impedance between two capacitor electrodes.

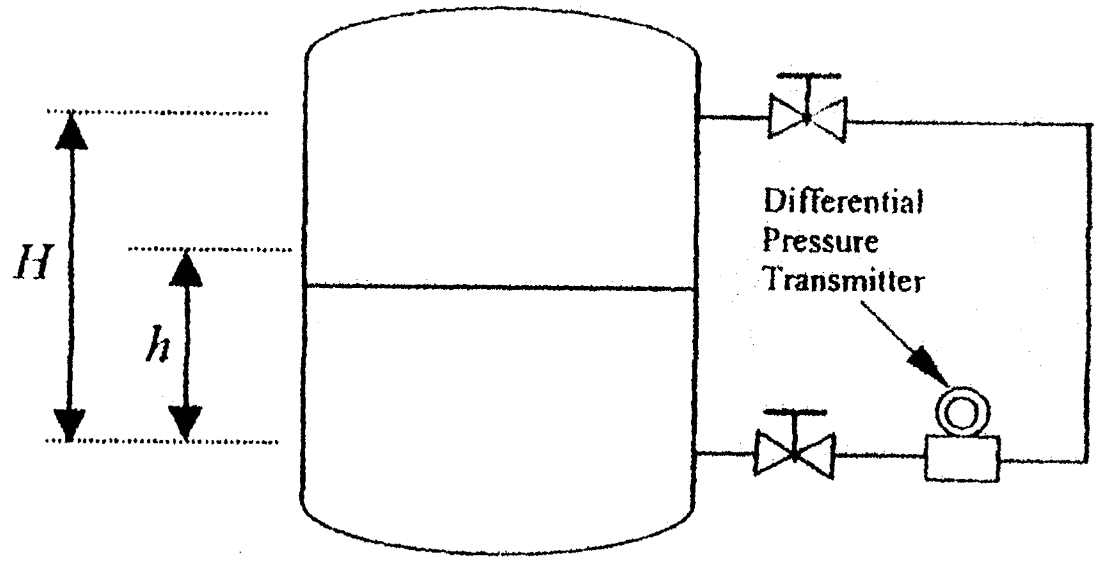


Figure 9.0: level Measurement Transducer

In addition to density, there are a number of factors that can influence the reliability of a level measurement. Plugged taps can occur without causing apparent discrepancies in the level measurement device. Excursions to high liquid levels can impact the reliability of the level measurement as can the presence of foam in the vessel.

The measurement and control of level in a vessel generally requires two taps into the vessel. It is important that these taps are properly valved. Since the level indicator can be used to monitor the amount of material in a vessel, it can be used to track chemical inventory within the process as well as to control the charging of chemicals into a batch process. Level measurements can be converted to electrical signals that can be used for control. The most common control loop that includes level measurement is with operation of pumps.

The final process variable that will be discussed is flow rate. Flow rate measurement will generally only be needed if a continuous flow process is used. There are a number of methods for measuring flow rates, but the most commonly used approach in chemical processes are differential pressure flowmeters and positive displacement flowmeters. Flowmeters can be used in monitoring and control. The most common control loop that includes flow rate is with operation of pumps

Differential flowmeters measure the difference in pressure between the two sides of a restriction in a confined stream. These flowmeters are based on restrictions imposed by a venturi tube, an orifice plate or a flow nozzle with the orifice plate meter being the most common. The orifice plate hole should be appropriately sized for the flow rate range of interest. If the hole is too large the resulting pressure change and, therefore, accuracy of the flow measurement will be inaccurate. In contrast, if the hole is too small, the flow rate measurement is at the cost of too high of a pressure drop. While orifice plate meters are typically used for flow rate measurement and subsequent control, it should be noted that the meters do have some potential problems.

First, this type of flowmeter is highly dependent on the density and viscosity of the liquid. Orifice plates can erode or have blockage, which will lead to inaccurate measurement. The pressure taps can become plugged leading to erroneous flow values.

Positive displacement flowmeters measure flow rates using the fluid to displace a measuring device. Most common are rotary displacement flow meters.

In these meters, flow rate is measured by the amount of rotation created by flow of the fluid past a rotary device. An example of a rotary flowmeter is a vane-liquid flowmeter in which a set of vanes mounted on a rotor with opposing pairs rotated in a cylindrical chamber.

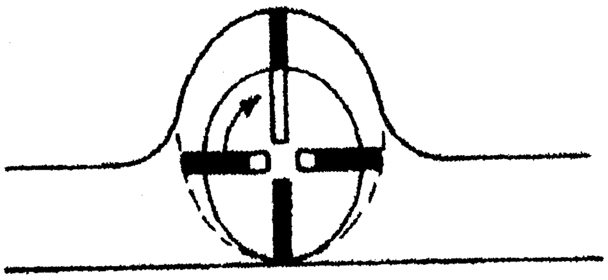


Figure 10: Vane-liquid Flowmeter

The overall monitor and control system for a process can be achieved by individual monitors and controllers located directly at the process. However, it is most common in the chemical processes to have a centralized system for monitoring and controlling. This can be readily accommodated for most processes by a PC based system. A number of different software options are readily available for these types of systems.

9.2 PROCESS CONTROL OF EQUIPMENTS

9.2.1 CONVERTER (REACTOR) CONTROL

The schemes used for reactor control depend on the process and the type of reactor. If a reliable on-line analyzer is available, and the reactor dynamics are suitable, the product composition can be monitored continuously and the reactor conditions and feed flows controlled automatically to maintain the desired product composition and yield. More often, the operator is the final link in the control loop, adjusting the controller set points to maintain the product within specification, based on periodic laboratory analyses.

Reactor temperature will normally be controlled by regulating the flow of the heating or cooling medium. Pressure is usually held constant. Material balance control will be necessary to maintain the correct flow of reactants to the reactor and the flow of products and unreacted materials from the reactor. A typical reactor control scheme is shown in Figure 9.1.

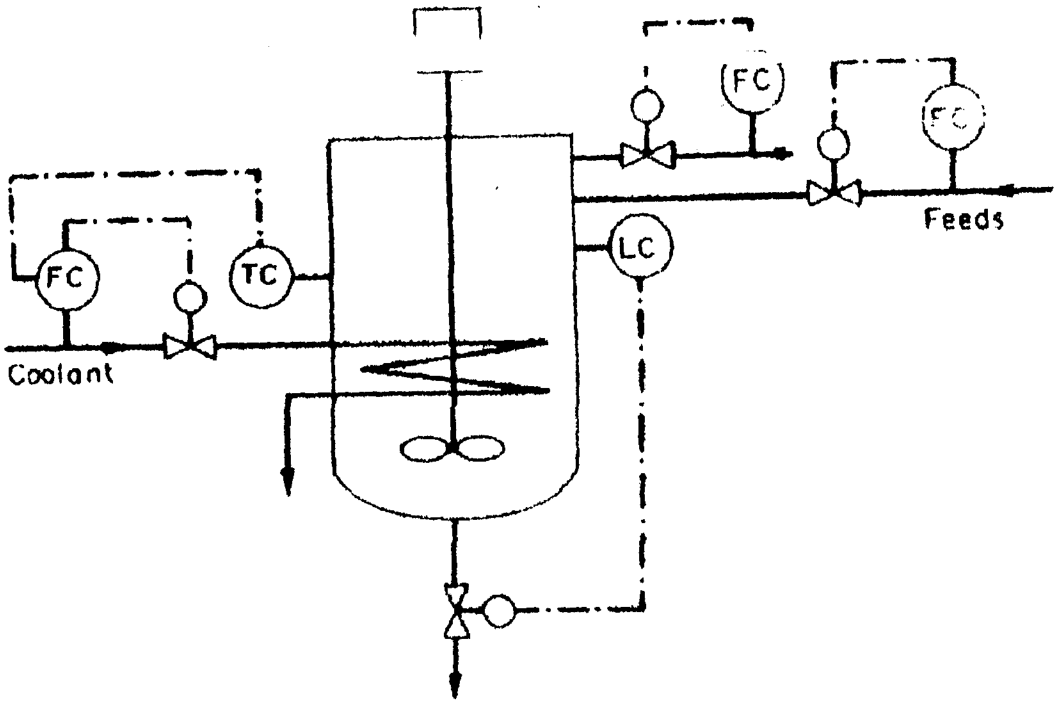


Figure 11: A stirred tank reactor control scheme, temperature: cascade control, and reagent: flow control

