Project Number CHE-RWT-1208

Evaluation of Algae Biodiesel Production by Transesterification

A Major Qualifying Project Report

Submitted to the Faculty and Staff of

WORCESTER POLYTECHNIC INSTITUTE

For the requirements to achieve the Degree of Bachelor of Science

in Chemical Engineering

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Date: March 2, 2012

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Abstract

With the ever-increasing demand for energy and impending depletion of fossil fuels, it has become necessary to research sustainable sources of energy. Promising alternatives to conventional fossil fuels include algae biofuels, particularly algae biodiesel. In an effort to better understand the processing procedures associated with producing biodiesel, ASPEN Plus software was used to simulate a transesterification reaction and the following separation steps. Specifically, analyses were conducted by varying operating parameters to observe how they affect separation throughout the process.

Acknowledgments

The group would like to thank our professor and advisor, R. W. Thompson, for his support and guidance throughout the project; our weekly meetings were very insightful. Also, we would like to thank Worcester Polytechnic Institute for giving us this learning opportunity and experience.

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Introduction

Over the past several decades demand for energy has grown, and is projected to continue growing, drastically around the world. This demand has been met largely by fossil fuels such as coal, oil, and natural gas. Figure 1 demonstrates the world energy usage and from which it clear that the major portion of the energy market is fed by fossil fuels. Furthermore, Figure 1 projects an increase in energy consumption of approximately 40% by the year 2030. This drastic increase in energy demand is not as severe in the U.S but still presents a major problem.

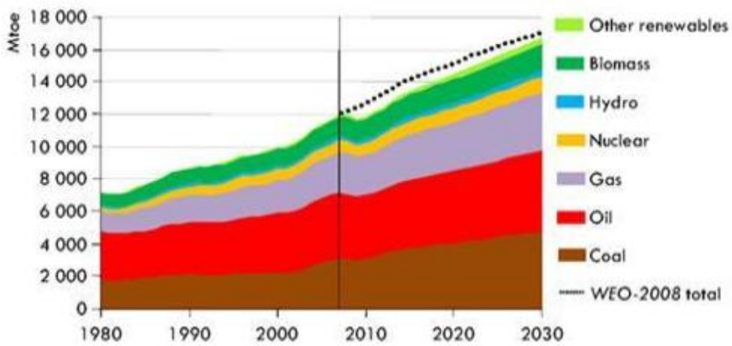

Figure 1: World Energy Demand (The Energy Groove, 2011)

Although U.S. energy demand is not increasing to the degree that world demand is, the U.S. is not immune to energy issues. Figure 2 illustrates the steady increase that the US has experienced since 1950 – an increase which shows no sign of slowing. As is the case with the rest of the world, the US feeds most of its energy needs with fossil fuels. While relatively abundant and inexpensive, these sources are finite and eventually will become depleted. This is disconcerting, considering the obvious reliance on fossil fuels. In addition, the combustion of fossil fuels produces large amounts of harmful air pollutants which accumulate in the atmosphere (Ophardt, 2003). It is for these reasons, among others, that growing concern has spurred research into alternative fuel sources. One of these particularly intriguing alternatives is biodiesel.

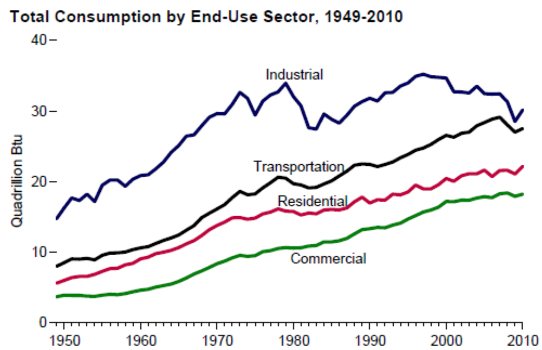

Figure 2: U.S. Energy Demand (U.S. Energy Administration, 2010)

Biodiesel is a domestically produced, clean-burning, and renewable substitute for petroleum diesel. In 2010 the United States imported more than 60% of its petroleum, two-thirds of which was used to fuel vehicles in the form of gasoline and diesel (U.S Department of Energy, 2011). A U.S Department of Energy study showed that the production and consumption of biodiesel, as opposed to petroleum diesel, resulted in a 78.5% reduction in carbon dioxide emissions (National Biodiesel Board, 2009). In addition, biodiesel can be produced from many different sources including plant oil, animal fats, cooking oil, and algae. Production of biodiesel from algae has been recognized as the most efficient way to make biofuel. Deriving biodiesel from algae oil has numerous advantages over any other biodiesel production feedstock since algae have the highest yield per-acre.

Biodiesel produced from algae certainly has its benefits, but there are still some major technical problems that need to be sorted out before it can compete economically within the current energy market. Further research must be conducted on contamination prevention into open air production configurations - the envisioned production system of choice due to high production and relatively low costs. Current research seeking to address this issue includes integrating the open pond system with closed photobioreactors to provide a more controlled growing environment. For large scale algal culture to become viable research into the basic biology of microalgae, species selection, genetic manipulation, and the metabolic switch for carbon sequestration and storage is necessary. It is also necessary to conduct investigations into the chemistry of biofuels synthesis (Greenwell et al., 2010). Biofuel synthesis can take several different pathways, each with its own set of benefits and problems.

The conversion technologies for utilizing algae biomass can be separated into two basic categories: thermochemical and biochemical conversion. The most popular thermochemical conversion processes are pyrolysis and gasification. Pyrolysis is the conversion of the biomass to bio-oil and syngas at medium to high temperatures while gasification involves partial oxidation into a gas mixture that is combustible at high temperatures. Biochemical conversion of algae biomass includes techniques such as anaerobic digestion, which involves the breakdown of organic matter to a gas. However, one of the most common methods to produce biodiesel from algae is a chemical reaction called transesterification.

In order to produce biofuel, one of the possible reactions available is transesterification. The transesterification reaction involves introducing a triacylglyceride (TAG) from the biomass with an alcohol (typically methanol) to produce a different alcohol (in this case glycerol) and a fatty acid methyl ester (FAME) - more commonly known as biodiesel. For the biodiesel production process, this reaction must also be accompanied by multiple pieces of ancillary equipment. Figure 3 displays a typical process path for producing biodiesel using transesterification. It is standard to find a series of separation and purification units after the reactor which removes the biodiesel from the process. Exiting the process are three major streams consisting of mainly methanol, biodiesel, and glycerol. The biodiesel and glycerol are sold as products while, if possible, the methanol is recycled back into the system to improve process efficiency.

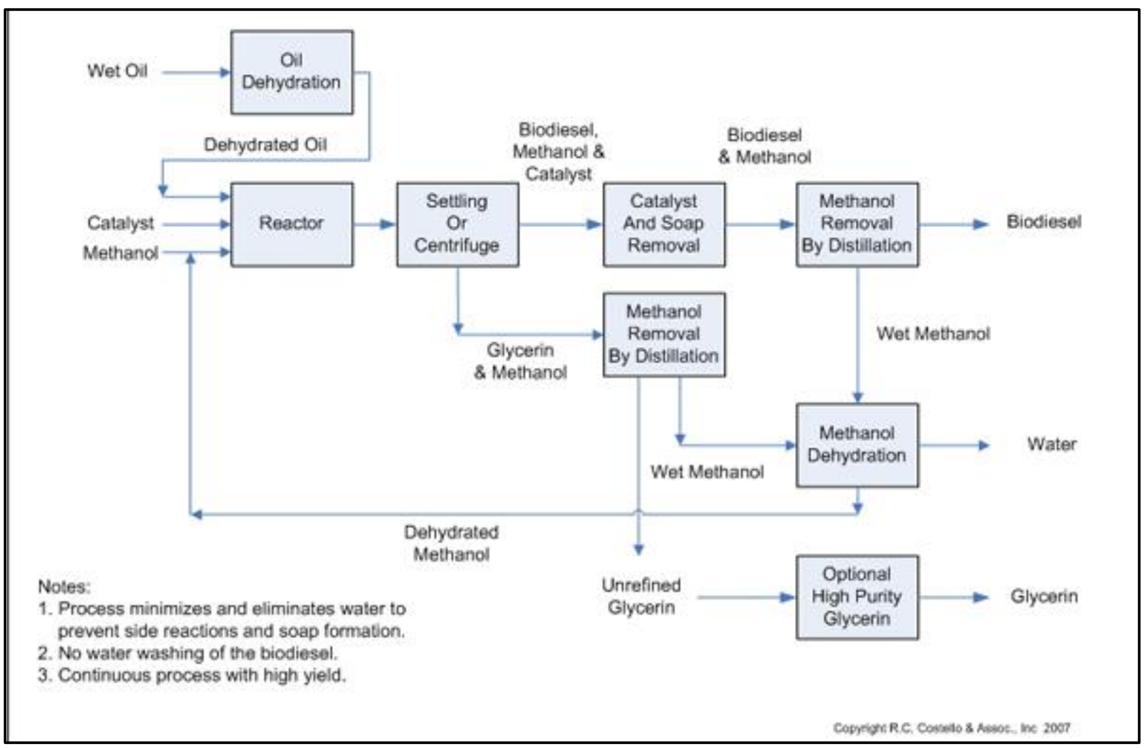

Figure 3: Generic Transesterification Process Diagram (Costello and Assoc., 2007)

The purpose of this study was to investigate biofuel production from microalgae. This entailed a review of the production, harvest, and oil extraction of microalgae. Also, research was completed on the various catalysts that can be used for the transesterification reaction. Additionally, research into the various methods to produce biofuels such as transesterification, supercritical fluid extraction, pyrolysis, anaerobic digestion, and gasification was conducted. With a focus on transesterification, a process for biodiesel production from microalgae was created using ASPEN simulation software. From this, process equipment analyses were conducted, primarily on the evaporators for separation. The analyses included studying the changes in energy requirements caused by changes in pressure, temperature, feed ratios, etc.

Background

In order to fully understand the necessity for biofuels research it was first essential to understand the rise, and inevitable fall, of oil as the dominant fuel source for transportation services. This decline has occurred over much of the past century in many countries – beginning with the U.S.

Oil: The Basics

Petroleum, commonly referred to as crude oil, is a naturally occurring liquid consisting of a complex mixture of hydrocarbons of varying molecular weights. It is found in geologic formations beneath the Earth's surface, formed by geological processes millions of years ago. Petroleum is recovered from these formations through drilling and pumping, in some cases miles beneath the ocean's surface. After extraction, the oil travels to a separation facility which uses stages of separation equipment to release useful products from the oil. The process utilizes operations such as distillation, catalytic cracking, hydro-treatment, chemical treating, and heat treating to bring out the various usable products (further details can be gathered from the example oil processing process flow diagram shown in Appendix A)(OSHA, 2012). Oil processing yields many products including asphalt, chemical reagents, pharmaceuticals, waxes, and lubricants. However, the most important products to modern society are the various fuels that are extracted. Oil products consist of refinery gas, ethane, liquid-propane gas (LPG), aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, fuel oil, naphtha, white spirit, lubricants, bitumen, paraffin waxes, petroleum coke and other oil products (such oil-based products consist of those obtained by distillation and are typically used outside of the refining industry) (International Energy Agency, 2012). These fuels drive the machinery, such as the automobile, that allow modern society to function on a daily basis.

Increasing U.S. Oil Consumption

Demand for oil increased dramatically in the early 20th century with the rise of the automobile industry, spurred by Henry Ford's revolutionary assembly line process and the gasoline-powered internal combustion engine. Henry Ford introduced his assembly line produced Ford Model-T in 1913 (Model-Ts were being made without an assembly line since 1908). In doing so, he greatly reduced manufacturing costs which were then passed on to the consumers. Lower purchasing costs allowed many more people to afford a Model-T and so sales increased dramatically. By 1920 the majority of Americans were driving one of Ford's gasoline powered cars (Bak, 2003). Ford's cheap gasoline powered motor vehicles helped to usher in the age of the automobile and, inherently, oil.

Since that era, the number of motor vehicles has been increasing steadily, which readily correlates with the large portion of oil consumption in the transportation sector. For example, in 2005 there were 247.7 million registered motor vehicles (Bryce, 2008). That number corresponds to a two-fold increase over the number of cars that were on the road in 1970 (that is the same as an annual increase of a little under 3%). This massive number of gasoline-consuming vehicles corresponds with Figure 4, which displays that in 2009, 72% of all petroleum (the largest energy source in the U.S.) was used in the transportation sector. Increases in transportation fuel consumption explain the increasing thirst for oil that the U.S. has experienced over the past century. As the number of vehicles on the road increased, so did the consumption of crude oil.

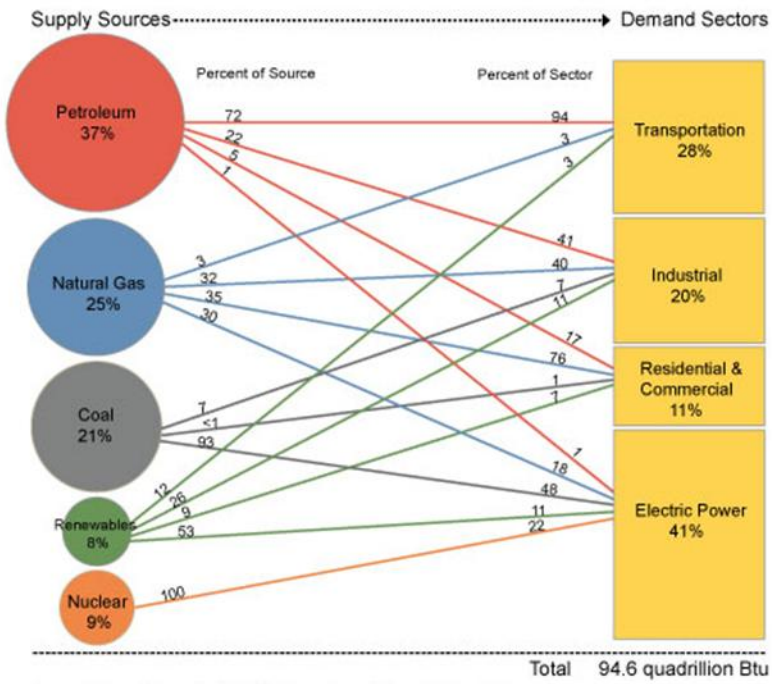

Figure 4: US Energy Supply and Demand (Enerdata, 2011)

U.S. oil consumption has steadily increased over the past century and shows little sign of slowing. As seen in Figure 5, consumption of oil has tripled from just over 5 million barrels per day in 1949 to about 18 million barrels per day in 2009, corresponding to an average increase of about 2% per year. Between 1983 and 2005, gasoline consumption rose by about 32% to around 140 billion gallons. Furthermore, the Energy Information Administration expects that by 2030, gasoline consumption will hit 192.1 billion gallons (Bryce, 2008). This steadily increasing demand for oil products is very disconcerting, given the fact that U.S. oil production peaked in early 1970 and world oil production has been predicted to peak in the near future by many respected modern geologists.

Hubbert's Peak

M. Hubbert King was an oil expert who predicted, with accuracy, the year in which U.S. oil production would peak. Hubbert was a respected geologist, making contributions through analyses of groundwater flow, size scaling, Darcy's law, hydrodynamic oil traps, and great thrust faults (Deffeyes, 2001). He worked in the petroleum industry with Shell for 25 years and upon reaching Shell's retirement age moved on to the United States Geological Survey (USGS). In 1956 he published his hypothesis that U.S. oil production would peak around 1972 (Deffeyes, 2001). Hubbert's statistical prediction was based on the notion that the amount of oil available is directly related to the amount of undiscovered oil. In other words, as more oil is discovered, it becomes more difficult to find any of the remainder. His prediction was proven correct when the nation's oil production peaked in early 1970 as demonstrated by the graph in Figure 5. The peak was completely confirmed when the government-appointed Texas Railroad Commission ended production rationing in the spring of 1971 (Deffeyes, 2001). This action meant that U.S. producers had reached their production capacity maximum. Years later, in 1969, Hubbert went further, predicting the imminent peak of world oil production to be 2000.

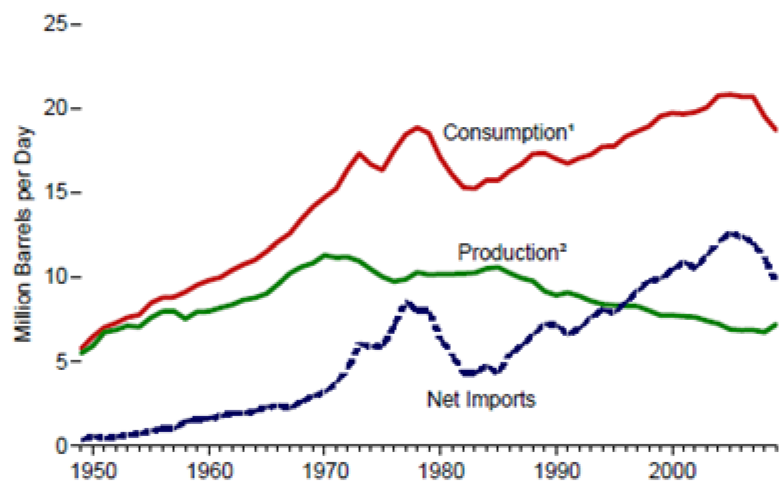

Figure 5: Historical US Oil Consumption, Production, and Imports (1949-2009) (US Energy Administration, 2010)

The United States reaching its peak production is not unique; other countries have or soon will reach their production peaks. The United Kingdom and Colombia reached their peaks in 1999, while Norway and Oman peaked in 2000. Mexico reached its peak in 2004. China and Russia are projected to reach their peaks in 2008 and 2012 respectively (Deffeyes, 2001). The production peaks of these countries suggest that the world oil production will peak relatively soon, simply because world oil production is composed of the sum of the production of all individual countries. Therefore, it is logical that Hubbert's prediction of world production occurring in 2000 was within the realm of possibility.

A geologist by the name of Kenneth Deffeyes used similar yet enhanced mathematical calculations to make his own prediction, and estimated the peak to occur in 2005 (Deffeyes, 2001). Deffeyes worked alongside Hubbert at the Shell Oil research laboratory in Houston. Deffeyes used Hubbert's mathematical methods but took it a step further by using a Gaussian curve to fit the data instead of a logistic curve (for further details about the mathematical methods used, refer to Deffeyes's books *Beyond Oil* and *Hubbert's Peak*). It was argued by Deffeyes that 2005 was the peak year because that was the year when oil production stopped growing, according to oil production data up to 2008. Although the actual year of the peak is disputed, many experts agree that it will occur in the near future.

Many respected petroleum and/or energy experts have conducted their own calculations that concur with Deffeye's prediction. An independent company called Science Applications International Corporation (SAIC) was called upon by the U.S. Government to investigate the consequences of world oil production peaking. The company released its report in 2005 called *Peaking of World Oil Production: Impacts, Mitigation, and Risk Management*. It includes a list of some of these experts, which is shown in Appendix A. The report goes on to state that according to research done, even the most optimistic forecasts suggested that world oil production would peak in less than 25 years (Hirsch et al., 2005). Another report on the topic written by Colin Campbell and Jean Laherre makes similar statements. According to Campbell and Laherre, the world faces an imminent end to cheap oil, likely within the next decade (the report was written in 1998). These two men worked within the oil industry for much of their careers, first as employees at major oil companies and later as independent consultants. In their careers they gained a great deal of experience in oil exploration, studying global reserve figures, and estimating the amount of undiscovered oil. The report goes into detail on the importance of understanding the bias and inaccuracy behind many oil reserve estimate figures proposed by various organizations due to conflicts of interest. Campbell and Laherre conducted a critical analysis of the discovery and production of oil fields around the world from which they concluded that within the next decade of the report release year the supply of conventional oil would be unable to meet global demand (Campbell and Laherre, 1998).

Massachusetts Institute of Technology Professor M. A. Adelman does not share the established view of diminishing economic oil production. He claims in his article *The Real Oil Problem* that the real crisis is that of intentional oil supply decreases due to greedy oil rich nations, specifically those in the Middle East, not in peak oil. He mentions that there is, and will be for the foreseeable future, plenty of oil to be produced and discovered in OPEC nations. He explains they purposely leave that oil in the ground to raise current oil prices upon which they depend for their national economies (Adelman, 2004). It is important to note that this article did not include any analytical results, only the conclusions from them.

After oil production peaked in the U.S., the nation turned to the world market to fill the expanding gap between domestic production and consumption. This fact is represented graphically in Figure 5 by the comparison of the annual production curve to the annual net imports curve. As the production curve steadily declines (on the whole) after 1970, the net imports curve rises rapidly to close the gap between demand and domestic supply. But what will happen when source countries hit their production peaks, as they inevitably will if they have not already? Where will the U.S., and the rest of the world, turn to for its insatiable thirst for oil? These vital questions are major incentives for the increasing research of petroleum alternatives.

Benefits of Biodiesel

Biodiesel is an alternative that deserves special attention because it has several distinct benefits over other fuels, including oil. Biodiesel can be used to immediately replace conventional diesel in the transportation market, whereas many other alternatives require further research or infrastructural changes in order to improve viability. Biodiesel has many environmental benefits over other fuels that help to reduce the human footprint on the natural world. It is highly versatile in that it can be produced from many different sources including animal fats, cooking oil, and plant oils, such as algae (National Biodiesel Board, 2009).

Biodiesel has the potential to immediately replace a portion of the oil consumed by automobiles because of the already in place diesel distribution infrastructure and vehicle fleet. Compression-ignition diesel engines in the transportation sector can operate on biodiesel with little or no costly alterations. The infrastructure for distributing the biodiesel to the consumer is already in place since a regular gas station can be used to dispense the biodiesel. These two benefits will make the transition to biodiesel much simpler than it would be for other alternatives. For example, the infrastructure for large scale distribution of hydrogen to the customer does not exist and so switching to hydrogen fuel cell vehicles on a large scale would be difficult. That increases the number of years it would take to convert from gasoline vehicles to hydrogen fuel cell vehicles. One specific source for biodiesel production that holds much potential is microalgae.

Introduction to Algae

Algae are plant-like organisms that are photosynthetic and aquatic with simple reproductive structures, but do not have roots, stems, leaves, or vascular tissue. Photosynthesis is the key to making solar energy available in useable forms for all organic life in our environment. Photosynthetic organisms utilize solar energy from the sun to combine water with carbon dioxide to create biomass. Algae are distributed worldwide in the sea, freshwater, and wastewater. Most algae are microscopic while some are quite large, exceeding fifty meters in length. The unicellular forms are known as microalgae whereas multicellular forms are known as macroalgae. Macroalgae are large multicellular algae that often grow in ponds. The largest macroalgae, called seaweed, is a kelp plant that can grow to be more than 100 feet long (Wen, 2011). Microalgae range from a few microns to hundreds of microns and exist individually, in chains, or in flocs in marine and/or freshwater systems. Microalgae contribute around 40 to 50 percent of the oxygen in the atmosphere and simultaneously consume carbon dioxide to grow photoautotrophically without additional carbon sources. It has been estimated that around 200,000-800,000 species exist but with only 35,000 species described in literature. The production of biofuel from microalgae has gained considerable attention due to the fact that they can be converted into several different types of renewable biofuels such as green diesel, jet fuel, methane biogas, ethanol, and butanol (Johnson & Wen, 2008).

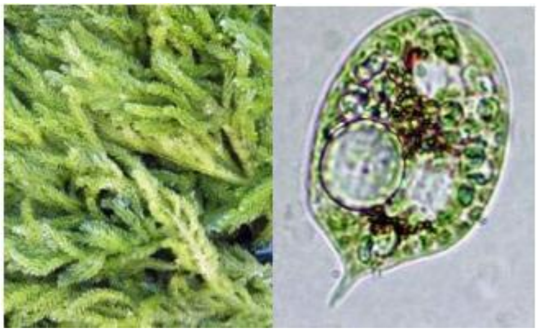

Figure 6: Macroalgae (left) and Microalgae (right) (Johnson and Wen, 2008)

Microalgae consume large amounts of nitrogen, phosphate, and carbon dioxide that are converted into biomass, which makes algae attractive for carbon dioxide mitigation and reduction of pollution and toxic chemicals (Park et al., 2011). Carbon dioxide fixation is regulated by temperature, light intensity, and the concentration of the carbon dioxide. Generally more carbon dioxide can be fixated at moderate temperatures and with increasing light intensity. Carbon dioxide mitigation is considered one of the primary benefits of algal biofuel production since it can be used to combat global warming (Ge et al., 2011).

Some species of microalgae can produce more than 50% of their dry mass as triacylglycerides or long chain hydrocarbons that can be converted to biodiesel and jet fuel. Algae can accumulate 20-75% of lipids as part of their dry mass. Most algae species produce triacylglycerides and alkanes from what is known as the fatty acid biosynthetic pathway (Niehaus et al., 2011). Algal biomass can also be used for the production of animal feed, bioethanol or methane. The free fatty acids that are formed from the hydrolysis of triacylglycerides can be used in the cosmetic and pharmaceutical industries. The glycerol can be used for the synthesis of chemicals or as a carbon source for microorganisms (Dasari et al., 2005).

Chemical Benefits of Algae

Algae have many different chemical benefits that are useful in the energy sector. Algae can also be used to generate energy in the form of heat or electricity. Under specialized growth conditions, some algae can even produce hydrogen gas. An advantage of using algae biomass for biodiesel production is the potential mitigation of carbon dioxide emissions from power plants. Through photosynthetic metabolism, microalgae absorb carbon dioxide, releasing oxygen. If an algae farm is built close to a power plant, carbon dioxide produced by the power plant could be utilized as a source for algal growth (Johnson & Wen, 2008).

One issue with biodiesel is that the production of large volumes of the fuel currently requires the use of large tracts of land. For example, soybeans, which comprise the main source of biodiesel fuel in the United States, produce only about 48 gallons of oil per acre. Using algae could increase the yield to as high as 20,000 gallons by some estimates (Tabak, 2009). There are several advantages of using algae rather than other plants for biodiesel production. The dry weight of some species of algae is as high as 60 percent oil by weight. By contrast, it is sometimes claimed that other plants, often times in the seed, are composed of 50 percent oil by weight. It is important to note that the seeds only represent a small part of the plant and that a great deal of energy is needed to produce the entire plant which, in some cases, is grown solely for the purpose of harvesting the seed. Sixty percent of the dry weight of algae is in the form of molecules that can be converted to biodiesel (Tabak, 2009). Furthermore, most conventional oil producing plant crops can be harvested just once or twice each year, whereas algae can be harvested much more rapidly.

Estimates of the amount of oil available per acre using algae as a feedstock vary widely. These estimates are greater than the amounts of oil produced by more conventional feedstock by roughly two orders of magnitude. It is estimated that algae-based biodiesel production methods can yield roughly 100 times as much oil per acre. Estimates range from 5,000 gallons per acre to 20,000 gallons per acre. With such yields, algae cultivation could produce enough oil to replace substantial amounts of petroleum (Tabak, 2009).

Algae Farming

There are several aspects to algae farming which have undergone extensive research in order to increase economic viability. One particular aspect involves studying how to provide algae with nutrients in order to grow and produce significant amounts of oil. Due to the fact that large-scale algae farming precludes the use of purchased algal fertilizer because of costs, research has been done into using waste products such as sewage or waste from agricultural and industrial processes for algae-growth nutrients. Using a carbon dioxide waste stream from a process is a possible nutrient source for algae farming. However, doing so only delays the release of carbon dioxide into the atmosphere, and once the biofuel is combusted the carbon dioxide is released. By using sewage or waste, no additional carbon dioxide is released into the atmosphere when the biofuel is combusted. Plants take in carbon dioxide, animals eat the plants and give off waste, the waste is used to make fuel, and then the fuel is combusted and releases carbon dioxide. In essence a closed cycle is created where there is no net creation or net loss of carbon dioxide.

One example of using waste for the growth of algae included the use of anaerobic digester effluents of three agriculture wastes: catfish processing waste, soybean field waste, and rice hulls. Once the waste products were digested, they were fed to the *Ettlia oleoabundans* algae in varying concentrations. The experiment demonstrated that results vary greatly depending on the nutrients supplied to the algae – some effluent combinations provided increased growth of algae, but minimal oil production, while others provided increased oil production without a substantial increase in algae growth (Yang et al. 2011). Overall, the ability to grow algae on waste was shown to be feasible, although further study is needed to optimize the algae growth and oil production.

In a similar experiment, *Neochloris oleoabundans* algae was grown using the anaerobic digester effluents of dairy cow manure. Within a week of inoculation, there was a 10-30% yield of fatty acids

(Levine et al., 2010). This suggests that there are many possible types of organic waste which may be used as a nutrient source for growing algae. However, more research is needed and since algae farming requires local sources of waste for nutrients to keep costs down, site-specific research would be necessary.

Algae Farming Designs

Methods for the production of algae involve either open or closed systems. Commonly used open systems include raceways, open ponds, or channels. Raceway ponds are the most commercially used of the open systems, and are typically placed outside to make use of natural illumination (Pokoo-Aikins et al., 2009). They can be either mixed or unmixed and are usually shallow with depths of 0.2-0.3 meters with areal dimensions ranging from 0.5 to 1 hectares (Greenwell et al., 2009). The dimensions of the ponds are set up this way to maximize the total surface area exposed to sunlight. Depending on the needs of the operation, direct carbon dioxide might be added in controlled amounts (del Campo et al., 2007). Raceway ponds do not produce optimal productivities but are favored because they are relatively simple and are low-cost (Sheehan et al., 1998). And yet, one of the major concerns for open systems is the risk of culture contamination and population crashes. Open systems make it difficult to control algae exposure (Pokoo-Aikins et al., 2009). An example of an open system raceway pond can be seen in the Figure 7 below.

Figure 7: Example Open System Raceway Pond (Greenwell et al., 2010)

Closed systems for producing algae include fully contained photobioreactors (PBRs). They are able to be located indoors or outdoors, although if placed outdoors they are able to make use of the free sunlight (Molina Grima et al., 2002). PBRs are typically designed to be transparent columns made of polyethylene or fiberglass with a diameter of approximately 0.4 meters with carbon-dioxide enriched air entering. Relatively small diameters are used to promote even exposure to light (Pokoo-Aikins et al., 2009). Figure 8 below shows an example of a closed system photobioreactor.

Figure 8: Tubular Photobioreactor (Greenwell et al., 2010)

One of the benefits of utilizing PBRs over open systems is the avoidance of potential contamination due to the higher degree of control that can be exerted over the system. Drawbacks that are encountered when using PBRs include higher construction and operating costs. As a result, there are not many large-scale commercial systems that utilize PBRs for producing algae. Because of these difficulties PBRs would not be cost effective for producing large-scale biomass for biofuel production, but instead might be used to produce contaminant-free algae for use in large open raceways (Pokoo-Aikins et al., 2009). Once the algae have been grown, harvesting is carried out to separate the algae oil from the cells.

Algae Harvesting

Harvesting of the algae can be a challenge due to the fact that algae cells have a relatively small diameter ranging from 3-30 micrometers (Molina Grima et al., 2002). Economically, harvesting is a significant step; some estimates determine that biomass recovery takes up approximately 20-30% of the cost of producing algae (Gudin and Therpenier, 1986).

When selecting a harvesting method for algae, the ability to produce large volumes of biomass is necessary to ensure economically sufficient amounts of product and to prevent the algae from spoiling. Techniques such as filtration are possible, but filtration can be quite slow. In addition, filter presses may be unable to recover algae species that are close to the size of bacteria (Mohn, 1980). Membrane microfiltration is something that has also been investigated, but they do not handle large volumes well.

At larger volumes, membrane replacement and pumping costs prevent this method from being economical (MacKay and Salusbury, 1988).

One technique that is commonly used for algae harvesting is centrifugation. Although it is dependent on the species of algae and the type of machine used, recovery can be quite rapid and reliable (Molina Grima et al., 2002). In a study that compared various types of machines for centrifugal recovery such as a self-cleaning disc-stack centrifuge, a nozzle discharge centrifuge, a decanter bowl centrifuge, and a hydrocyclone, all machines proved to be quite effective for biomass recovery except for the hydrocyclone (Mohn, 1980).

Another possible method is gravity sedimentation. While such a method is possible, gravity sedimentation is typically used for low-value products. Biomass recovery using sedimentation tanks are often seen in sewage-based processes (Venkataraman, 1978). Gravity sedimentation may not be a viable method for a biofuel production process, largely due to the fact that it is a very slow process and depending on the environment, might allow the biomass to spoil.

Due to the fact that algal cell size is potentially problematic when harvesting, methods of flocculation can be used to try and aggregate microalgal cells in order to make filtration or centrifugal recovery more effective (Elmaleh et al., 1991). Microalgal cells often carry a negative charge which typically prevents them from aggregating naturally. Flocculants that have been studied include multivalent metal salts, which have proven to be effective although depending on the application may be unacceptable for use (Molina Grima et al., 2002). Instead of using metal salts, cationic polymers have also been used which work by reducing the surface charge on cells (Tenney et al., 1969). Many factors affect the usefulness of flocculants such as the concentration of biomass, the pH of the broth, and the properties of the flocculants themselves. Care must also be taken in mixing – low levels of mixing can bring cells together, but higher levels of mixing may disrupt aggregates (Chisti, 1999). While many techniques have been investigated for laboratory scale production of microalgae, more research needs to be done regarding large volumes required for something such as a biodiesel production process.

Algae Oil Extraction

Once the biomass has been harvested, the following step is to dry and extract the oil. Special care should be taken when selecting the methods used for drying and extraction because algae contains many other products aside from oils that can be considered valuable. These products can be used in a variety of different industries such as pharmaceuticals or even other fuels. Some of the main products of interest include proteins, carbohydrates, pigments, or silica (Greenwell et al., 2009). The ability to extract things other than oils for biodiesel production is important because if these additional products can be generated and sold, the entire biodiesel production process becomes more economically feasible.

Drying the biomass after it has been harvested is a vital step, partially because it is the most energy intensive segment of the feedstock production process. Drying of the biomass can be important because depending on the climate, there is the possibility of having it spoil. There are various ways to dry the harvested algae such as spray drying, drum drying, freeze-drying, and sun drying. Little research has been conducted into evaluating the best possible methods of drying algae on a large scale with biodiesel production in mind. However, spray drying, freeze-drying, and drum drying have been shown to produce adequate dried product of *Dunaliella* algae in attempts to isolate b-carotene (Ben-Amotz and Avron, 1987). When trying to isolate high value products, spray drying is often the method of choice, however, there is the risk of causing deterioration of pigments or other components. In laboratories, freeze-drying is commonly used although it is too expensive to be used on a large scale (Molina Grima et al., 2002).

Extraction of materials from the dried biomass can either be done mechanically, chemically, or through some combination of the two. Many of the cell disruption techniques used for other organisms can also be applied to algae (Belarbi et al., 2000). Doing extraction chemically typically entails using solvents, such as hexane, and can be used with or without cell disruption first. Other possible solvents that might be used include ethanol, chloroform, and diethyl ether. However, one major drawback when using solvents is that certain side products may become denatured by the solvent, leading to difficult or expensive decontamination procedures. Also, when solvents like hexane are used on a large scale, there are associated risks of fire and explosion that would need to be taken into consideration (Greenwell et al., 2009).

Doing extraction mechanically involves separation using specialized machines. Mechanical methods of extraction are chosen in most cases to avoid contamination of products that might occur through chemical extraction (Chisti and Moo-Young, 1986). Ultrasonication, the use of sound to agitate particles, is able to disrupt algal cells. Though, such a method can only handle small amounts of biomass at a time, so it is not suitable for large scale extraction (Dunstan et al., 1992).

Two mechanical methods that have been studied at a large scale are cell homogenization and bead milling. Cell homogenization involves fluid being forced through an orifice. The change in diameter causes a high liquid shear, which can disrupt the algal cell walls. Bead milling uses vessels packed with small glass beads that are agitated at high speeds, which leads to disruption of the cells. Both methods depend on the strength of the algal cell walls, which will have impact when selecting the species of algae for biodiesel production. Additionally, with bead milling, the degree of disruption depends on the residence time of the algae in the system (Greenwell et al., 2009). Once cells have been disrupted, the extracts are filtered and then purified. Methods such as supercritical fluid chromatography, reverse phase chromatography, silica gel adsorption chromatography, and argentated silica gel chromatography have been used to obtain products such as metabolites and fatty acids (Molina Grima et al., 2002).

Algae to Biodiesel Conversion

There are different methodologies that can be utilized to process algae into various types of biofuels. Figure 9 shows a breakdown of these methods which are organized by the manner in which the product is generated, directly from the algae biomass or from the algae oil extracts. The processes that directly utilize the algae biomass for fuel production are anaerobic digestion, supercritical fluids processing, pyrolysis, and gasification. The processing types that require oil extraction are chemical transesterification, enzymatic conversion, and catalytic cracking. The following sections provide a review of each of these processes in turn.