Table 5.0: SPECIFICATION OF CONTROLLER/INSTRUMENT TYPE

TI	Temperature Indicator [thermocouples (Chromel-alumel)]
TC	Temperature Controller (PID – Proportional-Integral-Derivative controller)
PC	Pressure Controller (P – Proportional controller)
PI	Pressure Indicator (Differential Pressure Gauge - diaphragm)
LC	Level Controller (PI – Proportional-Integral controller)
LI	Level Indicator (Float-type indicator)
FC	Flow Controller (PI – Proportional-Integral controller)
FI	Flow Indicator (orifice plate)
-----	Pneumatic control due to high flammability of the process fluid

CHAPTER TEN

10.0 ENVIRONMENTAL ACCEPTABILITY

Any new project or technology involving hazardous materials requires a rational approach of assessing the suitability and acceptability to the environment and man.

Various legislations govern the emission of pollutants into the environment. The environmental friendliness of the process choice adopted from the design process is of utmost importance to the relevant government agencies responsible for environmental protection. Awareness of the relevant federal regulations is an essential component of a legally acceptable plant design.

Pollution is an inevitable consequence of human activities. Recent studies have called attention to the harm arising from air pollution, which menaces both the physical and chemical conditions of the whole atmosphere and indirectly biological equilibrium of the entire earth. The cost of preventing pollution and nuisances is less than the cost of repairing the damage caused and introduced anti-pollution measures (Wood, 1989).

Pollution prevention assessment and development of strategies involves the following steps:

i. Definition of the problem.
ii. Effect of pollution.
iii. Developing some conceptual pollution strategies.

10.1 DEFINITION OF THE PROBLEM

It is very necessary to understand what, where, when, how and why emissions and wastes are generated in order to develop appropriate preventive measures.

10.1.1 IDENTIFICATION OF POSSIBLE POLLUTANTS, SOURCES AND EFFECTS

The effects of the pollutants on the environment cannot be overemphasized. Their various effects are as described thus.

Chlorine Gas and Sodium Hypochlorite

Community and industrial concern regarding the potential health, environmental and safety risks associated with chlorine based disinfection has greatly increased over the past few years. The recent cryptosporidium scare in Sydney and the unprecedented political impact it has had on the Sydney Water Corporation has alerted the water industry to the potential consequences of any safety incident which can affect community health. Water boards have subsequently conducted risk assessments on all their operations concluding the "inherent risk" associated with the use of chlorine gas poses a potential safety concern.

Despite the outstanding safety record of the chlorine gas some water companies are considering converting their disinfection systems from chlorine gas to sodium hypochlorite due to the perceived safety benefit. The health risks associated with sodium hypochlorite, the increasing number of safety incidents occurring, the environmental damage from spills and the potential to greatly increase the cost of disinfection should be considered prior to conversion. This chapter discusses the issues associated with the application of chlorine based disinfection products for water and waste water.

It is our responsibility to set the market standard by operating to the highest ethical standards to ensure the safety of our customers, employees, the community and the environment.

Concern over the use of Chlorine disinfection is primarily due to environmental, regulatory and community perception of public risk. Public concern with acceptable levels of disinfection by-products has mounted pressure on government authorities to provide safe and "chemical free" potable water.

There is a requirement to provide chlorine and its derivatives as their use is application specific. In the case of chlorine based disinfection for water and waste water, chlorine gas offers customers the lowest health risk for consumers, is the safest in use, and is the most cost effective and environmentally safe alternative. Sodium hypochlorite is becoming the largest contributor of safety incidents involving chlorine based disinfection.

Hence for conversion to sodium hypochlorite, there is the need to conduct an independent risk assessment of the sites to determine if there is a real safety risk. It is important to fully investigate the suppliers to ensure that the product is fresh, has the required strength of available chlorine and is stored and transported in line with the strictest safety regulations. It is also strongly suggested that all chlorate levels are monitored in storage tanks and the receiving water.

Safety Considerations

The absence of fatalities in Nigeria related to the use of chlorine gas may be attributed to the rigorous safety practices (Hazop and Quantitative Risk Assessment) employed by manufacturers, distributors, regulators and customers of chlorine gas. The employment of these techniques to assess "inherent risk" (the potential to cause a fatality) has directly resulted in the dramatic reduction in "safety-in-use" incidents involving chlorine gas. Essentially, if you can forecast the potential risk of a chemical, you can eliminate safety incidents related to its use.

The minimization of safety risks associated with the use of chlorine gas has been based on assessment of the "inherent risk" (the potential to cause a fatality) rather than measurement of "safety-in-use risk" (the number of safety incidents caused during the transport/storage/use of chlorine gas). The assessment method most commonly employed to assess "inherent risk" is the Quantitative Risk Assessment (QRA) which estimates the risk associated with the operation of a facility, calculates the likely frequency, and gauges the severity of an incident for a range of distances from the facility. The results are then used to take action to reduce risk (if required). Hazop studies are also conducted at the end of the process design stage to eliminate any unforeseen safety hazards. These techniques have successfully forecasted potential safety hazards. The reward for this rigorous application of risk assessment has been an outstanding safety record for manufacturers and users of chlorine gas ie negligible "safety-in-use" incidents. The same rigorous risk assessment techniques have not been employed in ensuring the safe design, storage and transport of sodium hypochlorite. It appears that the reason for this oversight has been that sodium hypochlorite is considered as having an extremely low "inherent risk" and therefore, there has been little attention paid to "safety-in-use risk". Whilst it is true that sodium hypochlorite is an inherently safer chemical, it does have the potential to create very dangerous safety hazards when stored, transported or used incorrectly. It is this perception regarding the relative safety of sodium hypochlorite which has directly resulted in an alarming increase in safety-in-use incidents involving sodium hypochlorite. Additionally, there are few regulatory guidelines in place to ensure the safe storage, transport and use of sodium hypochlorite. Subsequently, standard risk management practices have often not been conduct.

Orica has been compiling safety incident data on chlorine gas and sodium hypochlorite since 1996 via the Emergency Response System. The data shows an alarming increase in the number of sodium hypochlorite safety incidents occurring on customer sites. These incidents primarily involve:

Ground contamination from tank ruptures and valve leaks caused by poor maintenance/unsuitable materials of construction;

- Pipe ruptures caused by hypo under pressure;
- Burns/inhalations to operators due to lack of training in safe handling practices and failure to use appropriate Personal Protection Equipment (PPE);
- Periods of non-disinfection due to absence of back-up supply on site.

Of most concern is the number of occurrences where sodium hypochlorite has been inadvertently mixed with acid creating an uncontrollable chlorine gas cloud. There have been far more incidents where members of the public have been exposed to chlorine gas in this way than via leaks from chlorine gas containers.

Health Considerations

Water Quality guidelines are becoming more stringent resulting in increased treatment and monitoring chemical. Additional to treatment costs is the enormous cost associated with public liability in the event of an incident involving public health (eg cryptosporidium). Chlorine gas can continually deliver the required level of disinfection when applied correctly, however there are serious doubts with regard to the use of sodium hypochlorite for disinfection of both potable water and waste water. These doubts have arisen for two reasons:

1. The degradation of sodium hypochlorite is virtually instantaneous. The resultant by-product, sodium chlorate, is dangerous to public health when it reaches defined levels. Consequently, countries such as USA have introduced water quality guidelines that prescribe the maximum allowable limit of chlorates in potable water. These guidelines can be met if the sodium hypochlorite is used soon after manufacture; however, for any Water Company storing sodium hypochlorite on site, it is strongly recommended that they implement chlorate testing before the sodium hypochlorite is used to ensure that they do not breach the guidelines. As the degradation process is strongly influenced by time and temperature, the storage time allowable for sodium hypochlorite will vary according to the customer's storage conditions.

2. The degradation of sodium hypochlorite also affects the strength of the product. Orica manufactures hypo each night for distribution the next day. Manufacture strength is typically 14 - 15% which ensures that the product is still at a minimum of 13% chlorine when it reaches our customers. However, depending upon temperature, storage conditions and storage time, the sodium hypochlorite will continue to lose strength. For customers storing

hypo on site, this may result in under chlorination of the water supply due to the consequent loss in strength. For many companies this may create a situation equivalent to a period of non-disinfection and a serious health concern.

Environmental Considerations

When considering the environmental risks of chlorine most people think of the dangers associated with the release of a chlorine cloud to the atmosphere. In reality a pure chlorine gas cloud will disperse very quickly and, according to the Chlorine Institute, is unlikely to reach/affect the Ozone layer. However, if chlorine is released in large quantities to the waterways, its strong oxidizing properties will cause it to form by-products which are detrimental to marine plant and animal life. The likelihood of an accidental release of chlorine gas into the waterways is negligible; however, there is an increasing frequency of accidental releases of sodium hypochlorite into these sensitive environments. The most common causes of such leaks are transport accidents and tank ruptures.

The likelihood of a transport or storage incident increases with the number of deliveries and quantities stored. A single deliver of 6 x 920kg drums of chlorine gas would require the equivalent of 6 separate deliveries of 9,200L of sodium hypochlorite. Therefore, the number of transport and storage related incidents with sodium hypochlorite are higher.

Another significant reason why chlorine gas has very few transport or storage incidents is because it is transported and stored in specially engineered containers which are strong enough to withstand a fall from a multistory building.

Sodium hypochlorite is still chlorine but in a liquid form, it has the same ability to negatively impact the environment, however, because it is perceived to be "safe" regulations do not specify the same safeguards for transport, storage and use. This is a dangerous oversight which must be rectified if sodium hypochlorite is to safely replace chlorine gas in water disinfection.

10.2 POLLUTION TREATMENT AND PREVENTION STRATEGIES

In treating the waste emitted from the Hypochlorite plant, various strategies could be implemented. These strategies, if well implemented, could lead to friendly and conducive environment. That is to say, the strategies would reduce, or even eliminate, the presence of pollutants in the atmosphere. The strategies are as follows:

i. Appropriate concentration analyzer should be used to detect the escape of any gases and other pollutants gases with the air leaving the Separator.

ii. The off-gases vented from the Separators could be channelled from the top of the Separators to serve as feedstock for the process industry, if possible and required.

iii. The product quality should be properly to reduce waste which could lead to pollution.

iv. Efforts should be made to find markets for the bye-products (the off-gases) of the Hypochlorite plant.

v. Routine monitor of the plant should be carried out to detect fugitive emissions or leaks.

vi. The process-contaminated air should be kept from heating and ventilation air.

vii. The reaction kinetics should be improved to reduce the generation of bye-product; that is, to increase the conversion of Sodium Hypochlorite.

CHAPTER ELEVEN

10.0 START UP AND SHUT DOWN PROCEDURE

Start up time may be defined as the time span between end of construction and the beginning of normal operations. Start up and shut down procedure must proceed safely and be flexible enough to be carried out in various ways. In other words, the start up and shut down of the Biodiesel plant should be such that it can be easily and safely operated. The operating limits of the plant should not be exceeded and dangerous mixtures must not be formed as a result of abnormal states of concentration, composition, temperature, phase, pressure, reactants and products.

It should be noted that some items of actions must be completed before even the start up of the plant in order to prepare the plant for the start up operation.

i. All scaffolds and temporary piping and supports should be removed.
ii. Lines and equipment should be flushed out.
iii. Pumps, motors/turbines and compressors should be run.
iv. Hydrostatic or pneumatic lines and equipment should be tested.
v. Laboratory and sampling schedule should be prepared.
vi. All instruments should be inspected and tested.

11.1 START UP PROCEDURES

For the Biodiesel plant designed, the following are the start up procedures:

i. The reactor should be heated up and maintained at their operating temperatures and pressures.
ii. The inlet and outlet valves of the reactors should be opened up.
iii. The compressor valve to supply air at a regulated pressure should be opened.
iv. All the inlet and outlet valves to the reactor should be shut as soon as the feed enters the reactor in order to achieve maximum conversion.

v. The outlet value of the reactor should be opened for the evacuation of the reactor contents.

vi. The outlet valve of the reactor should be locked before opening the inlet valve before further entering of the feed into the reactor.

11.2 SHUT DOWN PROCEDURES

The shut down procedures for the Biodiesel plant are as outlined below

i. The supply of the Raw material to the reactor should be cut off.

ii. The air supply into the converter should also be cut off.

iii. All the purge valves should be opened to discharge unconverted reactants

11.2.1 EMERGENCY SHUT DOWN OF PLANT

Emergency shutdown of plant is deemed necessary if there is abnormality, which might result in costly top (unwanted) event. This may be due to breakdown of any major equipment that is not easily replaceable. For example, if the Reactor has major problem or breakdown completely, there is no other option than to shut down the Biodiesel plant. Insufficient utility services may also necessitate emergency shut down of plant.

When there is emergency, the process trip system is designed to affect the emergency shut down of plant. Unit shut down is preferable; it would not affect production and quality because of the cost involved in starting up the whole unit.

A trip system carries out the appropriate activity on command from automatic actuation of the relay or other means. Such systems are closely associated to the shut down of plant when some units are operating on abnormal manner. The shut down can be designed to subdivide the plant into different segments. These segments include: operating utilities, pressure level, or volume of flammable material. Thus, it would be possible to reduce the volume of fluid that would be spilled in the event of pipe rupture.

This system must be reliable and respond only when required, so as to avoid unnecessary shut down of plant and also when necessary they must not fail. The trip setting should be designed to incorporate safety.

11.2.2 START UP AFTER EMERGENCY SHUT DOWN

When the trip system is being designed, each start up must be undertaken with care. It is necessary to consider what happens when the trip system occurs and when the trip system condition is removed. The necessary actions are planned for all those cases, which cannot be foreseen.

In addition, during the start up after emergency shut down,

i. Undesirable or toxic materials under pressure should be removed during the start up.
ii. Non-conforming specification process materials should be recycled.
iii. Air and undesirable materials or chemicals used for cleaning system should be removed.
iv. The controls and set points should be checked and adjusted.
v. It should be ensured that everything is in good order before the start up.