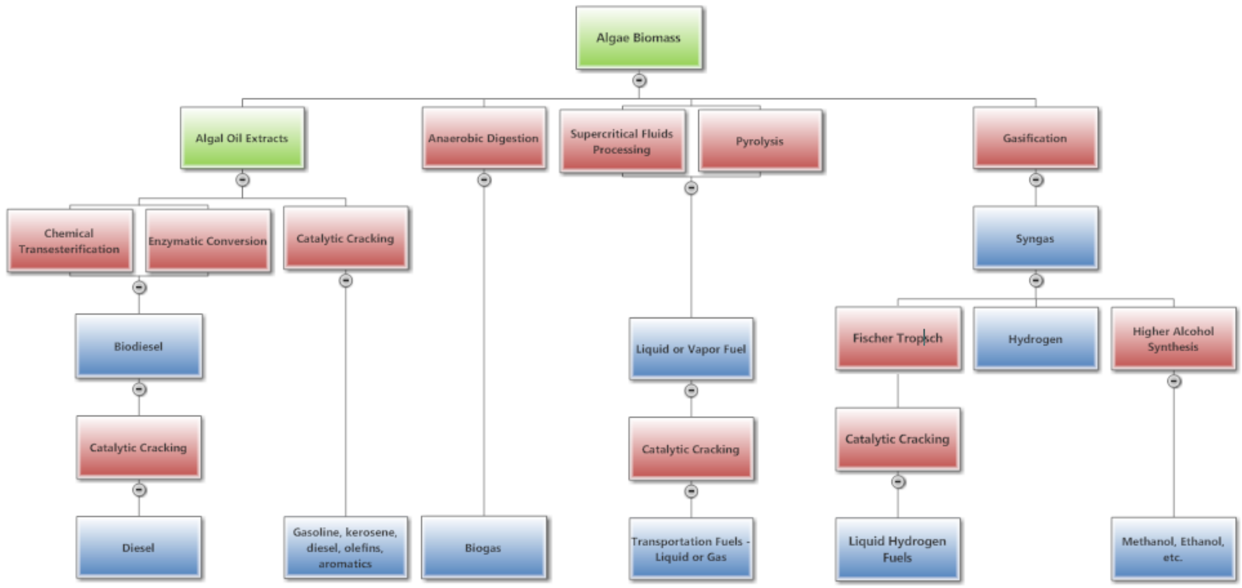

Figure 9: Algal Conversion Processes (U.S. Department of Energy, 2010)

Anaerobic Digestion

Anaerobic digestion is the conversion of organic wastes into a biogas, which primarily consists of carbon dioxide and methane, along with trace amounts of other gases. The production of biogas from macroalgae is an intriguing mode of biofuel production. The use of anaerobic digestion eliminates several key obstacles that results in high costs associated with the production of algae biofuels, including drying, extraction, and fuel conversion (Brennan and Owende, 2009). This conversion process occurs in three sequential stages: hydrolysis, fermentation, and methanogenesis. In hydrolysis, compounds are broken down into soluble sugars. Fermentative bacteria then convert these sugars into alcohols, acetic acid, fatty acids, and a gas containing hydrogen and carbon dioxide, which is metabolized into primarily methane and carbon dioxide by methanogenesis. When anaerobic digestion is applied to microalgae, it becomes possible to supply nutrients with wastewater (Fishman et al., 2010).

Supercritical Fluids Processing

Supercritical fluids processing is a recently developed technique that is capable of simultaneously extracting and converting oils into biofuels. In this process, supercritical methanol or ethanol is employed as both the oil extraction medium and the catalyst used in the transesterification reaction (Fishman et al., 2010). Supercritical fluid extraction of algal oil is far more efficient than traditional separation methods that involve a solvent. This technique has been demonstrated to be extremely powerful in the extraction of other components within algae (Mendes, 2007). Extractions are efficient at modest operating temperatures. At less than 50°C, maximum product stability and quality is ensured.

In addition, supercritical fluids can be used on algae without dewatering, thus increasing the efficiency of the process. The supercritical extraction process can be coupled with a transesterification reaction to enhance biofuel production. Although it has only been demonstrated on vegetable oils, it is possible to use this method for the processing of algae. In the case of combined extraction and transesterification of algae, it remains to be seen whether the processing of whole algae in this fashion is superior in terms of yield, cost, and efficiency to the transesterification of the algal oil extracts (Fishman et al., 2010).

Pyrolysis

Pyrolysis is the chemical decomposition of a condensed substance by heating. Pyrolysis does not involve reactions with oxygen or any reagents. The thermochemical treatment of the algae can result in a wide range of products. This method has one major advantage over other conversion methods in that it is extremely fast, with reaction times of the order of seconds to minutes (Fishman et al., 2010). Although synthetic diesel fuel cannot yet be produced directly by pyrolysis of algae, a degradable liquid called bio-oil can be produced. This liquid can enter directly into the refinery system and produce a suitable feedstock for generating standard diesel fuel. Higher efficiency can be achieved by flash pyrolysis technology where ground feedstock is quickly heated to 350-500°C for less than two seconds. For this process, typical biomass feedstock must be ground into fine particles. This is one area where algae have a major advantage over other biomass sources because it already exists in small units (Fishman et al., 2010).

A significant challenge in using pyrolysis for algae conversion is the moisture content as significant dehydration must be performed upstream for the process to work efficiently. While algal oil may be similar to bio-oil from other biomass sources, it has a different range of compounds and compositions depending on the type of algae and upstream processing conditions (Zhang et al., 1994). There are significant gaps in the information available about the specifications for converting algal oil and the resulting products.

Gasification

Gasification provides a flexible way to produce different liquid fuels, primarily through Fishcer-Tropsch Synthesis (FTS) or mixed alcohol synthesis of syngas. In FTS, syngas components are cleaned and upgraded to liquid fuels through a water-gas shift and carbon monoxide hydrogenation. The components of syngas are carbon monoxide, carbon dioxide, water, and hydrogen. The synthesis of mixed alcohols is relatively well-studied and it is reasonable to expect that once water content is adjusted for the gasification of algae, the production of biofuels would be relatively straightforward (Fishman et al., 2010).

One of the advantages of gasification is that it is possible to create a variety of fuels with known properties. In addition, syngas is a versatile feedstock that can be used to produce a number of products, thus making the production process more flexible. It may also be possible to feed algae to a coal gasification plant to improve efficiency through economy of scale (Fishman et al., 2010). A key challenge for this method is that FTS tends to require a very large scale production in order for the process to be efficient. The most significant problem with FTS is the cost of clean-up and tar removal. Tar deposits lead to more frequent maintenance and make the process less efficient economically (Boerrigter, 2005).

Enzymatic Conversion

Although enzymatic conversion of feedstock has become attractive, it has not been demonstrated on a large-scale due to the price of the enzymatic catalysts and their short operational life caused by excess methanol and glycerol. Enzymatic conversion is a method of non-chemical transesterification that uses enzymes such as lipases as the catalyst. Research and development is needed in the discovery, engineering, and optimization of enzymes that are capable of producing reactions in different environments on different feedstock. One major area that still needs to be investigated is the temperature and solvent tolerance of the enzymes (Lopez-Hernandez et al., 2005). Use of enzymatic catalysts in the transesterification reaction addresses many problems such as the high amount of energy involved in the process, the difficulty in removing the glycerol, and the required removal of alkaline catalyst from the product. The use of these catalysts is also an attractive environmental option as opposed to conventional processes (Fang et al., 2006).

Catalytic Cracking

Another conversion technology for biodiesel production is known as catalytic cracking. When a feedstock is fed in the presence of a heated catalyst under near-normal atmospheric pressure conditions, a decarbonization reaction takes place on the catalyst itself which causes the triglycerides to form fuel oil constituents. It is important to note that the fuel produced by catalytic cracking is not considered biodiesel even though it is considered a biofuel similar to diesel oil. The product is considered to be more similar to gasoline rather than diesel. Byproducts of the decarbonization reaction include carbon monoxide or carbon dioxide. A major advantage of this conversion method is that it does not use chemicals such as methanol or acids. In addition, it is environmentally attractive (Higashi). The primary obstacle to utilizing algae to make renewable fuels is catalyst development. Catalysts that are currently used have been optimized for existing feedstock. It will be desirable to optimize catalysts so that the amount of carbon monoxide and carbon dioxide lost can be minimized.

Chemical Transesterification

Plant oils and animal fats are comprised of a family of chemicals called triglycerides. Triacylglycerides (TAGs) are esters derived from three fatty acids and a glycerol. TAGs are the dominant components in all naturally formed plant oils and animal fats. Glycerol is a polyhydric alcohol that has three hydrophilic alcoholic hydroxyl groups. Fatty acids are carboxylic acids with long hydrocarbon chains (Crocker, 2010). The hydrocarbon chain length may vary from 10-30 carbons. In the structure of TAGs, three fatty acids R'-COOH, R''-COOH and R'''- COOH are linked chemically to the glycerol. Under certain conditions, fatty acids in glycerides may dissociate and become free fatty acids (FFAs) (Orphardt, 2003). The general structure of a TAG is shown below, where R_1, R_2, and R_3 are alkyl chains. TAGs are important because of their necessity during a transesterification reaction.

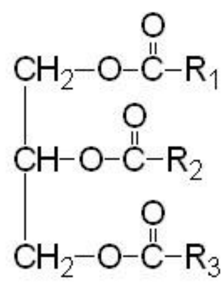

Figure 10: TAG General Structure (King, 2012)

Transesterification is the reaction between an alcohol and an ester which produces a new alcohol and a new ester. In transesterification, a simple alcohol such as methanol is used with a catalyst. Figure 11 shows the transesterification reaction for a generalized triglyceride with methanol to form fatty acid methyl esters (FAMEs), more commonly known as biodiesel. Chemically, transesterification involves taking a triglyceride molecule or a complex fatty acid, neutralizing the free fatty acids, removing the glycerol, and creating an alcohol ester. After the reaction, FAMEs rise to the top of the mixing tank while the glycerol and catalyst settle at the bottom. After some time, the glycerol and catalyst are drawn off the bottom, leaving FAMEs in the tank. In most cases, the FAMEs need to be washed with water to remove any remaining traces of alcohol, catalyst, and glycerol (Pahl, 2005).

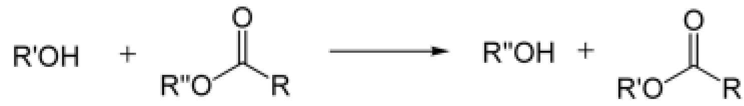

Figure 11: Generalized Transesterification Reaction (King, 2012)

It is important to understand the different parameters involved in the transesterification reaction. The alcohol used in the process is usually ethanol or methanol in industry. Methanol is usually preferred because it is cheaper and has a tendency to produce a more predictable reaction. On the down side, methanol dissolves rubber, and must be handled with extreme caution. Ethanol is generally more expensive and may not always produce a consistent, stable reaction. An advantage of ethanol is that it is less toxic. Another important parameter in the transesterification process is the catalyst that is used to initiate the reaction (Pahl, 2005).

Transesterification Catalyst Investigation

To fully understand the transesterification process it is important to develop a strong background on the catalysts that are available. Catalysts require purification and removal from the product stream, which increases the overall cost of the process. A solution to this problem would be the development of heterogeneous or homogeneous catalysts that are inexpensive and extremely efficient. The two main types of catalysts that can be used during the process are acidic or basic which can be either homogenous or heterogenous.

Base-catalyzed Transesterification

There are numerous basic catalysts that have been used and proven effective in chemical transesterification processes. Potassium hydroxide (KOH) in the form of boiler ashes has been used in the ethanolysis and methanolysis of palm and coconut oils with yields as high as 90% (Graille, 1986; Encinar, 2002; Ejikeme, 2007; Ejikeme et al., 2008). Methanolysis has reportedly yielded FAMEs in the range of 96-98% when palm oil has been processed for 2 hours using catalyst sources of coconut-shell ash among others from the combustion of plant wastes. Furthermore, it has been reported that calcium oxide attached to magnesium oxide is the best catalyst system compared to potassium carbonate, sodium carbonate, iron III oxide, sodium methoxide, sodium aluminate, zinc, copper, tin, lead, and zinc oxide in methanol transesterification of low-erucic rapeseed oil (Peterson and Scarrah, 1984).

The general mechanism for base-catalyzed transesterification of vegetable oils involves four major steps, as displayed in Figure 12. The first step is the reaction of the base with alcohol, producing an alkoxide and a protonated catalyst. The second is the nucleophilic attack from the alkoxide on the carbonyl group of the triacylglyceride, generating a tetrahedral intermediate (Taft et al., 1947; Guthrie, 1991; Meher et al., 2006). In the third step the alkyl ester and corresponding anion of the diglyceride are formed. The fourth and final step occurs when the catalyst is deprotonated thereby regenerating the catalyst.

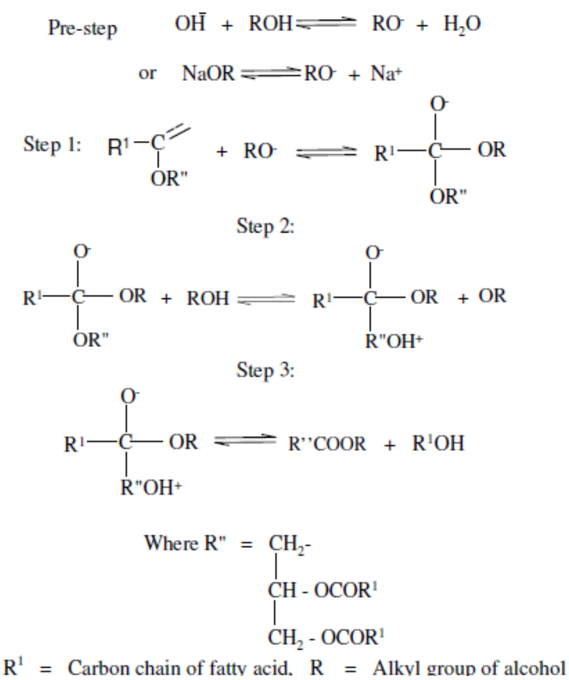

Figure 12: Basic Catalyst Transesterification Mechanism (Ejikeme et al., 2009)

According to one study, base-catalyzed transesterification of vegetable oils are reported to proceed faster than acid-catalyzed reactions (Freedman et al., 1986). Faster reaction speed coupled with less corrosive characteristics has led many industrial processes to favor base catalysts, especially metal alkoxides and hydroxides as well as sodium and potassium carbonates (Graille et al., 1985). Alkaline metal alkoxides (CH_3ONa for methanolysis) are the most active catalysts, in some cases achieving FAME yields greater than 98% in a relatively short reaction time of 30 minutes. Unfortunately, the requirement of the absence of water makes them unsuitable for many industrial processes in which water cannot be entirely avoided (Freedman et al., 1984).

More often than not, alkaline metal hydroxides such as KOH and NaOH are cheaper than metal alkoxides but are less chemically active. This activity drawback can be easily remedied by increasing the catalyst concentration in the reaction chamber by 1 or 2 mole percent. However, these catalysts always produce some amount of water by the reaction of hydroxide and alcohol. Water in the system gives rise to hydrolysis of produced ester which yields an amount, even if small, of soap formation. In 2003, metal complexes of the type M(3-hydroxy-2-methyl-4-pyrone)$_2$(H_2O_2), where M is either Tin (Sn), Zinc (Sn), Lead (Pb), or Mercury (Hg) were used in turn for the soybean oil methanolysis under homogenous conditions (Abreu et al., 2003). The results demonstrated that the Sn complex at a molar ratio of 400:100:1 methanol:oil:catalyst yielded 90% FAME conversion in 3 hours. Under the same conditions, the Zn complex only produced 40% conversion. This undesirable saponification reaction decreases FAME yields and greatly increases the difficulty of glycerol recovery due to the formation of emulsions and increases in viscosity, resulting in higher separation costs. The mechanism for this inhibiting saponification process is displayed in Figure 13.

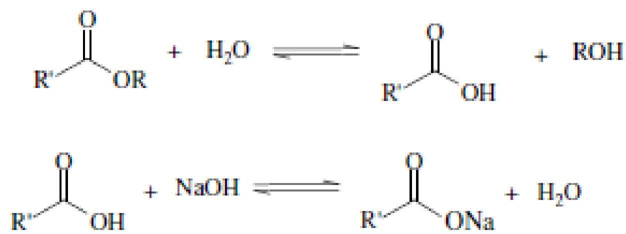

Figure 13: Ester Hydrolysis and Soap Formation from Water (Ejikeme et al., 2009)

Used in a concentration of 2 to 3 mole percent, potassium carbonate induces high yields of fatty acid alkyl esters and inhibits soap formations. This occurs because bicarbonate forms during reaction instead of water, reducing an ingredient required for soap formation. Furthermore, there have been a variety of heterogeneous basic catalysts used in industry that have yielded promising results (Kim et al., 2004; Gryglyewicz, 1999). Solid bimetallic Sn-Ni (Uresta et al., 2000), exchange resins and zeolites (Leclereq et al., 2001; Reis et al., 2003), organometallic compounds (Georghiu, 1996), and mixed oxides have all been tested, developed, and used in transesterification reactions. Additionally, P($RNCH_2CH_2$)3N (Ilankumaran and Verkade, 1999), multifunctionalized and organosulphonix-acid functionalized mesoporous silicas (Mbaraka et al., 2003) are all available for industrial applications and require high pressure and temperature. The mechanism for the bicarbonate formation process is displayed in Figure 14 below.

$$K_2CO_3 + ROH \rightleftharpoons ROK + KHCO_3$$

Figure 14: Bicarbonate Formation Reaction (Ejikeme et al., 2009)

In summary there are key characteristics that basic catalysts have that have caused its widespread use in industry. Low operating temperatures can be employed during reaction, typically around 60°C. High conversion rates can be achieved, on the scale of 90-98% conversion to FAMEs. Minimal side reactions take place in the reactor. High rates of conversion are seen, consequently decreasing reaction time necessary for the same conversion rates as compared to systems utilizing other catalysts. Furthermore, FAMEs are generated with no intermediate steps simplifying the process and keeping efficiency high.

Although it is clear that basic catalysts have many advantages, there are also several disadvantages that should be discussed. Homogenous alkali catalyst reactions require relatively high energy demands. Post-reaction treatment involves catalyst removal from the biodiesel which increases separation and equipment costs. Interferences from the sopanification due to the presence of free fatty acids and water disrupts the tranesterification reaction. Glycerol recovery after reaction can be difficult, requiring several operations. Finally, post-reaction treatment of the alkaline wastewater is often necessary to reduce environmental effects of disposal.

Acid-catalyzed Transesterification

One possible alternative to base-catalyzed transesterification is acid-catalyzed transesterification. Such catalysts work by protonating the carbonyl group of the ester, producing a carbocation. The carbocation engages in a nucleophilic attack of the alcohol to produce a tetrahedral intermediate. It is from this tetrahedral intermediate that the FAMEs are formed. Additionally, this is how the catalyst becomes reprotonated and regenerated (Ejikeme et al., 2009). The general reactions for the acid-catalyzed transesterification process can be seen in Figure 15.

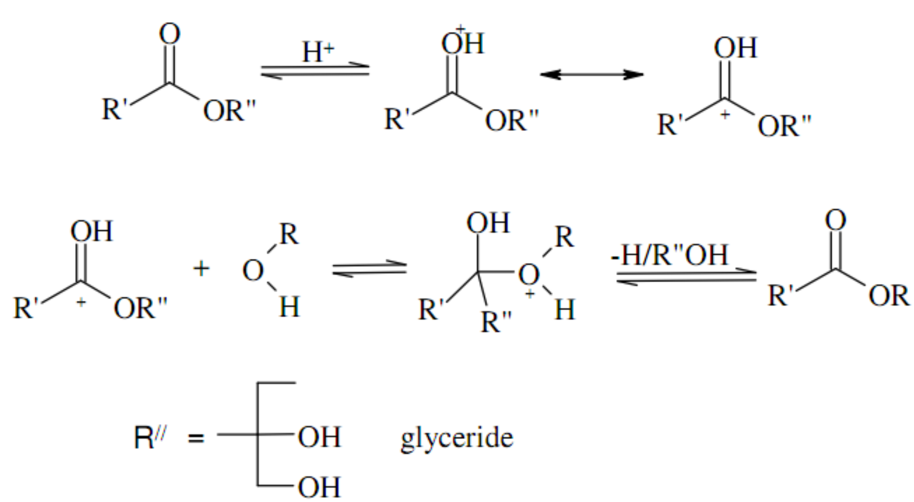

Figure 15: Mechanism of Acid-Catalyzed Process (Ejikeme et al., 2009)

Typical catalysts for the acid-catalyzed process are Bronsted acids such as hydrochloric acid, boron trifluoride, phosphoric acid, sulfuric acid, and sulfonic acids. For homogenous acid-catalyzed processes, sulfuric acid and hydrochloric acid are typically used (Xie and Yang, 2011). One study showed that using methanol at an alcohol:oil molar ratio of 30:1 with 1 mol% of sulfuric acid, produced 99% conversion of vegetable oil – but it required 50 hours (Freedman et al., 1986). In fact, one of the main problems to using homogenous acid catalysts is the fact that the time needed to reach completion can be quite long. This is due to the fact that the protonation of the carbonyl carbon can be difficult (Boey et al., 2011). One way to improve these poor reaction rates is to use additional catalyst. One study demonstrated that by increasing sulfuric acid concentration from 1 to 5 wt. %, the conversion rose from 72.7 to 95.0% for the same reaction duration (Canakci and Gerpen, 1999). However, even this solution is imperfect; using higher concentrations of catalyst requires that more base is needed to neutralize the catalyst after the transesterification reaction. Other problems with homogenous acid-catalyzed processes include requiring a higher reaction temperature and larger methanol to oil ratios. Additionally, there are also problems regarding the catalysts' corrosive nature and difficulty in recycling (Guan et al., 2008).

Due to the drawbacks of using homogenous acid-catalyzed processes, it is often desirable to substitute them with heterogeneous acid-catalyzed processes. Solid acid catalysts possess the advantage of being easier to separate and recycle. Additionally, they are able to catalyze both transesterification of TAGs and esterification of free fatty acids (Zieba et al., 2010). In laboratory experiments, solid acid catalysts such as sulfated zirconia, tungstated zirconia, and sulfonated polystyrene have proved to be efficient at biodiesel production (Xie and Yang, 2011). A new class of sulfonated carbon catalysts, prepared by the incomplete carbonization of simple carbohydrates such as starch, cellulose, glucose, etc., have been proposed as well (Zieba et al., 2010). One problem that solid acid catalysts sometimes face is deactivation which can be caused by partial blockage of the acid centers due to polar reagents such as glycerol (Melero et al., 2009). However, studies have suggested that incorporating hydrophobic organic groups around active centers can help stop this (Xu et al., 2009).

As opposed to basic catalysts, acidic catalysts in the biodiesel production process face several disadvantages. As stated earlier acid catalysts can be toxic, requiring significant waste treatment. Also, they can be corrosive, making their use in industry less attractive. From an energy standpoint, they also face several disadvantages compared to base catalysts – typically, the time needed for complete conversion can be much longer and require higher temperatures and higher amounts of reagents. Another potential difficulty involving acid catalysts is the presence of water – having more than 0.5% water in the oil decreases the conversion to under 90% (Canakci and Gerpen, 2001). However, one key advantage that acid catalysts do have is the lack of a negative effect when dealing with free fatty acids. As stated in an earlier section, a large concentration of free fatty acids can interfere with the reaction and lower the yield of FAMEs. Acid catalysts are not as negatively affected by the presence of free fatty acids. Therefore, using acid catalysts is advantageous when trying to produce biodiesel from low-cost feedstocks which typically have a larger concentration of free fatty acids such as frying oil or waste animal fat (Ejikeme et al., 2010). Since this report deals with algae, a higher cost feedstock, acid catalysts might not be as beneficial as base catalysts.

Process Simulation with ASPEN Plus

ASPEN is widely used chemical engineering simulation software that was first developed by MIT Chemical Engineering Professor Larry Evans from 1976 to 1981 during the ASPEN Project. The software represents the introduction of new computer technology to the chemical engineering industry. Upon finishing initial developments, Evans founded ASPEN Technology in 1981 in which he served as Chairman until his retirement in 2005. Under his management leadership ASPEN Technology grew from the initial start-up venture to become the leading provider of chemical engineering simulation software for chemical process industries worldwide (Evans). The company currently provides software that is used for design, operation, and optimization of process equipment and facilities worldwide. ASPEN Plus is the direct result of the beginnings of ASPEN Technology and its groundbreaking software which has many powerful capabilities.

ASPEN Plus is able to simulate various pieces of process equipment based on a database of chemical properties along with user input and design specifications. The equipment that the software can simulate includes separators, mixers, heat exchangers, reactors, pressure changers, as well as some miscellaneous equipment. Typical inputs necessary for successful simulations of these pieces of process equipment are the properties of the incoming stream such as temperature, pressure, components, flow rates, and compositions as well as exiting stream or equipment design targets. ASPEN Plus uses the input information along with the selected property method to calculate any system or stream unknowns. Common unknowns that can be calculated include heat duty, height, length, diameter, number of stages, reflux ratio, and exiting stream conditions such as composition, temperature, and pressure. Calculating unknowns such as these allow for fast and effective equipment design. For example, by calculating the required heat exchanger area and/or heat duty for a range of input stream and operating specifications, the economically optimal design for that heat exchanger can be determined. In using ASPEN Plus for designing chemical equipment it is very important to keep in mind the software's limitations.

Although ASPEN Plus is powerful process simulation software, it is also limited in several ways. ASPEN conducts all of its calculations based on the user's selected thermodynamic property method. There is a very long list of these methods several of which are Van Laar, ideal, UNIQUAC, and UNIFAC, just to name a few. These methods use varying equations to conduct the physical property calculations of the components of the streams flowing throughout the simulation. In many cases, if the wrong method is chosen, the results will not accurately reflect reality and will not allow for accurate process design, essentially rendering the simulation useless. This makes it critical for the user to select the appropriate property method for the situation. Another case in which ASPEN Plus is found lacking is in situations with non-ideal conditions such as formaldehyde-methanol-water distillation. Formaldehyde is attracted to water in the distillation column and it passes into the bottoms stream with the water even though it is the most volatile component and so should, theoretically, pass through the column into the distillate. As ASPEN Plus attempts to conduct its calculations based on the volatilities of the components, it calculates the exiting streams of the column entirely incorrectly in this situation. This non-ideality needs to be compensated for when selecting the property method and inputs of the process. In the end, the software is only as accurate and useful as the user makes it.

Methodology

There were several reasons why transesterification was the process studied in detail and not any other processes. At the beginning of the project the initial intention was to develop a strong comparison between available biodiesel production processes using algae oil. As a result two processes were considered to be of most interest for studying; transesterification and pyrolysis (supercritical fluids processes were not considered because they require extremely high energy requirements, making it an unlikely commercial candidate for most applications). At this point the group was of a mind to study and compare production via transesterification and pyrolysis. However, the pyrolysis investigation was abandoned due to the lack of time for developing a proper simulation for the process. Attempts were made but it was determined that ASPEN would not easily handle the user-inputs for many of the chemical compounds resulting from the heat treating of algae biomass. Furthermore, the comparison between transesterification and pyrolysis biofuel production with algae turned out to be too qualitatively similar to a previous WPI MQP project in which these two processes were compared in the production of biodiesel from jatropha plant oil. Therefore, in order to differentiate the report as much as possible, the group decided to delve deeply into the details associated with transesterification production, specifically the separation procedures. To that end, a simulation was produced to generate biodiesel from transesterification with the various separation procedures studied in detail.

Simulation Basis

The intention of this simulation was to investigate the chemical production of biodiesel from algal oil, so it was desired that a TAG be selected corresponding to productive strains of algae. However, ASPEN Plus only contains one TAG, triolein, which is typically found in vegetable oil. Although triolein may not be found in large amounts in the feedstock of many algal oils, it still produces the same desired products in a transesterification reaction: FAMEs and glycerol. The FAME produced from a reaction using triolein as the TAG is methyl oleate. For simulation simplicity, free fatty acid amounts were considered negligible in this simulation. The final process flow diagram for the transesterification simulation used throughout the analyses is displayed below in Figure 16.

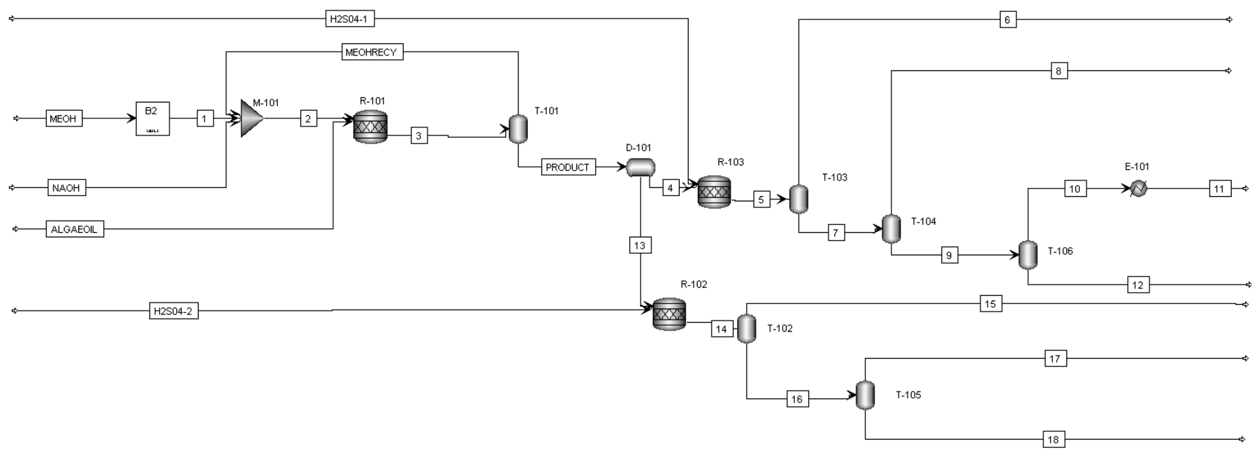

Figure 16: Transesterification Simulation Process Flow Diagram

Sodium hydroxide was chosen to represent the catalyst due to its common use in industry for this process and based on the benefits of basic catalysts mentioned earlier. Although it did not incur any changes in the reactions (reaction rates were not considered during this simulation) it was still of interest to include for its involvement in the neutralization and separation steps.

Another important consideration of the feed streams entering the system was the amount of methanol for the transesterification reaction. This ratio was varied during portions of the simulation to investigate its effects on the process. This was done by controlling the ratio of methanol to triolein using a MULTI block in ASPEN, which multiplies the feed amount by a chosen factor. The methanol to triolein ratio was varied from 6:1 to 50:1 to study its effects on the separation processes.

Before conducting the simulation it was determined that using an evaporator would be preferred because of the small energy usage compared with a more energy-intensive distillation column. This was possible because of methanol's low boiling point compared to the other stream components. This strategy was used successfully throughout the simulation studies to minimize energy costs of separation. Tables 1 and 2 provide the feed and equipment information which was used during simulation procedures.

Table 1: Simulation Feed Conditions

Feed Streams	Pressure (atm)	Temperature (°C)	Mole Flow (kmol/day)
Triolein	1	25	4.95
NaOH	1	25	0.0495
MeOH	1	25	4.95
BD Path H2SO4	1	25	0.0495
Glycerol Path H2SO4	1	25	0.0495

Table 2: Simulation Equipment Conditions

Unit Name	Unit Description	MeOH:Triolein	Pressure (atm)	Temperature (°C)	Heat Duty (kw)
M-101	Mixer	NA	1	25	NA
D-101	Phase Separator	NA	1	25	NA
R-101	Transesterification Reactor	NA	1	65	NA
R-102	Glycerol Path Neut. Reactor	NA	1	25	NA
R-103	BD Path Neut. Reactor	NA	1	25	NA
T-101	Methanol Recovery Evaporator	6:1 to 50:1	0.5 to 40	NA	0 to 2000
T-102	Glycerol Path BD Recovery Evaporator 1	6:1	0.5 to 1	NA	0 to 25
T-103	BD Path Methanol Evaporator	6:1 to 50:1	0.5 to 50	NA	0 to 180
T-104	BD Path Water Removal Evaporator	6:1 to 50:1	0.5 to 10	NA	0 to 60
T-105	Glycerol Path BD Recovery Evaporator	6:1	0.5 to 1	NA	0 to 25
T-106	BD Path Triolein Removal Evaporator	6:1	1	NA	1
E-101	Biodiesel Condenser	6:1	1	350	0.976

Process Description and Simulation Procedures

The first operation in the simulation was mixing the methanol recycle stream with the incoming methanol and sodium hydroxide catalyst streams. The exiting mixed stream entered the reactor along with a feed stream of triolein. In the reactor, R-101, transesterification was set to take place at 65° C and 1 atm. As the intention was not to study reaction rates, the reactor block was given a constant 97 percent conversion of the limiting reactant triolein. These conditions were left constant throughout all simulation studies. The stream exiting the reactor then entered the first in a series of separation blocks to purify biodiesel.

The first separation block in the simulation, T-101, was the methanol recovery evaporator designated by a Flash2 block. The purpose of this block was not only to separate a large portion of the excess methanol which would leave as vapor, but also to recycle it back through the system. High methanol recycle is desirable in a transesterification reaction process because it reduces feed costs. Evaporation was chosen in the procedure instead of a distillation column, contrary to similar simulations (Dhar and Kirtania, 2009). This was because only a simple separation was needed due to methanol's low boiling point compared to the other components. In order to study the energy costs associated with methanol recovery and recycle, the heat duty was varied at different methanol to triolein ratios. After gathering results, the percent recovery was graphed according to heat duty for all of the ratios sampled. All of this was completed at a pressure of one atmosphere. After the ratio study was completed, a pressure analysis was conducted to determine affects from pressure changes. The methanol to oil ratio was kept constant at 6:1 and then constant 50:1 as pressure was varied. This produced a graph of the percent recovery methanol against heat duty for several different pressures.

The phase separator block after the transesterification reaction was meant to separate glycerol from the biodiesel via differences in density. The block operated at standard operating pressure and temperature. The components were left to settle and physically separated based on density differences. Methanol left with both streams so further separation blocks to purify the remaining streams were necessary. After exiting the phase separator block the top stream, containing methanol, triolein, biodiesel, and sodium hydroxide, traveled to a neutralization reactor at the beginning of the biodiesel-rich chemical pathway.

Biodiesel-Rich Path

The biodiesel neutralization reactor, R-102, was in place to neutralize any sodium hydroxide in the stream. To do this an equal amount of sulfuric acid as sodium hydroxide was fed into a reactor. The resulting reaction produced water and sodium sulfate. The reaction products, along with the neutral components, traveled to a methanol separation evaporator.

The second methanol separation evaporator of this pathway, T-103, removed any remaining excess methanol from the biodiesel stream, with methanol leaving as vapor and the remaining components as liquid. The analyses of this evaporator were carried out at varied operating conditions to study condition effects. This simulation analysis was carried out in exactly the same manner as the first distillation column, studying the effects of pressure and the methanol to oil ratio on the separation, with one exception. It was determined that high heat duties disrupt separation by forcing the biodiesel to leave as vapor with the methanol instead of separating the methanol from the biodiesel. To determine the heat duty maximum, a further study was carried out in which the heat duty was varied along with the methanol to oil ratio. A graph of the heat duty against the mass flow rates of biodiesel and methanol leaving through the distillate was produced. This showed the exact heat duty at which biodiesel would begin leaving as vapor instead of liquid and, therefore, which heat duty value not to exceed to ensure that all biodiesel exiting the system was liquid.

The water removal evaporator, T-104, in the biodiesel-rich path was studied in a manner similar to the previously mentioned evaporators. At a constant methanol to oil ratio (6:1), heat duty was varied over a large range for several pressures and graphed accordingly to determine the effects of pressure changes on the separation. However, the methanol to oil ratio was not studied since the methanol had already been removed by the first two methanol evaporators. Therefore, the methanol to oil ratio would not have affected the separation procedure.

The final evaporator in the biodiesel-rich path, T-106, was not analyzed for operating condition dependence because the required heat duty was so small that any gains would be negligible. The main interest was that it produced an acceptable biodiesel stream according to ASTM biodiesel standards. To that end, the stream's components' amounts produced at a heat duty of 1 kW and a pressure of 1 atm were compared to current ASTM guidelines. Of particular concern in this simulation was the amount of water in the stream; no other components threatened to deviate from accepted standards. To analyze the water level more thoroughly the heat duty of T-104 (the water removal evaporator) was varied to determine its effects on water levels in the exiting stream. Because it exited the evaporator as vapor it was necessary to condense the biodiesel back to liquid, for transportation and storage purposes, with heat exchanger, E-101.

Glycerol Path

One important component of the biodiesel production process is the glycerol separator – an evaporator used to purify the glycerol-rich stream from the phase separator block. The ability to separate glycerol from other components is useful since the glycerol product can be sold for use in other industries, such as the pharmaceutical or chemical industries, thus increasing the economic viability of the biodiesel production process.

The effluent from the reactor which neutralizes the sodium hydroxide catalyst with sulfuric acid became the inlet for the first glycerol evaporator. The stream contained mostly glycerol, methanol, and methyl oleate, but also contained other components such as water, sodium sulfate, as well as unreacted sulfuric acid, sodium hydroxide, and triolein.

The ASPEN inputs for the glycerol separator required two of three possible inputs: temperature, pressure, and heat duty. For this simulation, the inputs selected were heat duty and pressure. To perform an analysis on the glycerol separator – specifically, a study on the conditions to best evaporate only the methanol in an initial glycerol purification step – a sensitivity analysis was run. In the first sensitivity analysis, the variables to be recorded by the ASPEN software were the mass flows of the methanol, glycerol, and methyl oleate in the vapor stream, measured in kilograms per second. The variable varied by the ASPEN software was chosen to be the heat duty, and set to vary between zero and 25 kilowatts in increments of 100 watts. The reason why mass flow rates of methanol, glycerol, and methyl oleate were recorded was to determine the optimal heat duty for separation.

Following this, a study was conducted to observe the effect of pressure on the glycerol recovery. The inputs of the glycerol separator were changed from one to 0.5 atm. At each pressure, the previously mentioned sensitivity analyses were re-run. Using this data, the methanol vaporization curves for each evaporator pressure could be shown on the same graph in order to visually compare the effects of pressure.

The liquid from T-102 contained mostly glycerol and methyl oleate with a small, yet not negligible, amount of methanol. This liquid stream entered another evaporator, T-105, in order to vaporize the methyl oleate, leaving glycerol in the liquid phase. The same analyses that were run on the first glycerol purification evaporator were run on this evaporator as well, except these analyses were performed on the liquid phase since glycerol was the component of interest. Since glycerol and methyl oleate have boiling points that are close together, the analyses were performed with special attention being paid to the glycerol recovery and purity that heat duties produced.

Results and Discussion

Methanol Recovery Evaporator, T-101

The first piece of equipment studied in the transesterification process simulation was the methanol recovery evaporator. As mentioned previously, the study included determining the effects of varying the methanol to TAG ratio as well as changes in operating pressure. The evaporator's responses to changing methanol to TAG ratio are displayed in Figure 17 below, in which the methanol recycle percent was plotted according to heat duty for a wide range of ratios. A large ratio range was used throughout the studies, 6:1 to 50:1, to demonstrate a large pool of possible outcomes.

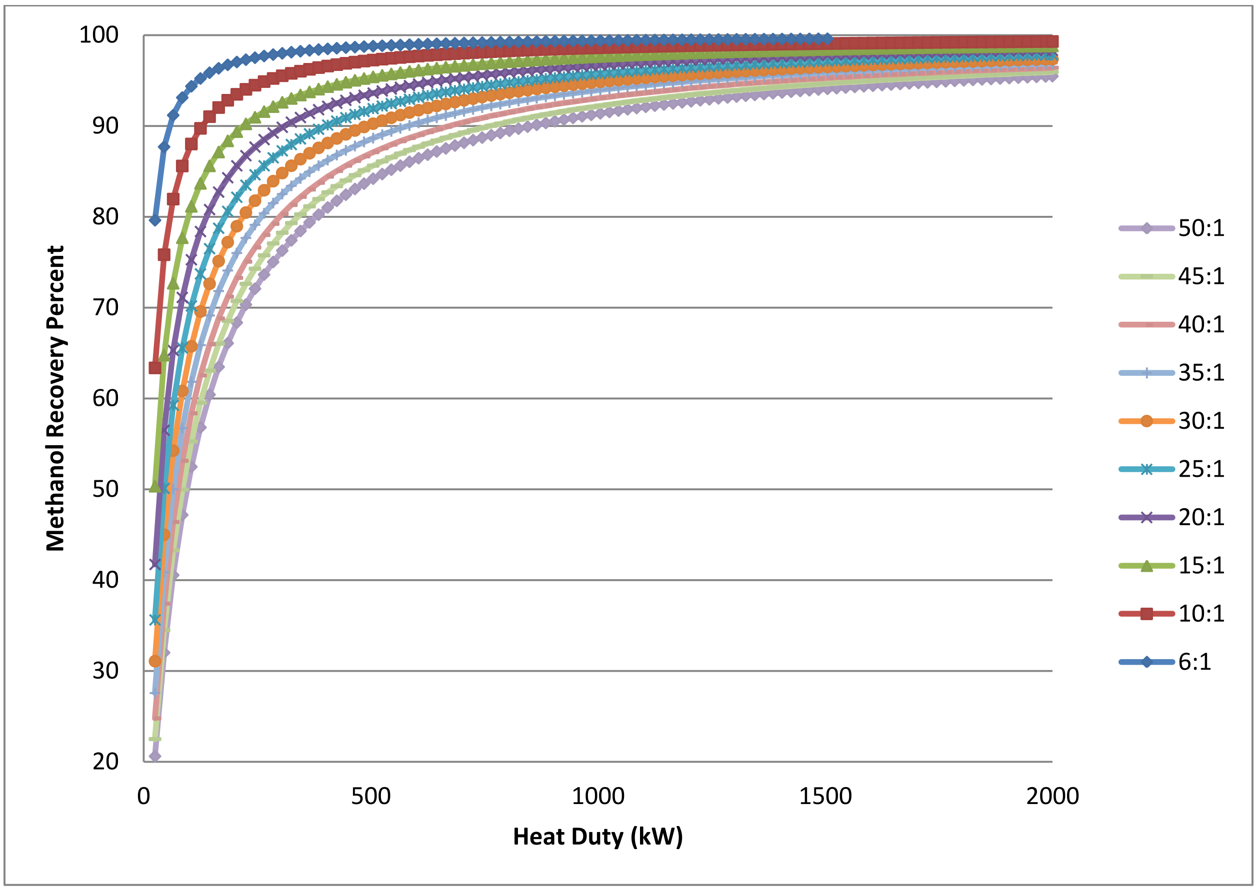

Figure 17: Ratio Study on Methanol Recovery Evaporator, T-101 (1 atm)

The trends displayed in Figure 17 were expected based on current literature and basic chemical engineering principles. As the percent methanol recovered increased, the heat duty required increased for all methanol to TAG ratios. This trend is logical because in separation processes it takes more energy to achieve higher separation efficiency. Higher ratios resulted in higher heat duties because it was necessary to recover increasingly higher amounts of methanol. These results suggest that over the studied range of methanol to TAG ratios, the most efficient methanol recovery occurs in the range of about 80 to 85%. However, beyond this range the heat duty required increases drastically for minor increases in recovered methanol. All of these trends were consistent with those found in a similar simulation conducted by Dhar and Kirtania in 2009. One major difference was that heat duties were much smaller overall in this simulation, likely because an evaporator was used whereas Dhar and Kirtania used a distillation column. As previously mentioned, it was determined that using an evaporator was preferred because of the small energy usage compared with a more energy-intensive distillation column.

Continuing the study of the methanol recovery unit, the pressure was varied and the system responses were plotted. The results are shown in Figures 18 and 19 below in which the fraction of methanol recovered was graphed according to heat duty for various system operating pressures. The results are displayed in two graphs to show effects of pressure at different methanol to TAG ratios (6:1 and 50:1 were chosen to provide the largest range possible). The results demonstrate that increasing pressure beyond ambient pressure requires more energy and that operating at vacuum conditions has negligible effects on heat duty requirements. Both trends suggest that the system should be operated at ambient pressure for the optimal balance between operating energy requirements and equipment costs. This trend was expected because increasing pressure decreases the boiling point of substances and therefore more energy is required to induce methanol vaporization and separation. Again, this trend was supported by literature although larger changes with vacuum conditions were reported – possibly enough to warrant further investigation (Dhar and Kirtania, 2009). The differences are possibly due to the simulation being conducted with a distillation column instead of an evaporator.

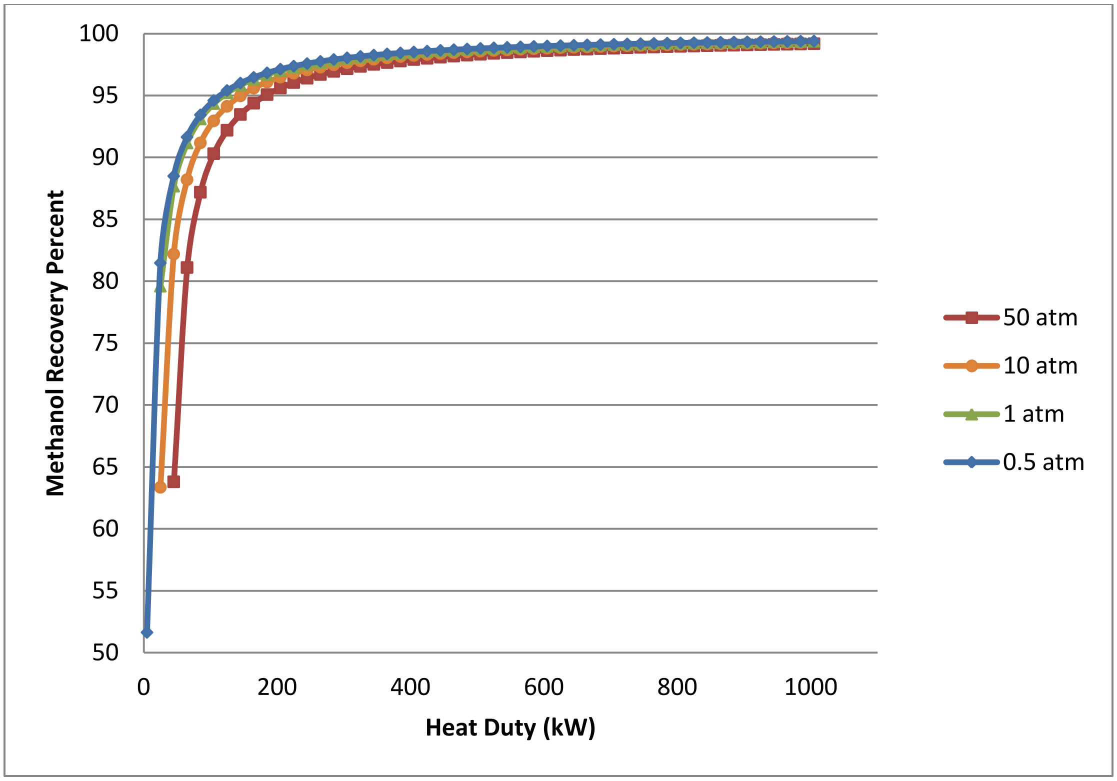

Figure 18: Effects of Pressure Changes on Methanol Recovery Evaporator, T-101 (6:1 Methanol:TAG)

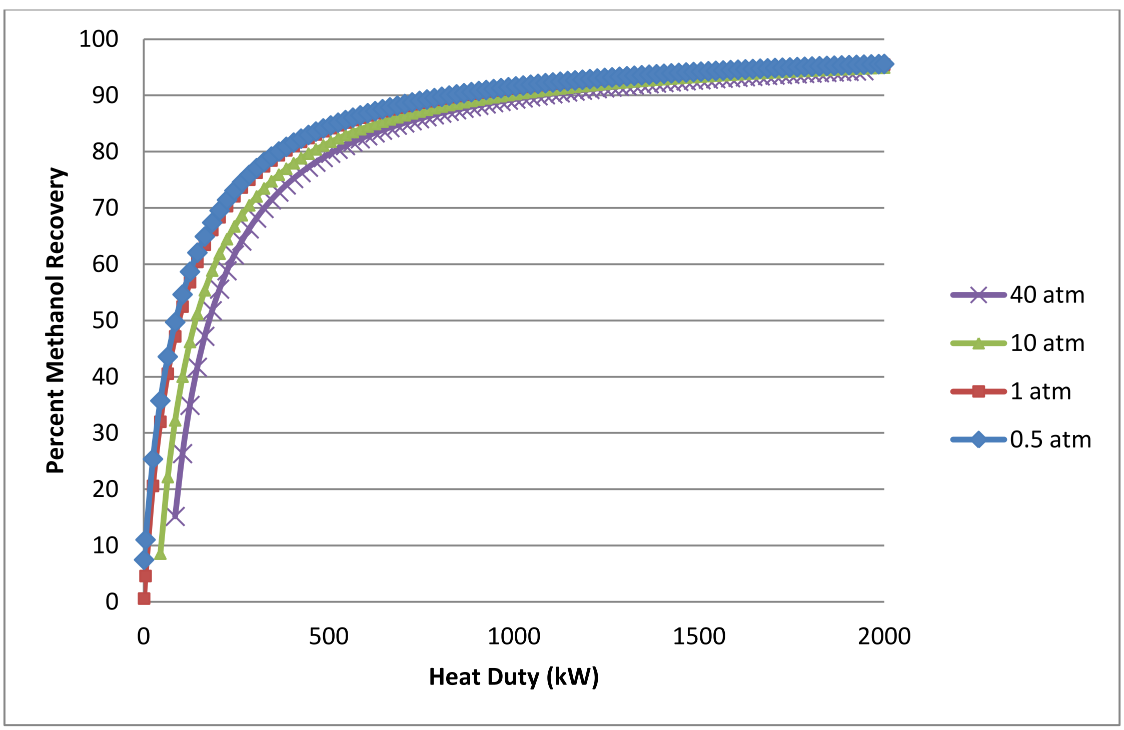

Figure 19: Effects of Pressure Changes on Methanol Recovery Evaporator, T-101 (50:1 Methanol:TAG)

Glycerol Path

The purpose of the first evaporator in the glycerol-rich path was to evaporate the methanol – thus methanol was the component of interest. The purpose of the second evaporator was to evaporate the methyl oleate thereby achieving higher glycerol purity in the liquid stream.

First Glycerol Recovery Evaporator, T-102

For the first evaporator in the glycerol separation system, it was desirable to evaporate as much of the methanol as possible without evaporating too much of the glycerol. The first study conducted on the evaporator entailed studying the mass flow of components in the vapor stream as the heat duty of the evaporator changed. The compositions of the three major components were studied: methanol, glycerol, and methyl oleate. The result was Figure 20 presented below. The results show that there existed a range of heat duties at which nearly all the methanol vaporized while the majority of glycerol and methyl oleate remained liquid.

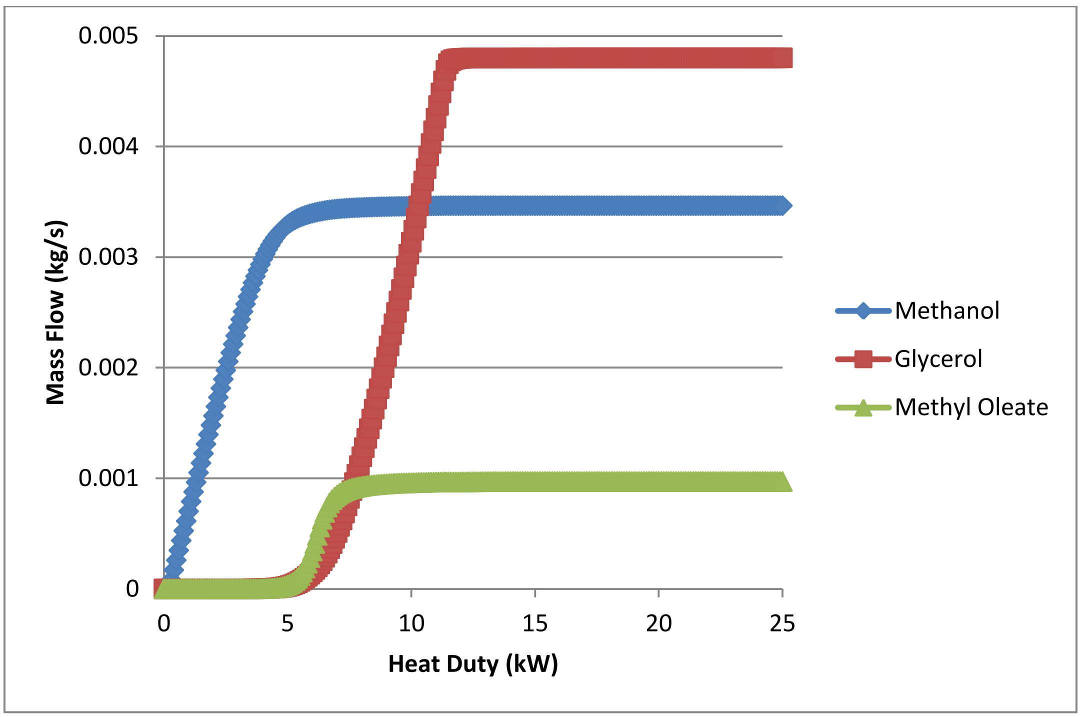

Figure 20: Effects of Heat Duty on Stream Components Exiting Methanol Evaporator T-102 (6:1 Methanol:TAG)

Assuming a 95% by weight recovery of methanol is desired, the results reveal that the lowest heat duty to achieve this separation is five kilowatts. At this heat duty, less than 1% of the glycerol or the methyl oleate evaporated.

In addition to studying the effect of varying the heat duty in the evaporator, another analysis was performed involving pressure. While the initial heat duty analysis was done at a pressure of one atmosphere, the pressure was changed to 0.5 atm to see if vacuum conditions were favorable.

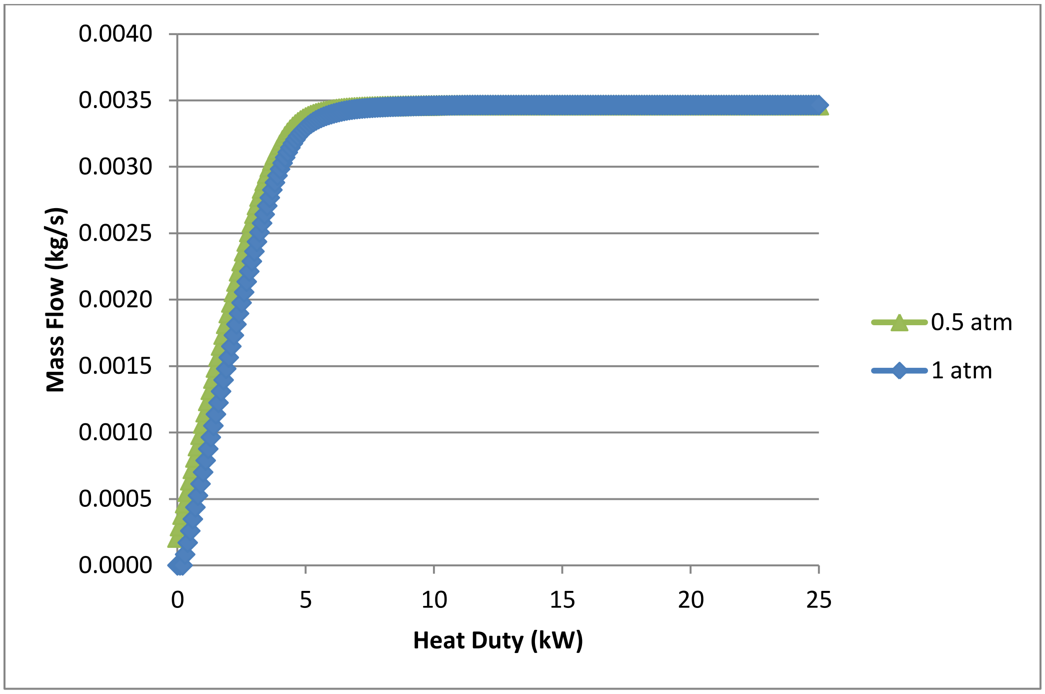

Figure 21: Effects of Pressure on Methanol Evaporator T-102 (6:1 Methanol:TAG)

As Figure 21 demonstrates, lowering the pressure in the evaporator had a negligible effect on the heat duty required to fully recover the methanol in the vapor stream. According to the results, at 0.5 atm, the vapor stream attained a 95% recovery at 4.5 kW, while at 1 atm, this value was 5 kW. This meant that between 0.5 atm and 1 atm, there was a heat duty difference of only 0.5 kW. As previously mentioned, the costs associated with implementing a system capable of operating at low-pressure conditions would likely outweigh the small decrease in operating costs. Therefore it would be most economical to operate at ambient pressure.

Analyses were also conducted on the second evaporator in the glycerol separation system. Liquid from T-102 entered the second evaporator consisting mainly of glycerol and methyl oleate. As the analysis showed, a heat duty of approximately 5 kW was sufficient to recover nearly all methanol in the vapor phase. Therefore, the heat duty of the first evaporator was set to 5 kW as the sensitivity analysis on the second evaporator was conducted.

Biodiesel Recovery Evaporator, T-105

The purpose of the second evaporator in the glycerol-rich path was to purify the glycerol leaving in the liquid stream by evaporating methyl oleate. Although, the main components of the stream entering the second evaporator were glycerol and methyl oleate, methanol was still included in the analyses. The results demonstrated that glycerol and methyl oleate began to vaporize at similar heat duties. Therefore, this analysis aimed to find the range of heat duties where an acceptable balance between glycerol purity and recovery existed. Since glycerol was the component of interest for this evaporator, the sensitivity analysis focused on the liquid outlet stream, as opposed to the vapor outlet stream for the first evaporator.

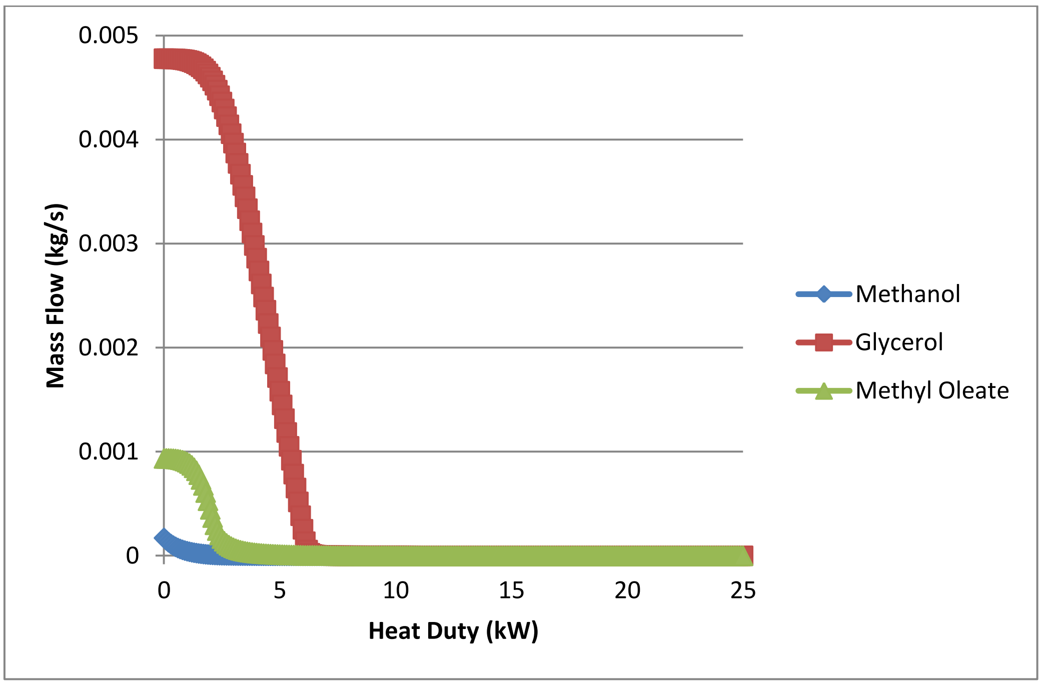

Figure 22: Effects of Heat Duty on Liquid Stream Components from Methanol Evaporator T-105 (6:1 Methanol:TAG)

As the graph demonstrates, methanol evaporated first, followed by methyl oleate, and then glycerol. The graph suggests that a small range of heat duties exist where most of the methyl oleate was evaporated without losing much of the glycerol. A second graph was created to show how the recovery of glycerol in the liquid stream varied as the heat duty increased.

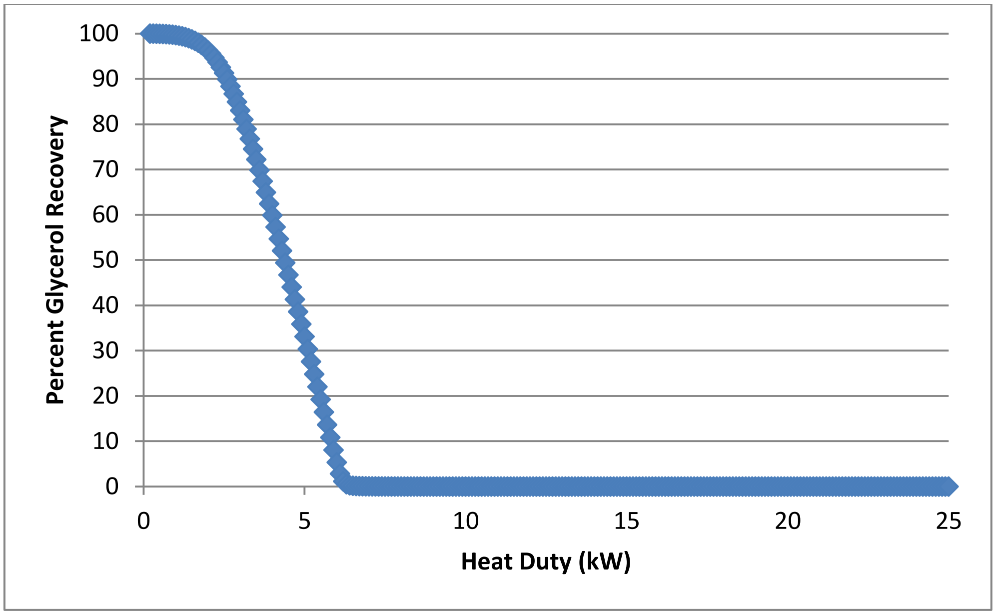

Figure 24: Effect of Heat Duty on Percent Liquid Glycerol Recovery for Methanol Evaporator T-105 (6:1 Methanol:TAG)

The above graph shows that around 2.1 kW, the percent recovery of the glycerol in the liquid stream dips below 95%. Therefore, not too much heating can be utilized in the evaporator or too much of the desired glycerol product is lost. However, if too little heating is used then not enough of the methyl oleate is evaporated, thus adversely affecting the purity of the glycerol product. Another graph was generated to show how glycerol purity was affected by changing heat duty.

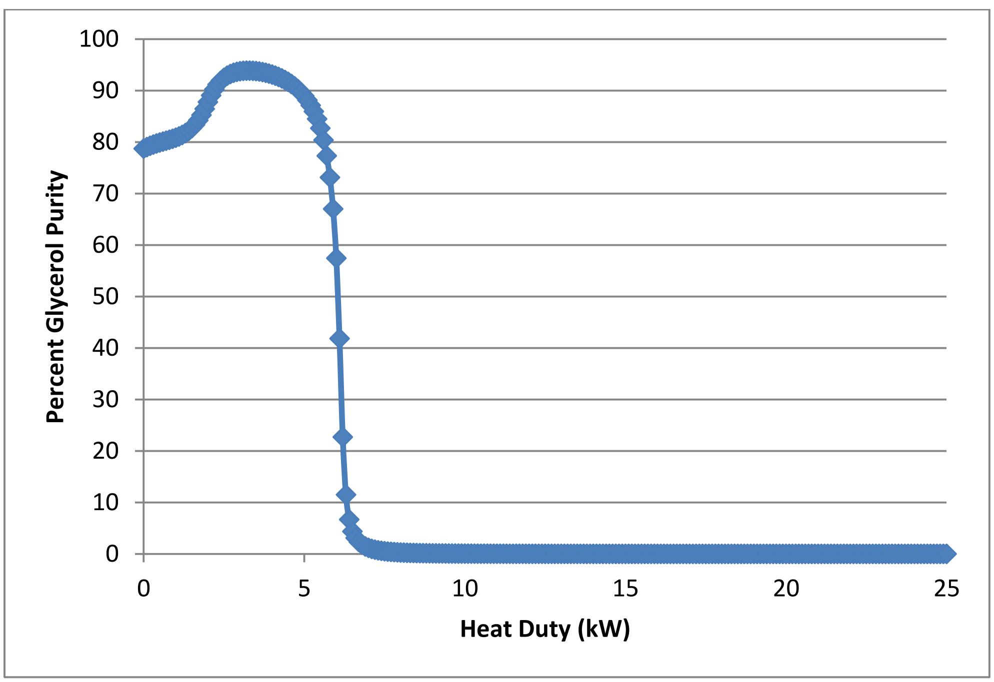

Figure 25: Effect of Heat Duty on Percent Liquid Glycerol Purity Exiting Methanol Evaporator T-105 (6:1 Methanol:TAG)

As Figure 25 shows, the liquid stream entering the evaporator was only 80% glycerol by mass. As the heat duty increased and the methanol and the methyl oleate evaporated, the purity rose to near 95%. It remained at this purity for a small range of heat duties before rapidly declining. However, when comparing the previous two graphs, peak purity of the glycerol product stream occured at unsatisfactory glycerol recoveries. In fact, according to the results, achieving a 95% glycerol recovery in the liquid product only corresponds to an approximate 89% glycerol purity at 2.1 kW. Additionally, the height of the glycerol purity, 93.9%, leads to only a 78.9% glycerol recovery at 3.2 kW. Therefore, the choice in this trade-off would be dependent on the economics of the glycerol market and the desired product purity.

As with the first evaporator in the glycerol-rich path, another analysis was run to test the effect or pressure on the evaporator and the component of interest, glycerol.

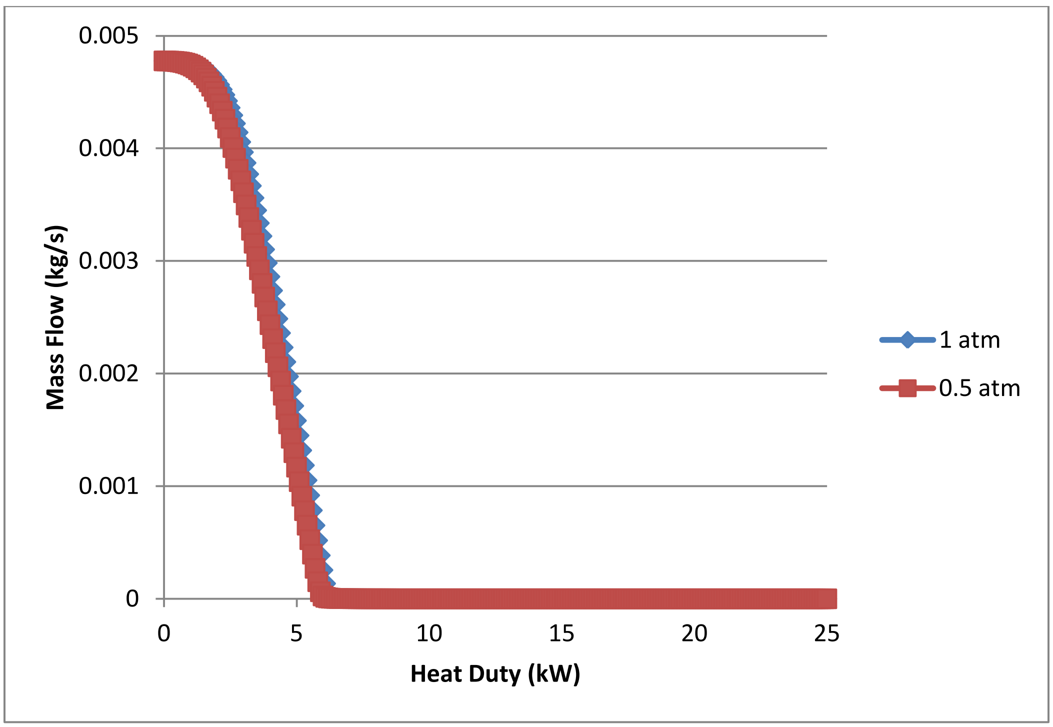

Figure 26: Effect of Pressure on Glycerol Evaporation in the Glycerol Purification Evaporator, T-105 (6:1 Methanol:TAG)

As with the T-102 evaporator, changing the pressure had only a very slight effect on the heat duty needed to vaporize the components. Since additional costs would result from either vacuum conditions or higher pressures, keeping the evaporators at atmospheric pressure in an actual process would be preferred.

Although the main component in this path was glycerol, the T-105 evaporator did evaporate most of the methyl oleate that was present in the evaporator. Therefore, it was worthwhile to observe the quality of the methyl oleate to see if it was usable. Figure 27 below shows a graph of the methyl oleate purity in the vapor stream as heat duty varied.

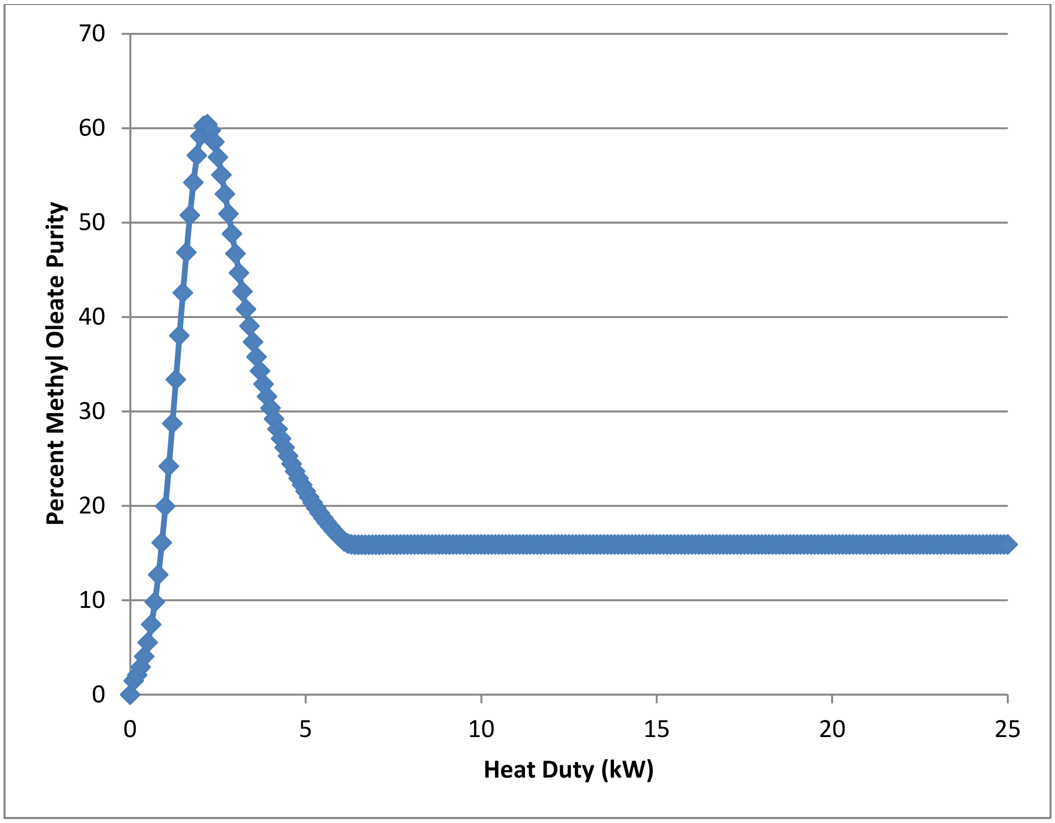

Figure 27: Effect of Heat Duty on Percent Liquid Methyl Oleate Purity Exiting Evaporator T-105 (6:1 Methanol:TAG)

As the above figure shows, the vaporized methyl oleate never achieves an acceptable purity level, reaching a maximum purity of 60.4% methyl oleate by mass at a heat duty of 2.2 kW. This is due to the fact that there is a small amount of methanol that initially evaporates with the methyl oleate. At higher heat duties, glycerol begins to evaporate, as shown in the decrease after the peak. Therefore, the methyl oleate that is produced from this evaporator is not immediately ready for use. Additional equipment could be utilized to create a methyl oleate product of acceptable product, but this would entail a condenser to return the vapor stream to a liquid, as well as another evaporator to separate the methanol from the methyl oleate. The market for biodiesel would have to determine whether such additional equipment is economically feasible.

Biodiesel Path

The biodiesel separation system was comprised of a reactor, two evaporators, and one heat exchanger. However, the analyses conducted on the biodiesel separation path only involved the two evaporators for removing methanol and purifying the biodiesel.

Methanol Separation Evaporator, T-103

The third methanol separation evaporator in the simulation was utilized in the biodiesel production process to remove any remaining methanol from the entering stream. Figure 28 shows the sensitivity analysis results of the effect of methanol to oil ratio on the percent recovery of methanol in the vapor distillate stream. The percent recovery of methanol was plotted according to evaporator heat duty for varying ratios.

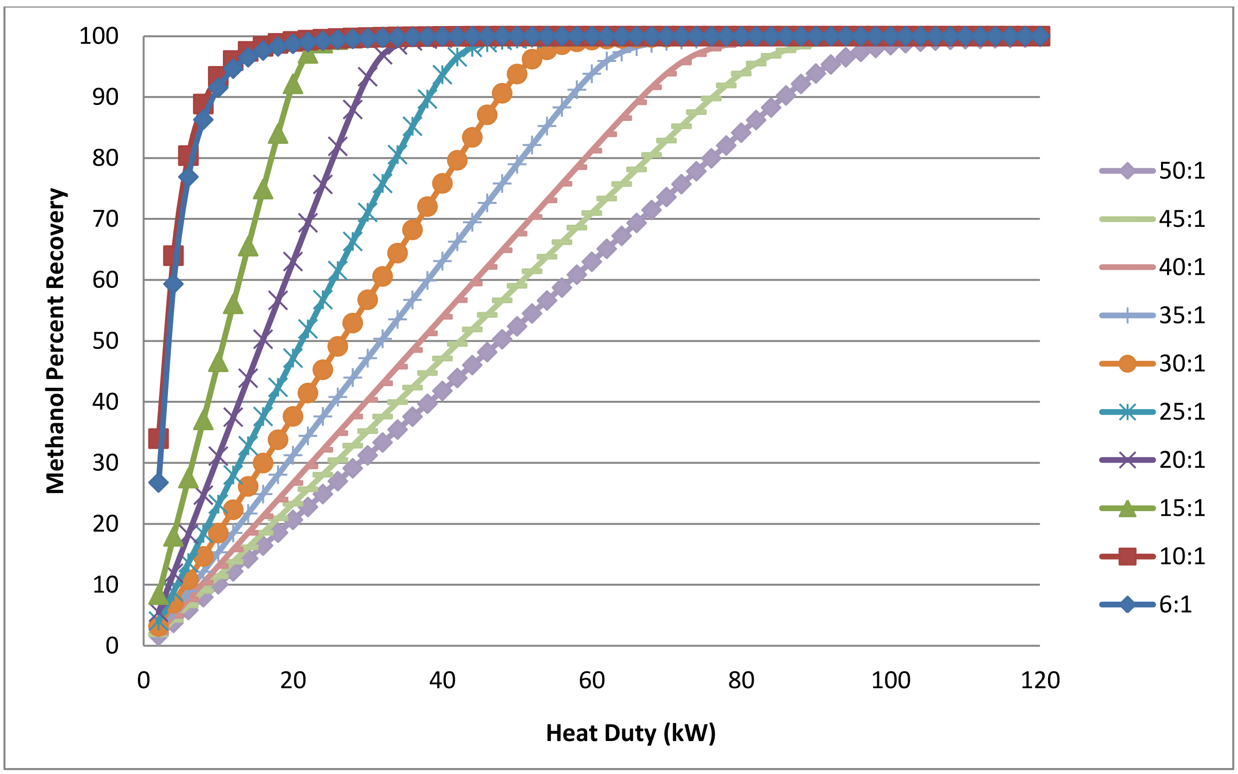

Figure 28: Effect of Heat Duty on Methanol Percent Recovery in Evaporator T-103

As shown above, methanol to oil ratios of 6:1 and 10:1 were the least energy extensive, while the ratio of 50:1 was the most energy intensive. To obtain optimal recovery of methanol, about 105 KW was required at 50:1 while only about 20 KW of energy was required at 6:1 or 10:1. If a higher methanol to oil stoichiometric ratio was used, the cost of the process would increase due to the increase in heat duty. Therefore, to minimize separation costs it is necessary to keep the stoichiometric ratio low. This trend has been shown in all preceding evaporator studies which reinforces the reliability of the results.

To visualize the effect of pressure on methanol recovery in the distillate stream, another sensitivity analysis was done in which pressure was varied from 0.5 to 50 atmospheres at methanol to oil ratios, 6:1 and 50:1. Figures 29 and 30 display the results of these analyses. It can be seen that increasing pressure increases the amount of energy required, which increases the cost of the production process. In addition, it is clearly best to use a lower methanol to oil ratio since it is much more energy efficient. A high recovery of methanol can be achieved with minimal energy consumption if the system is operated at a stoichiometric ratio of 6:1 as opposed to a ratio of 50:1. The simulation results indicate that the heat duty required for separation can be reduced if the system was operated under vacuum conditions, although the necessary equipment costs may outweigh the resulting decrease in operating costs. It is important to note that the temperature of the product streams must be kept at low levels under vacuum conditions.