CHAPTER TWELVE

12.0 SITE FOR PLANT LOCATION

Many factors must be considered when selecting a suitable site, and a review of the principal factors will be given in this chapter of this design project for the production of Biodiesel. The location of the Biodiesel plant, just as any other plant, would definitely have a crucial effect on the profitability of the Biodiesel production project and the scope for future expansion. The principal factors to be considered are:

i. Location, with respect to the marketing area.
ii. Raw materials supply and price.
iii. Transport facilities.
iv. Cheap and readily available of labour.
v. Availability of utilities.
vi. Availability of suitable land.
vii. Environmental impact and effluent disposal.
viii. Local community considerations.
ix. Climate.
x. Political and strategic considerations.

12.1 THE MAJOR FACTORS TO BE CONSIDERED FOR SITE AND PLANT LOCATION

The factors considered for site and plant location are as described thus.

12.1.1 PROXIMITY TO THE MARKETING

Economically, for a material produced in bulk quantities such as the Biodiesel; where the cost of the product per tonne is relatively low and the cost of transport is a significant fraction of the sales price, the plant should be located close to the primary market.

12.1.2 AVAILABILITY OF RAW MATERIALS

The availability and price of suitable raw materials will often determine the site location. Plants producing bulk chemical as the Biodiesel plant are best located close to the source of the major raw materials (which is Methanol and Rapeseed oil); where this is also close to the marketing area.

12.1.3 AVAILABILITY OF LABOUR

Labour will be needed for construction of the plant and its operation. Skilled construction workers will usually be brought in from outside the site area, but there should be an adequate pool of unskilled labour available locally; and labour suitable for training to operate the plant. Skilled tradesmen will be needed for plant maintenance. Local trade union customs and restrictive practices will have to be considered when assessing the availability and suitability of the local labour for recruitment and training.

12.1.4 AVAILABILITY OF RELIABLE TRANSPORTATION SYSTEM

The transport of materials and products to and from the plant will be an overriding consideration for site selection.

If practicable, a site should be selected that is close to at least two major forms of transport systems: road, rail, waterway (canal or river), or a sea port. Road transport is being increasingly used, and is suitable for local distribution from a central warehouse. Rail transport will be cheaper for the long-distance transport of bulk chemicals.

12.1.5 UTILITIES (SERVICES)

Chemical processes usually require large volumes of water for process use, and the plant must be located near a source of water of suitable quality. Process water may be drawn from a river, from wells, or purchased from a local authority.

At some sites, the cooling water required can be taken from a river or lake, or from the sea; at other locations cooling towers will be needed. Electrical power will be needed at all sites. Electrochemical processes that require large quantities of power may hereto need to be located close to a cheap source of power. A competitively priced fuel must be available on site for steam and power generation.

The word "utilities" is now generally used for the auxiliary services needed in the operation of any production process. These services will normally be supplied from a central facility; which include:

a. **Electricity:** - power required for electrochemical processes, motors, lightings, and general use.

b. **Steam for process heating:** - The steams required for the process are generated in the Tube boilers using most economic fuel.

c. **Cooling water:** - Natural and forced draft cooling towers are generally used to provide the cooling water required on site.

d. **Water for general use:** - The water required for the general purpose will be taken from local water supplies like rivers, lakes and seas. Because of this reason all the plants located on the banks of river.

e. **Dematerialized water:** - Dematerialized water, from which all the minerals have been removed by ion-exchange is used where pure water is needed for the process use, in boiler feed water.

f. **Refrigeration:** - Refrigeration is needed for the processes, which require temperatures below that are provided by the cooling water.

g. **Inert-gas supplies:**- This is the supply of the inert gas like nitrogen to the plant.

h. **Compressed air:** - In the Terephthalic acid plant compressed air is one of the raw materials. It is also needed for pneumatic controllers etc.

i. **Effluent disposal facilities:** - facilities must be provided for the effective disposal of the effluent without any public nuisance.

12.1.6 ENVIRONMENTAL IMPACT AND WASTE DISPOSAL

All industrial processes produce by-products, and full consideration must be given to the difficulties and coat of their disposal. The disposal of toxic and harmful effluents will be covered by local regulations, and the appropriate authorities must be consulted during the initial site survey to determine the standards that must be met.

12.1.7 LOCAL COMMUNITY CONSIDERATIONS

Full consideration must be given to the safe location of the plant so that it does not impose a significant additional risk to the community. Therefore, the proposed plant must be fit in with and be acceptable to the local community

On a new site, the local community must be able to provide adequate facilities for the plant personnel: schools, banks, housing, and recreational and cultural facilities.

12.1.8 COST AND SUITABLE LAND

The land should be ideally flat, well drained and have suitable load bearing capacity. A full site evaluation should be made to determine the need for pining or other special foundations. It should also be available at a relatively low cost.

12.1.9 CLIMATIC CONDITIONS

Adverse climatic conditions at a site will increase costs. Abnormally low temperatures will require the provision of additional insulation & special heating for equipment & pipe runs. Stronger structures will be needed at locations subject to high winds or earthquakes.

12.1.10 POLITICAL AND STRATEGIC CONSIDERATION

Capital grants, tax concessions and other incentives provided by governments to direct new investment to preferred locations, such as areas of high un-employment should be the overriding considerations in the site selection.

12.2 SITE SELECTION

Careful consideration of the factors for the site selection outlined above reveals that the best site for this project (that is, production of Biodiesel) is Lagos State, Nigeria.

12.3 JUSTIFICATION OF THE SELECTED SITE

Actually, the suburb of Lagos State, Nigeria, has been chosen for this project. The selection was based on some requirements, which the site was able to meet among the factors for the site selection discussed above. The justifications for the selected site are as follows:

12.3.1 AVAILABILITY OF RAW MATERIALS

The major raw material in the production of Biodiesel is the Methanol. Looking at it very well, the major source of this major raw material, Methanol and is the Petrochemical industries. In addition, considering the situations in Landmarks of Lagos State, Nigeria, River State could be an alternative. So, siting the Biodiesel plant in the suburb of Lagos State is sitting the plant close the source of the raw material.

12.3.2 NEARNESS TO MARKETING AREA

Since Biodiesel is used as Biofuel, siting its plant close to the place of primary marketing area, that is, highly industrialized areas (process industries) will be very ideal. River and Lagos State are located close to process industries in the country.

12.3.3 TRANSPORT

Regarding the transport facilities, Lagos is close to seaport and a waterway. Besides, it is close to a major airport (that is, Lagos Airport). So, the good and many means of transportation present in the area will ensure effective transportation of the raw materials, products and even the skilled experts at low cost. Another advantage is that Lagos has good road network.

12.3.4 AVAILABILITY OF LABOUR

For the fact that Lagos is highly populated, youths, both skilled and unskilled, are now trooping into the area to seek their source of living. That is to say, all kinds of labour force are available there.

12.3.5 CLIMATE

The absence of adverse climatic conditions such as too low temperature or too high wind loads or earthquakes has made Lagos or River state a good site for the Biodiesel plant.

12.3.6 POLITICAL AND STRATEGIC CONSIDERATIONS

In an attempt to woo investors to Rivers State, the Rivers State government has given capital grants and other inducements to direct new investment to Rivers State. Thus, availability of such grants is an overriding consideration in selecting River as the alternative favourable site for the Biodiesel plant.

12.3.7 UTILITIES

Since the silver process of Biodiesel production requires large quantities of services such as steam for the Reactor, cooling water for the condensers and other services, it is important that the Biodiesel plant should be sited in a place where there is abundance of water; Lagos is one of such areas. Further, the readily available gas powered electricity generation plant in Rivers State is another reason for the choice of this site for the Biodiesel plant.