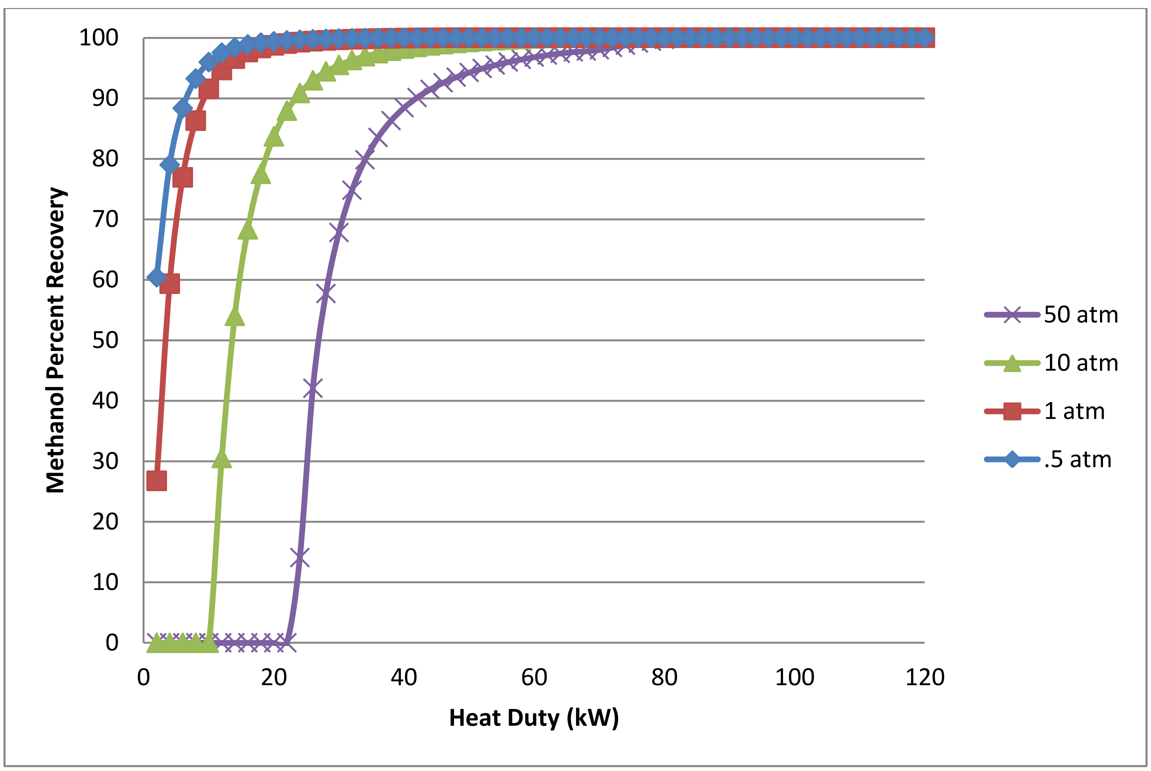

Figure 29: Pressure Analysis Results for Evaporator T-103 (6:1 Methanol:TAG)

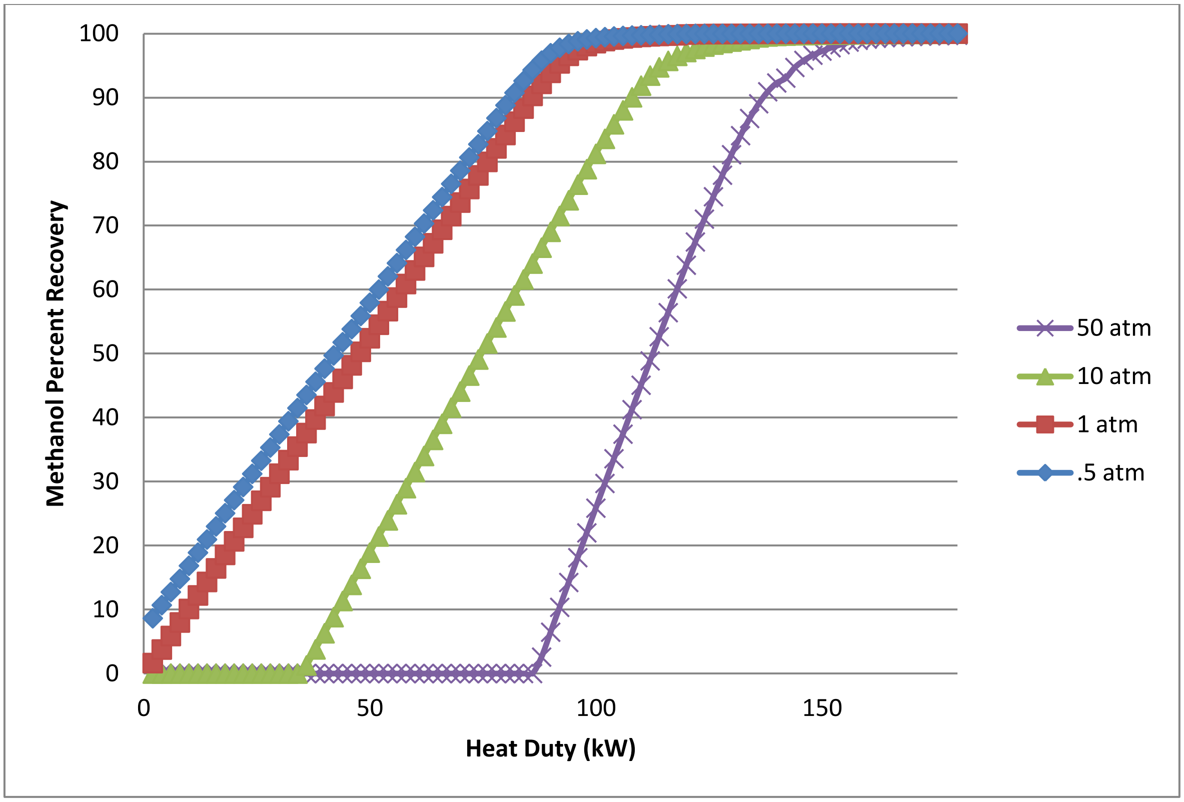

Figure 30: Pressure Analysis Results for Evaporator T-103 (50:1 Methanol:TAG)

Figure 31 below displays the mass flow of methyl oleate in the distillate stream versus the heat duty required for a ratio of 6:1. A ratio of 6:1 was chosen because it required the least amount of energy for separation. This graph aided in determining the maximum allowable heat duty after which the methyl oleate vaporized, which would be undesirable. The results showed that the maximum heat duty for this ratio was approximately 25 kW. This value was used as the heat duty for the evaporator while running simulations downstream.

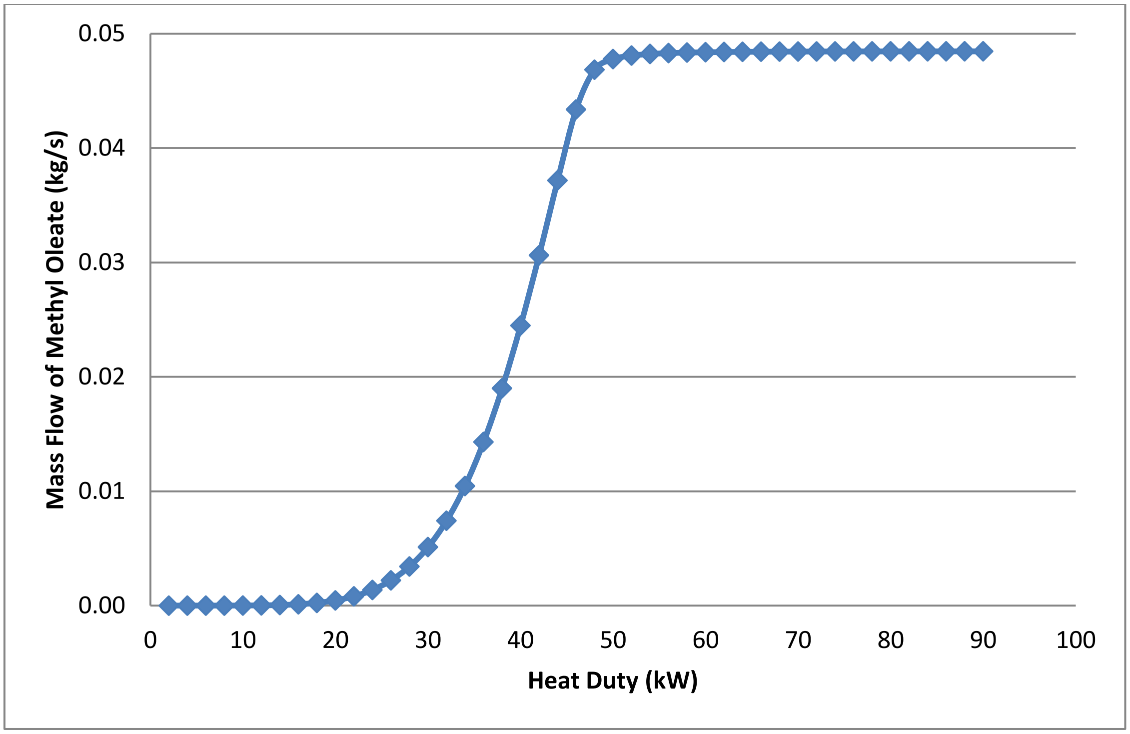

Figure 31: Effects of Heat Duty on Methyl Oleate Vapor From Evaporator T-103 (6:1 Methanol:TAG)

Water Removal Evaporator, T-104

The next portion of the simulation analysis regarded the biodiesel purification evaporator near the end of the biodiesel path. Only the effects of pressure changes were studied for this evaporator because there was no methanol in the incoming stream and, as such, changes in methanol to TAG ratio would not affect the process. Results obtained for the pressure study are displayed in Figure 32 below in which the recovery fraction of biodiesel was plotted against heat duty for various pressures. As with the other evaporation equipment studied, the results suggest that increasing pressure requires more energy and is therefore undesirable. Also as previously demonstrated, decreasing pressure to vacuum conditions provided little energy return on investment. As such, it would likely be most cost effective to operate the biodiesel purification evaporator at ambient pressure to minimize energy and equipment capital costs.

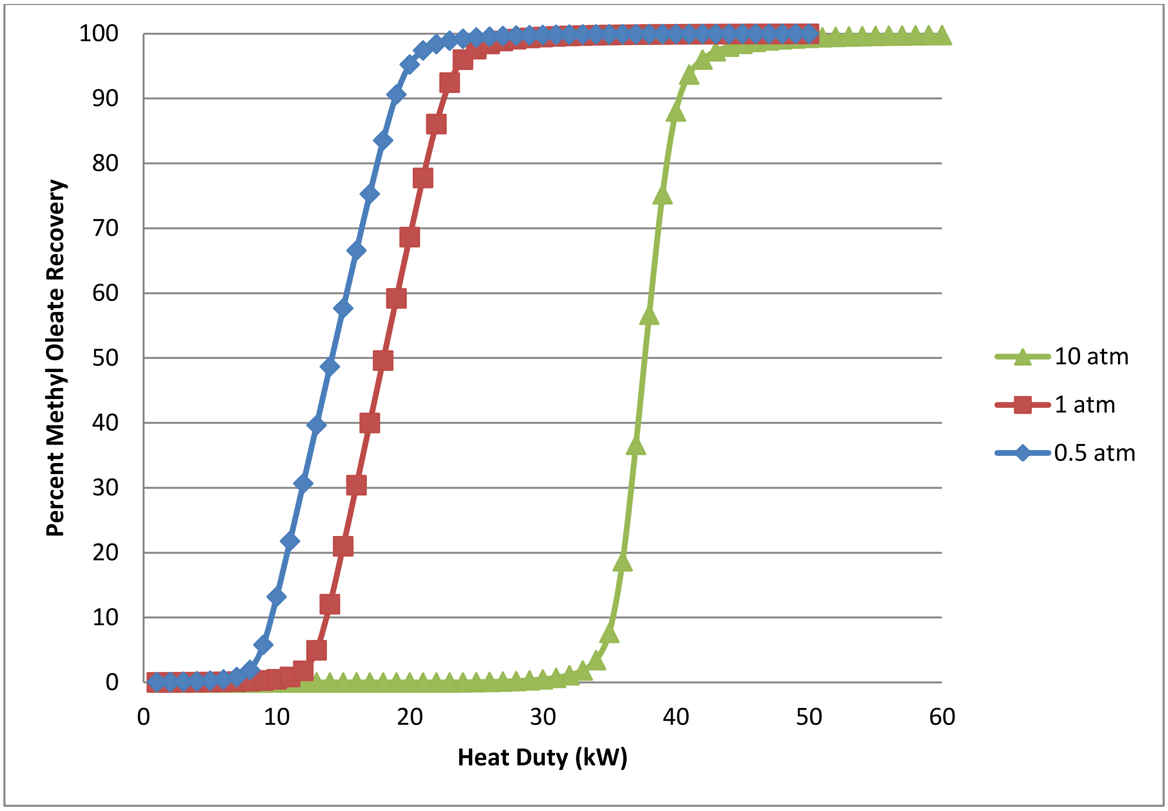

Figure 32: Effects of Pressure on Evaporator T-104 Biodiesel Recovery (6:1 Methanol:TAG)

Excess Triolein Removal Evaporator, T-106

In the effort to achieve ASTM biodiesel fuel standards it was necessary to add an additional evaporator to remove the remaining unreacted triolein. An evaporator was considered suitable for the process because there is a large difference between the boiling point of biodiesel which ranges from 351-353°C at 1 atm (*Penta Manufacturing Company, 2012)* and triolein which is 818°C at 1 atm (World Wide Chemnet). These boiling points also mean that upon separation the biodiesel leaves as vapor and the triolein as liquid. Therefore, in order to bring the biodiesel back to liquid form a condenser was required, although minimal energy (only about 1 kW) was needed to do this. It was determined that about 1 kW of energy was more than enough to ensure a very near complete separation of the biodiesel from the triolein entering stream.

The amount of water within the exiting biodiesel stream was of concern. The water in the stream was controlled by the heat duty of evaporator T-104, because any water not boiled off in that stage went through to become boiled off at this evaporator. To determine the relationship between the amount of water in the stream and the heat duty of T-104, Figure 33 was produced. By Figure 33 it can be seen that the previously chosen heat duty value of 30 kW was acceptable for evaporator T-104 because at this heat duty the amount of water in the vapor biodiesel stream was determined to be 0. 3.57E-09 mg H_2O/kg biodiesel. This purity falls well within the limits required by ASTM standard D 6751-07b (Biofuel Systems Group Ltd.), with less than 500mg water/kg biodiesel (equal to a mass composition of 0.005). This result means that the chosen heat duty for T-104 successfully removed enough water from the stream while ensuring that most of the biodiesel continued as liquid to the final evaporator.

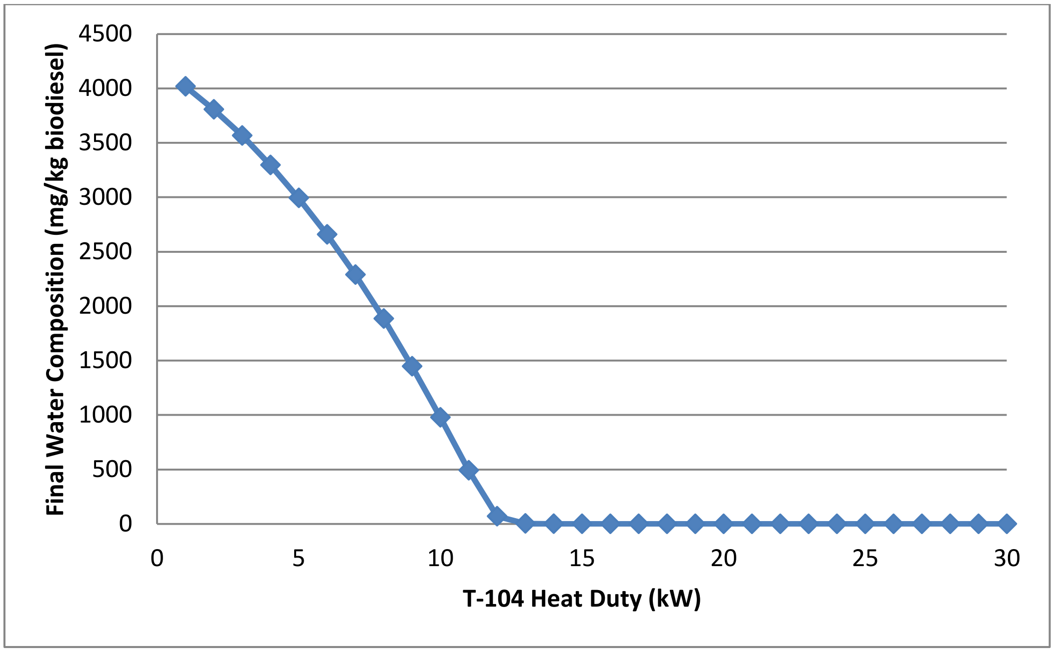

Figure 33: Effects of T-104 Heat Duty on Water in Stream Exiting Evaporator T-106 (6:1 Methanol:TAG)

To guarantee that the purity of the biodiesel met the remaining applicable ASTM requirements further analysis was conducted on the stream's components. With the heat duty and pressure of the final purification evaporator set to 1 kW and 1 atm, the mass composition of the final biodiesel stream was determined and the results of which are displayed in Table 3 along with the associated ASTM standards. As can be seen from the table, all of the ASTM requirements were met for the achieved biodiesel from this simulation study.

Table 3: Final Biodiesel Composition Compared to ASTM Requirements

Component	Mass Fraction	ASTM Maximum
Biodiesel	0.99994	NA
Free Glycerol	3.28E-06	0.02
Total Glycerol	3.28E-06	0.24
Methanol	9.60E-07	0.2
Sulfiric Acid	5.27E-05	0.5
Water	3.57E-09	0.0005
Total	1	NA

Conclusion and Recommendations

Based on the simulation results obtained for the transesterification reaction and the resulting separation steps, there are several conclusions that can be made. In all of the separation procedures it was shown that increased methanol to oil ratio required higher heat duties for the same separation results. Therefore, based on the assumption of a continuous process, the optimal ratio of methanol to oil is 6:1 for the entire process since it yielded the highest separation for the least energy. Another prevalent trend of all of the analyses is that increasing pressure beyond ambient pressure of 1 atmosphere resulted in higher heat duties required for the same amount of separation. Conversely, decreasing pressure to vacuum conditions did improve the separation, but in most cases the benefits would be considered negligible compared to the increase in equipment costs. Therefore, it is recommended that all separation evaporators following the transesterification reaction operate either at ambient pressure, or slightly above ambient pressure for leak-detecting purposes.

The simulation also produced several insights into an industrial transesterification process. Based on the heat duties recorded by the ASPEN simulation software, the greatest amount of necessary heat/energy associated with the process is in the transesterification reactor R-101 as well as the methanol evaporator T-101. This is logical since those pieces of equipment dealt with the highest stream flows. Additionally, this simulation provided insight into the difficulties that might arise in a biodiesel industrial process. Methyl oleate and glycerol have similar boiling points, and thus separating the two can be a difficult procedure. Although it was not done in this simulation, this difficulty might call for use of a distillation column instead of an evaporator. In all other cases, however, evaporators were sufficient to separate components due to larger boiling point differences.

The group has several recommendations for future research into the topics discussed. One possible topic for future research is investigating the effectiveness of conducting the biodiesel generation process by simultaneously reacting the algal oil and separating the biodiesel with a reactive distillation column. This investigation could include a simulation with ASPEN software and could involve trying different operating conditions and catalysts. This process shows promise because by combining the reaction and separation process would help to reduce equipment costs and possible operating costs if enough operations can be replaced by the single distillation column.

Another recommendation is to use a distillation column to achieve the methyl oleate/glycerol separation, as previously stated. Use of this piece of equipment could lead to analyses on pressure, temperature, reflux ratio, or column size.

Also, while this simulation used a simplification to assume that triolein was the triacylglyceride extracted from algae, simulations could possibly be done using other TAGs that are present in algae. In this simulation, free fatty acids were assumed negligible; further study might involve including the presence of free fatty acids.

A final recommendation could be to study reaction rates associated with the transesterification reaction. ASPEN provides a reactor block that allows analyses to be performed on the reaction rates. This might result in a study being more focused on the reaction itself, rather than the separation procedures. This could provide insight into the use of various catalysts.

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Appendix A: Extra Figures

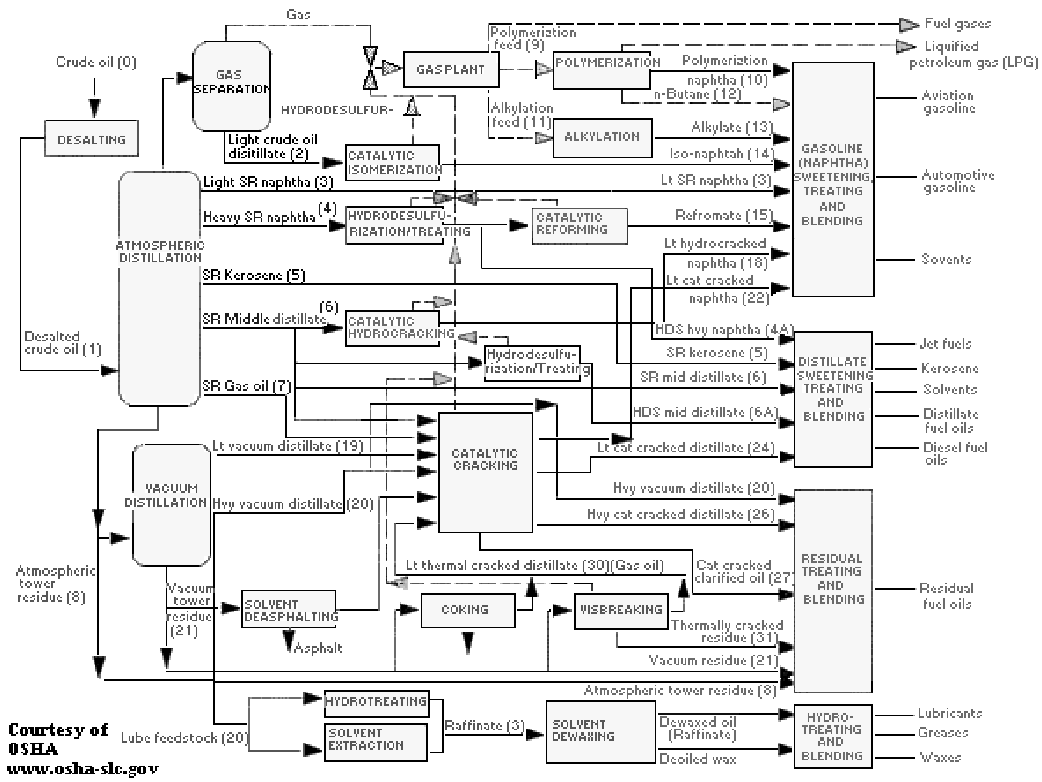

Figure 33: Example Refinery Process

Projected Date	Source of Projection	Background & Reference
2006-2007	Bakhitari, A.M.S.	Iranian Oil Executive
2007-2009	Simmons, M.R.	Investment banker
After 2007	Skrebowski, C.	Petroleum journal Editor
Before 2009	Deffeyes, K.S.	Oil company geologist (ret.)
Before 2010	Goodstein, D.	Vice Provost, Cal Tech
Around 2010	Campbell, C.J.	Oil company geologist (ret.)
After 2010	World Energy Council	World Non-Government Org.
2010-2020	Laherrere, J.	Oil company geologist (ret.)
2016	EIA nominal case	DOE analysis/ information
After 2020	CERA	Energy consultants
2025 or later	Shell	Major oil company
No visible peak	Lynch, M.C.	Energy economist

Figure 34: List of Peak Oil Reports

Appendix B: T-101 Data

Table 4: T-101 Recovered Methanol Purity Verification

MeOH:TAG Ratio	MeOH Mol Fraction
6	99.9981
10	99.9992
15	99.9995
20	99.9996
25	99.9997
30	99.9998
35	99.9998
40	99.9998
45	99.9998
50	99.9998

Table 5: T-101 Ratio Analysis

6 to 1				10 to 1			
kw	Mol Flow In	Mol Flow Out	% Recovery	kw	Mol Flow In	Mol Flow Out	% Recovery
25	0.028	0.022	79.600	25	0.036	0.022	63.349
45	0.046	0.040	87.681	45	0.054	0.041	75.812
65	0.064	0.059	91.164	65	0.072	0.059	81.934
85	0.082	0.077	93.108	85	0.090	0.077	85.579
105	0.100	0.095	94.350	105	0.108	0.095	87.998
125	0.118	0.113	95.212	125	0.127	0.114	89.721
145	0.137	0.131	95.846	145	0.145	0.132	91.011
165	0.155	0.149	96.331	165	0.163	0.150	92.013
185	0.173	0.167	96.715	185	0.181	0.168	92.814
205	0.191	0.185	97.026	205	0.199	0.186	93.469
225	0.209	0.203	97.283	225	0.217	0.204	94.014
245	0.227	0.221	97.499	245	0.236	0.223	94.475
265	0.245	0.239	97.684	265	0.254	0.241	94.871
285	0.263	0.257	97.843	285	0.272	0.259	95.213
305	0.281	0.275	97.981	305	0.290	0.277	95.513
325	0.299	0.293	98.103	325	0.308	0.295	95.777
345	0.317	0.311	98.211	345	0.326	0.313	96.012
365	0.335	0.329	98.307	365	0.345	0.331	96.222
385	0.353	0.347	98.394	385	0.363	0.350	96.411
405	0.371	0.366	98.472	405	0.381	0.368	96.582
425	0.389	0.384	98.543	425	0.399	0.386	96.738

445	0.407	0.402	98.607	445	0.417	0.404	96.880
465	0.425	0.420	98.666	465	0.435	0.422	97.010
485	0.443	0.438	98.721	485	0.453	0.440	97.129
505	0.461	0.456	98.771	505	0.472	0.459	97.240
525	0.479	0.474	98.817	525	0.490	0.477	97.342
545	0.498	0.492	98.860	545	0.508	0.495	97.437
565	0.516	0.510	98.900	565	0.526	0.513	97.526
585	0.534	0.528	98.937	585	0.544	0.531	97.608
605	0.552	0.546	98.972	605	0.562	0.549	97.685
625	0.570	0.564	99.004	625	0.580	0.567	97.758
645	0.588	0.582	99.035	645	0.599	0.586	97.826
665	0.606	0.600	99.064	665	0.617	0.604	97.890
685	0.624	0.618	99.091	685	0.635	0.622	97.950
705	0.642	0.636	99.116	705	0.653	0.640	98.007
725	0.660	0.654	99.140	725	0.671	0.658	98.061
745	0.678	0.672	99.163	745	0.689	0.676	98.112
765	0.696	0.690	99.185	765	0.707	0.694	98.160
785	0.714	0.708	99.206	785	0.726	0.713	98.206
805	0.732	0.726	99.225	805	0.744	0.731	98.250
825	0.750	0.744	99.244	825	0.762	0.749	98.292
845	0.768	0.762	99.262	845	0.780	0.767	98.331
865	0.786	0.781	99.279	865	0.798	0.785	98.369
885	0.804	0.799	99.295	885	0.816	0.803	98.406
905	0.822	0.817	99.310	905	0.834	0.821	98.440
925	0.840	0.835	99.325	925	0.853	0.840	98.474
945	0.858	0.853	99.339	945	0.871	0.858	98.505
965	0.876	0.871	99.353	965	0.889	0.876	98.536
985	0.894	0.889	99.366	985	0.907	0.894	98.565
1005	0.913	0.907	99.378	1005	0.925	0.912	98.593
1025	0.931	0.925	99.390	1025	0.943	0.930	98.620
1045	0.949	0.943	99.402	1045	0.962	0.949	98.646
1065	0.967	0.961	99.413	1065	0.980	0.967	98.671
1085	0.985	0.979	99.424	1085	0.998	0.985	98.696
1105	1.003	0.997	99.434	1105	1.016	1.003	98.719
1125	1.021	1.015	99.444	1125	1.034	1.021	98.741
1145	1.039	1.033	99.454	1145	1.052	1.039	98.763
1165	1.057	1.051	99.463	1165	1.070	1.057	98.784
1185	1.075	1.069	99.472	1185	1.089	1.076	98.804
1205	1.093	1.087	99.481	1205	1.107	1.094	98.824
1225	1.111	1.105	99.489	1225	1.125	1.112	98.843
1245	1.129	1.123	99.498	1245	1.143	1.130	98.861

1265	1.147	1.141	99.505	1265	1.161	1.148	98.879
1285	1.165	1.159	99.513	1285	1.179	1.166	98.896
1305	1.183	1.177	99.521	1305	1.197	1.184	98.913
1325	1.201	1.196	99.528	1325	1.216	1.203	98.929
1345	1.219	1.214	99.535	1345	1.234	1.221	98.945
1365	1.237	1.232	99.542	1365	1.252	1.239	98.960
1385	1.255	1.250	99.548	1385	1.270	1.257	98.975
1405	1.273	1.268	99.555	1405	1.288	1.275	98.990
1425	1.291	1.286	99.561	1425	1.306	1.293	99.004
1445	1.309	1.304	99.567	1445	1.324	1.311	99.017
1465	1.327	1.322	99.573	1465	1.343	1.330	99.031
1485	1.346	1.340	99.578	1485	1.361	1.348	99.044
1505	1.364	1.358	99.584	1505	1.379	1.366	99.056
				1525	1.397	1.384	99.068
				1545	1.415	1.402	99.080
				1565	1.433	1.420	99.092
				1585	1.451	1.438	99.103
				1605	1.470	1.457	99.114
				1625	1.488	1.475	99.125
				1645	1.506	1.493	99.136
				1665	1.524	1.511	99.146
				1685	1.542	1.529	99.156
				1705	1.560	1.547	99.166
				1725	1.578	1.565	99.175
				1745	1.597	1.584	99.185
				1765	1.615	1.602	99.194
				1785	1.633	1.620	99.203
				1805	1.651	1.638	99.212
				1825	1.669	1.656	99.220
				1845	1.687	1.674	99.229
				1865	1.706	1.692	99.237
				1885	1.724	1.711	99.245
				1905	1.742	1.729	99.253
				1925	1.760	1.747	99.260
				1945	1.778	1.765	99.268
				1965	1.796	1.783	99.275
				1985	1.814	1.801	99.283
				2000	1.828	1.815	99.288

15 to 1				20 to 1			
kw	**Mol Flow In**	**Mol Flow Out**	**% Recovery**	**kw**	**Mol Flow In**	**Mol Flow Out**	**% Recovery**
25	0.045	0.022	50.317	25	0.054	0.022	41.701
45	0.063	0.041	64.750	45	0.072	0.041	56.482
65	0.081	0.059	72.670	65	0.090	0.059	65.273
85	0.099	0.077	77.680	85	0.109	0.077	71.104
105	0.118	0.095	81.135	105	0.127	0.095	75.256
125	0.136	0.114	83.663	125	0.145	0.114	78.364
145	0.154	0.132	85.592	145	0.163	0.132	80.778
165	0.172	0.150	87.114	165	0.181	0.150	82.707
185	0.190	0.168	88.345	185	0.200	0.168	84.283
205	0.209	0.186	89.361	205	0.218	0.186	85.597
225	0.227	0.205	90.214	225	0.236	0.205	86.707
245	0.245	0.223	90.941	245	0.254	0.223	87.659
265	0.263	0.241	91.566	265	0.272	0.241	88.483
285	0.281	0.259	92.111	285	0.291	0.259	89.204
305	0.300	0.277	92.590	305	0.309	0.277	89.840
325	0.318	0.296	93.014	325	0.327	0.296	90.405
345	0.336	0.314	93.392	345	0.345	0.314	90.911
365	0.354	0.332	93.732	365	0.363	0.332	91.366
385	0.372	0.350	94.038	385	0.382	0.350	91.778
405	0.390	0.368	94.315	405	0.400	0.368	92.152
425	0.409	0.386	94.568	425	0.418	0.387	92.494
445	0.427	0.405	94.800	445	0.436	0.405	92.807
465	0.445	0.423	95.012	465	0.454	0.423	93.095
485	0.463	0.441	95.208	485	0.473	0.441	93.360
505	0.481	0.459	95.389	505	0.491	0.459	93.607
525	0.499	0.477	95.557	525	0.509	0.478	93.835
545	0.518	0.495	95.713	545	0.527	0.496	94.048
565	0.536	0.514	95.858	565	0.545	0.514	94.246
585	0.554	0.532	95.994	585	0.563	0.532	94.432
605	0.572	0.550	96.121	605	0.582	0.550	94.606
625	0.590	0.568	96.241	625	0.600	0.568	94.770
645	0.609	0.586	96.353	645	0.618	0.587	94.924
665	0.627	0.605	96.459	665	0.636	0.605	95.069
685	0.645	0.623	96.558	685	0.654	0.623	95.206
705	0.663	0.641	96.653	705	0.673	0.641	95.336
725	0.681	0.659	96.742	725	0.691	0.659	95.458
745	0.699	0.677	96.827	745	0.709	0.678	95.575
765	0.718	0.695	96.907	765	0.727	0.696	95.686
785	0.736	0.714	96.984	785	0.745	0.714	95.791

805	0.754	0.732	97.056	805	0.764	0.732	95.891
825	0.772	0.750	97.126	825	0.782	0.750	95.987
845	0.790	0.768	97.192	845	0.800	0.769	96.078
865	0.808	0.786	97.255	865	0.818	0.787	96.165
885	0.827	0.804	97.315	885	0.836	0.805	96.249
905	0.845	0.823	97.373	905	0.854	0.823	96.328
925	0.863	0.841	97.428	925	0.873	0.841	96.405
945	0.881	0.859	97.481	945	0.891	0.859	96.478
965	0.899	0.877	97.532	965	0.909	0.878	96.549
985	0.918	0.895	97.581	985	0.927	0.896	96.617
1005	0.936	0.914	97.628	1005	0.945	0.914	96.682
1025	0.954	0.932	97.673	1025	0.964	0.932	96.744
1045	0.972	0.950	97.717	1045	0.982	0.950	96.805
1065	0.990	0.968	97.759	1065	1.000	0.969	96.863
1085	1.008	0.986	97.799	1085	1.018	0.987	96.919
1105	1.027	1.004	97.838	1105	1.036	1.005	96.973
1125	1.045	1.023	97.876	1125	1.055	1.023	97.025
1145	1.063	1.041	97.912	1145	1.073	1.041	97.075
1165	1.081	1.059	97.947	1165	1.091	1.060	97.124
1185	1.099	1.077	97.981	1185	1.109	1.078	97.171
1205	1.117	1.095	98.014	1205	1.127	1.096	97.217
1225	1.136	1.113	98.046	1225	1.146	1.114	97.261
1245	1.154	1.132	98.076	1245	1.164	1.132	97.304
1265	1.172	1.150	98.106	1265	1.182	1.151	97.346
1285	1.190	1.168	98.135	1285	1.200	1.169	97.386
1305	1.208	1.186	98.163	1305	1.218	1.187	97.425
1325	1.226	1.204	98.190	1325	1.236	1.205	97.463
1345	1.245	1.222	98.217	1345	1.255	1.223	97.499
1365	1.263	1.241	98.243	1365	1.273	1.241	97.535
1385	1.281	1.259	98.267	1385	1.291	1.260	97.570
1405	1.299	1.277	98.292	1405	1.309	1.278	97.604
1425	1.317	1.295	98.315	1425	1.327	1.296	97.636
1445	1.336	1.313	98.338	1445	1.346	1.314	97.668
1465	1.354	1.332	98.360	1465	1.364	1.332	97.700
1485	1.372	1.350	98.382	1485	1.382	1.351	97.730
1505	1.390	1.368	98.403	1505	1.400	1.369	97.759
1525	1.408	1.386	98.424	1525	1.418	1.387	97.788
1545	1.426	1.404	98.444	1545	1.437	1.405	97.816
1565	1.445	1.422	98.464	1565	1.455	1.423	97.843
1585	1.463	1.441	98.483	1585	1.473	1.442	97.870
1605	1.481	1.459	98.501	1605	1.491	1.460	97.896

1625	1.499	1.477	98.520	1625	1.509	1.478	97.921
1645	1.517	1.495	98.537	1645	1.527	1.496	97.946
1665	1.535	1.513	98.555	1665	1.546	1.514	97.970
1685	1.554	1.531	98.571	1685	1.564	1.532	97.994
1705	1.572	1.550	98.588	1705	1.582	1.551	98.017
1725	1.590	1.568	98.604	1725	1.600	1.569	98.039
1745	1.608	1.586	98.620	1745	1.618	1.587	98.061
1765	1.626	1.604	98.635	1765	1.637	1.605	98.083
1785	1.645	1.622	98.650	1785	1.655	1.623	98.104
1805	1.663	1.640	98.665	1805	1.673	1.642	98.125
1825	1.681	1.659	98.680	1825	1.691	1.660	98.145
1845	1.699	1.677	98.694	1845	1.709	1.678	98.165
1865	1.717	1.695	98.708	1865	1.728	1.696	98.184
1885	1.735	1.713	98.721	1885	1.746	1.714	98.203
1905	1.754	1.731	98.734	1905	1.764	1.733	98.221
1925	1.772	1.750	98.747	1925	1.782	1.751	98.240
1945	1.790	1.768	98.760	1945	1.800	1.769	98.257
1965	1.808	1.786	98.772	1965	1.818	1.787	98.275
1985	1.826	1.804	98.785	1985	1.837	1.805	98.292
2000	1.840	1.818	98.794	2000	1.850	1.819	98.304