12.4 PLANT LAYOUT

The economic construction and operation of a process unit will depend on how well the plant equipment specified on the process flow sheet and laid out. The principal factors to be considered are:

a. Economic consideration: construction and operation cost.

b. The process requirement

c. Convenience of operation

d. Convenience of maintenance

e. Safety

f. Future expansion

g. Modular construction

12.4.1 COSTS

The cost of construction can be minimized by adopting a layout that gives shortest run of connecting pipes between equipment, and adopting the least amount of structural steel work. However, this will not necessarily be the best arrangement for operation and maintenance.

12.4.2 PROCESS REQUIREMENT

All the required equipments have to be placed properly within process. Even the installation of the auxiliaries should be done in such a way that it will occupy the least space.

12.4.3 OPERATION

Equipment that needs to have frequent operation should be located convenient to the control room. Valves, sample points, and instruments should be located at convenient position and height. Sufficient working space and headroom must be provided to allow easy access to equipment.

12.4.4 MAINTENANCE

Vessels that require frequent replacement of catalyst or packing should be located on the outside of buildings. Equipment that requires dismantling for maintenance, such as compressors and large pumps, should be placed under cover.

12.4.5 HAZARDS AND SAFETY

Blast walls may be needed to isolate potentially hazardous equipment, and confine the effects of an explosion. At least two escape routes for operator must be provided from each level in the process building.

12.4.6 PLANT MODIFICATION AND EXPANSIONION

Equipment should be located so that it can be conveniently fit in with any layout modification or expansion of the process. Space should be left on pipe alleys for future needs, service pipes over-sized to allow for future requirements.

12.4.7 MODULE CONSTRUCTION

In recent years, there has been a move to assemble sections of the plant at the manufacturer site. These modules will include the equipment, structural steel, piping and instrumentation. The modules then transported to the plant site, by road or sea.

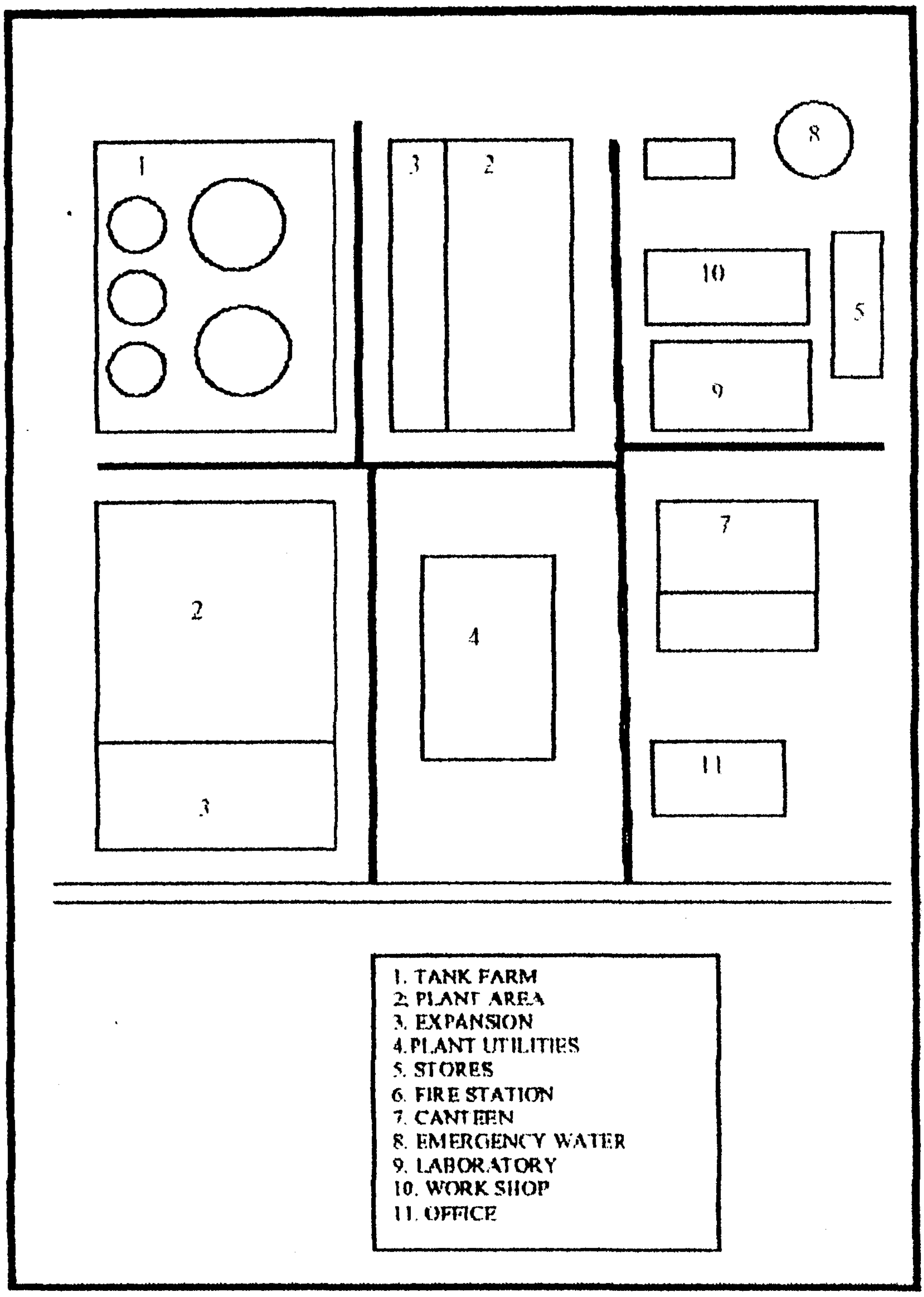


Figure 12.0: Biodiesel site layout

CHAPTER THIRTEEN

13.0 ECONOMIC ANALYSIS

13.1 INTRODUCTION

For any industrial plant to be put into operation, huge sum of money must have been invested in it to purchase and install the necessary machinery and equipment. Land and service facilities must be obtained and the plant must be erected complete with the piping, controls, and service. In addition to all these cost, it is necessary to have money available for the payment of expenses involved in plant operation.

The capital requires to have the necessary manufacturing and plant facilities is called the fixed capital investment. That which is necessary for operation of the plant is termed the working capital. The sum of the fixed investment and the working capital is the total capital equipment (TCI).

13.2 ACCURACY AND PURPOSE OF CAPITAL COST ESTIMATES

The accuracy of an estimate depends on the amount of design detail available: the accuracy of the cost data available; and the time spend on preparing the estimate. In the early stages of a project only an appropriate estimate will be required, and justified, by the amount of information by then developed.

13.3 FIXED AND WORKING CAPITAL

13.3.1 FIXED CAPITAL

Fixed capital is the total cost of the plant ready for start-up. It is the cost paid to the contractors.

It includes the cost of:

1. Design, and other engineering and construction supervision.
2. All items of equipment and their installation.
3. All piping, instrumentation and control systems.
4. Buildings and structures.
5. Auxiliary facilities, such as utilities, land and civil engineering work.

It is a once-only cost that is not recovered at the end of the project life, other than the scrap value.

13.3.2 WORKING CAPITAL

Working capital is the additional investments needed, over and above the fixed capital, to start the plant and operate it to the point when income is earned.

It includes the cost of:

1. Start-up.
2. Initial catalyst charges.
3. Raw materials and intermediates in the process.
4. Finished product inventories.
5. Funds to cover outstanding accounts from customers.