25 to 1				**30 to 1**			
kw	**Mol Flow In**	**Mol Flow Out**	**% Recovery**	**kw**	**Mol Flow In**	**Mol Flow Out**	**% Recovery**
25	0.063	0.022	35.601	25	0.072	0.022	31.061
45	0.081	0.041	50.084	45	0.090	0.041	44.989
65	0.099	0.059	59.240	65	0.109	0.059	54.228
85	0.118	0.077	65.553	85	0.127	0.077	60.807
105	0.136	0.095	70.171	105	0.145	0.095	65.730
125	0.154	0.114	73.696	125	0.163	0.114	69.554
145	0.172	0.132	76.476	145	0.182	0.132	72.609
165	0.191	0.150	78.723	165	0.200	0.150	75.107
185	0.209	0.168	80.579	185	0.218	0.168	77.187
205	0.227	0.186	82.137	205	0.236	0.186	78.946
225	0.245	0.205	83.463	225	0.254	0.205	80.453
245	0.263	0.223	84.606	245	0.273	0.223	81.759
265	0.282	0.241	85.601	265	0.291	0.241	82.901
285	0.300	0.259	86.475	285	0.309	0.259	83.909
305	0.318	0.277	87.249	305	0.327	0.278	84.804
325	0.336	0.296	87.939	325	0.345	0.296	85.605
345	0.354	0.314	88.559	345	0.364	0.314	86.326

365	0.373	0.332	89.118	365	0.382	0.332	86.978
385	0.391	0.350	89.624	385	0.400	0.350	87.570
405	0.409	0.368	90.086	405	0.418	0.369	88.111
425	0.427	0.387	90.508	425	0.437	0.387	88.607
445	0.445	0.405	90.896	445	0.455	0.405	89.063
465	0.464	0.423	91.254	465	0.473	0.423	89.484
485	0.482	0.441	91.584	485	0.491	0.441	89.874
505	0.500	0.459	91.890	505	0.509	0.460	90.236
525	0.518	0.478	92.175	525	0.528	0.478	90.573
545	0.536	0.496	92.440	545	0.546	0.496	90.887
565	0.555	0.514	92.689	565	0.564	0.514	91.182
585	0.573	0.532	92.921	585	0.582	0.532	91.457
605	0.591	0.550	93.139	605	0.600	0.551	91.716
625	0.609	0.569	93.344	625	0.619	0.569	91.960
645	0.627	0.587	93.537	645	0.637	0.587	92.190
665	0.646	0.605	93.719	665	0.655	0.605	92.407
685	0.664	0.623	93.891	685	0.673	0.623	92.613
705	0.682	0.641	94.054	705	0.691	0.642	92.807
725	0.700	0.660	94.209	725	0.710	0.660	92.992
745	0.718	0.678	94.355	745	0.728	0.678	93.167
765	0.737	0.696	94.495	765	0.746	0.696	93.334
785	0.755	0.714	94.628	785	0.764	0.714	93.492
805	0.773	0.732	94.754	805	0.782	0.733	93.644
825	0.791	0.751	94.875	825	0.801	0.751	93.788
845	0.809	0.769	94.990	845	0.819	0.769	93.927
865	0.828	0.787	95.100	865	0.837	0.787	94.059
885	0.846	0.805	95.206	885	0.855	0.805	94.185
905	0.864	0.823	95.306	905	0.873	0.824	94.306
925	0.882	0.842	95.403	925	0.892	0.842	94.423
945	0.900	0.860	95.496	945	0.910	0.860	94.534
965	0.919	0.878	95.585	965	0.928	0.878	94.641
985	0.937	0.896	95.671	985	0.946	0.897	94.744
1005	0.955	0.914	95.754	1005	0.964	0.915	94.844
1025	0.973	0.933	95.833	1025	0.983	0.933	94.939
1045	0.991	0.951	95.910	1045	1.001	0.951	95.031
1065	1.010	0.969	95.983	1065	1.019	0.969	95.120
1085	1.028	0.987	96.054	1085	1.037	0.988	95.206
1105	1.046	1.005	96.123	1105	1.055	1.006	95.288
1125	1.064	1.024	96.189	1125	1.074	1.024	95.368
1145	1.082	1.042	96.253	1145	1.092	1.042	95.445
1165	1.101	1.060	96.315	1165	1.110	1.060	95.520

1185	1.119	1.078	96.375	1185	1.128	1.079	95.592
1205	1.137	1.096	96.433	1205	1.146	1.097	95.662
1225	1.155	1.115	96.490	1225	1.165	1.115	95.730
1245	1.173	1.133	96.544	1245	1.183	1.133	95.796
1265	1.192	1.151	96.597	1265	1.201	1.151	95.860
1285	1.210	1.169	96.648	1285	1.219	1.170	95.921
1305	1.228	1.187	96.698	1305	1.238	1.188	95.981
1325	1.246	1.206	96.746	1325	1.256	1.206	96.040
1345	1.264	1.224	96.793	1345	1.274	1.224	96.096
1365	1.283	1.242	96.838	1365	1.292	1.242	96.151
1385	1.301	1.260	96.882	1385	1.310	1.261	96.205
1405	1.319	1.278	96.925	1405	1.329	1.279	96.257
1425	1.337	1.297	96.967	1425	1.347	1.297	96.307
1445	1.355	1.315	97.008	1445	1.365	1.315	96.357
1465	1.374	1.333	97.048	1465	1.383	1.333	96.405
1485	1.392	1.351	97.086	1485	1.401	1.352	96.451
1505	1.410	1.369	97.124	1505	1.420	1.370	96.497
1525	1.428	1.388	97.160	1525	1.438	1.388	96.541
1545	1.446	1.406	97.196	1545	1.456	1.406	96.584
1565	1.465	1.424	97.231	1565	1.474	1.424	96.627
1585	1.483	1.442	97.265	1585	1.492	1.443	96.668
1605	1.501	1.460	97.298	1605	1.511	1.461	96.708
1625	1.519	1.479	97.331	1625	1.529	1.479	96.747
1645	1.537	1.497	97.362	1645	1.547	1.497	96.785
1665	1.555	1.515	97.393	1665	1.565	1.515	96.823
1685	1.574	1.533	97.423	1685	1.583	1.534	96.859
1705	1.592	1.551	97.453	1705	1.602	1.552	96.895
1725	1.610	1.570	97.481	1725	1.620	1.570	96.930
1745	1.628	1.588	97.510	1745	1.638	1.588	96.964
1765	1.646	1.606	97.537	1765	1.656	1.606	96.997
1785	1.665	1.624	97.564	1785	1.674	1.625	97.030
1805	1.683	1.642	97.590	1805	1.693	1.643	97.062
1825	1.701	1.661	97.616	1825	1.711	1.661	97.093
1845	1.719	1.679	97.641	1845	1.729	1.679	97.124
1865	1.737	1.697	97.666	1865	1.747	1.697	97.154
1885	1.756	1.715	97.690	1885	1.765	1.716	97.183
1905	1.774	1.733	97.714	1905	1.784	1.734	97.212
1925	1.792	1.752	97.737	1925	1.802	1.752	97.240
1945	1.810	1.770	97.760	1945	1.820	1.770	97.268
1965	1.828	1.788	97.782	1965	1.838	1.789	97.295
1985	1.847	1.806	97.804	1985	1.856	1.807	97.321

2000	1.860	1.820	97.820	2000	1.870	1.820	97.341

35 to 1				40 to 1			
kw	**Mol Flow In**	**Mol Flow Out**	**% Recovery**	**kw**	**Mol Flow In**	**Mol Flow Out**	**% Recovery**
25	0.081	0.022	27.550	25	0.090	0.022	24.758
45	0.100	0.041	40.837	45	0.109	0.041	37.390
65	0.118	0.059	50.001	65	0.127	0.059	46.386
85	0.136	0.077	56.704	85	0.145	0.077	53.119
105	0.154	0.095	61.819	105	0.163	0.095	58.348
125	0.173	0.114	65.853	125	0.182	0.114	62.527
145	0.191	0.132	69.117	145	0.200	0.132	65.944
165	0.209	0.150	71.809	165	0.218	0.150	68.789
185	0.227	0.168	74.070	185	0.236	0.168	71.195
205	0.245	0.186	75.995	205	0.255	0.187	73.257
225	0.264	0.205	77.654	225	0.273	0.205	75.043
245	0.282	0.223	79.098	245	0.291	0.223	76.605
265	0.300	0.241	80.367	265	0.309	0.241	77.984
285	0.318	0.259	81.491	285	0.327	0.259	79.208
305	0.336	0.278	82.493	305	0.346	0.278	80.304
325	0.355	0.296	83.391	325	0.364	0.296	81.290
345	0.373	0.314	84.202	345	0.382	0.314	82.182
365	0.391	0.332	84.938	365	0.400	0.332	82.993
385	0.409	0.350	85.608	385	0.419	0.350	83.733
405	0.428	0.369	86.221	405	0.437	0.369	84.411
425	0.446	0.387	86.784	425	0.455	0.387	85.036
445	0.464	0.405	87.303	445	0.473	0.405	85.612
465	0.482	0.423	87.782	465	0.491	0.423	86.145
485	0.500	0.441	88.227	485	0.510	0.442	86.640
505	0.519	0.460	88.641	505	0.528	0.460	87.101
525	0.537	0.478	89.026	525	0.546	0.478	87.531
545	0.555	0.496	89.386	545	0.564	0.496	87.934
565	0.573	0.514	89.723	565	0.583	0.514	88.311
585	0.591	0.533	90.040	585	0.601	0.533	88.666
605	0.610	0.551	90.337	605	0.619	0.551	88.999
625	0.628	0.569	90.618	625	0.637	0.569	89.314
645	0.646	0.587	90.882	645	0.655	0.587	89.611
665	0.664	0.605	91.132	665	0.674	0.606	89.892
685	0.682	0.624	91.369	685	0.692	0.624	90.158
705	0.701	0.642	91.593	705	0.710	0.642	90.410
725	0.719	0.660	91.806	725	0.728	0.660	90.650

745	0.737	0.678	92.008	745	0.746	0.678	90.878
765	0.755	0.696	92.201	765	0.765	0.697	91.096
785	0.774	0.715	92.385	785	0.783	0.715	91.303
805	0.792	0.733	92.560	805	0.801	0.733	91.501
825	0.810	0.751	92.727	825	0.819	0.751	91.690
845	0.828	0.769	92.887	845	0.838	0.769	91.870
865	0.846	0.787	93.040	865	0.856	0.788	92.043
885	0.865	0.806	93.187	885	0.874	0.806	92.209
905	0.883	0.824	93.327	905	0.892	0.824	92.368
925	0.901	0.842	93.462	925	0.910	0.842	92.521
945	0.919	0.860	93.591	945	0.929	0.861	92.668
965	0.937	0.879	93.716	965	0.947	0.879	92.809
985	0.956	0.897	93.836	985	0.965	0.897	92.944
1005	0.974	0.915	93.951	1005	0.983	0.915	93.075
1025	0.992	0.933	94.062	1025	1.001	0.933	93.201
1045	1.010	0.951	94.169	1045	1.020	0.952	93.322
1065	1.028	0.970	94.272	1065	1.038	0.970	93.440
1085	1.047	0.988	94.372	1085	1.056	0.988	93.553
1105	1.065	1.006	94.468	1105	1.074	1.006	93.662
1125	1.083	1.024	94.561	1125	1.093	1.024	93.768
1145	1.101	1.042	94.651	1145	1.111	1.043	93.870
1165	1.120	1.061	94.738	1165	1.129	1.061	93.969
1185	1.138	1.079	94.822	1185	1.147	1.079	94.065
1205	1.156	1.097	94.904	1205	1.165	1.097	94.157
1225	1.174	1.115	94.983	1225	1.184	1.116	94.247
1245	1.192	1.133	95.060	1245	1.202	1.134	94.335
1265	1.211	1.152	95.134	1265	1.220	1.152	94.419
1285	1.229	1.170	95.206	1285	1.238	1.170	94.501
1305	1.247	1.188	95.276	1305	1.256	1.188	94.581
1325	1.265	1.206	95.344	1325	1.275	1.207	94.658
1345	1.283	1.225	95.410	1345	1.293	1.225	94.734
1365	1.302	1.243	95.474	1365	1.311	1.243	94.807
1385	1.320	1.261	95.537	1385	1.329	1.261	94.878
1405	1.338	1.279	95.597	1405	1.348	1.279	94.947
1425	1.356	1.297	95.657	1425	1.366	1.298	95.015
1445	1.374	1.316	95.714	1445	1.384	1.316	95.080
1465	1.393	1.334	95.770	1465	1.402	1.334	95.144
1485	1.411	1.352	95.825	1485	1.420	1.352	95.206
1505	1.429	1.370	95.878	1505	1.439	1.370	95.267
1525	1.447	1.388	95.930	1525	1.457	1.389	95.326
1545	1.466	1.407	95.980	1545	1.475	1.407	95.384

1565	1.484	1.425	96.030	1565	1.493	1.425	95.440
1585	1.502	1.443	96.078	1585	1.511	1.443	95.495
1605	1.520	1.461	96.125	1605	1.530	1.462	95.549
1625	1.538	1.479	96.171	1625	1.548	1.480	95.601
1645	1.557	1.498	96.215	1645	1.566	1.498	95.652
1665	1.575	1.516	96.259	1665	1.584	1.516	95.702
1685	1.593	1.534	96.302	1685	1.603	1.534	95.751
1705	1.611	1.552	96.344	1705	1.621	1.553	95.799
1725	1.629	1.570	96.385	1725	1.639	1.571	95.846
1745	1.648	1.589	96.425	1745	1.657	1.589	95.891
1765	1.666	1.607	96.464	1765	1.675	1.607	95.936
1785	1.684	1.625	96.502	1785	1.694	1.625	95.980
1805	1.702	1.643	96.539	1805	1.712	1.644	96.022
1825	1.720	1.662	96.576	1825	1.730	1.662	96.064
1845	1.739	1.680	96.612	1845	1.748	1.680	96.105
1865	1.757	1.698	96.647	1865	1.766	1.698	96.145
1885	1.775	1.716	96.681	1885	1.785	1.717	96.185
1905	1.793	1.734	96.715	1905	1.803	1.735	96.223
1925	1.811	1.753	96.748	1925	1.821	1.753	96.261
1945	1.830	1.771	96.780	1945	1.839	1.771	96.298
1965	1.848	1.789	96.812	1965	1.858	1.789	96.334
1985	1.866	1.807	96.843	1985	1.876	1.808	96.370
2000	1.880	1.821	96.866	2000	1.889	1.821	96.396

45 to 1				**50 to 1**			
kw	**Mol Flow In**	**Mol Flow Out**	**% Recovery**	**kw**	**Mol Flow In**	**Mol Flow Out**	**% Recovery**
25	0.100	0.022	22.482	25	0.109	0.022	20.591
45	0.118	0.041	34.481	45	0.127	0.041	31.994
65	0.136	0.059	43.260	65	0.145	0.059	40.530
85	0.154	0.077	49.962	85	0.164	0.077	47.161
105	0.173	0.095	55.247	105	0.182	0.095	52.460
125	0.191	0.114	59.522	125	0.200	0.114	56.793
145	0.209	0.132	63.051	145	0.218	0.132	60.402
165	0.227	0.150	66.013	165	0.237	0.150	63.454
185	0.246	0.168	68.536	185	0.255	0.168	66.069
205	0.264	0.187	70.710	205	0.273	0.187	68.334
225	0.282	0.205	72.602	225	0.291	0.205	70.316
245	0.300	0.223	74.265	245	0.309	0.223	72.065
265	0.318	0.241	75.738	265	0.328	0.241	73.618
285	0.337	0.259	77.051	285	0.346	0.259	75.008

305	0.355	0.278	78.229	305	0.364	0.278	76.259
325	0.373	0.296	79.292	325	0.382	0.296	77.391
345	0.391	0.314	80.257	345	0.401	0.314	78.420
365	0.410	0.332	81.135	365	0.419	0.332	79.359
385	0.428	0.351	81.938	385	0.437	0.351	80.219
405	0.446	0.369	82.676	405	0.455	0.369	81.011
425	0.464	0.387	83.356	425	0.473	0.387	81.742
445	0.482	0.405	83.985	445	0.492	0.405	82.419
465	0.501	0.423	84.568	465	0.510	0.423	83.047
485	0.519	0.442	85.109	485	0.528	0.442	83.632
505	0.537	0.460	85.614	505	0.546	0.460	84.178
525	0.555	0.478	86.086	525	0.565	0.478	84.689
545	0.574	0.496	86.528	545	0.583	0.496	85.167
565	0.592	0.515	86.943	565	0.601	0.515	85.617
585	0.610	0.533	87.333	585	0.619	0.533	86.040
605	0.628	0.551	87.701	605	0.637	0.551	86.439
625	0.646	0.569	88.047	625	0.656	0.569	86.816
645	0.665	0.587	88.375	645	0.674	0.587	87.173
665	0.683	0.606	88.685	665	0.692	0.606	87.510
685	0.701	0.624	88.979	685	0.710	0.624	87.831
705	0.719	0.642	89.258	705	0.729	0.642	88.135
725	0.738	0.660	89.523	725	0.747	0.660	88.425
745	0.756	0.678	89.776	745	0.765	0.679	88.700
765	0.774	0.697	90.017	765	0.783	0.697	88.963
785	0.792	0.715	90.246	785	0.801	0.715	89.214
805	0.810	0.733	90.466	805	0.820	0.733	89.454
825	0.829	0.751	90.675	825	0.838	0.751	89.683
845	0.847	0.770	90.876	845	0.856	0.770	89.903
865	0.865	0.788	91.068	865	0.874	0.788	90.113
885	0.883	0.806	91.252	885	0.893	0.806	90.315
905	0.901	0.824	91.429	905	0.911	0.824	90.509
925	0.920	0.842	91.599	925	0.929	0.843	90.695
945	0.938	0.861	91.762	945	0.947	0.861	90.874
965	0.956	0.879	91.919	965	0.965	0.879	91.046
985	0.974	0.897	92.070	985	0.984	0.897	91.212
1005	0.993	0.915	92.216	1005	1.002	0.915	91.372
1025	1.011	0.934	92.356	1025	1.020	0.934	91.526
1045	1.029	0.952	92.491	1045	1.038	0.952	91.675
1065	1.047	0.970	92.622	1065	1.057	0.970	91.818
1085	1.065	0.988	92.748	1085	1.075	0.988	91.957
1105	1.084	1.006	92.870	1105	1.093	1.007	92.091

1125	1.102	1.025	92.988	1125	1.111	1.025	92.221
1145	1.120	1.043	93.102	1145	1.129	1.043	92.346
1165	1.138	1.061	93.212	1165	1.148	1.061	92.468
1185	1.157	1.079	93.319	1185	1.166	1.079	92.585
1205	1.175	1.097	93.423	1205	1.184	1.098	92.700
1225	1.193	1.116	93.523	1225	1.202	1.116	92.810
1245	1.211	1.134	93.621	1245	1.221	1.134	92.918
1265	1.229	1.152	93.715	1265	1.239	1.152	93.022
1285	1.248	1.170	93.807	1285	1.257	1.171	93.123
1305	1.266	1.189	93.896	1305	1.275	1.189	93.221
1325	1.284	1.207	93.983	1325	1.293	1.207	93.317
1345	1.302	1.225	94.067	1345	1.312	1.225	93.409
1365	1.320	1.243	94.149	1365	1.330	1.243	93.500
1385	1.339	1.261	94.228	1385	1.348	1.262	93.588
1405	1.357	1.280	94.306	1405	1.366	1.280	93.673
1425	1.375	1.298	94.381	1425	1.385	1.298	93.756
1445	1.393	1.316	94.455	1445	1.403	1.316	93.837
1465	1.412	1.334	94.526	1465	1.421	1.335	93.916
1485	1.430	1.353	94.596	1485	1.439	1.353	93.994
1505	1.448	1.371	94.664	1505	1.457	1.371	94.069
1525	1.466	1.389	94.730	1525	1.476	1.389	94.142
1545	1.484	1.407	94.795	1545	1.494	1.407	94.213
1565	1.503	1.425	94.858	1565	1.512	1.426	94.283
1585	1.521	1.444	94.920	1585	1.530	1.444	94.351
1605	1.539	1.462	94.980	1605	1.549	1.462	94.418
1625	1.557	1.480	95.039	1625	1.567	1.480	94.482
1645	1.576	1.498	95.096	1645	1.585	1.499	94.546
1665	1.594	1.516	95.152	1665	1.603	1.517	94.608
1685	1.612	1.535	95.207	1685	1.621	1.535	94.668
1705	1.630	1.553	95.260	1705	1.640	1.553	94.728
1725	1.648	1.571	95.313	1725	1.658	1.571	94.786
1745	1.667	1.589	95.364	1745	1.676	1.590	94.842
1765	1.685	1.608	95.414	1765	1.694	1.608	94.898
1785	1.703	1.626	95.463	1785	1.713	1.626	94.952
1805	1.721	1.644	95.511	1805	1.731	1.644	95.005
1825	1.740	1.662	95.558	1825	1.749	1.663	95.057
1845	1.758	1.680	95.604	1845	1.767	1.681	95.108
1865	1.776	1.699	95.649	1865	1.785	1.699	95.158
1885	1.794	1.717	95.693	1885	1.804	1.717	95.207
1905	1.812	1.735	95.737	1905	1.822	1.735	95.255
1925	1.831	1.753	95.779	1925	1.840	1.754	95.302

1945	1.849	1.772	95.821	1945	1.858	1.772	95.348
1965	1.867	1.790	95.862	1965	1.876	1.790	95.393
1985	1.885	1.808	95.902	1985	1.895	1.808	95.438
2000	1.899	1.822	95.931	2000	1.908	1.822	95.470

Table 6: T-101 Pressure Analysis at 6:1 MeOH:TAG

.5 atm				1 atm			
kw	**Mol Flow In**	**Mol Flow Out**	**% Recovery**	**kw**	**Mol Flow In**	**Mol Flow Out**	**% Recovery**
5	0.012	0.006	51.632	25	0.028	0.022	79.600
25	0.031	0.025	81.473	45	0.046	0.040	87.681
45	0.049	0.044	88.492	65	0.064	0.059	91.164
65	0.068	0.062	91.644	85	0.082	0.077	93.108
85	0.086	0.081	93.438	105	0.100	0.095	94.350
105	0.105	0.099	94.597	125	0.118	0.113	95.212
125	0.124	0.118	95.407	145	0.137	0.131	95.846
145	0.142	0.136	96.006	165	0.155	0.149	96.331
165	0.161	0.155	96.467	185	0.173	0.167	96.715
185	0.179	0.173	96.832	205	0.191	0.185	97.026
205	0.198	0.192	97.129	225	0.209	0.203	97.283
225	0.216	0.210	97.374	245	0.227	0.221	97.499
245	0.235	0.229	97.582	265	0.245	0.239	97.684
265	0.253	0.247	97.758	285	0.263	0.257	97.843
285	0.272	0.266	97.911	305	0.281	0.275	97.981
305	0.290	0.284	98.044	325	0.299	0.293	98.103
325	0.309	0.303	98.162	345	0.317	0.311	98.211
345	0.327	0.321	98.266	365	0.335	0.329	98.307
365	0.346	0.340	98.358	385	0.353	0.347	98.394
385	0.364	0.358	98.442	405	0.371	0.366	98.472
405	0.383	0.377	98.517	425	0.389	0.384	98.543
425	0.401	0.395	98.585	445	0.407	0.402	98.607
445	0.420	0.414	98.648	465	0.425	0.420	98.666
465	0.438	0.432	98.705	485	0.443	0.438	98.721
485	0.457	0.451	98.757	505	0.461	0.456	98.771
505	0.475	0.469	98.806	525	0.479	0.474	98.817
525	0.493	0.488	98.851	545	0.498	0.492	98.860
545	0.512	0.506	98.892	565	0.516	0.510	98.900
565	0.530	0.525	98.931	585	0.534	0.528	98.937
585	0.549	0.543	98.967	605	0.552	0.546	98.972
605	0.567	0.562	99.000	625	0.570	0.564	99.004
625	0.586	0.580	99.032	645	0.588	0.582	99.035

645	0.604	0.599	99.062	665	0.606	0.600	99.064
665	0.623	0.617	99.089	685	0.624	0.618	99.091
685	0.641	0.636	99.116	705	0.642	0.636	99.116
705	0.660	0.654	99.140	725	0.660	0.654	99.140
725	0.678	0.673	99.164	745	0.678	0.672	99.163
745	0.697	0.691	99.186	765	0.696	0.690	99.185
765	0.715	0.710	99.207	785	0.714	0.708	99.206
785	0.734	0.728	99.227	805	0.732	0.726	99.225
805	0.752	0.747	99.246	825	0.750	0.744	99.244
825	0.771	0.765	99.264	845	0.768	0.762	99.262
845	0.789	0.784	99.281	865	0.786	0.781	99.279
865	0.808	0.802	99.298	885	0.804	0.799	99.295
885	0.826	0.821	99.314	905	0.822	0.817	99.310
905	0.845	0.839	99.329	925	0.840	0.835	99.325
925	0.863	0.858	99.343	945	0.858	0.853	99.339
945	0.882	0.876	99.357	965	0.876	0.871	99.353
965	0.900	0.895	99.370	985	0.894	0.889	99.366
985	0.919	0.913	99.383	1005	0.913	0.907	99.378
1005	0.937	0.932	99.395				

10 atm				**50 atm**			
kw	**Mol Flow In**	**Mol Flow Out**	**% Recovery**	**kw**	**Mol Flow In**	**Mol Flow Out**	**% Recovery**
	0.015	0.010	63.355	45.00	0.016	0.010	63.801
25	0.032	0.026	82.190	65.00	0.030	0.024	81.106
45	0.048	0.042	88.206	85.00	0.044	0.039	87.190
65	0.064	0.059	91.177	105.00	0.058	0.053	90.303
85	0.080	0.075	92.950	125.00	0.073	0.067	92.196
105	0.097	0.091	94.128	145.00	0.087	0.081	93.470
125	0.113	0.107	94.969	165.00	0.101	0.095	94.386
145	0.129	0.123	95.599	185.00	0.115	0.110	95.076
165	0.145	0.139	96.088	205.00	0.129	0.124	95.615
185	0.161	0.155	96.480	225.00	0.144	0.138	96.048
205	0.177	0.172	96.800	245.00	0.158	0.152	96.403
225	0.193	0.188	97.067	265.00	0.172	0.166	96.699
245	0.209	0.204	97.292	285.00	0.186	0.180	96.950
265	0.226	0.220	97.486	305.00	0.200	0.194	97.166
285	0.242	0.236	97.653	325.00	0.214	0.209	97.353
305	0.258	0.252	97.800	345.00	0.228	0.223	97.517
325	0.274	0.268	97.929	365.00	0.243	0.237	97.662
345	0.290	0.284	98.044	385.00	0.257	0.251	97.791

365	0.306	0.301	98.147	405.00	0.271	0.265	97.906
385	0.322	0.317	98.240	425.00	0.285	0.279	98.010
405	0.338	0.333	98.324	445.00	0.299	0.294	98.104
425	0.355	0.349	98.400	465.00	0.313	0.308	98.189
445	0.371	0.365	98.469	485.00	0.327	0.322	98.268
465	0.387	0.381	98.533	505.00	0.342	0.336	98.340
485	0.403	0.397	98.592	525.00	0.356	0.350	98.406
505	0.419	0.413	98.646	545.00	0.370	0.364	98.467
525	0.435	0.429	98.696	565.00	0.384	0.378	98.523
545	0.451	0.446	98.743	585.00	0.398	0.392	98.575
565	0.467	0.462	98.786	605.00	0.412	0.407	98.624
585	0.483	0.478	98.827	625.00	0.427	0.421	98.670
605	0.500	0.494	98.864	645.00	0.441	0.435	98.713
625	0.516	0.510	98.900	665.00	0.455	0.449	98.753
645	0.532	0.526	98.933	685.00	0.469	0.463	98.790
665	0.548	0.542	98.965	705.00	0.483	0.477	98.826
685	0.564	0.558	98.994	725.00	0.497	0.492	98.859
705	0.580	0.574	99.022	745.00	0.511	0.506	98.891
725	0.596	0.591	99.049	765.00	0.526	0.520	98.921
745	0.612	0.607	99.074	785.00	0.540	0.534	98.949
765	0.628	0.623	99.097	805.00	0.554	0.548	98.976
785	0.644	0.639	99.120	825.00	0.568	0.562	99.001
805	0.661	0.655	99.141	845.00	0.582	0.576	99.026
825	0.677	0.671	99.162	865.00	0.596	0.591	99.049
845	0.693	0.687	99.181	885.00	0.610	0.605	99.071
865	0.709	0.703	99.200	905.00	0.625	0.619	99.092
885	0.725	0.719	99.218	925.00	0.639	0.633	99.112
905	0.741	0.735	99.235	945.00	0.653	0.647	99.131
925	0.757	0.752	99.251	965.00	0.667	0.661	99.149
945	0.773	0.768	99.267	985.00	0.681	0.675	99.167
965	0.789	0.784	99.281	1005.00	0.695	0.690	99.184
985	0.806	0.800	99.296				

Table 7: T-101 Pressure Analysis at 50:1 MeOH:TAG

.5 atm				1 atm			
kw	**Mol Flow In**	**Mol Flow Out**	**% Recovery**	**kw**	**Mol Flow In**	**Mol Flow Out**	**% Recovery**
1	0.093	0.007	7.458	1	0.087	0.000	0.572
5	0.097	0.011	11.017	5	0.091	0.004	4.583
25	0.116	0.029	25.364	25	0.109	0.022	20.591
45	0.134	0.048	35.724	45	0.127	0.041	31.994

65	0.153	0.067	43.555	65	0.145	0.059	40.530
85	0.172	0.085	49.683	85	0.164	0.077	47.161
105	0.190	0.104	54.610	105	0.182	0.095	52.460
125	0.209	0.123	58.657	125	0.200	0.114	56.793
145	0.228	0.141	62.041	145	0.218	0.132	60.402
165	0.246	0.160	64.913	165	0.237	0.150	63.454
185	0.265	0.179	67.381	185	0.255	0.168	66.069
205	0.284	0.197	69.524	205	0.273	0.187	68.334
225	0.302	0.216	71.403	225	0.291	0.205	70.316
245	0.321	0.234	73.065	245	0.309	0.223	72.065
265	0.340	0.253	74.543	265	0.328	0.241	73.618
285	0.358	0.272	75.867	285	0.346	0.259	75.008
305	0.377	0.290	77.061	305	0.364	0.278	76.259
325	0.395	0.309	78.141	325	0.382	0.296	77.391
345	0.414	0.328	79.125	345	0.401	0.314	78.420
365	0.433	0.346	80.024	365	0.419	0.332	79.359
385	0.451	0.365	80.848	385	0.437	0.351	80.219
405	0.470	0.384	81.609	405	0.455	0.369	81.011
425	0.489	0.402	82.310	425	0.473	0.387	81.742
445	0.507	0.421	82.960	445	0.492	0.405	82.419
465	0.526	0.439	83.563	465	0.510	0.423	83.047
485	0.545	0.458	84.126	485	0.528	0.442	83.632
505	0.563	0.477	84.651	505	0.546	0.460	84.178
525	0.582	0.495	85.142	525	0.565	0.478	84.689
545	0.600	0.514	85.603	545	0.583	0.496	85.167
565	0.619	0.533	86.037	565	0.601	0.515	85.617
585	0.638	0.551	86.444	585	0.619	0.533	86.040
605	0.656	0.570	86.829	605	0.637	0.551	86.439
625	0.675	0.589	87.193	625	0.656	0.569	86.816
645	0.694	0.607	87.537	645	0.674	0.587	87.173
665	0.712	0.626	87.864	665	0.692	0.606	87.510
685	0.731	0.644	88.173	685	0.710	0.624	87.831
705	0.750	0.663	88.467	705	0.729	0.642	88.135
725	0.768	0.682	88.747	725	0.747	0.660	88.425
745	0.787	0.700	89.013	745	0.765	0.679	88.700
765	0.805	0.719	89.267	765	0.783	0.697	88.963
785	0.824	0.738	89.510	785	0.801	0.715	89.214
805	0.843	0.756	89.742	805	0.820	0.733	89.454
825	0.861	0.775	89.964	825	0.838	0.751	89.683
845	0.880	0.794	90.176	845	0.856	0.770	89.903
865	0.899	0.812	90.380	865	0.874	0.788	90.113

885	0.917	0.831	90.575	885	0.893	0.806	90.315
905	0.936	0.849	90.763	905	0.911	0.824	90.509
925	0.954	0.868	90.943	925	0.929	0.843	90.695
945	0.973	0.887	91.117	945	0.947	0.861	90.874
965	0.992	0.905	91.283	965	0.965	0.879	91.046
985	1.010	0.924	91.444	985	0.984	0.897	91.212
1005	1.029	0.943	91.599	1005	1.002	0.915	91.372
1025	1.048	0.961	91.748	1025	1.020	0.934	91.526
1045	1.066	0.980	91.893	1045	1.038	0.952	91.675
1065	1.085	0.999	92.033	1065	1.057	0.970	91.818
1085	1.104	1.017	92.167	1085	1.075	0.988	91.957
1105	1.122	1.036	92.297	1105	1.093	1.007	92.091
1125	1.141	1.054	92.423	1125	1.111	1.025	92.221
1145	1.160	1.073	92.545	1145	1.129	1.043	92.346
1165	1.178	1.092	92.662	1165	1.148	1.061	92.468
1185	1.197	1.110	92.777	1185	1.166	1.079	92.585
1205	1.215	1.129	92.887	1205	1.184	1.098	92.700
1225	1.234	1.148	92.995	1225	1.202	1.116	92.810
1245	1.253	1.166	93.099	1245	1.221	1.134	92.918
1265	1.271	1.185	93.200	1265	1.239	1.152	93.022
1285	1.290	1.203	93.298	1285	1.257	1.171	93.123
1305	1.309	1.222	93.394	1305	1.275	1.189	93.221
1325	1.327	1.241	93.486	1325	1.293	1.207	93.317
1345	1.346	1.259	93.577	1345	1.312	1.225	93.409
1365	1.364	1.278	93.664	1365	1.330	1.243	93.500
1385	1.383	1.297	93.750	1385	1.348	1.262	93.588
1405	1.402	1.315	93.833	1405	1.366	1.280	93.673
1425	1.420	1.334	93.914	1425	1.385	1.298	93.756
1445	1.439	1.352	93.992	1445	1.403	1.316	93.837
1465	1.458	1.371	94.069	1465	1.421	1.335	93.916
1485	1.476	1.390	94.144	1485	1.439	1.353	93.994
1505	1.495	1.408	94.217	1505	1.457	1.371	94.069
1525	1.513	1.427	94.288	1525	1.476	1.389	94.142
1545	1.532	1.446	94.358	1545	1.494	1.407	94.213
1565	1.551	1.464	94.425	1565	1.512	1.426	94.283
1585	1.569	1.483	94.492	1585	1.530	1.444	94.351
1605	1.588	1.502	94.556	1605	1.549	1.462	94.418
1625	1.607	1.520	94.619	1625	1.567	1.480	94.482
1645	1.625	1.539	94.681	1645	1.585	1.499	94.546
1665	1.644	1.557	94.741	1665	1.603	1.517	94.608
1685	1.662	1.576	94.800	1685	1.621	1.535	94.669

1705	1.681	1.595	94.858	1705	1.640	1.553	94.728
1725	1.700	1.613	94.915	1725	1.658	1.571	94.786
1745	1.719	1.632	94.970	1745	1.676	1.590	94.842
1765	1.737	1.651	95.024	1765	1.694	1.608	94.898
1785	1.756	1.669	95.077	1785	1.713	1.626	94.952
1805	1.774	1.688	95.128	1805	1.731	1.644	95.005
1825	1.793	1.707	95.179	1825	1.749	1.663	95.057
1845	1.812	1.725	95.228	1845	1.767	1.681	95.108
1865	1.830	1.744	95.277	1865	1.785	1.699	95.158
1885	1.849	1.762	95.325	1885	1.804	1.717	95.207
1905	1.868	1.781	95.371	1905	1.822	1.735	95.255
1925	1.886	1.800	95.417	1925	1.840	1.754	95.302
1945	1.905	1.818	95.462	1945	1.858	1.772	95.348
1965	1.923	1.837	95.506	1965	1.876	1.790	95.393
1985	1.942	1.856	95.549	1985	1.895	1.808	95.438
2000	1.956	1.870	95.581	2000	1.908	1.822	95.470

10 atm				**50 atm**			
kw	**Mol Flow In**	**Mol Flow Out**	**% Recovery**	**kw**	**Mol Flow In**	**Mol Flow Out**	**% Recovery**
45	0.095	0.008	8.556	85.00	0.102	0.015	15.162
65	0.111	0.025	22.163	105.00	0.117	0.031	26.330
85	0.128	0.041	32.243	125.00	0.133	0.046	34.897
105	0.144	0.058	40.008	145.00	0.148	0.062	41.677
125	0.161	0.074	46.175	165.00	0.164	0.077	47.177
145	0.177	0.091	51.192	185.00	0.179	0.093	51.729
165	0.194	0.107	55.352	205.00	0.195	0.108	55.558
185	0.210	0.124	58.859	225.00	0.210	0.123	58.824
205	0.227	0.140	61.855	245.00	0.225	0.139	61.643
225	0.243	0.157	64.444	265.00	0.241	0.154	64.100
245	0.260	0.173	66.703	285.00	0.256	0.170	66.262
265	0.276	0.190	68.693	305.00	0.272	0.185	68.178
285	0.293	0.206	70.458	325.00	0.287	0.201	69.887
305	0.309	0.223	72.035	345.00	0.302	0.216	71.423
325	0.326	0.239	73.452	365.00	0.318	0.231	72.809
345	0.342	0.256	74.732	385.00	0.333	0.247	74.067
365	0.359	0.272	75.894	405.00	0.349	0.262	75.214
385	0.375	0.289	76.954	425.00	0.364	0.278	76.264
405	0.392	0.305	77.925	445.00	0.380	0.293	77.228
425	0.408	0.322	78.818	465.00	0.395	0.309	78.117
445	0.425	0.338	79.640	485.00	0.410	0.324	78.939