Most of the working capital is recovered at the end of the project. The total investment needed for a project is the sum of the fixed and working capital.

Working capital can vary from as low as 5 per cent of the fixed capital for a simple, single-product, and process with little or no finished product storage; to s high as 30 per cent for a process producing a diverse range of product grades for a sophisticated market such a synthetic fibres.

13.4 OPERATING COSTS

An estimate of the operating costs, the cost of producing the product, is needed to judge the viability of a project, and to make choices between alternative processing possible schemes. These costs can be estimated from the flow-sheet, which gives the raw material and service requirements, and the capital cost estimate.

The cost of producing a chemical product will include the items listed below. They are divided into two groups.

1. Fixed operating costs: costs that do not vary with production rate. These are the bills that have to be paid whatever the quantity produced.

2. Variable operating costs: costs that ate dependent on the amount of product produced.

13.4.1 FIXED OPERATING COSTS

1. Maintenance (labour and materials).
2. Operating labour.
3. Laboratory costs.
4. Supervision.
5. Plant overheads.
6. Capital charges.
7. Rates (and any other local taxed).
8. Insurance.
9. License fees and royally payments.

13.4.2 VARIABLE OPERATING COSTS

1. Raw materials.
2. Miscellaneous operating materials.
3. Utilities (services).
4. Shipping and packaging.

The costs listed above are the direct costs of producing the product at the plant site. In addition to these costs the site will have to carry its share of the company's general operating expenses. These will include:

1. General overheads.
2. Research and development costs.
3. Sales of expense.
4. Reserves.

13.5 COMPUTER-AIDED ALGORITHM FOR COSTING

Most large manufacturing and contracting organisations use computer programs to

Acceptable plant design must present a process that is capable of operating under conditions which will yield profit. Since net profit equals total value minus all expenses, it is essential that the chemical engineer be aware of the many different types of cost involved in the manufacturing processes. Capital must be allocated for the direct, plant expenses, such as those for raw material, labour and equipment. Besides direct expenses many others indirect expenses are incurred, and these must be included if a complete analysis of the total cost is to be obtained. Some examples of these indirect expenses are administrative salary, product distribution cost and cost for interplant communication. A capital investment is required for every industrial process and determination of necessary investment is an important part of a plant design process. The total investment for any process consist of fixed capital investment for practical equipment and facilities in the plant plus working capital, which must be available to pay salaries, keep raw material and products at hand, and handle other special items requiring the direct cost outline.

When the cost for any type of commercial process is to be determined, sufficient accuracy has to be provided for reliable decision. There are many factors affecting investment and production cost. These are;

1. Source of equipment
2. Price fluctuation
3. Company policies
4. Operating and rate of production
5. Governmental policies

Before an industrial plant can be put into operation, a large sum of money must be supplied to purchase and install the necessary machinery and equipment.

Aid in the preparation of cost estimates and in process evaluation. Many have developed their own programs, using cost data available from company records to ensure that the estimates are reliable.

Consequently, in order to the cost analysis of this design project, a computer software known as MathCAD will be used to prepare the cost analysis algorithm.

Below is the MathCAD sheet for the algorithm.

13.5.1 COST ESTIMATION, EQUIPMENT AND ECONOMIC ANALYSIS

Acceptable plant design must present a process that is capable of operating under conditions which will yield profit. Since net profit equals total value minus all expenses, it is essential that the chemical engineer be aware of the many different types of cost involved in the manufacturing processes. Capital must be allocated for the direct, plant expenses, such as those for raw material, labour and equipment. Besides direct expenses many others indirect expenses are incurred, and these must be included if a complete analysis of the total cost is to be obtained. Some examples of these indirect expenses are administrative salary, product distribution cost and cost for interplant communication. A capital investment is required for every industrial process and determination of necessary investment is an important part of a plant design process. The total investment for any process consist of fixed capital investment for practical equipment and facilities in the plant plus working capital, which must be available to pay salaries, keep raw material and products at hand, and handle other special items requiring the direct cost outline.

When the cost for any type of commercial process is to be determined, sufficient accuracy has to be provided for reliable decision. There are many factors affecting investment and production cost. These are;

1. Source of equipment
2. Price fluctuation

3. Company policies

4. Operating and rate of production

5. Governmental policies

Before an industrial plant can be put into operation, a large sum of money must be supplied to purchase and install the necessary machinery and equipment.

13.6 ECONOMIC ANALYSIS CALCULATIONS

13.6.1 CALCULATION OF FIXED CAPITAL INVESTMENT

The cost are based on cost data of 2004 which were available in Pounds

Exchange rate ER	350 Naira= 1 Pound	
Therefore	ER=350 Naira	Naira ≡ 1

13.6.2 Purchased Cost Data:

The purchased cost data for process equipments is given below as:

Bridgwater, IChemE (1988), gives a developed relatively simple correlation for plants that are predominantly liquid and/or solid phase handing processes.

His equation, adjusted to **2004 prices** is:

for plant capacities under 60,000 tonne per year:

$$\mathbf{C = 150{,}000\ N\ (Q/s)^{0.30}}$$

and above 60,000 t/y:

$$\mathbf{C = 150\ N\ (Q/s)^{0.675}}$$

where C = capital cost in pounds sterling

N = Number of functional units

Q = plant capacity, tonne per year

s = reactor conversion

By the Plant for the production of Biodiesel from Rapeseed oil, there are nine functional units (number of significant processing steps), the capacity is 100,000 tonnes/annum and 98 % conversion.

$N := 4$ $\text{Pounds} \equiv 1$

The plant capacity in tonne/yr is given as:

$Q := 100000$

$s := 0.98$

Capital cost in Pounds sterling is given as:

$$C := 150 \cdot N \cdot \left(\frac{Q}{s}\right)^{0.675}$$

$C = 1.442 \times 10^{6}$ Pounds

This gives the capital cost (Purchased cost of equipment) in the year 2004.

By cost Index estimation, this gives the value in year 2004.

By 2008, i.e. current year, the cost will be calculated as follows:

Average increase in cost is about 2.5% per year, so that by 2008:

$C_2 := C \cdot (1.075)^{2}$

$C_2 = 1.667 \times 10^{6} \cdot \text{Pounds}$

Now, making

$FCI := C_2 \cdot ER$

$FCI = 5.834 \times 10^8 \cdot Naira$

13.7 ECONOMIC ESTIMATION OF TOTAL CAPITAL INVESTIMENT

The total capital investment can be given by

$T_{inv} = TFC + WC + TLC$

where, TFC =total fixed cost

WC=working capital

TLC=total land cost

13.7.1 Total fixed cost

The factorial method can be used with the relationship below

Table 6.0: Factors for estimation of project Fixed Capital Cost

Item	Process type		
	Fluids	Fluids–solids	Solids
1. Major equipment, total purchase cost	**PCE**	**PCE**	**PCE**
f_1 Equipment erection	0.4	0.45	0.50
f_2 Piping	0.70	0.45	0.20
f_3 Instrumentation	0.20	0.15	0.10
f_4 Electrical	0.10	0.10	0.10
f_5 Buildings, process	0.15	0.10	0.05
***f_6 Utilities**	0.50	0.45	0.25
***f_7 Storages**	0.15	0.20	0.25
***f_8 Site development**	0.05	0.05	0.05
***f_9 Ancillary buildings**	0.15	0.20	0.30
2. Total physical plant cost (PPC)			
$PPC = PCE(1 + f_1 + \cdots + f_9)$			
$= PCE \times$	3.40	3.15	2.80
f_{10} Design and Engineering	0.30	0.25	0.20
f_{11} Contractor's fee	0.05	0.05	0.05
f_{12} Contingency	0.10	0.10	0.10
Fixed capital $= PPC(1 + f_{10} + f_{11} + f_{12})$			
$= PPC \times$	1.45	1.40	1.35