465	0.441	0.355	80.402	505.00	0.426	0.339	79.702
485	0.458	0.371	81.108	525.00	0.441	0.355	80.411
505	0.474	0.388	81.766	545.00	0.457	0.370	81.073
525	0.491	0.404	82.379	565.00	0.472	0.386	81.691
545	0.507	0.421	82.952	585.00	0.488	0.401	82.270
565	0.524	0.437	83.489	605.00	0.503	0.417	82.814
585	0.540	0.454	83.993	625.00	0.518	0.432	83.325
605	0.557	0.470	84.468	645.00	0.534	0.447	83.807
625	0.573	0.487	84.915	665.00	0.549	0.463	84.261
645	0.590	0.503	85.337	685.00	0.565	0.478	84.691
665	0.606	0.520	85.736	705.00	0.580	0.494	85.098
685	0.623	0.536	86.114	725.00	0.596	0.509	85.484
705	0.639	0.553	86.472	745.00	0.611	0.524	85.850
725	0.656	0.569	86.813	765.00	0.626	0.540	86.199
745	0.672	0.586	87.136	785.00	0.642	0.555	86.530
765	0.689	0.602	87.445	805.00	0.657	0.571	86.846
785	0.705	0.619	87.738	825.00	0.673	0.586	87.148
805	0.721	0.635	88.019	845.00	0.688	0.602	87.436
825	0.738	0.652	88.286	865.00	0.703	0.617	87.711
845	0.754	0.668	88.542	885.00	0.719	0.632	87.975
865	0.771	0.685	88.788	905.00	0.734	0.648	88.227
885	0.787	0.701	89.022	925.00	0.750	0.663	88.470
905	0.804	0.718	89.248	945.00	0.765	0.679	88.702
925	0.820	0.734	89.464	965.00	0.781	0.694	88.925
945	0.837	0.751	89.671	985.00	0.796	0.710	89.140
965	0.853	0.767	89.871	1005.00	0.811	0.725	89.346
985	0.870	0.783	90.063	1025.00	0.827	0.740	89.545
1005	0.886	0.800	90.248	1045.00	0.842	0.756	89.736
1025	0.903	0.816	90.426	1065.00	0.858	0.771	89.921
1045	0.919	0.833	90.598	1085.00	0.873	0.787	90.099
1065	0.936	0.849	90.764	1105.00	0.889	0.802	90.271
1085	0.952	0.866	90.924	1125.00	0.904	0.817	90.437
1105	0.969	0.882	91.078	1145.00	0.919	0.833	90.597
1125	0.985	0.899	91.227	1165.00	0.935	0.848	90.752
1145	1.002	0.915	91.372	1185.00	0.950	0.864	90.902
1165	1.018	0.932	91.512	1205.00	0.966	0.879	91.048
1185	1.035	0.948	91.647	1225.00	0.981	0.895	91.188
1205	1.051	0.965	91.778	1245.00	0.996	0.910	91.325
1225	1.068	0.981	91.905	1265.00	1.012	0.925	91.457
1245	1.084	0.998	92.028	1285.00	1.027	0.941	91.585
1265	1.101	1.014	92.147	1305.00	1.043	0.956	91.710

1285	1.117	1.031	92.263	1325.00	1.058	0.972	91.830
1305	1.134	1.047	92.376	1345.00	1.074	0.987	91.948
1325	1.150	1.064	92.485	1365.00	1.089	1.003	92.062
1345	1.167	1.080	92.591	1385.00	1.104	1.018	92.173
1365	1.183	1.097	92.695	1405.00	1.120	1.033	92.280
1385	1.200	1.113	92.795	1425.00	1.135	1.049	92.385
1405	1.216	1.130	92.893	1445.00	1.151	1.064	92.487
1425	1.233	1.146	92.988	1465.00	1.166	1.080	92.587
1445	1.249	1.163	93.080	1485.00	1.181	1.095	92.683
1465	1.266	1.179	93.171	1505.00	1.197	1.110	92.778
1485	1.282	1.196	93.258	1525.00	1.212	1.126	92.869
1505	1.299	1.212	93.344	1545.00	1.228	1.141	92.959
1525	1.315	1.229	93.428	1565.00	1.243	1.157	93.046
1545	1.332	1.245	93.509	1585.00	1.259	1.172	93.132
1565	1.348	1.262	93.588	1605.00	1.274	1.188	93.215
1585	1.365	1.278	93.666	1625.00	1.289	1.203	93.296
1605	1.381	1.295	93.741	1645.00	1.305	1.218	93.375
1625	1.398	1.311	93.815	1665.00	1.320	1.234	93.452
1645	1.414	1.328	93.887	1685.00	1.336	1.249	93.528
1665	1.431	1.344	93.958	1705.00	1.351	1.265	93.602
1685	1.447	1.361	94.027	1725.00	1.367	1.280	93.674
1705	1.464	1.377	94.094	1745.00	1.382	1.295	93.745
1725	1.480	1.394	94.160	1765.00	1.397	1.311	93.814
1745	1.497	1.410	94.224	1785.00	1.413	1.326	93.881
1765	1.513	1.427	94.287	1805.00	1.428	1.342	93.947
1785	1.530	1.443	94.349	1825.00	1.444	1.357	94.012
1805	1.546	1.460	94.409	1845.00	1.459	1.373	94.075
1825	1.563	1.476	94.468	1865.00	1.474	1.388	94.137
1845	1.579	1.493	94.526	1885.00	1.490	1.403	94.198
1865	1.596	1.509	94.582	1905.00	1.505	1.419	94.257
1885	1.612	1.526	94.638	1925.00	1.521	1.434	94.316
1905	1.629	1.542	94.692	1945.00	1.536	1.450	94.373
1925	1.645	1.559	94.745	1965.00	1.552	1.465	94.429
1945	1.662	1.575	94.798	1985.00	1.567	1.481	94.483
1965	1.678	1.592	94.849	2000.00	1.579	1.492	94.524
1985	1.695	1.608	94.899				
2000	1.707	1.621	94.936				

Appendix C: T-102 Data

Table 8: T-102 Vapor Composition Data

Heat Duty (kw)	Vapor Mass Flow (kg/s)			
	Glycerol	Methyl Oleate	Methanol (1 atm)	Methanol (0.5 atm)
0	0	0	0	0.000209
0.1	0	0	0	0.000295
0.2	0	0	0	0.000382
0.3	0	0	0.000082	0.000468
0.4	0	0	0.000171	0.000555
0.5	0	0	0.000259	0.000641
0.6	0	0	0.000348	0.000727
0.7	0	0	0.000437	0.000812
0.8	0	0	0.000525	0.000898
0.9	0	0	0.000613	0.000983
1	0	0	0.000701	0.001068
1.1	0	0	0.000789	0.001153
1.2	0	0	0.000877	0.001238
1.3	0	0	0.000964	0.001322
1.4	0	0	0.001051	0.001406
1.5	0	0	0.001138	0.001489
1.6	0	0	0.001224	0.001572
1.7	0	0	0.001310	0.001655
1.8	0	0	0.001395	0.001737
1.9	0	0	0.001480	0.001818
2	0	0	0.001565	0.001899
2.1	0	0	0.001648	0.001979
2.2	0	0	0.001732	0.002058
2.3	0	0	0.001814	0.002137
2.4	0	0	0.001896	0.002214
2.5	0	0	0.001977	0.002290
2.6	0	0	0.002056	0.002365
2.7	0	0	0.002135	0.002438
2.8	0	0	0.002212	0.002510
2.9	0	0	0.002288	0.002579
3	0	0	0.002363	0.002647
3.1	0	0	0.002436	0.002713
3.2	0.000001	0	0.002507	0.002776
3.3	0.000001	0	0.002575	0.002836
3.4	0.000001	0.000001	0.002642	0.002893
3.5	0.000001	0.000001	0.002706	0.002948
3.6	0.000001	0.000001	0.002767	0.002998
3.7	0.000001	0.000001	0.002826	0.003046

3.8	0.000002	0.000001	0.002881	0.003090
3.9	0.000002	0.000002	0.002934	0.003130
4	0.000002	0.000002	0.002982	0.003167
4.1	0.000003	0.000003	0.003028	0.003200
4.2	0.000004	0.000004	0.003070	0.003229
4.3	0.000005	0.000005	0.003109	0.003256
4.4	0.000006	0.000007	0.003144	0.003279
4.5	0.000007	0.000009	0.003176	0.003300
4.6	0.000009	0.000011	0.003205	0.003318
4.7	0.000012	0.000015	0.003231	0.003334
4.8	0.000015	0.000020	0.003254	0.003348
4.9	0.000019	0.000026	0.003275	0.003361
5	0.000024	0.000035	0.003293	0.003371
5.1	0.000030	0.000045	0.003310	0.003380
5.2	0.000037	0.000058	0.003324	0.003389
5.3	0.000046	0.000075	0.003337	0.003396
5.4	0.000056	0.000096	0.003349	0.003402
5.5	0.000068	0.000121	0.003359	0.003407
5.6	0.000082	0.000151	0.003368	0.003412
5.7	0.000097	0.000188	0.003376	0.003417
5.8	0.000114	0.000232	0.003383	0.003421
5.9	0.000133	0.000283	0.003390	0.003425
6	0.000154	0.000342	0.003396	0.003428
6.1	0.000176	0.000409	0.003402	0.003431
6.2	0.000200	0.000483	0.003407	0.003434
6.3	0.000226	0.000559	0.003412	0.003437
6.4	0.000254	0.000630	0.003416	0.003439
6.5	0.000287	0.000690	0.003420	0.003441
6.6	0.000323	0.000739	0.003424	0.003443
6.7	0.000364	0.000777	0.003427	0.003444
6.8	0.000409	0.000807	0.003430	0.003446
6.9	0.000457	0.000830	0.003432	0.003447
7	0.000509	0.000849	0.003434	0.003448
7.1	0.000565	0.000864	0.003437	0.003449
7.2	0.000623	0.000876	0.003438	0.003450
7.3	0.000685	0.000886	0.003440	0.003451
7.4	0.000750	0.000895	0.003442	0.003452
7.5	0.000818	0.000903	0.003443	0.003453
7.6	0.000888	0.000909	0.003444	0.003453
7.7	0.000961	0.000914	0.003445	0.003454
7.8	0.001037	0.000919	0.003447	0.003454
7.9	0.001115	0.000924	0.003448	0.003455
8	0.001195	0.000927	0.003449	0.003456

8.1	0.001277	0.000931	0.003449	0.003456
8.2	0.001361	0.000934	0.003450	0.003457
8.3	0.001447	0.000936	0.003451	0.003457
8.4	0.001535	0.000939	0.003452	0.003457
8.5	0.001625	0.000941	0.003453	0.003458
8.6	0.001716	0.000943	0.003453	0.003458
8.7	0.001809	0.000945	0.003454	0.003459
8.8	0.001904	0.000947	0.003455	0.003459
8.9	0.002000	0.000948	0.003455	0.003459
9	0.002097	0.000950	0.003456	0.003460
9.1	0.002196	0.000951	0.003456	0.003460
9.2	0.002296	0.000952	0.003457	0.003460
9.3	0.002397	0.000953	0.003457	0.003461
9.4	0.002499	0.000954	0.003458	0.003461
9.5	0.002603	0.000955	0.003458	0.003461
9.6	0.002707	0.000956	0.003459	0.003461
9.7	0.002812	0.000957	0.003459	0.003462
9.8	0.002919	0.000958	0.003459	0.003462
9.9	0.003026	0.000959	0.003460	0.003462
10	0.003134	0.000960	0.003460	0.003462
10.1	0.003242	0.000960	0.003460	0.003463
10.2	0.003353	0.000961	0.003461	0.003463
10.3	0.003463	0.000962	0.003461	0.003463
10.4	0.003575	0.000962	0.003461	0.003463
10.5	0.003687	0.000963	0.003462	0.003463
10.6	0.003800	0.000963	0.003462	0.003464
10.7	0.003913	0.000964	0.003462	0.003464
10.8	0.004027	0.000964	0.003463	0.003464
10.9	0.004141	0.000965	0.003463	0.003464
11	0.004256	0.000965	0.003463	0.003464
11.1	0.004370	0.000966	0.003464	0.003464
11.2	0.004483	0.000966	0.003464	0.003464
11.3	0.004593	0.000967	0.003464	0.003465
11.4	0.004688	0.000967	0.003464	0.003465
11.5	0.004748	0.000967	0.003464	0.003465
11.6	0.004774	0.000966	0.003464	0.003465
11.7	0.004785	0.000966	0.003464	0.003465
11.8	0.004790	0.000966	0.003464	0.003465
11.9	0.004794	0.000966	0.003465	0.003465
12	0.004795	0.000967	0.003465	0.003465
12.1	0.004797	0.000967	0.003465	0.003465
12.2	0.004798	0.000967	0.003465	0.003465
12.3	0.004798	0.000968	0.003465	0.003465

12.4	0.004799	0.000968	0.003465	0.003465
12.5	0.004799	0.000968	0.003465	0.003465
12.6	0.004800	0.000969	0.003465	0.003465
12.7	0.004800	0.000969	0.003465	0.003465
12.8	0.004800	0.000969	0.003465	0.003465
12.9	0.004800	0.000969	0.003465	0.003465
13	0.004800	0.000969	0.003465	0.003465
13.1	0.004800	0.000969	0.003465	0.003465
13.2	0.004801	0.000970	0.003465	0.003465
13.3	0.004801	0.000970	0.003465	0.003465
13.4	0.004801	0.000970	0.003465	0.003465
13.5	0.004801	0.000970	0.003465	0.003465
13.6	0.004801	0.000970	0.003465	0.003465
13.7	0.004801	0.000970	0.003465	0.003465
13.8	0.004801	0.000970	0.003465	0.003465
13.9	0.004801	0.000970	0.003465	0.003465
14	0.004801	0.000970	0.003465	0.003465
14.1	0.004801	0.000970	0.003465	0.003465
14.2	0.004801	0.000970	0.003465	0.003465
14.3	0.004801	0.000970	0.003465	0.003465
14.4	0.004801	0.000970	0.003465	0.003465
14.5	0.004801	0.000970	0.003465	0.003465
14.6	0.004801	0.000970	0.003465	0.003465
14.7	0.004801	0.000970	0.003465	0.003465
14.8	0.004801	0.000970	0.003465	0.003465
14.9	0.004801	0.000970	0.003465	0.003465
15	0.004801	0.000970	0.003465	0.003465
15.1	0.004801	0.000970	0.003465	0.003465
15.2	0.004801	0.000970	0.003465	0.003465
15.3	0.004801	0.000970	0.003465	0.003465
15.4	0.004801	0.000970	0.003465	0.003465
15.5	0.004801	0.000970	0.003465	0.003465
15.6	0.004801	0.000970	0.003465	0.003465
15.7	0.004801	0.000970	0.003465	0.003465
15.8	0.004801	0.000970	0.003465	0.003465
15.9	0.004801	0.000970	0.003465	0.003465
16	0.004801	0.000970	0.003465	0.003465
16.1	0.004801	0.000970	0.003465	0.003465
16.2	0.004801	0.000970	0.003465	0.003465
16.3	0.004801	0.000970	0.003465	0.003465
16.4	0.004801	0.000970	0.003465	0.003465
16.5	0.004801	0.000970	0.003465	0.003465
16.6	0.004801	0.000970	0.003465	0.003465

16.7	0.004801	0.000970	0.003465	0.003465
16.8	0.004801	0.000970	0.003465	0.003465
16.9	0.004801	0.000970	0.003465	0.003465
17	0.004801	0.000970	0.003465	0.003465
17.1	0.004801	0.000970	0.003465	0.003465
17.2	0.004801	0.000970	0.003465	0.003465
17.3	0.004801	0.000970	0.003465	0.003465
17.4	0.004801	0.000970	0.003465	0.003465
17.5	0.004801	0.000970	0.003465	0.003465
17.6	0.004801	0.000970	0.003465	0.003465
17.7	0.004801	0.000970	0.003465	0.003465
17.8	0.004801	0.000970	0.003465	0.003465
17.9	0.004801	0.000970	0.003465	0.003465
18	0.004801	0.000970	0.003465	0.003465
18.1	0.004801	0.000970	0.003465	0.003465
18.2	0.004801	0.000970	0.003465	0.003465
18.3	0.004801	0.000970	0.003465	0.003465
18.4	0.004801	0.000970	0.003465	0.003465
18.5	0.004801	0.000970	0.003465	0.003465
18.6	0.004801	0.000970	0.003465	0.003465
18.7	0.004801	0.000970	0.003465	0.003465
18.8	0.004801	0.000970	0.003465	0.003465
18.9	0.004801	0.000970	0.003465	0.003465
19	0.004801	0.000970	0.003465	0.003465
19.1	0.004801	0.000970	0.003465	0.003465
19.2	0.004801	0.000970	0.003465	0.003465
19.3	0.004801	0.000970	0.003465	0.003465
19.4	0.004801	0.000970	0.003465	0.003465
19.5	0.004801	0.000970	0.003465	0.003465
19.6	0.004801	0.000970	0.003465	0.003465
19.7	0.004801	0.000970	0.003465	0.003465
19.8	0.004801	0.000970	0.003465	0.003465
19.9	0.004801	0.000970	0.003465	0.003465
20	0.004801	0.000970	0.003465	0.003465
20.1	0.004801	0.000970	0.003465	0.003465
20.2	0.004801	0.000970	0.003465	0.003465
20.3	0.004801	0.000970	0.003465	0.003465
20.4	0.004801	0.000970	0.003465	0.003465
20.5	0.004801	0.000970	0.003465	0.003465
20.6	0.004801	0.000970	0.003465	0.003465
20.7	0.004801	0.000970	0.003465	0.003465
20.8	0.004801	0.000970	0.003465	0.003465
20.9	0.004801	0.000970	0.003465	0.003465

21	0.004801	0.000970	0.003465	0.003465
21.1	0.004801	0.000970	0.003465	0.003465
21.2	0.004801	0.000970	0.003465	0.003465
21.3	0.004801	0.000970	0.003465	0.003465
21.4	0.004801	0.000970	0.003465	0.003465
21.5	0.004801	0.000970	0.003465	0.003465
21.6	0.004801	0.000970	0.003465	0.003465
21.7	0.004801	0.000970	0.003465	0.003465
21.8	0.004801	0.000970	0.003465	0.003465
21.9	0.004801	0.000970	0.003465	0.003465
22	0.004801	0.000970	0.003465	0.003465
22.1	0.004801	0.000970	0.003465	0.003465
22.2	0.004801	0.000970	0.003465	0.003465
22.3	0.004801	0.000970	0.003465	0.003465
22.4	0.004801	0.000970	0.003465	0.003465
22.5	0.004801	0.000970	0.003465	0.003465
22.6	0.004801	0.000970	0.003465	0.003465
22.7	0.004801	0.000970	0.003465	0.003465
22.8	0.004801	0.000970	0.003465	0.003465
22.9	0.004801	0.000970	0.003465	0.003465
23	0.004801	0.000970	0.003465	0.003465
23.1	0.004801	0.000970	0.003465	0.003465
23.2	0.004801	0.000970	0.003465	0.003465
23.3	0.004801	0.000970	0.003465	0.003465
23.4	0.004801	0.000970	0.003465	0.003465
23.5	0.004801	0.000970	0.003465	0.003465
23.6	0.004801	0.000970	0.003465	0.003465
23.7	0.004801	0.000970	0.003465	0.003465
23.8	0.004801	0.000970	0.003465	0.003465
23.9	0.004801	0.000970	0.003465	0.003465
24	0.004801	0.000970	0.003465	0.003465
24.1	0.004801	0.000970	0.003465	0.003465
24.2	0.004801	0.000970	0.003465	0.003465
24.3	0.004801	0.000970	0.003465	0.003465
24.4	0.004801	0.000970	0.003465	0.003465
24.5	0.004801	0.000970	0.003465	0.003465
24.6	0.004801	0.000970	0.003465	0.003465
24.7	0.004801	0.000970	0.003465	0.003465
24.8	0.004801	0.000970	0.003465	0.003465
24.9	0.004801	0.000970	0.003465	0.003465
25	0.004801	0.000970	0.003465	0.003465

Appendix D: T-103 Data

Table 9: T-103 Methanol RatioAnalysis

6 to 1					10 to 1				
kW	W	in	out	% recovery	kW	W	in	out	% recovery
2	2000	0.002207	5.91E-04	0.26777	2	2000	0.003111	0.001057	0.339819
4	4000	0.002207	0.00131	0.59351	4	4000	0.003111	0.001991	0.639956
6	6000	0.002207	0.001698	0.76918	6	6000	0.003111	0.002501	0.804069
8	8000	0.002207	0.001905	0.86296	8	8000	0.003111	0.002764	0.888666
10	10000	0.002207	0.002021	0.91549	10	10000	0.003111	0.002905	0.934044
12	12000	0.002207	0.00209	0.94666	12	12000	0.003111	0.002986	0.960033
14	14000	0.002207	0.002131	0.96541	14	14000	0.003111	0.003033	0.974991
16	16000	0.002207	0.002155	0.97636	16	16000	0.003111	0.003059	0.983286
18	18000	0.002207	0.00217	0.98302	18	18000	0.003111	0.003074	0.988166
20	20000	0.002207	0.002179	0.98736	20	20000	0.003111	0.003083	0.991297
22	22000	0.002207	0.002186	0.99038	22	22000	0.003111	0.00309	0.993445
24	24000	0.002207	0.002191	0.99257	24	24000	0.003111	0.003095	0.994985
26	26000	0.002207	0.002195	0.99423	26	26000	0.003111	0.003099	0.996139
28	28000	0.002207	0.002197	0.99551	28	28000	0.003111	0.003101	0.997023
30	30000	0.002207	0.0022	0.99653	30	30000	0.003111	0.003103	0.997721
32	32000	0.002207	0.002201	0.99735	32	32000	0.003111	0.003105	0.998274
34	34000	0.002207	0.002203	0.99802	34	34000	0.003111	0.003107	0.99872
36	36000	0.002207	0.002204	0.99855	36	36000	0.003111	0.003108	0.999077
38	38000	0.002207	0.002205	0.99897	38	38000	0.003111	0.003109	0.999367
40	40000	0.002207	0.002206	0.99930	40	40000	0.003111	0.003109	0.999595
42	42000	0.002207	0.002206	0.99956	42	42000	0.003111	0.00311	0.999772
44	44000	0.002207	0.002207	0.99976	44	44000	0.003111	0.00311	0.999904
46	46000	0.002207	0.002207	0.99990	46	46000	0.003111	0.00311	0.999968
48	48000	0.002207	0.002207	0.99996	48	48000	0.003111	0.00311	0.999981
50	50000	0.002207	0.002207	0.99998	50	50000	0.003111	0.003111	0.999987
52	52000	0.002207	0.002207	0.99999	52	52000	0.003111	0.003111	0.99999
54	54000	0.002207	0.002207	0.99999	54	54000	0.003111	0.003111	0.999994
56	56000	0.002207	0.002207	0.99999	56	56000	0.003111	0.003111	0.999994
58	58000	0.002207	0.002207	1.00000	58	58000	0.003111	0.003111	0.999994
60	60000	0.002207	0.002207	1.00000	60	60000	0.003111	0.003111	0.999997
62	62000	0.002207	0.002207	1.00000	62	62000	0.003111	0.003111	0.999997
64	64000	0.002207	0.002207	1.00000	64	64000	0.003111	0.003111	0.999997
66	66000	0.002207	0.002207	1.00000	66	66000	0.003111	0.003111	0.999997
68	68000	0.002207	0.002207	1.00000	68	68000	0.003111	0.003111	0.999997
70	70000	0.002207	0.002207	1.00000	70	70000	0.003111	0.003111	0.999997
72	72000	0.002207	0.002207	1.00000	72	72000	0.003111	0.003111	1

74	74000	0.002207	0.002207	1.00000	74	74000	0.003111	0.003111	1
76	76000	0.002207	0.002207	1.00000	76	76000	0.003111	0.003111	1
78	78000	0.002207	0.002207	1.00000	78	78000	0.003111	0.003111	1
80	80000	0.002207	0.002207	1.00000	80	80000	0.003111	0.003111	1
82	82000	0.002207	0.002207	1.00000	82	82000	0.003111	0.003111	1
84	84000	0.002207	0.002207	1.00000	84	84000	0.003111	0.003111	1
86	86000	0.002207	0.002207	1.00000	86	86000	0.003111	0.003111	1
88	88000	0.002207	0.002207	1.00000	88	88000	0.003111	0.003111	1
90	90000	0.002207	0.002207	1.00000	90	90000	0.003111	0.003111	1
92	92000	0.002207	0.002207	1.00000	92	92000	0.003111	0.003111	1
94	94000	0.002207	0.002207	1.00000	94	94000	0.003111	0.003111	1
96	96000	0.002207	0.002207	1.00000	96	96000	0.003111	0.003111	1
98	98000	0.002207	0.002207	1.00000	98	98000	0.003111	0.003111	1
100	100000	0.002207	0.002207	1.00000	100	100000	0.003111	0.003111	1
102	102000	0.002207	0.002207	1.00000	102	102000	0.003111	0.003111	1
104	104000	0.002207	0.002207	1.00000	104	104000	0.003111	0.003111	1
106	106000	0.002207	0.002207	1.00000	106	106000	0.003111	0.003111	1
108	108000	0.002207	0.002207	1.00000	108	108000	0.003111	0.003111	1
110	110000	0.002207	0.002207	1.00000	110	110000	0.003111	0.003111	1
112	112000	0.002207	0.002207	1.00000	112	112000	0.003111	0.003111	1
114	114000	0.002207	0.002207	1.00000	114	114000	0.003111	0.003111	1
116	116000	0.002207	0.002207	1.00000	116	116000	0.003111	0.003111	1
118	118000	0.002207	0.002207	1.00000	118	118000	0.003111	0.003111	1
120	120000	0.002207	0.002207	1.00000	120	120000	0.003111	0.003111	1

15 to 1					**20 to 1**				
kW	**W**	**in**	**out**	**% recovery**	**kW**	**W**	**in**	**out**	**% recovery**
2	2000	0.018985	0.001593	0.083899	2	2000	0.02841	0.001565	0.0550899
4	4000	0.018985	0.003409	0.17954527	4	4000	0.02841	0.003384	0.11912555
6	6000	0.018985	0.005223	0.27513307	6	6000	0.02841	0.005203	0.18315241
8	8000	0.018985	0.007036	0.37060814	8	8000	0.02841	0.007022	0.24715955
10	10000	0.018985	0.008845	0.46591888	10	10000	0.02841	0.00884	0.31114205
12	12000	0.018985	0.01065	0.56096888	12	12000	0.02841	0.010656	0.37509358
14	14000	0.018985	0.012446	0.65556167	14	14000	0.02841	0.012472	0.43900464
16	16000	0.018985	0.014223	0.74920213	16	16000	0.02841	0.014286	0.50286113
18	18000	0.018985	0.015953	0.84028054	18	18000	0.02841	0.016098	0.56664019
20	20000	0.018985	0.0175	0.92181345	20	20000	0.02841	0.017907	0.63030379
22	22000	0.018985	0.018447	0.97165951	22	22000	0.02841	0.01971	0.69377802
24	24000	0.018985	0.018768	0.98857826	24	24000	0.02841	0.021504	0.75691998
26	26000	0.018985	0.018876	0.99424225	26	26000	0.02841	0.023276	0.81929602
28	28000	0.018985	0.018922	0.99671317	28	28000	0.02841	0.024991	0.87965868

30	30000	0.018985	0.018948	0.99808163	30	30000	0.02841	0.026519	0.93343919
32	32000	0.018985	0.018965	0.99894706	32	32000	0.02841	0.027544	0.9695098
34	34000	0.018985	0.01898	0.99974559	34	34000	0.02841	0.027999	0.98552276
36	36000	0.018985	0.018983	0.99989781	36	36000	0.02841	0.028185	0.99206761
38	38000	0.018985	0.018985	0.99998156	38	38000	0.02841	0.028272	0.99512673
40	40000	0.018985	0.018985	0.99999315	40	40000	0.02841	0.028319	0.99678706
42	42000	0.018985	0.018985	0.99999579	42	42000	0.02841	0.028348	0.99781205
44	44000	0.018985	0.018985	0.99999737	44	44000	0.02841	0.028368	0.99850405
46	46000	0.018985	0.018985	0.99999842	46	46000	0.02841	0.028396	0.9994861
48	48000	0.018985	0.018985	0.99999895	48	48000	0.02841	0.028401	0.9996899
50	50000	0.018985	0.018985	0.99999895	50	50000	0.02841	0.028405	0.9998145
52	52000	0.018985	0.018985	0.99999947	52	52000	0.02841	0.028407	0.99990356
54	54000	0.018985	0.018985	0.99999947	54	54000	0.02841	0.028409	0.99996762
56	56000	0.018985	0.018985	0.99999947	56	56000	0.02841	0.02841	0.99999014
58	58000	0.018985	0.018985	0.99999947	58	58000	0.02841	0.02841	0.99999402
60	60000	0.018985	0.018985	1	60	60000	0.02841	0.02841	0.99999578
62	62000	0.018985	0.018985	1	62	62000	0.02841	0.02841	0.99999683
64	64000	0.018985	0.018985	1	64	64000	0.02841	0.02841	0.99999754
66	66000	0.018985	0.018985	1	66	66000	0.02841	0.02841	0.99999824
68	68000	0.018985	0.018985	1	68	68000	0.02841	0.02841	0.99999859
70	70000	0.018985	0.018985	1	70	70000	0.02841	0.02841	0.99999894
72	72000	0.018985	0.018985	1	72	72000	0.02841	0.02841	0.99999894
74	74000	0.018985	0.018985	1	74	74000	0.02841	0.02841	0.9999993
76	76000	0.018985	0.018985	1	76	76000	0.02841	0.02841	0.9999993
78	78000	0.018985	0.018985	1	78	78000	0.02841	0.02841	0.9999993
80	80000	0.018985	0.018985	1	80	80000	0.02841	0.02841	0.99999965
82	82000	0.018985	0.018985	1	82	82000	0.02841	0.02841	0.99999965
84	84000	0.018985	0.018985	1	84	84000	0.02841	0.02841	0.99999965
86	86000	0.018985	0.018985	1	86	86000	0.02841	0.02841	0.99999965
88	88000	0.018985	0.018985	1	88	88000	0.02841	0.02841	0.99999965
90	90000	0.018985	0.018985	1	90	90000	0.02841	0.02841	0.99999965
92	92000	0.018985	0.018985	1	92	92000	0.02841	0.02841	1
94	94000	0.018985	0.018985	1	94	94000	0.02841	0.02841	1
96	96000	0.018985	0.018985	1	96	96000	0.02841	0.02841	1
98	98000	0.018985	0.018985	1	98	98000	0.02841	0.02841	1
100	100000	0.018985	0.018985	1	100	100000	0.02841	0.02841	1
102	102000	0.018985	0.018985	1	102	102000	0.02841	0.02841	1
104	104000	0.018985	0.018985	1	104	104000	0.02841	0.02841	1
106	106000	0.018985	0.018985	1	106	106000	0.02841	0.02841	1
108	108000	0.018985	0.018985	1	108	108000	0.02841	0.02841	1
110	110000	0.018985	0.018985	1	110	110000	0.02841	0.02841	1

112	112000	0.018985	0.018985	1	112	112000	0.02841	0.02841	1
114	114000	0.018985	0.018985	1	114	114000	0.02841	0.02841	1
116	116000	0.018985	0.018985	1	116	116000	0.02841	0.02841	1
118	118000	0.018985	0.018985	1	118	118000	0.02841	0.02841	1
120	120000	0.018985	0.018985	1	120	120000	0.02841	0.02841	1

25 to 1					**30 to 1**				
kW	**W**	**in**	**out**	**% recovery**	**kW**	**W**	**in**	**out**	**% recovery**
2	2000	0.037972	0.00154	0.04056504	2	2000	0.0476	0.001515	0.03181932
4	4000	0.037972	0.00336	0.08848058	4	4000	0.0476	0.003335	0.0700704
6	6000	0.037972	0.005181	0.13643957	6	6000	0.0476	0.005158	0.1083553
8	8000	0.037972	0.007002	0.18439381	8	8000	0.0476	0.00698	0.14663916
10	10000	0.037972	0.008822	0.2323428	10	10000	0.0476	0.008802	0.18492217
12	12000	0.037972	0.010643	0.28028519	12	12000	0.0476	0.010624	0.22320435
14	14000	0.037972	0.012463	0.32821995	14	14000	0.0476	0.012447	0.26148526
16	16000	0.037972	0.014283	0.37614549	16	16000	0.0476	0.014269	0.29976512
18	18000	0.037972	0.016102	0.42405971	18	18000	0.0476	0.016091	0.33804331
20	20000	0.037972	0.017921	0.47195945	20	20000	0.0476	0.017913	0.3763196
22	22000	0.037972	0.019739	0.51984022	22	22000	0.0476	0.019735	0.41459379
24	24000	0.037972	0.021556	0.56769492	24	24000	0.0476	0.021556	0.45286504
26	26000	0.037972	0.023372	0.61551301	26	26000	0.0476	0.023378	0.49113251
28	28000	0.037972	0.025186	0.66327527	28	28000	0.0476	0.025199	0.52939451
30	30000	0.037972	0.026996	0.71094721	30	30000	0.0476	0.02702	0.56764896
32	32000	0.037972	0.0288	0.75845744	32	32000	0.0476	0.02884	0.60589247
34	34000	0.037972	0.030592	0.80566586	34	34000	0.0476	0.03066	0.64411856
36	36000	0.037972	0.032358	0.85216402	36	36000	0.0476	0.032478	0.68231649
38	38000	0.037972	0.034056	0.89689244	38	38000	0.0476	0.034294	0.72046736
40	40000	0.037972	0.035572	0.93679409	40	40000	0.0476	0.036106	0.75853356
42	42000	0.037972	0.036674	0.96582631	42	42000	0.0476	0.03791	0.79643968
44	44000	0.037972	0.037273	0.98161311	44	44000	0.0476	0.0397	0.83403782
46	46000	0.037972	0.037563	0.98923064	46	46000	0.0476	0.041457	0.87094646
48	48000	0.037972	0.03771	0.99311696	48	48000	0.0476	0.043138	0.90626306
50	50000	0.037972	0.037793	0.99529201	50	50000	0.0476	0.044643	0.93788616
52	52000	0.037972	0.037843	0.99662195	52	52000	0.0476	0.045805	0.96229766
54	54000	0.037972	0.037877	0.99750287	54	54000	0.0476	0.046532	0.97756057
56	56000	0.037972	0.0379	0.9981265	56	56000	0.0476	0.046935	0.98602995
58	58000	0.037972	0.037942	0.9992181	58	58000	0.0476	0.047159	0.99074595
60	60000	0.037972	0.037952	0.99948988	60	60000	0.0476	0.047291	0.99352181
62	62000	0.037972	0.037958	0.99964447	62	62000	0.0476	0.047374	0.99525774
64	64000	0.037972	0.037962	0.99975192	64	64000	0.0476	0.047429	0.99640691
66	66000	0.037972	0.037965	0.9998333	66	66000	0.0476	0.047467	0.99720986

68	68000	0.037972	0.037968	0.99989835	68	68000	0.0476	0.047495	0.99780062
70	70000	0.037972	0.03797	0.99995075	70	70000	0.0476	0.047519	0.99830881
72	72000	0.037972	0.037971	0.99998341	72	72000	0.0476	0.047566	0.99929516
74	74000	0.037972	0.037971	0.99999184	74	74000	0.0476	0.047575	0.99948214
76	76000	0.037972	0.037971	0.99999421	76	76000	0.0476	0.047581	0.99960945
78	78000	0.037972	0.037971	0.99999579	78	78000	0.0476	0.047586	0.9997042
80	80000	0.037972	0.037971	0.99999658	80	80000	0.0476	0.047589	0.99977899
82	82000	0.037972	0.037972	0.99999737	82	82000	0.0476	0.047592	0.99984055
84	84000	0.037972	0.037972	0.99999789	84	84000	0.0476	0.047595	0.99989223
86	86000	0.037972	0.037972	0.99999816	86	86000	0.0476	0.047597	0.99993613
88	88000	0.037972	0.037972	0.99999842	88	88000	0.0476	0.047598	0.9999708
90	90000	0.037972	0.037972	0.99999868	90	90000	0.0476	0.047599	0.99998782
92	92000	0.037972	0.037972	0.99999895	92	92000	0.0476	0.047599	0.99999244
94	94000	0.037972	0.037972	0.99999895	94	94000	0.0476	0.047599	0.99999454
96	96000	0.037972	0.037972	0.99999921	96	96000	0.0476	0.047599	0.99999559
98	98000	0.037972	0.037972	0.99999921	98	98000	0.0476	0.0476	0.99999643
100	100000	0.037972	0.037972	0.99999921	100	100000	0.0476	0.0476	0.99999706
102	102000	0.037972	0.037972	0.99999947	102	102000	0.0476	0.0476	0.99999748
104	104000	0.037972	0.037972	0.99999947	104	104000	0.0476	0.0476	0.9999979
106	106000	0.037972	0.037972	0.99999947	106	106000	0.0476	0.0476	0.99999811
108	108000	0.037972	0.037972	0.99999947	108	108000	0.0476	0.0476	0.99999832
110	110000	0.037972	0.037972	0.99999974	110	110000	0.0476	0.0476	0.99999853
112	112000	0.037972	0.037972	0.99999974	112	112000	0.0476	0.0476	0.99999874
114	114000	0.037972	0.037972	0.99999974	114	114000	0.0476	0.0476	0.99999895
116	116000	0.037972	0.037972	0.99999974	116	116000	0.0476	0.0476	0.99999895
118	118000	0.037972	0.037972	0.99999974	118	118000	0.0476	0.0476	0.99999916
120	120000	0.037972	0.037972	0.99999974	120	120000	0.0476	0.0476	0.99999916