***Omitted for minor extensions or additions to existing sites.**

Total physical plant cost (Direct cost)

$PPC := 0.45FCI$

$PPC = 2.625\times 10^{8}\cdot Naira$

Fixed Capital cost (Indirect cost)

$TFC := 0.20PPC$

$TFC = 5.251\times 10^{7}\cdot Naira$

Working capital

$WC := 0.02\cdot TFC$

$WC = 1.05\times 10^{6}\cdot Naira$

Total land cost

$TLC := 0.02\cdot TFC$

$TLC = 1.05\times 10^{6}\cdot Naira$

$T_{inv} := TLC + WC + TFC$

$T_{inv} = 5.461\times 10^{7}\cdot Naira$

3.4.3.2 Operating cost

This is divided into Fixed and Variable operating cost

Let the plant life be 15yrs $n := 15yr$

13.7.2 Fixed operating cost

Direct labour cost

$Lb_c := 0.06TFC$

$Lb_c = 3.15\times 10^6 \cdot \text{Naira}$

Plant maintenace and repairs

$M_c := 0.08TFC$

$M_c = 4.2\times 10^6 \cdot \text{Naira}$

Insurance

$Ins_c := 0.01TFC$

$Ins_c = 5.251\times 10^5 \cdot \text{Naira}$

Local Taxes

$Ltx_c := 0.02TFC$

$Ltx_c = 1.05\times 10^6 \cdot \text{Naira}$

Royalties and licences fee

$Roy_c := 0.01\cdot TFC$

$Roy_c = 5.251\times 10^5 \cdot \text{Naira}$

Laboratory cost

$Lab_c := 0.2Lb_c$

$Lab_c = 6.301\times 10^5 \cdot \text{Naira}$

Supervision

$S_c := 0.2Lb_c$

$S_c = 6.301\times 10^5 \cdot \text{Naira}$

Plant overhead cost

$POH_c := 0.5Lb_c$

$POH_c = 1.575\times 10^6 \cdot \text{Naira}$

GENERAL EXPENSES

i administrative

$ADM_c := 0.25Lb_c$

$ADM_c = 7.876\times 10^5 \cdot \text{Naira}$

ii. Research and development

$RAD_c := 0.015TFC$

$RAD_c = 7.876\times 10^5 \cdot \text{Naira}$

Total fixed operating cost

$TFO_c := RAD_c + ADM_c + POH_c + Lab_c + Roy_c + Ltx_c + Ins_c + M_c + Lb_c + S_c$

$TFO_c = 1.386\times 10^7 \cdot \text{Naira}$

Annual fixed operating cost

$$TFO_{annum} := \frac{TFO_c}{n}$$

$$TFO_{annum} = 9.241\times 10^5 \cdot \frac{\text{Naira}}{\text{yr}}$$

13.7.3 Variable operating cost

Miscellaneuos

$Ms_c := 0.05Lb_c$

$Ms_c = 1.575\times 10^5\cdot Naira$ $TFO_{annum} = 0.029\frac{1}{s}$

Utilities cost

$Ut_c := 0.02I.b_c$

$Ut_c = 6.301\times 10^4\cdot Naira$

packaging

$PA_c := 0.001I.b_c\cdot Naira$

$PA_c = 3.15\times 10^3$ Naira

Total variable operating cost

$TVO_c := PA_c + Ms_c + ACRM + Ut_c$

$TVO_c = 2.237\times 10^5$ Naira

Annual variable operating cost

$$TVO_{annum} := \frac{TVO_c}{n}$$

$$TVO_{annum} = 1.491\times 10^4\cdot\frac{Naira}{yr}$$

Total annual operating cost

$AOC_c := TFO_{annum} + TVO_{annum}$

$$AOC_c = 9.39\times 10^5\cdot\frac{Naira}{yr}$$

3.4.3.3 Profit analysis

Annual sales of Product or Revenue (A_{sp})

$annum := 336day$ $USDollar := 15$

Sales of Biodiesel

$Naira := 1$

$\frac{SAP_c + Ms_c + Ut_c}{n} + ACR$

$$Biodiesel_{sales} := \left(50 \frac{tonne}{annum}\right) \cdot \frac{0.90 \cdot ER}{kg}$$

$$Biodiesel_{sales} = 1.575 \times 10^7 \cdot \frac{Naira}{annum}$$

Sales of Glycerol

The Glycerol gotten is also sold for use in Petrochemical industries.

$$Glycerol_{sales} := \left(7.955 \frac{kg}{hr}\right) \cdot \frac{120 \cdot USDollar}{tonne}$$

$$Glycerol_{sales} = 1.155 \times 10^6 \cdot \frac{Naira}{annum}$$

Total Sales

$$Tot_{sales} := Biodiesel_{sales} + Glycerol_{sales}$$

$$Tot_{sales} = 2.096 \times 10^3 \cdot \frac{Naira}{hr}$$

Annual sales of product

$$As_p := Tot_{sales} \cdot \left(8.064 \times 10^3 \frac{hr}{yr}\right)$$

$$As_p = 1.69 \times 10^7 \cdot \frac{Naira}{yr}$$

Profit before tax (PBT)

$$PBT := As_p - AOC_c$$

$$PBT = 1.597 \times 10^7 \cdot \frac{Naira}{yr}$$

$320\text{day} = 7.68 \times 10^{3} \cdot \text{hr}$

Annual depreciation (Depr)

let S = Salvage Value after n years of the plant. Assume plant life of 15 yrs

Then $S := 10 \cdot 10^{7} \text{Naira}$ $n := 15$

$\text{Depr} := \dfrac{T_{inv} - S}{n}$ $T_{inv} = 5.461 \times 10^{7}$

$\text{Depr} = -3.026 \times 10^{6} \cdot \dfrac{\text{Naira}}{\text{yr}}$ $\text{Depr} := \text{Depr} \cdot \dfrac{\text{Naira}}{\text{yr}}$

Tax payable (TP)

Assume tax ratio of 5% and depreciation is tax allowable, hence $\text{Tax\_ratio} := 0.05$

$TP := (PBT - \text{Depr}) \cdot \text{Tax\_ratio}$

$TP = 9.496 \times 10^{5} \cdot \dfrac{\text{Naira}}{\text{yr}}$

Profit after tax (PAT)

$PAT := PBT - TP$

$PAT = 1.502 \times 10^{7} \cdot \dfrac{\text{Naira}}{\text{yr}}$

Net income (NIN)

$NIN := PAT + \text{Depr}$

$NIN = 1.199 \times 10^{7} \cdot \dfrac{\text{Naira}}{\text{yr}}$

Pay back period (PBP)

$PBP := \dfrac{T_{inv}}{NIN}$

$PBT = 1.597 \times 10^7 \cdot \frac{Naira}{yr}$

$NIN := NIN \cdot yr \; Depr := Depr \cdot yr$

$PBP = 4.554 \, yr$

Rate of Return (ROR)

$$ROR := \frac{NIN + Depr}{T_{inv}} \cdot 10($$

$ROR = 16.415 \; \%$

CHAPTER FOURTEEN

14.0 RECOMMENDATIONS

The following sets of recommendations were proposed to the industrialists to be noted during the construction, start-up and operating phases of the work based on this design work that was carried out:

i. Procurement of raw materials and equipments should be based on strict regulation of specification and maximum quality
ii. The recycle design should be considered, since it is useful in reducing the level of plant effluent, and it also reduces costs.
iii. Plant should not be operated above the design specification to avoid abnormal conditions and explosions.
iv. Alternative sources of energy should be available at all times to avoid plant failure and possible sources of failure.
v. The water and air around the plant should be monitored regularly to ensure compliance with the Environmental Protection Agency Standards.

14.1 CONCLUSION

The following conclusions can be drawn from the design of the Biodiesel plant that has been carried out

1. Economic analysis of the project gave the following results:

Return of Return	16.4 %
Payback period	4.5 years
Total capital investment	#54.6 million
Net Profit	#15.02 million

2. The plant is therefore profitable to invest in and shall be beneficial to the country because it shall cater for the international demand of the Biodiesel and its precursor, provide employment, and enhance industrial development.
3. The plant designed can be scaled up to increase production rate.

Finally, Biodiesel is an important new alternative transportation fuel. It can be produced from many vegetable oil or animal fat feedstocks. Conventional processing involves an alkali catalyzed process but this is unsatisfactory for lower cost high free fatty acid feedstocks due to soap formation. Pretreatment processes using strong acid catalysts have been shown to provide good conversion yields and high quality final products. These techniques have even been extended to allow biodiesel production from feedstocks like soap stock that are often considered to be waste. Adherence to a quality standard is essential for proper performance of the fuel in the engine and will be necessary for widespread use of biodiesel.

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APPENDIX

SUMMARY OF MASS BALANCE

n =

	0	1	2	3	4	5
0	$1.298\cdot10^{4}$	$1.298\cdot10^{4}$	0	0	0	$1.298\cdot10^{4}$
1	0	0	$8.466\cdot10^{3}$	0	$8.466\cdot10^{3}$	$8.466\cdot10^{3}$
2	0	0	0	8.808	8.808	8.808
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	...

$\frac{kg}{hr}$

n =

	6	7	8	9	10	11
0	259.66	0	259.66	0	259.66	0
1	$4.318\cdot10^{3}$	$4.296\cdot10^{3}$	21.588	0	21.588	0
2	8.808	0	8.808	0	8.808	0
3	$3.975\cdot10^{3}$	0	$3.975\cdot10^{3}$	$3.935\cdot10^{3}$	39.748	0
4	$1.28\cdot10^{4}$	0	$1.28\cdot10^{4}$	127.963	$1.267\cdot10^{4}$	0
5	0	0	0	0	0	...

$\frac{kg}{hr}$

n =

	11	12	13
0	0	0	259.66
1	0	0	21.588
2	0	0	8.808
3	0	19.874	19.874
4	0	$1.266\cdot10^{4}$	12.668
5	$5.199\cdot10^{3}$	0	...

$\frac{kg}{hr}$

N =

	0
0	$1.298\cdot10^{4}$
1	$1.298\cdot10^{4}$
2	$8.466\cdot10^{3}$
3	8.808
4	$8.475\cdot10^{3}$
5	$2.146\cdot10^{4}$
6	$2.136\cdot10^{4}$
7	$4.296\cdot10^{3}$
8	$1.706\cdot10^{4}$
9	$4.063\cdot10^{3}$
10	$1.3\cdot10^{4}$
11	$5.199\cdot10^{3}$
12	$1.268\cdot10^{4}$
13	$5.522\cdot10^{3}$

$\frac{kg}{hr}$

SUMMARY OF MOLAR OF COMPONENT

z =

	0	1	2	3	4	5
0	44.039	44.039	0	0	0	44.039
1	0	0	264.231	0	264.231	264.231
2	0	0	0	0.22	0.22	0.22
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	...

$\frac{\textbf{kmol}}{\textbf{hr}}$

z =

	6	7	8	9	10	11
0	0.881	0	0.881	0	0.881	0
1	134.758	134.084	0.674	0	0.674	0
2	0.22	0	0.22	0	0.22	0
3	43.158	0	43.158	42.726	0.432	0
4	43.158	0	43.158	0.432	42.726	0
5	0	0	0	0	0	...

$\frac{\textbf{kmol}}{\textbf{hr}}$

z =

	11	12	13
0	0	0	0.881
1	0	0	0.674
2	0	0	0.22
3	0	0.216	0.216
4	0	42.684	0.043
5	288.527	0	...

$\frac{\textbf{kmol}}{\textbf{hr}}$

Z =

	0
0	44.039
1	44.039
2	264.231
3	0.22
4	264.452
5	308.49
6	222.175
7	134.084
8	88.09
9	43.158
10	44.933
11	288.527
12	42.899
13	290.56

$\frac{\textbf{kmol}}{\textbf{hr}}$

SUMMARY OF ENERGY BALANCE

$$H = \begin{array}{|c|c|c|c|c|c|}\hline & 0 & 1 & 2 & 3 & 4 \\ \hline 0 & 1.207\cdot10^{3} & 2.989\cdot10^{5} & 0 & 0 & 0 \\ \hline 1 & 0 & 0 & 1.278\cdot10^{4} & 0 & 4.169\cdot10^{5} \\ \hline 2 & 0 & 0 & 0 & 9.97 & 324.627 \\ \hline 3 & 0 & 0 & 0 & 0 & 0 \\ \hline 4 & 0 & 0 & 0 & 0 & 0 \\ \hline 5 & 0 & 0 & 0 & 0 & \ldots \\ \hline \end{array} \ \frac{\mathrm{kJ}}{\mathrm{hr}}$$

$$H = \begin{array}{|c|c|c|c|c|c|}\hline & 5 & 6 & 7 & 8 & 9 \\ \hline 0 & -3.193\cdot10^{7} & 5.977\cdot10^{3} & 0 & 3.259\cdot10^{3} & 0 \\ \hline 1 & -5.11\cdot10^{7} & 1.55\cdot10^{6} & 8.553\cdot10^{5} & 4.298\cdot10^{3} & 0 \\ \hline 2 & 1.643\cdot10^{3} & 2.338\cdot10^{3} & 0 & 1.305\cdot10^{3} & 0 \\ \hline 3 & 0 & 3.542\cdot10^{5} & 0 & 1.948\cdot10^{5} & 1.928\cdot10^{5} \\ \hline 4 & 0 & 3.642\cdot10^{5} & 0 & 1.99\cdot10^{5} & 1.99\cdot10^{3} \\ \hline 5 & 0 & 0 & 0 & 0 & \ldots \\ \hline \end{array} \ \frac{\mathrm{kJ}}{\mathrm{hr}}$$

$$H = \begin{array}{|c|c|c|c|c|c|}\hline & 9 & 10 & 11 & 12 & 13 \\ \hline 0 & 0 & 1.219\cdot10^{4} & 0 & 0 & 7.932\cdot10^{3} \\ \hline 1 & 0 & 1.534\cdot10^{4} & 0 & 0 & 1.018\cdot10^{4} \\ \hline 2 & 0 & 4.566\cdot10^{3} & 0 & 0 & 3.057\cdot10^{3} \\ \hline 3 & 1.928\cdot10^{5} & 7.118\cdot10^{3} & 0 & 2.338\cdot10^{3} & 2.338\cdot10^{3} \\ \hline 4 & 1.99\cdot10^{3} & 7.333\cdot10^{5} & 0 & 4.775\cdot10^{5} & 477.93 \\ \hline 5 & 0 & 0 & 2.553\cdot10^{4} & 0 & \ldots \\ \hline \end{array} \ \frac{\mathrm{kJ}}{\mathrm{hr}}$$