35 to 1					40 to 1				
kW	**W**	**in**	**out**	**% recovery**	**kW**	**W**	**in**	**out**	**% recovery**
2	2000	0.057262	0.001489	0.02600398	2	2000	0.066945	0.001464	0.02186358
4	4000	0.057262	0.003311	0.05782548	4	4000	0.066945	0.003287	0.0491035
6	6000	0.057262	0.005134	0.08966514	6	6000	0.066945	0.005111	0.07634715
8	8000	0.057262	0.006958	0.12150549	8	8000	0.066945	0.006935	0.10359155
10	10000	0.057262	0.008781	0.15334619	10	10000	0.066945	0.008759	0.13083685
12	12000	0.057262	0.010604	0.18518742	12	12000	0.066945	0.010583	0.15808319
14	14000	0.057262	0.012427	0.21702935	14	14000	0.066945	0.012407	0.18533058
16	16000	0.057262	0.014251	0.24887198	16	16000	0.066945	0.014231	0.21257917
18	18000	0.057262	0.016074	0.2807153	18	18000	0.066945	0.016055	0.2398291
20	20000	0.057262	0.017898	0.3125595	20	20000	0.066945	0.01788	0.26708052
22	22000	0.057262	0.019721	0.34440457	22	22000	0.066945	0.019704	0.29433343

24	24000	0.057262	0.021545	0.37625069	24	24000	0.066945	0.021529	0.32158814
26	26000	0.057262	0.023368	0.40809785	26	26000	0.066945	0.023353	0.34884464
28	28000	0.057262	0.025192	0.43994607	28	28000	0.066945	0.025178	0.37610324
30	30000	0.057262	0.027016	0.47179533	30	30000	0.066945	0.027003	0.40336422
32	32000	0.057262	0.02884	0.50364529	32	32000	0.066945	0.028828	0.43062759
34	34000	0.057262	0.030663	0.53549595	34	34000	0.066945	0.030654	0.4578935
36	36000	0.057262	0.032487	0.56734626	36	36000	0.066945	0.032479	0.4851624
38	38000	0.057262	0.034311	0.59919534	38	38000	0.066945	0.034305	0.51243414
40	40000	0.057262	0.036134	0.63104111	40	40000	0.066945	0.036131	0.53970901
42	42000	0.057262	0.037958	0.66287955	42	42000	0.066945	0.037957	0.56698687
44	44000	0.057262	0.03978	0.69470418	44	44000	0.066945	0.039783	0.59426757
46	46000	0.057262	0.041601	0.72650332	46	46000	0.066945	0.04161	0.62155022
48	48000	0.057262	0.043419	0.75825531	48	48000	0.066945	0.043436	0.6488339
50	50000	0.057262	0.045232	0.78991876	50	50000	0.066945	0.045263	0.6761158
52	52000	0.057262	0.047036	0.82142015	52	52000	0.066945	0.047089	0.70339187
54	54000	0.057262	0.04882	0.852585	54	54000	0.066945	0.048914	0.73065434
56	56000	0.057262	0.050567	0.88308554	56	56000	0.066945	0.050737	0.75788978
58	58000	0.057262	0.052231	0.91215441	58	58000	0.066945	0.052557	0.78507324
60	60000	0.057262	0.053729	0.93830282	60	60000	0.066945	0.05437	0.81215422
62	62000	0.057262	0.054932	0.95931777	62	62000	0.066945	0.056172	0.83907269
64	64000	0.057262	0.055761	0.97380025	64	64000	0.066945	0.05795	0.86563533
66	66000	0.057262	0.056274	0.98275494	66	66000	0.066945	0.059686	0.89156672
68	68000	0.057262	0.056584	0.98816607	68	68000	0.066945	0.061336	0.91621213
70	70000	0.057262	0.056776	0.99152591	70	70000	0.066945	0.062827	0.93848813
72	72000	0.057262	0.056901	0.99370014	72	72000	0.066945	0.064061	0.95692069
74	74000	0.057262	0.056985	0.99516674	74	74000	0.066945	0.06497	0.97050032
76	76000	0.057262	0.057044	0.99619588	76	76000	0.066945	0.065581	0.97961913
78	78000	0.057262	0.057087	0.99694665	78	78000	0.066945	0.065977	0.98553233
80	80000	0.057262	0.05712	0.99751893	80	80000	0.066945	0.066235	0.98939669
82	82000	0.057262	0.057148	0.99800966	82	82000	0.066945	0.066409	0.9919906
84	84000	0.057262	0.05721	0.99910691	84	84000	0.066945	0.066529	0.99378581
86	86000	0.057262	0.057223	0.99932677	86	86000	0.066945	0.066615	0.99506581
88	88000	0.057262	0.057231	0.99947364	88	88000	0.066945	0.066678	0.99600553
90	90000	0.057262	0.057238	0.99958227	90	90000	0.066945	0.066725	0.99671656
92	92000	0.057262	0.057243	0.99966714	92	92000	0.066945	0.066763	0.99727583
94	94000	0.057262	0.057247	0.9997363	94	94000	0.066945	0.066796	0.99776608
96	96000	0.057262	0.05725	0.9997941	96	96000	0.066945	0.066873	0.99892509
98	98000	0.057262	0.057253	0.9998437	98	98000	0.066945	0.06689	0.99917798
100	100000	0.057262	0.057255	0.99988684	100	100000	0.066945	0.066901	0.99934364
102	102000	0.057262	0.057257	0.99992473	102	102000	0.066945	0.066909	0.99946568
104	104000	0.057262	0.057259	0.99995704	104	104000	0.066945	0.066916	0.99956068

106	106000	0.057262	0.05726	0.99998027	106	106000	0.066945	0.066921	0.99963776
108	108000	0.057262	0.057261	0.99998987	108	108000	0.066945	0.066925	0.9997017
110	110000	0.057262	0.057261	0.99999301	110	110000	0.066945	0.066929	0.99975637
112	112000	0.057262	0.057261	0.99999459	112	112000	0.066945	0.066932	0.99980357
114	114000	0.057262	0.057261	0.99999563	114	114000	0.066945	0.066935	0.99984525
116	116000	0.057262	0.057261	0.99999633	116	116000	0.066945	0.066937	0.99988229
118	118000	0.057262	0.057261	0.99999686	118	118000	0.066945	0.066939	0.99991545
120	120000	0.057262	0.057261	0.99999738	120	120000	0.066945	0.066941	0.99994488

45 to 1					**50 to 1**				
kW	**W**	**in**	**out**	**% recovery**	**kW**	**W**	**in**	**out**	**% recovery**
2	2000	0.07664	0.001441	0.01880276	2	2000	0.086346	0.001417	0.01640553
4	4000	0.07664	0.003266	0.04260931	4	4000	0.086346	0.003242	0.03754458
6	6000	0.07664	0.00509	0.06641442	6	6000	0.086346	0.005067	0.05867796
8	8000	0.07664	0.006912	0.09019083	8	8000	0.086346	0.006891	0.07981226
10	10000	0.07664	0.008737	0.11399634	10	10000	0.086346	0.008716	0.10094772
12	12000	0.07664	0.010561	0.13780289	12	12000	0.086346	0.010539	0.12205643
14	14000	0.07664	0.012386	0.16161048	14	14000	0.086346	0.012364	0.14319259
16	16000	0.07664	0.014211	0.18541951	16	16000	0.086346	0.014189	0.1643299
18	18000	0.07664	0.016035	0.20922985	18	18000	0.086346	0.016014	0.18546849
20	20000	0.07664	0.01786	0.23304162	20	20000	0.086346	0.01784	0.20660847
22	22000	0.07664	0.019685	0.25685495	22	22000	0.086346	0.019665	0.22774995
24	24000	0.07664	0.021511	0.28067012	24	24000	0.086346	0.021491	0.24889294
26	26000	0.07664	0.023336	0.30448711	26	26000	0.086346	0.023317	0.27003755
28	28000	0.07664	0.025161	0.32830618	28	28000	0.086346	0.025143	0.29118413
30	30000	0.07664	0.026987	0.35212748	30	30000	0.086346	0.026969	0.31233256
32	32000	0.07664	0.028813	0.37595112	32	32000	0.086346	0.028795	0.3334832
34	34000	0.07664	0.030639	0.3997775	34	34000	0.086346	0.030621	0.35463603
36	36000	0.07664	0.032465	0.42360676	36	36000	0.086346	0.032448	0.37579141
38	38000	0.07664	0.034292	0.44743901	38	38000	0.086346	0.034275	0.39694945
40	40000	0.07664	0.036118	0.47127479	40	40000	0.086346	0.036102	0.4181104
42	42000	0.07664	0.037945	0.49511409	42	42000	0.086346	0.03793	0.43927435
44	44000	0.07664	0.039773	0.51895731	44	44000	0.086346	0.039757	0.46044177
46	46000	0.07664	0.0416	0.5428047	46	46000	0.086346	0.041585	0.4816129
48	48000	0.07664	0.043428	0.56665627	48	48000	0.086346	0.043414	0.50278786
50	50000	0.07664	0.045257	0.5905124	50	50000	0.086346	0.045242	0.5239671
52	52000	0.07664	0.047085	0.61437284	52	52000	0.086346	0.047072	0.54515074
54	54000	0.07664	0.048914	0.63823719	54	54000	0.086346	0.048901	0.56633924
56	56000	0.07664	0.050744	0.66210481	56	56000	0.086346	0.050731	0.58753261
58	58000	0.07664	0.052573	0.68597386	58	58000	0.086346	0.052561	0.6087313
60	60000	0.07664	0.054402	0.70984161	60	60000	0.086346	0.054392	0.62993509

62	62000	0.07664	0.056231	0.73370283	62	62000	0.086346	0.056224	0.65114398
64	64000	0.07664	0.058058	0.75754865	64	64000	0.086346	0.058055	0.67235738
66	66000	0.07664	0.059884	0.78136342	66	66000	0.086346	0.059887	0.69357403
68	68000	0.07664	0.061704	0.80511791	68	68000	0.086346	0.061719	0.71479207
70	70000	0.07664	0.063517	0.82877532	70	70000	0.086346	0.063551	0.7360079
72	72000	0.07664	0.065315	0.85223923	72	72000	0.086346	0.065382	0.75721528
74	74000	0.07664	0.067088	0.87536663	74	74000	0.086346	0.067212	0.77840413
76	76000	0.07664	0.068812	0.89786329	76	76000	0.086346	0.069038	0.79955627
78	78000	0.07664	0.070449	0.91922307	78	78000	0.086346	0.070859	0.82063695
80	80000	0.07664	0.071936	0.93862265	80	80000	0.086346	0.072671	0.84162568
82	82000	0.07664	0.073193	0.95502926	82	82000	0.086346	0.074465	0.86240409
84	84000	0.07664	0.074165	0.96770465	84	84000	0.086346	0.076231	0.88285174
86	86000	0.07664	0.074859	0.97675778	86	86000	0.086346	0.077944	0.90269877
88	88000	0.07664	0.075335	0.98297922	88	88000	0.086346	0.07957	0.92153071
90	90000	0.07664	0.075662	0.98723914	90	90000	0.086346	0.081054	0.93871485
92	92000	0.07664	0.075889	0.99020118	92	92000	0.086346	0.082331	0.95349853
94	94000	0.07664	0.07605	0.99230661	94	94000	0.086346	0.083352	0.96532863
96	96000	0.07664	0.076168	0.99383793	96	96000	0.086346	0.084117	0.97418533
98	98000	0.07664	0.076255	0.99497742	98	98000	0.086346	0.084668	0.98056445
100	100000	0.07664	0.076321	0.99584485	100	100000	0.086346	0.085061	0.98511591
102	102000	0.07664	0.076373	0.99652191	102	102000	0.086346	0.085343	0.988383
104	104000	0.07664	0.076415	0.99707006	104	104000	0.086346	0.085549	0.99076574
106	106000	0.07664	0.076453	0.9975638	106	106000	0.086346	0.085701	0.99253468
108	108000	0.07664	0.076544	0.99875261	108	108000	0.086346	0.085817	0.99387209
110	110000	0.07664	0.076566	0.99903784	110	110000	0.086346	0.085906	0.99490144
112	112000	0.07664	0.07658	0.99922038	112	112000	0.086346	0.085975	0.99570889
114	114000	0.07664	0.07659	0.99935464	114	114000	0.086346	0.086031	0.99635651
116	116000	0.07664	0.076598	0.99945929	116	116000	0.086346	0.086078	0.9968947
118	118000	0.07664	0.076605	0.99954384	118	118000	0.086346	0.086121	0.99739374
120	120000	0.07664	0.07661	0.99961417	120	120000	0.086346	0.086224	0.99858766

Table 10: T-103 Pressure Analysis Data

6 to 1 (0.5 atm)					6 to 1 (1 atm)				
kW	**W**	**in**	**out**	**% recovery**	**kW**	**W**	**in**	**out**	**% recovery**
2	2000	0.002207	1.33E-03	0.60412	2	2000	0.002207	5.91E-04	0.26761
4	4000	0.002207	0.001744	0.78991	4	4000	0.002207	0.00131	0.59349
6	6000	0.002207	0.00195	0.88346	6	6000	0.002207	0.001698	0.76917
8	8000	0.002207	0.002058	0.93234	8	8000	0.002207	0.001905	0.86296
10	10000	0.002207	0.002118	0.95960	10	10000	0.002207	0.002021	0.91549
12	12000	0.002207	0.002152	0.97519	12	12000	0.002207	0.002089	0.94666

14	14000	0.002207	0.002171	0.98374	14	14000	0.002207	0.002131	0.96540
16	16000	0.002207	0.002182	0.98867	16	16000	0.002207	0.002155	0.97636
18	18000	0.002207	0.002189	0.99177	18	18000	0.002207	0.00217	0.98301
20	20000	0.002207	0.002194	0.99386	20	20000	0.002207	0.002179	0.98736
22	22000	0.002207	0.002197	0.99536	22	22000	0.002207	0.002186	0.99037
24	24000	0.002207	0.002199	0.99647	24	24000	0.002207	0.002191	0.99257
26	26000	0.002207	0.002201	0.99732	26	26000	0.002207	0.002194	0.99423
28	28000	0.002207	0.002203	0.99799	28	28000	0.002207	0.002197	0.99551
30	30000	0.002207	0.002204	0.99851	30	30000	0.002207	0.0022	0.99653
32	32000	0.002207	0.002205	0.99892	32	32000	0.002207	0.002201	0.99735
34	34000	0.002207	0.002206	0.99923	34	34000	0.002207	0.002203	0.99801
36	36000	0.002207	0.002206	0.99948	36	36000	0.002207	0.002204	0.99855
38	38000	0.002207	0.002206	0.99966	38	38000	0.002207	0.002205	0.99897
40	40000	0.002207	0.002207	0.99981	40	40000	0.002207	0.002206	0.99930
42	42000	0.002207	0.002207	0.99991	42	42000	0.002207	0.002206	0.99956
44	44000	0.002207	0.002207	0.99997	44	44000	0.002207	0.002207	0.99975
46	46000	0.002207	0.002207	0.99998	46	46000	0.002207	0.002207	0.99990
48	48000	0.002207	0.002207	0.99999	48	48000	0.002207	0.002207	0.99996
50	50000	0.002207	0.002207	0.99999	50	50000	0.002207	0.002207	0.99998
52	52000	0.002207	0.002207	0.99999	52	52000	0.002207	0.002207	0.99998
54	54000	0.002207	0.002207	1.00000	54	54000	0.002207	0.002207	0.99999
56	56000	0.002207	0.002207	1.00000	56	56000	0.002207	0.002207	0.99999
58	58000	0.002207	0.002207	1.00000	58	58000	0.002207	0.002207	0.99999
60	60000	0.002207	0.002207	1.00000	60	60000	0.002207	0.002207	0.99999
62	62000	0.002207	0.002207	1.00000	62	62000	0.002207	0.002207	1.00000
64	64000	0.002207	0.002207	1.00000	64	64000	0.002207	0.002207	1.00000
66	66000	0.002207	0.002207	1.00000	66	66000	0.002207	0.002207	1.00000
68	68000	0.002207	0.002207	1.00000	68	68000	0.002207	0.002207	1.00000
70	70000	0.002207	0.002207	1.00000	70	70000	0.002207	0.002207	1.00000
72	72000	0.002207	0.002207	1.00000	72	72000	0.002207	0.002207	1.00000
74	74000	0.002207	0.002207	1.00000	74	74000	0.002207	0.002207	1.00000
76	76000	0.002207	0.002207	1.00000	76	76000	0.002207	0.002207	1.00000
78	78000	0.002207	0.002207	1.00000	78	78000	0.002207	0.002207	1.00000
80	80000	0.002207	0.002207	1.00000	80	80000	0.002207	0.002207	1.00000
82	82000	0.002207	0.002207	1.00000	82	82000	0.002207	0.002207	1.00000
84	84000	0.002207	0.002207	1.00000	84	84000	0.002207	0.002207	1.00000
86	86000	0.002207	0.002207	1.00000	86	86000	0.002207	0.002207	1.00000
88	88000	0.002207	0.002207	1.00000	88	88000	0.002207	0.002207	1.00000
90	90000	0.002207	0.002207	1.00000	90	90000	0.002207	0.002207	1.00000
92	92000	0.002207	0.002207	1.00000	92	92000	0.002207	0.002207	1.00000
94	94000	0.002207	0.002207	1.00000	94	94000	0.002207	0.002207	1.00000

96	96000	0.002207	0.002207	1.00000	96	96000	0.002207	0.002207	1.00000
98	98000	0.002207	0.002207	1.00000	98	98000	0.002207	0.002207	1.00000
100	100000	0.002207	0.002207	1.00000	100	100000	0.002207	0.002207	1.00000
102	102000	0.002207	0.002207	1.00000	102	102000	0.002207	0.002207	1.00000
104	104000	0.002207	0.002207	1.00000	104	104000	0.002207	0.002207	1.00000
106	106000	0.002207	0.002207	1.00000	106	106000	0.002207	0.002207	1.00000
108	108000	0.002207	0.002207	1.00000	108	108000	0.002207	0.002207	1.00000
110	110000	0.002207	0.002207	1.00000	110	110000	0.002207	0.002207	1.00000
112	112000	0.002207	0.002207	1.00000	112	112000	0.002207	0.002207	1.00000
114	114000	0.002207	0.002207	1.00000	114	114000	0.002207	0.002207	1.00000
116	116000	0.002207	0.002207	1.00000	116	116000	0.002207	0.002207	1.00000
118	118000	0.002207	0.002207	1.00000	118	118000	0.002207	0.002207	1.00000
120	120000	0.002207	0.002207	1.00000	120	120000	0.002207	0.002207	1.00000

6 to 1 (10 atm)					**6 to 1 (50 atm)**				
kW	**W**	**in**	**out**	**% recovery**	**kW**	**W**	**in**	**out**	**% recovery**
2	2000	0.002207	0.00E+00	0.00000	2	2000	0.002207	0.00E+00	0.00000
4	4000	0.002207	0	0.00000	4	4000	0.002207	0	0.00000
6	6000	0.002207	0	0.00000	6	6000	0.002207	0	0.00000
8	8000	0.002207	0	0.00000	8	8000	0.002207	0	0.00000
10	10000	0.002207	0	0.00000	10	10000	0.002207	0	0.00000
12	12000	0.002207	0.000674	0.30543	12	12000	0.002207	0	0.00000
14	14000	0.002207	0.001193	0.54036	14	14000	0.002207	0	0.00000
16	16000	0.002207	0.001508	0.68330	16	16000	0.002207	0	0.00000
18	18000	0.002207	0.001711	0.77508	18	18000	0.002207	0	0.00000
20	20000	0.002207	0.001847	0.83688	20	20000	0.002207	0	0.00000
22	22000	0.002207	0.001941	0.87943	22	22000	0.002207	0	0.00000
24	24000	0.002207	0.002005	0.90860	24	24000	0.002207	0.000311	0.14082
26	26000	0.002207	0.002052	0.92964	26	26000	0.002207	0.000929	0.42067
28	28000	0.002207	0.002084	0.94437	28	28000	0.002207	0.001274	0.57719
30	30000	0.002207	0.002108	0.95510	30	30000	0.002207	0.001497	0.67807
32	32000	0.002207	0.002126	0.96318	32	32000	0.002207	0.001651	0.74798
34	34000	0.002207	0.00214	0.96948	34	34000	0.002207	0.001762	0.79823
36	36000	0.002207	0.002151	0.97449	36	36000	0.002207	0.001843	0.83520
38	38000	0.002207	0.00216	0.97858	38	38000	0.002207	0.001905	0.86297
40	40000	0.002207	0.002167	0.98199	40	40000	0.002207	0.001952	0.88432
42	42000	0.002207	0.002174	0.98486	42	42000	0.002207	0.001989	0.90111
44	44000	0.002207	0.002179	0.98732	44	44000	0.002207	0.002019	0.91459
46	46000	0.002207	0.002184	0.98946	46	46000	0.002207	0.002043	0.92563
48	48000	0.002207	0.002188	0.99133	48	48000	0.002207	0.002063	0.93481
50	50000	0.002207	0.002192	0.99299	50	50000	0.002207	0.00208	0.94256

52	52000	0.002207	0.002195	0.99445	52	52000	0.002207	0.002095	0.94917
54	54000	0.002207	0.002198	0.99574	54	54000	0.002207	0.002108	0.95488
56	56000	0.002207	0.0022	0.99688	56	56000	0.002207	0.002119	0.95985
58	58000	0.002207	0.002203	0.99787	58	58000	0.002207	0.002128	0.96419
60	60000	0.002207	0.002204	0.99871	60	60000	0.002207	0.002137	0.96799
62	62000	0.002207	0.002206	0.99937	62	62000	0.002207	0.002144	0.97131
64	64000	0.002207	0.002207	0.99976	64	64000	0.002207	0.00215	0.97416
66	66000	0.002207	0.002207	0.99988	66	66000	0.002207	0.002155	0.97645
68	68000	0.002207	0.002207	0.99992	68	68000	0.002207	0.002158	0.97788
70	70000	0.002207	0.002207	0.99994	70	70000	0.002207	0.002163	0.97994
72	72000	0.002207	0.002207	0.99995	72	72000	0.002207	0.002172	0.98395
74	74000	0.002207	0.002207	0.99995	74	74000	0.002207	0.00218	0.98765
76	76000	0.002207	0.002207	0.99996	76	76000	0.002207	0.002188	0.99107
78	78000	0.002207	0.002207	0.99997	78	78000	0.002207	0.002195	0.99426
80	80000	0.002207	0.002207	0.99997	80	80000	0.002207	0.002201	0.99713
82	82000	0.002207	0.002207	0.99997	82	82000	0.002207	0.002205	0.99906
84	84000	0.002207	0.002207	0.99998	84	84000	0.002207	0.002206	0.99960
86	86000	0.002207	0.002207	0.99998	86	86000	0.002207	0.002207	0.99975
88	88000	0.002207	0.002207	0.99998	88	88000	0.002207	0.002207	0.99981
90	90000	0.002207	0.002207	0.99998	90	90000	0.002207	0.002207	0.99985
92	92000	0.002207	0.002207	0.99998	92	92000	0.002207	0.002207	0.99987
94	94000	0.002207	0.002207	0.99998	94	94000	0.002207	0.002207	0.99989
96	96000	0.002207	0.002207	0.99999	96	96000	0.002207	0.002207	0.99990
98	98000	0.002207	0.002207	0.99999	98	98000	0.002207	0.002207	0.99991
100	100000	0.002207	0.002207	0.99999	100	100000	0.002207	0.002207	0.99992
102	102000	0.002207	0.002207	0.99999	102	102000	0.002207	0.002207	0.99992
104	104000	0.002207	0.002207	0.99999	104	104000	0.002207	0.002207	0.99993
106	106000	0.002207	0.002207	0.99999	106	106000	0.002207	0.002207	0.99994
108	108000	0.002207	0.002207	0.99999	108	108000	0.002207	0.002207	0.99994
110	110000	0.002207	0.002207	0.99999	110	110000	0.002207	0.002207	0.99994
112	112000	0.002207	0.002207	0.99999	112	112000	0.002207	0.002207	0.99995
114	114000	0.002207	0.002207	0.99999	114	114000	0.002207	0.002207	0.99995
116	116000	0.002207	0.002207	0.99999	116	116000	0.002207	0.002207	0.99995
118	118000	0.002207	0.002207	0.99999	118	118000	0.002207	0.002207	0.99995
120	120000	0.002207	0.002207	0.99999	120	120000	0.002207	0.002207	0.99995

50 to 1 (.5 atm)					**50 to 1 (1 atm)**				
kW	**W**	**in**	**out**	**% recovery**	**kW**	**W**	**in**	**out**	**% recovery**
2	2000	0.086348	7.46E-03	0.08638	2	2000	0.086348	0.001416	0.01639
4	4000	0.086348	0.009229	0.10688	4	4000	0.086348	0.003242	0.03754
6	6000	0.086348	0.011	0.12739	6	6000	0.086348	0.005067	0.05868

8	8000	0.086348	0.012772	0.14791	8	8000	0.086348	0.006891	0.07981
10	10000	0.086348	0.014543	0.16843	10	10000	0.086348	0.008714	0.10092
12	12000	0.086348	0.016315	0.18895	12	12000	0.086348	0.010539	0.12205
14	14000	0.086348	0.018087	0.20947	14	14000	0.086348	0.012364	0.14319
16	16000	0.086348	0.019859	0.22999	16	16000	0.086348	0.014189	0.16433
18	18000	0.086348	0.021632	0.25052	18	18000	0.086348	0.016014	0.18546
20	20000	0.086348	0.023404	0.27105	20	20000	0.086348	0.01784	0.20660
22	22000	0.086348	0.025177	0.29158	22	22000	0.086348	0.019665	0.22775
24	24000	0.086348	0.02695	0.31211	24	24000	0.086348	0.021491	0.24889
26	26000	0.086348	0.028723	0.33265	26	26000	0.086348	0.023317	0.27003
28	28000	0.086348	0.030497	0.35319	28	28000	0.086348	0.025143	0.29118
30	30000	0.086348	0.032271	0.37373	30	30000	0.086348	0.026969	0.31233
32	32000	0.086348	0.034045	0.39428	32	32000	0.086348	0.028795	0.33348
34	34000	0.086348	0.03582	0.41483	34	34000	0.086348	0.030621	0.35463
36	36000	0.086348	0.037595	0.43539	36	36000	0.086348	0.032448	0.37578
38	38000	0.086348	0.03937	0.45595	38	38000	0.086348	0.034275	0.39694
40	40000	0.086348	0.041146	0.47651	40	40000	0.086348	0.036102	0.41810
42	42000	0.086348	0.042922	0.49708	42	42000	0.086348	0.03793	0.43926
44	44000	0.086348	0.044699	0.51766	44	44000	0.086348	0.039757	0.46043
46	46000	0.086348	0.046476	0.53824	46	46000	0.086348	0.041585	0.48160
48	48000	0.086348	0.048254	0.55883	48	48000	0.086348	0.043414	0.50278
50	50000	0.086348	0.050033	0.57943	50	50000	0.086348	0.045242	0.52396
52	52000	0.086348	0.051812	0.60004	52	52000	0.086348	0.047071	0.54514
54	54000	0.086348	0.053592	0.62065	54	54000	0.086348	0.048901	0.56633
56	56000	0.086348	0.055373	0.64128	56	56000	0.086348	0.050731	0.58752
58	58000	0.086348	0.057154	0.66191	58	58000	0.086348	0.052561	0.60872
60	60000	0.086348	0.058937	0.68255	60	60000	0.086348	0.054392	0.62992
62	62000	0.086348	0.06072	0.70321	62	62000	0.086348	0.056224	0.65113
64	64000	0.086348	0.062504	0.72387	64	64000	0.086348	0.058055	0.67234
66	66000	0.086348	0.064289	0.74453	66	66000	0.086348	0.059887	0.69356
68	68000	0.086348	0.066073	0.76520	68	68000	0.086348	0.061719	0.71478
70	70000	0.086348	0.067857	0.78586	70	70000	0.086348	0.063551	0.73599
72	72000	0.086348	0.069639	0.80650	72	72000	0.086348	0.065382	0.75720
74	74000	0.086348	0.071417	0.82708	74	74000	0.086348	0.067212	0.77839
76	76000	0.086348	0.073188	0.84759	76	76000	0.086348	0.069038	0.79954
78	78000	0.086348	0.074944	0.86793	78	78000	0.086348	0.070859	0.82062
80	80000	0.086348	0.076676	0.88799	80	80000	0.086348	0.072671	0.84161
82	82000	0.086348	0.078361	0.90750	82	82000	0.086348	0.074465	0.86239
84	84000	0.086348	0.079964	0.92608	84	84000	0.086348	0.076231	0.88283
86	86000	0.086348	0.081432	0.94308	86	86000	0.086348	0.077944	0.90268
88	88000	0.086348	0.082696	0.95771	88	88000	0.086348	0.079571	0.92151

90	90000	0.086348	0.083699	0.96932	90	90000	0.086348	0.081055	0.93870
92	92000	0.086348	0.084436	0.97786	92	92000	0.086348	0.082331	0.95349
94	94000	0.086348	0.084954	0.98385	94	94000	0.086348	0.083353	0.96532
96	96000	0.086348	0.085312	0.98800	96	96000	0.086348	0.084118	0.97418
98	98000	0.086348	0.085561	0.99089	98	98000	0.086348	0.084669	0.98056
100	100000	0.086348	0.085739	0.99295	100	100000	0.086348	0.085062	0.98511
102	102000	0.086348	0.085866	0.99443	102	102000	0.086348	0.085344	0.98838
104	104000	0.086348	0.08596	0.99552	104	104000	0.086348	0.08555	0.99076
106	106000	0.086348	0.086031	0.99633	106	106000	0.086348	0.085703	0.99253
108	108000	0.086348	0.086085	0.99695	108	108000	0.086348	0.085818	0.99387
110	110000	0.086348	0.086126	0.99744	110	110000	0.086348	0.085907	0.99490
112	112000	0.086348	0.08616	0.99782	112	112000	0.086348	0.085977	0.99571
114	114000	0.086348	0.086188	0.99815	114	114000	0.086348	0.086033	0.99636
116	116000	0.086348	0.086261	0.99900	116	116000	0.086348	0.08608	0.99689
118	118000	0.086348	0.086282	0.99924	118	118000	0.086348	0.086123	0.99739
120	120000	0.086348	0.086295	0.99939	120	120000	0.086348	0.086226	0.99859
122	122000	0.086348	0.086304	0.99949	122	122000	0.086348	0.086253	0.99890
124	124000	0.086348	0.086311	0.99957	124	124000	0.086348	0.08627	0.99910
126	126000	0.086348	0.086317	0.99964	126	126000	0.086348	0.086283	0.99925
128	128000	0.086348	0.086321	0.99969	128	128000	0.086348	0.086293	0.99936
130	130000	0.086348	0.086325	0.99974	130	130000	0.086348	0.086301	0.99945
132	132000	0.086348	0.086328	0.99977	132	132000	0.086348	0.086307	0.99953
134	134000	0.086348	0.086331	0.99981	134	134000	0.086348	0.086313	0.99959
136	136000	0.086348	0.086334	0.99984	136	136000	0.086348	0.086317	0.99965
138	138000	0.086348	0.086336	0.99986	138	138000	0.086348	0.086322	0.99970
140	140000	0.086348	0.086338	0.99989	140	140000	0.086348	0.086325	0.99974
142	142000	0.086348	0.08634	0.99991	142	142000	0.086348	0.086329	0.99978
144	144000	0.086348	0.086341	0.99993	144	144000	0.086348	0.086332	0.99982
146	146000	0.086348	0.086343	0.99994	146	146000	0.086348	0.086334	0.99985
148	148000	0.086348	0.086344	0.99996	148	148000	0.086348	0.086337	0.99988
150	150000	0.086348	0.086345	0.99997	150	150000	0.086348	0.086339	0.99990
152	152000	0.086348	0.086346	0.99999	152	152000	0.086348	0.086341	0.99993
154	154000	0.086348	0.086347	0.99999	154	154000	0.086348	0.086343	0.99995
156	156000	0.086348	0.086347	0.99999	156	156000	0.086348	0.086345	0.99997
158	158000	0.086348	0.086347	1.00000	158	158000	0.086348	0.086346	0.99998
160	160000	0.086348	0.086347	1.00000	160	160000	0.086348	0.086347	0.99999
162	162000	0.086348	0.086347	1.00000	162	162000	0.086348	0.086347	0.99999
164	164000	0.086348	0.086347	1.00000	164	164000	0.086348	0.086347	0.99999
166	166000	0.086348	0.086348	1.00000	166	166000	0.086348	0.086347	1.00000
168	168000	0.086348	0.086348	1.00000	168	168000	0.086348	0.086347	1.00000
170	170000	0.086348	0.086348	1.00000	170	170000	0.086348	0.086347	1.00000

172	172000	0.086348	0.086348	1.00000	172	172000	0.086348	0.086347	1.00000
174	174000	0.086348	0.086348	1.00000	174	174000	0.086348	0.086347	1.00000
176	176000	0.086348	0.086348	1.00000	176	176000	0.086348	0.086347	1.00000
178	178000	0.086348	0.086348	1.00000	178	178000	0.086348	0.086347	1.00000
180	180000	0.086348	0.086348	1.00000	180	180000	0.086348	0.086348	1.00000

50 to 1 (10 atm)					**50 to 1 (50 atm)**				
kW	**W**	**in**	**out**	**% recovery**	**kW**	**W**	**in**	**out**	**% recovery**
2	2000	0.086348	0	0.00000	2	2000	0.086348	0	0.00000
4	4000	0.086348	0	0.00000	4	4000	0.086348	0	0.00000
6	6000	0.086348	0	0.00000	6	6000	0.086348	0	0.00000
8	8000	0.086348	0	0.00000	8	8000	0.086348	0	0.00000
10	10000	0.086348	0	0.00000	10	10000	0.086348	0	0.00000
12	12000	0.086348	0	0.00000	12	12000	0.086348	0	0.00000
14	14000	0.086348	0	0.00000	14	14000	0.086348	0	0.00000
16	16000	0.086348	0	0.00000	16	16000	0.086348	0	0.00000
18	18000	0.086348	0	0.00000	18	18000	0.086348	0	0.00000
20	20000	0.086348	0	0.00000	20	20000	0.086348	0	0.00000
22	22000	0.086348	0	0.00000	22	22000	0.086348	0	0.00000
24	24000	0.086348	0	0.00000	24	24000	0.086348	0	0.00000
26	26000	0.086348	0	0.00000	26	26000	0.086348	0	0.00000
28	28000	0.086348	0	0.00000	28	28000	0.086348	0	0.00000
30	30000	0.086348	0	0.00000	30	30000	0.086348	0	0.00000
32	32000	0.086348	0	0.00000	32	32000	0.086348	0	0.00000
34	34000	0.086348	0	0.00000	34	34000	0.086348	0	0.00000
36	36000	0.086348	0.00109	0.01263	36	36000	0.086348	0	0.00000
38	38000	0.086348	0.00326	0.03776	38	38000	0.086348	0	0.00000
40	40000	0.086348	0.005438	0.06297	40	40000	0.086348	0	0.00000
42	42000	0.086348	0.007615	0.08819	42	42000	0.086348	0	0.00000
44	44000	0.086348	0.009792	0.11340	44	44000	0.086348	0	0.00000
46	46000	0.086348	0.011968	0.13860	46	46000	0.086348	0	0.00000
48	48000	0.086348	0.014144	0.16381	48	48000	0.086348	0	0.00000
50	50000	0.086348	0.01632	0.18900	50	50000	0.086348	0	0.00000
52	52000	0.086348	0.018495	0.21419	52	52000	0.086348	0	0.00000
54	54000	0.086348	0.02067	0.23938	54	54000	0.086348	0	0.00000
56	56000	0.086348	0.022844	0.26456	56	56000	0.086348	0	0.00000
58	58000	0.086348	0.025017	0.28973	58	58000	0.086348	0	0.00000
60	60000	0.086348	0.02719	0.31489	60	60000	0.086348	0	0.00000
62	62000	0.086348	0.029362	0.34005	62	62000	0.086348	0	0.00000
64	64000	0.086348	0.031534	0.36519	64	64000	0.086348	0	0.00000
66	66000	0.086348	0.033704	0.39033	66	66000	0.086348	0	0.00000

68	68000	0.086348	0.035873	0.41545	68	68000	0.086348	0	0.00000
70	70000	0.086348	0.038041	0.44056	70	70000	0.086348	0	0.00000
72	72000	0.086348	0.040208	0.46565	72	72000	0.086348	0	0.00000
74	74000	0.086348	0.042373	0.49073	74	74000	0.086348	0	0.00000
76	76000	0.086348	0.044537	0.51579	76	76000	0.086348	0	0.00000
78	78000	0.086348	0.046698	0.54082	78	78000	0.086348	0	0.00000
80	80000	0.086348	0.048857	0.56582	80	80000	0.086348	0	0.00000
82	82000	0.086348	0.051016	0.59082	82	82000	0.086348	0	0.00000
84	84000	0.086348	0.05317	0.61577	84	84000	0.086348	0	0.00000
86	86000	0.086348	0.05532	0.64067	86	86000	0.086348	0	0.00000
88	88000	0.086348	0.057466	0.66552	88	88000	0.086348	0.002223	0.02575
90	90000	0.086348	0.059606	0.69030	90	90000	0.086348	0.005577	0.06459
92	92000	0.086348	0.061738	0.71499	92	92000	0.086348	0.008934	0.10346
94	94000	0.086348	0.063859	0.73956	94	94000	0.086348	0.012287	0.14230
96	96000	0.086348	0.065967	0.76397	96	96000	0.086348	0.015635	0.18107
98	98000	0.086348	0.068058	0.78819	98	98000	0.086348	0.018979	0.21980
100	100000	0.086348	0.070122	0.81209	100	100000	0.086348	0.022317	0.25845
102	102000	0.086348	0.072147	0.83554	102	102000	0.086348	0.025648	0.29703
104	104000	0.086348	0.074114	0.85832	104	104000	0.086348	0.028983	0.33566
106	106000	0.086348	0.075994	0.88010	106	106000	0.086348	0.032301	0.37408
108	108000	0.086348	0.077752	0.90045	108	108000	0.086348	0.035608	0.41238
110	110000	0.086348	0.079327	0.91869	110	110000	0.086348	0.038903	0.45054
112	112000	0.086348	0.080683	0.93440	112	112000	0.086348	0.042184	0.48854
114	114000	0.086348	0.081793	0.94725	114	114000	0.086348	0.045449	0.52634
116	116000	0.086348	0.082667	0.95738	116	116000	0.086348	0.048692	0.56390
118	118000	0.086348	0.083344	0.96521	118	118000	0.086348	0.051909	0.60116
120	120000	0.086348	0.083867	0.97127	120	120000	0.086348	0.055092	0.63803
122	122000	0.086348	0.084276	0.97601	122	122000	0.086348	0.058232	0.67439
124	124000	0.086348	0.084602	0.97978	124	124000	0.086348	0.061315	0.71009
126	126000	0.086348	0.084866	0.98284	126	126000	0.086348	0.064333	0.74505
128	128000	0.086348	0.085086	0.98538	128	128000	0.086348	0.067241	0.77872
130	130000	0.086348	0.085274	0.98757	130	130000	0.086348	0.070006	0.81074
132	132000	0.086348	0.085446	0.98955	132	132000	0.086348	0.072576	0.84051
134	134000	0.086348	0.085622	0.99159	134	134000	0.086348	0.074888	0.86729
136	136000	0.086348	0.085838	0.99410	136	136000	0.086348	0.076879	0.89034
138	138000	0.086348	0.085962	0.99554	138	138000	0.086348	0.078499	0.90910
140	140000	0.086348	0.086031	0.99633	140	140000	0.086348	0.079685	0.92284
142	142000	0.086348	0.086079	0.99688	142	142000	0.086348	0.080338	0.93040
144	144000	0.086348	0.086115	0.99731	144	144000	0.086348	0.081777	0.94706
146	146000	0.086348	0.086144	0.99764	146	146000	0.086348	0.082733	0.95814
148	148000	0.086348	0.086169	0.99794	148	148000	0.086348	0.083431	0.96622

150	150000	0.086348	0.086191	0.99818	150	150000	0.086348	0.08398	0.97257
152	152000	0.086348	0.086209	0.99839	152	152000	0.086348	0.08444	0.97791
154	154000	0.086348	0.086225	0.99858	154	154000	0.086348	0.08485	0.98266
156	156000	0.086348	0.086239	0.99875	156	156000	0.086348	0.085201	0.98672
158	158000	0.086348	0.086252	0.99889	158	158000	0.086348	0.085443	0.98952
160	160000	0.086348	0.086264	0.99903	160	160000	0.086348	0.085599	0.99133
162	162000	0.086348	0.086274	0.99915	162	162000	0.086348	0.085709	0.99261
164	164000	0.086348	0.086284	0.99926	164	164000	0.086348	0.085793	0.99357
166	166000	0.086348	0.086293	0.99937	166	166000	0.086348	0.085859	0.99434
168	168000	0.086348	0.086301	0.99946	168	168000	0.086348	0.085914	0.99498
170	170000	0.086348	0.086309	0.99955	170	170000	0.086348	0.085961	0.99552
172	172000	0.086348	0.086316	0.99963	172	172000	0.086348	0.086002	0.99599
174	174000	0.086348	0.086323	0.99971	174	174000	0.086348	0.086038	0.99641
176	176000	0.086348	0.086329	0.99978	176	176000	0.086348	0.086069	0.99678
178	178000	0.086348	0.086334	0.99984	178	178000	0.086348	0.086098	0.99711
180	180000	0.086348	0.086339	0.99990	180	180000	0.086348	0.086124	0.99741

Table 11: T-103 Maximum Heat Duty Determination Data

6:1 ratio			10:1 ratio			15:1 ratio		
kW	**W**	**Biodiesel Out**	**kW**	**W**	**Biodiesel Out**	**kW**	**W**	**Biodiesel Out**
2	2000	0.00000	2	2000	0.00000	2	2000	0.00000
4	4000	0.00000	4	4000	0.00000	4	4000	0.00000
6	6000	0.00000	6	6000	0.00000	6	6000	0.00000
8	8000	0.00000	8	8000	0.00000	8	8000	0.00000
10	10000	0.00001	10	10000	0.00001	10	10000	0.00000
12	12000	0.00002	12	12000	0.00002	12	12000	0.00000
14	14000	0.00005	14	14000	0.00006	14	14000	0.00000
16	16000	0.00012	16	16000	0.00014	16	16000	0.00000
18	18000	0.00024	18	18000	0.00030	18	18000	0.00000
20	20000	0.00046	20	20000	0.00060	20	20000	0.00000
22	22000	0.00081	22	22000	0.00109	22	22000	0.00000
24	24000	0.00137	24	24000	0.00185	24	24000	0.00004
26	26000	0.00221	26	26000	0.00299	26	26000	0.00019
28	28000	0.00342	28	28000	0.00461	28	28000	0.00058
30	30000	0.00512	30	30000	0.00681	30	30000	0.00121
32	32000	0.00742	32	32000	0.00969	32	32000	0.00197
34	34000	0.01046	34	34000	0.01331	34	34000	0.00249
36	36000	0.01430	36	36000	0.01771	36	36000	0.00531
38	38000	0.01900	38	38000	0.02283	38	38000	0.00834
40	40000	0.02448	40	40000	0.02859	40	40000	0.00882

42	42000	0.03062	42	42000	0.03478	42	42000	0.00887
44	44000	0.03717	44	44000	0.04075	44	44000	0.00889
46	46000	0.04337	46	46000	0.04407	46	46000	0.00889
48	48000	0.04684	48	48000	0.04489	48	48000	0.00890
50	50000	0.04777	50	50000	0.04515	50	50000	0.00890
52	52000	0.04808	52	52000	0.04526	52	52000	0.00890
54	54000	0.04822	54	54000	0.04533	54	54000	0.00890
56	56000	0.04830	56	56000	0.04536	56	56000	0.00890
58	58000	0.04835	58	58000	0.04539	58	58000	0.00890
60	60000	0.04838	60	60000	0.04540	60	60000	0.00890
62	62000	0.04840	62	62000	0.04541	62	62000	0.00890
64	64000	0.04841	64	64000	0.04542	64	64000	0.00890
66	66000	0.04842	66	66000	0.04543	66	66000	0.00890
68	68000	0.04843	68	68000	0.04543	68	68000	0.00890
70	70000	0.04843	70	70000	0.04544	70	70000	0.00890
72	72000	0.04844	72	72000	0.04544	72	72000	0.00890
74	74000	0.04844	74	74000	0.04544	74	74000	0.00890
76	76000	0.04845	76	76000	0.04544	76	76000	0.00890
78	78000	0.04845	78	78000	0.04544	78	78000	0.00890
80	80000	0.04845	80	80000	0.04545	80	80000	0.00890
82	82000	0.04845	82	82000	0.04545	82	82000	0.00890
84	84000	0.04845	84	84000	0.04545	84	84000	0.00890
86	86000	0.04845	86	86000	0.04545	86	86000	0.00890
88	88000	0.04845	88	88000	0.04545	88	88000	0.00890
90	90000	0.04846	90	90000	0.04545	90	90000	0.00890
92	92000	0.04846	92	92000	0.04545	92	92000	0.00890
94	94000	0.04846	94	94000	0.04545	94	94000	0.00890
96	96000	0.04846	96	96000	0.04545	96	96000	0.00890
98	98000	0.04846	98	98000	0.04545	98	98000	0.00890
100	100000	0.04846	100	100000	0.04545	100	100000	0.00890
102	102000	0.04846	102	102000	0.04545	102	102000	0.00890
104	104000	0.04846	104	104000	0.04545	104	104000	0.00890
106	106000	0.04846	106	106000	0.04545	106	106000	0.00890
108	108000	0.04846	108	108000	0.04545	108	108000	0.00890
110	110000	0.04846	110	110000	0.04545	110	110000	0.00890
112	112000	0.04846	112	112000	0.04545	112	112000	0.00890
114	114000	0.04846	114	114000	0.04545	114	114000	0.00890
116	116000	0.04846	116	116000	0.04545	116	116000	0.00890
118	118000	0.04846	118	118000	0.04545	118	118000	0.00890
120	120000	0.04846	120	120000	0.04545	120	120000	0.00890
122	122000	0.0484596	122	122000	0.04545	122	122000	0.00890

124	124000	0.04845968	124	124000	0.04545	124	124000	0.00890
126	126000	0.04845976	126	126000	0.04545	126	126000	0.00890
128	128000	0.04845982	128	128000	0.04545	128	128000	0.00890
130	130000	0.04845989	130	130000	0.04545	130	130000	0.00890
132	132000	0.04845994	132	132000	0.04545	132	132000	0.00890
134	134000	0.04845999	134	134000	0.04545	134	134000	0.00890
136	136000	0.04846004	136	136000	0.04545	136	136000	0.00890
138	138000	0.04846008	138	138000	0.04545	138	138000	0.00890
140	140000	0.04846012	140	140000	0.04545	140	140000	0.00890
142	142000	0.04846016	142	142000	0.04545	142	142000	0.00890
144	144000	0.04846019	144	144000	0.04545	144	144000	0.00890
146	146000	0.04846022	146	146000	0.04545	146	146000	0.00890
148	148000	0.04846025	148	148000	0.04545	148	148000	0.00890
150	150000	0.04846027	150	150000	0.04545	150	150000	0.00890
152	152000	0.0484603	152	152000	0.04545	152	152000	0.00890
154	154000	0.04846032	154	154000	0.04545	154	154000	0.00890
156	156000	0.04846034	156	156000	0.04545	156	156000	0.00890
158	158000	0.04846036	158	158000	0.04545	158	158000	0.00890
160	160000	0.04846038	160	160000	0.04545	160	160000	0.00890
162	162000	0.04846039	162	162000	0.04545	162	162000	0.00890
164	164000	0.04846041	164	164000	0.04545	164	164000	0.00890
166	166000	0.04846042	166	166000	0.04545	166	166000	0.00890
168	168000	0.04846044	168	168000	0.04545	168	168000	0.00890
170	170000	0.04846045	170	170000	0.04545	170	170000	0.00890
172	172000	0.04846046	172	172000	0.04545	172	172000	0.00890
174	174000	0.04846047	174	174000	0.04545	174	174000	0.00890
176	176000	0.04846048	176	176000	0.04545	176	176000	0.00890
178	178000	0.04846049	178	178000	0.04545	178	178000	0.00890
180	180000	0.0484605	180	180000	0.04545	180	180000	0.00890

20:1 ratio			25:1 ratio			30:1 ratio		
kW	**W**	**Biodiesel Out**	**kW**	**W**	**Biodiesel Out**	**kW**	**W**	**Biodiesel Out**
2	2000	0.00000	2	2000	0.00000	2	2000	0.00000
4	4000	0.00000	4	4000	0.00000	4	4000	0.00000
6	6000	0.00000	6	6000	0.00000	6	6000	0.00000
8	8000	0.00000	8	8000	0.00000	8	8000	0.00000
10	10000	0.00000	10	10000	0.00000	10	10000	0.00000
12	12000	0.00000	12	12000	0.00000	12	12000	0.00000
14	14000	0.00000	14	14000	0.00000	14	14000	0.00000
16	16000	0.00000	16	16000	0.00000	16	16000	0.00000
18	18000	0.00000	18	18000	0.00000	18	18000	0.00000

20	20000	0.00000	20	20000	0.00000	20	20000	0.00000
22	22000	0.00000	22	22000	0.00000	22	22000	0.00000
24	24000	0.00000	24	24000	0.00000	24	24000	0.00000
26	26000	0.00000	26	26000	0.00000	26	26000	0.00000
28	28000	0.00000	28	28000	0.00000	28	28000	0.00000
30	30000	0.00000	30	30000	0.00000	30	30000	0.00000
32	32000	0.00000	32	32000	0.00000	32	32000	0.00000
34	34000	0.00002	34	34000	0.00000	34	34000	0.00000
36	36000	0.00007	36	36000	0.00000	36	36000	0.00000
38	38000	0.00021	38	38000	0.00000	38	38000	0.00000
40	40000	0.00051	40	40000	0.00000	40	40000	0.00000
42	42000	0.00098	42	42000	0.00000	42	42000	0.00000
44	44000	0.00156	44	44000	0.00001	44	44000	0.00000
46	46000	0.00152	46	46000	0.00003	46	46000	0.00000
48	48000	0.00318	48	48000	0.00009	48	48000	0.00000
50	50000	0.00568	50	50000	0.00022	50	50000	0.00000
52	52000	0.00891	52	52000	0.00046	52	52000	0.00000
54	54000	0.01243	54	54000	0.00083	54	54000	0.00001
56	56000	0.01395	56	56000	0.00128	56	56000	0.00002
58	58000	0.01416	58	58000	0.00107	58	58000	0.00004
60	60000	0.01422	60	60000	0.00210	60	60000	0.00011
62	62000	0.01425	62	62000	0.00371	62	62000	0.00022
64	64000	0.01426	64	64000	0.00594	64	64000	0.00042
66	66000	0.01426	66	66000	0.00879	66	66000	0.00071
68	68000	0.01427	68	68000	0.01217	68	68000	0.00107
70	70000	0.01427	70	70000	0.01587	70	70000	0.00130
72	72000	0.01427	72	72000	0.01874	72	72000	0.00154
74	74000	0.01427	74	74000	0.01950	74	74000	0.00263
76	76000	0.01427	76	76000	0.01968	76	76000	0.00417
78	78000	0.01427	78	78000	0.01974	78	78000	0.00622
80	80000	0.01427	80	80000	0.01978	80	80000	0.00877
82	82000	0.01427	82	82000	0.01980	82	82000	0.01180
84	84000	0.01427	84	84000	0.01981	84	84000	0.01525
86	86000	0.01427	86	86000	0.01981	86	86000	0.01899
88	88000	0.01427	88	88000	0.01982	88	88000	0.02260
90	90000	0.01427	90	90000	0.01982	90	90000	0.02459
92	92000	0.01427	92	92000	0.01982	92	92000	0.02510
94	94000	0.01427	94	94000	0.01982	94	94000	0.02528
96	96000	0.01427	96	96000	0.01983	96	96000	0.02535
98	98000	0.01427	98	98000	0.01983	98	98000	0.02539
100	100000	0.01427	100	100000	0.01983	100	100000	0.02542

102	102000	0.01427	102	102000	0.01983	102	102000	0.02543
104	104000	0.01427	104	104000	0.01983	104	104000	0.02544
106	106000	0.01427	106	106000	0.01983	106	106000	0.02545
108	108000	0.01427	108	108000	0.01983	108	108000	0.02546
110	110000	0.01427	110	110000	0.01983	110	110000	0.02546
112	112000	0.01427	112	112000	0.01983	112	112000	0.02546
114	114000	0.01427	114	114000	0.01983	114	114000	0.02547
116	116000	0.01427	116	116000	0.01983	116	116000	0.02547
118	118000	0.01427	118	118000	0.01983	118	118000	0.02547
120	120000	0.01427	120	120000	0.01983	120	120000	0.02547
122	122000	0.01427	122	122000	0.01983	122	122000	0.02547
124	124000	0.01427	124	124000	0.01983	124	124000	0.02547
126	126000	0.01427	126	126000	0.01983	126	126000	0.02547
128	128000	0.01427	128	128000	0.01983	128	128000	0.02547
130	130000	0.01427	130	130000	0.01983	130	130000	0.02547
132	132000	0.01427	132	132000	0.01983	132	132000	0.02547
134	134000	0.01427	134	134000	0.01983	134	134000	0.02547
136	136000	0.01427	136	136000	0.01983	136	136000	0.02547
138	138000	0.01427	138	138000	0.01983	138	138000	0.02547
140	140000	0.01427	140	140000	0.01983	140	140000	0.02547
142	142000	0.01427	142	142000	0.01983	142	142000	0.02547
144	144000	0.01427	144	144000	0.01983	144	144000	0.02547
146	146000	0.01427	146	146000	0.01983	146	146000	0.02547
148	148000	0.01427	148	148000	0.01983	148	148000	0.02547
150	150000	0.01427	150	150000	0.01983	150	150000	0.02547
152	152000	0.01427	152	152000	0.01983	152	152000	0.02547
154	154000	0.01427	154	154000	0.01983	154	154000	0.02547
156	156000	0.01427	156	156000	0.01983	156	156000	0.02547
158	158000	0.01427	158	158000	0.01983	158	158000	0.02547
160	160000	0.01427	160	160000	0.01983	160	160000	0.02547
162	162000	0.01427	162	162000	0.01983	162	162000	0.02547
164	164000	0.01427	164	164000	0.01983	164	164000	0.02547
166	166000	0.01427	166	166000	0.01983	166	166000	0.02547
168	168000	0.01427	168	168000	0.01983	168	168000	0.02547
170	170000	0.01427	170	170000	0.01983	170	170000	0.02547
172	172000	0.01427	172	172000	0.01983	172	172000	0.02547
174	174000	0.01427	174	174000	0.01983	174	174000	0.02547
176	176000	0.01427	176	176000	0.01983	176	176000	0.02547
178	178000	0.01427	178	178000	0.01983	178	178000	0.02547
180	180000	0.01427	180	180000	0.01983	180	180000	0.02547

35:1 ratio			40:1 ratio			45:1 ratio		
kW	**W**	**Biodiesel Out**	**kW**	**W**	**Biodiesel Out**	**kW**	**W**	**Biodiesel Out**
2	2000	0.00000	2	2000	0.00000	2	2000	0.00000
4	4000	0.00000	4	4000	0.00000	4	4000	0.00000
6	6000	0.00000	6	6000	0.00000	6	6000	0.00000
8	8000	0.00000	8	8000	0.00000	8	8000	0.00000
10	10000	0.00000	10	10000	0.00000	10	10000	0.00000
12	12000	0.00000	12	12000	0.00000	12	12000	0.00000
14	14000	0.00000	14	14000	0.00000	14	14000	0.00000
16	16000	0.00000	16	16000	0.00000	16	16000	0.00000
18	18000	0.00000	18	18000	0.00000	18	18000	0.00000
20	20000	0.00000	20	20000	0.00000	20	20000	0.00000
22	22000	0.00000	22	22000	0.00000	22	22000	0.00000
24	24000	0.00000	24	24000	0.00000	24	24000	0.00000
26	26000	0.00000	26	26000	0.00000	26	26000	0.00000
28	28000	0.00000	28	28000	0.00000	28	28000	0.00000
30	30000	0.00000	30	30000	0.00000	30	30000	0.00000
32	32000	0.00000	32	32000	0.00000	32	32000	0.00000
34	34000	0.00000	34	34000	0.00000	34	34000	0.00000
36	36000	0.00000	36	36000	0.00000	36	36000	0.00000
38	38000	0.00000	38	38000	0.00000	38	38000	0.00000
40	40000	0.00000	40	40000	0.00000	40	40000	0.00000
42	42000	0.00000	42	42000	0.00000	42	42000	0.00000
44	44000	0.00000	44	44000	0.00000	44	44000	0.00000
46	46000	0.00000	46	46000	0.00000	46	46000	0.00000
48	48000	0.00000	48	48000	0.00000	48	48000	0.00000
50	50000	0.00000	50	50000	0.00000	50	50000	0.00000
52	52000	0.00000	52	52000	0.00000	52	52000	0.00000
54	54000	0.00000	54	54000	0.00000	54	54000	0.00000
56	56000	0.00000	56	56000	0.00000	56	56000	0.00000
58	58000	0.00000	58	58000	0.00000	58	58000	0.00000
60	60000	0.00000	60	60000	0.00000	60	60000	0.00000
62	62000	0.00000	62	62000	0.00000	62	62000	0.00000
64	64000	0.00000	64	64000	0.00000	64	64000	0.00000
66	66000	0.00001	66	66000	0.00000	66	66000	0.00000
68	68000	0.00003	68	68000	0.00000	68	68000	0.00000
70	70000	0.00006	70	70000	0.00000	70	70000	0.00000
72	72000	0.00012	72	72000	0.00000	72	72000	0.00000
74	74000	0.00023	74	74000	0.00000	74	74000	0.00000
76	76000	0.00040	76	76000	0.00001	76	76000	0.00000
78	78000	0.00064	78	78000	0.00002	78	78000	0.00000

80	80000	0.00093	80	80000	0.00004	80	80000	0.00000
82	82000	0.00117	82	82000	0.00007	82	82000	0.00000
84	84000	0.00122	84	84000	0.00013	84	84000	0.00000
86	86000	0.00200	86	86000	0.00023	86	86000	0.00001
88	88000	0.00312	88	88000	0.00038	88	88000	0.00001
90	90000	0.00462	90	90000	0.00058	90	90000	0.00002
92	92000	0.00653	92	92000	0.00083	92	92000	0.00005
94	94000	0.00887	94	94000	0.00104	94	94000	0.00008
96	96000	0.01162	96	96000	0.00103	96	96000	0.00014
98	98000	0.01475	98	98000	0.00163	98	98000	0.00024
100	100000	0.01823	100	100000	0.00247	100	100000	0.00037
102	102000	0.02198	102	102000	0.00360	102	102000	0.00054
104	104000	0.02581	104	104000	0.00506	104	104000	0.00075
106	106000	0.02897	106	106000	0.00687	106	106000	0.00094
108	108000	0.03033	108	108000	0.00904	108	108000	0.00092
110	110000	0.03075	110	110000	0.01158	110	110000	0.00138
112	112000	0.03092	112	112000	0.01446	112	112000	0.00204
114	114000	0.03101	114	114000	0.01766	114	114000	0.00293
116	116000	0.03105	116	116000	0.02116	116	116000	0.00407
118	118000	0.03109	118	118000	0.02491	118	118000	0.00550
120	120000	0.03111	120	120000	0.02879	120	120000	0.00723
122	122000	0.03112	122	122000	0.03249	122	122000	0.00928361
124	124000	0.03113	124	124000	0.03506	124	124000	0.01164984
126	126000	0.03114	126	126000	0.03606	126	126000	0.01432722
128	128000	0.03114	128	128000	0.03642	128	128000	0.01730372
130	130000	0.03115	130	130000	0.03659	130	130000	0.02056162
132	132000	0.03115	132	132000	0.03669	132	132000	0.02407657
134	134000	0.03115	134	134000	0.03674	134	134000	0.02781272
136	136000	0.03115	136	136000	0.03678	136	136000	0.03170569
138	138000	0.03116	138	138000	0.03680	138	138000	0.03559504
140	140000	0.03116	140	140000	0.03682	140	140000	0.03899431
142	142000	0.03116	142	142000	0.03683	142	142000	0.04099123
144	144000	0.03116	144	144000	0.03684	144	144000	0.04177493
146	146000	0.03116	146	146000	0.03685	146	146000	0.04210408
148	148000	0.03116	148	148000	0.03686	148	148000	0.04227182
150	150000	0.03116	150	150000	0.03686	150	150000	0.04236963
152	152000	0.03116	152	152000	0.03687	152	152000	0.04243181
154	154000	0.03116	154	154000	0.03687	154	154000	0.04247373
156	156000	0.03116	156	156000	0.03687	156	156000	0.04250322
158	158000	0.03116	158	158000	0.03687	158	158000	0.04252465
160	160000	0.03116	160	160000	0.03687	160	160000	0.04254062

162	162000	0.03116	162	162000	0.03688	162	162000	0.04255277
164	164000	0.03116	164	164000	0.03688	164	164000	0.04256219
166	166000	0.03116	166	166000	0.03688	166	166000	0.04256959
168	168000	0.03116	168	168000	0.03688	168	168000	0.04257549
170	170000	0.03116	170	170000	0.03688	170	170000	0.04258024
172	172000	0.03116	172	172000	0.03688	172	172000	0.0425841
174	174000	0.03116	174	174000	0.03688	174	174000	0.04258728
176	176000	0.03116	176	176000	0.03688	176	176000	0.04258991
178	178000	0.03116	178	178000	0.03688	178	178000	0.0425921
180	180000	0.03116	180	180000	0.03688	180	180000	0.04259394

50:1 ratio		
kW	W	Biodiesel Out
2	2000	0.00000
4	4000	0.00000
6	6000	0.00000
8	8000	0.00000
10	10000	0.00000
12	12000	0.00000
14	14000	0.00000
16	16000	0.00000
18	18000	0.00000
20	20000	0.00000
22	22000	0.00000
24	24000	0.00000
26	26000	0.00000
28	28000	0.00000
30	30000	0.00000
32	32000	0.00000
34	34000	0.00000
36	36000	0.00000
38	38000	0.00000
40	40000	0.00000
42	42000	0.00000
44	44000	0.00000
46	46000	0.00000
48	48000	0.00000
50	50000	0.00000
52	52000	0.00000
54	54000	0.00000
56	56000	0.00000

58	58000	0.00000
60	60000	0.00000
62	62000	0.00000
64	64000	0.00000
66	66000	0.00000
68	68000	0.00000
70	70000	0.00000
72	72000	0.00000
74	74000	0.00000
76	76000	0.00000
78	78000	0.00000
80	80000	0.00000
82	82000	0.00000
84	84000	0.00000
86	86000	0.00000
88	88000	0.00000
90	90000	0.00000
92	92000	0.00000
94	94000	0.00000
96	96000	0.00001
98	98000	0.00001
100	100000	0.00002
102	102000	0.00003
104	104000	0.00006
106	106000	0.00009
108	108000	0.00015
110	110000	0.00024
112	112000	0.00036
114	114000	0.00051
116	116000	0.00069
118	118000	0.00086
120	120000	0.00084
122	122000	0.00122
124	124000	0.00175
126	126000	0.00247
128	128000	0.00338
130	130000	0.00453
132	132000	0.00594
134	134000	0.00761
136	136000	0.00956
138	138000	0.01179

140	140000	0.01430
142	142000	0.01709
144	144000	0.02014
146	146000	0.02343
148	148000	0.02696
150	150000	0.03068
152	152000	0.03457
154	154000	0.03852
156	156000	0.04230
158	158000	0.04529
160	160000	0.04685
162	162000	0.04750
164	164000	0.04781
166	166000	0.04797
168	168000	0.04808
170	170000	0.04814
172	172000	0.04819
174	174000	0.04822
176	176000	0.04825
178	178000	0.04827
180	180000	0.04828

Appendix E: T-104 Data

Table 12: T-104 Biodiesel Purity Analysis

1 atm						10 atm					
kw	watt	Biodiesel In	Biodiesel Out	mass fract	%	kw	watt	Biodiesel In	Biodiesel Out	mass fract	%
1	1000	0.04670924	2.15E-06	0.4760	0.0046	1	1000	0.04670924	0	0	0.0000
2	2000	0.04670924	5.37E-06	0.5402	0.0115	2	2000	0.04670924	0	0	0.0000
3	3000	0.04670924	1.01E-05	0.6019	0.0215	3	3000	0.04670924	0	0	0.0000
4	4000	0.04670924	1.68E-05	0.6600	0.0359	4	4000	0.04670924	0	0	0.0000
5	5000	0.04670924	2.64E-05	0.7139	0.0566	5	5000	0.04670924	0	0	0.0000
6	6000	0.04670924	4.03E-05	0.7633	0.0863	6	6000	0.04670924	0	0	0.0000
7	7000	0.04670924	6.06E-05	0.8081	0.1298	7	7000	0.04670924	0	0	0.0000
8	8000	0.04670924	9.14E-05	0.8484	0.1956	8	8000	0.04670924	0	0	0.0000
9	9000	0.04670924	0.00014034	0.8845	0.3005	9	9000	0.04670924	0	0	0.0000
10	10000	0.04670924	0.00022522	0.9165	0.4822	10	10000	0.04670924	0	0	0.0000
11	11000	0.04670924	0.00039522	0.9447	0.8461	11	11000	0.04670924	0	0	0.0000
12	12000	0.04670924	0.00083357	0.9685	1.7846	12	12000	0.04670924	0	0	0.0000
13	13000	0.04670924	0.00231203	0.9853	4.9498	13	13000	0.04670924	0	0	0.0000
14	14000	0.04670924	0.00563249	0.9925	12.0586	14	14000	0.04670924	0	0	0.0000
15	15000	0.04670924	0.00979869	0.9951	20.9781	15	15000	0.04670924	0	0	0.0000
16	16000	0.04670924	0.01420033	0.9964	30.4015	16	16000	0.04670924	0	0	0.0000
17	17000	0.04670924	0.01867729	0.9972	39.9863	17	17000	0.04670924	0	0	0.0000
18	18000	0.04670924	0.02317169	0.9977	49.6084	18	18000	0.04670924	0	0	0.0000
19	19000	0.04670924	0.0276468	0.9980	59.1891	19	19000	0.04670924	0	0	0.0000
20	20000	0.04670924	0.03205767	0.9983	68.6324	20	20000	0.04670924	0	0	0.0000
21	21000	0.04670924	0.03631549	0.9985	77.7480	21	21000	0.04670924	0	0	0.0000
22	22000	0.04670924	0.04019619	0.9986	86.0562	22	22000	0.04670924	0	0	0.0000
23	23000	0.04670924	0.04317909	0.9987	92.4423	23	23000	0.04670924	0	0	0.0000
24	24000	0.04670924	0.04483552	0.9987	95.9885	24	24000	0.04670924	3.27E-06	0.8243	0.0070
25	25000	0.04670924	0.04559261	0.9987	97.6094	25	25000	0.04670924	1.77E-05	0.8450	0.0379
26	26000	0.04670924	0.04596634	0.9988	98.4095	26	26000	0.04670924	3.70E-05	0.8643	0.0792
27	27000	0.04670924	0.04617719	0.9988	98.8609	27	27000	0.04670924	6.31E-05	0.8822	0.1350
28	28000	0.04670924	0.04630903	0.9988	99.1432	28	28000	0.04670924	9.88E-05	0.8988	0.2116
29	29000	0.04670924	0.04639763	0.9988	99.3329	29	29000	0.04670924	0.00014911	0.9143	0.3192
30	30000	0.04670924	0.04646031	0.9988	99.4671	30	30000	0.04670924	0.00022245	0.9288	0.4762
31	31000	0.04670924	0.04650639	0.9988	99.5657	31	31000	0.04670924	0.000335	0.9422	0.7172
32	32000	0.04670924	0.04654127	0.9988	99.6404	32	32000	0.04670924	0.00052101	0.9548	1.1154
33	33000	0.04670924	0.04656832	0.9988	99.6983	33	33000	0.04670924	0.00086389	0.9667	1.8495
34	34000	0.04670924	0.04658969	0.9988	99.7441	34	34000	0.04670924	0.00160665	0.9778	3.4397
35	35000	0.04670924	0.04660686	0.9988	99.7808	35	35000	0.04670924	0.00357447	0.9876	7.6526
36	36000	0.04670924	0.04662085	0.9988	99.8108	36	36000	0.04670924	0.00872396	0.9941	18.6772

37	37000	0.04670924	0.04663238	0.9988	99.8355
38	38000	0.04670924	0.04664199	0.9988	99.8560
39	39000	0.04670924	0.04665006	0.9988	99.8733
40	40000	0.04670924	0.04665691	0.9988	99.8880
41	41000	0.04670924	0.04666276	0.9988	99.9005
42	42000	0.04670924	0.04666778	0.9988	99.9112
43	43000	0.04670924	0.04667213	0.9988	99.9206
44	44000	0.04670924	0.0466759	0.9988	99.9286
45	45000	0.04670924	0.04667918	0.9988	99.9356
46	46000	0.04670924	0.04668206	0.9988	99.9418
47	47000	0.04670924	0.04668459	0.9988	99.9472
48	48000	0.04670924	0.04668682	0.9988	99.9520
49	49000	0.04670924	0.0466888	0.9988	99.9562
50	50000	0.04670924	0.04669056	0.9988	99.9600

37	37000	0.04670924	0.01711223	0.9968	36.6356
38	38000	0.04670924	0.0264753	0.9979	56.6811
39	39000	0.04670924	0.03514752	0.9984	75.2475
40	40000	0.04670924	0.04110527	0.9986	88.0024
41	41000	0.04670924	0.04376496	0.9987	93.6966
42	42000	0.04670924	0.04484428	0.9987	96.0073
43	43000	0.04670924	0.04544215	0.9987	97.2873
44	44000	0.04670924	0.04577021	0.9988	97.9896
45	45000	0.04670924	0.04597657	0.9988	98.4314
46	46000	0.04670924	0.04611767	0.9988	98.7335
47	47000	0.04670924	0.04621975	0.9988	98.9520
48	48000	0.04670924	0.04629665	0.9988	99.1167
49	49000	0.04670924	0.04635638	0.9988	99.2446
50	50000	0.04670924	0.04640387	0.9988	99.3462
51	51000	0.04670924	0.04644238	0.99876947	99.4287
52	52000	0.04670924	0.04647408	0.99877029	99.4965
53	53000	0.04670924	0.04650054	0.99877097	99.5532
54	54000	0.04670924	0.04652287	0.99877154	99.6010
55	55000	0.04670924	0.04654189	0.99877203	99.6417
56	56000	0.04670924	0.04655824	0.99877245	99.6767
57	57000	0.04670924	0.04657239	0.99877281	99.7070
58	58000	0.04670924	0.04658473	0.99877313	99.7334
59	59000	0.04670924	0.04659555	0.99877341	99.7566
60	60000	0.04670924	0.04660509	0.99877365	99.7770

Appendix F: T-105 Data

Table 13: T-105 Separation Analyses Data

Heat Duty (kW)	Liquid Mass Flow Rate (kg/s)				Vapor Mass Flow Rate (kg/s)	Liquid Glycerol Recovery Percentage (%)	Liquid Glycerol Purity Percentage (%)	Vapor Methyl Oleate Purity Percentage (%)
	Methanol	Methyl Oleate	Glycerol (1 atm)	Glycerol (0.5 atm)	Methyl Oleate			
0	0.000171	0.000936	0.004777	0.004777	0	100.00	78.71	0
0.1	0.000149	0.000936	0.004777	0.004776	0	100.00	79.00	1.47
0.2	0.000130	0.000935	0.004777	0.004775	0.000001	100.00	79.26	2.08
0.3	0.000113	0.000934	0.004776	0.004774	0.000002	99.99	79.49	2.92
0.4	0.000098	0.000933	0.004776	0.004772	0.000003	99.97	79.70	4.04
0.5	0.000086	0.000931	0.004775	0.004770	0.000005	99.95	79.89	5.53
0.6	0.000075	0.000928	0.004773	0.004767	0.000008	99.92	80.07	7.43
0.7	0.000066	0.000924	0.004771	0.004762	0.000012	99.88	80.25	9.81
0.8	0.000058	0.000918	0.004769	0.004757	0.000018	99.83	80.42	12.70
0.9	0.000051	0.000910	0.004765	0.004750	0.000025	99.76	80.61	16.09
1.0	0.000044	0.000900	0.004761	0.004741	0.000036	99.67	80.83	19.95
1.1	0.000039	0.000887	0.004756	0.004729	0.000049	99.55	81.07	24.20
1.2	0.000034	0.000869	0.004749	0.004715	0.000067	99.41	81.36	28.71
1.3	0.000030	0.000846	0.004740	0.004698	0.000090	99.22	81.71	33.36
1.4	0.000026	0.000817	0.004729	0.004677	0.000119	99.00	82.14	38.02
1.5	0.000023	0.000780	0.004716	0.004653	0.000156	98.72	82.68	42.55
1.6	0.000020	0.000734	0.004700	0.004624	0.000202	98.38	83.36	46.83
1.7	0.000017	0.000677	0.004681	0.004590	0.000259	97.98	84.19	50.77
1.8	0.000015	0.000608	0.004658	0.004552	0.000328	97.50	85.22	54.24
1.9	0.000012	0.000530	0.004631	0.004507	0.000406	96.94	86.43	57.10
2.0	0.000011	0.000446	0.004600	0.004455	0.000490	96.30	87.75	59.15
2.1	0.000009	0.000368	0.004565	0.004396	0.000568	95.55	89.04	60.24
2.2	0.000008	0.000298	0.004523	0.004331	0.000638	94.68	90.21	60.40
2.3	0.000007	0.000243	0.004475	0.004259	0.000693	93.68	91.15	59.76
2.4	0.000006	0.000200	0.004421	0.004180	0.000736	92.55	91.88	58.53
2.5	0.000005	0.000166	0.004361	0.004096	0.000770	91.29	92.45	56.91
2.6	0.000005	0.000140	0.004294	0.004007	0.000796	89.89	92.88	55.04
2.7	0.000004	0.000119	0.004221	0.003913	0.000817	88.36	93.20	53.02
2.8	0.000004	0.000102	0.004142	0.003814	0.000834	86.70	93.44	50.92
2.9	0.000003	0.000088	0.004057	0.003712	0.000847	84.92	93.62	48.80
3.0	0.000003	0.000077	0.003966	0.003606	0.000859	83.03	93.74	46.71
3.1	0.000003	0.000068	0.003871	0.003497	0.000868	81.03	93.81	44.67
3.2	0.000002	0.000060	0.003771	0.003386	0.000876	78.94	93.85	42.70
3.3	0.000002	0.000053	0.003667	0.003273	0.000883	76.77	93.85	40.82
3.4	0.000002	0.000048	0.003560	0.003157	0.000888	74.52	93.82	39.04

3.5	0.000002	0.000043	0.003449	0.003040	0.000893	72.21	93.76	37.36
3.6	0.000002	0.000039	0.003336	0.002921	0.000897	69.84	93.68	35.77
3.7	0.000001	0.000035	0.003220	0.002801	0.000901	67.41	93.57	34.28
3.8	0.000001	0.000032	0.003102	0.002680	0.000904	64.94	93.44	32.89
3.9	0.000001	0.000029	0.002982	0.002558	0.000907	62.43	93.28	31.58
4.0	0.000001	0.000026	0.002861	0.002434	0.000910	59.88	93.09	30.35
4.1	0.000001	0.000024	0.002737	0.002310	0.000912	57.30	92.87	29.20
4.2	0.000001	0.000022	0.002613	0.002186	0.000914	54.69	92.63	28.13
4.3	0.000001	0.000020	0.002487	0.002060	0.000916	52.06	92.35	27.12
4.4	0.000001	0.000019	0.002360	0.001934	0.000917	49.41	92.03	26.17
4.5	0.000001	0.000017	0.002232	0.001808	0.000919	46.73	91.67	25.28
4.6	0.000001	0.000016	0.002104	0.001681	0.000920	44.04	91.26	24.44
4.7	0.000001	0.000015	0.001974	0.001553	0.000921	41.33	90.80	23.65
4.8	0	0.000013	0.001844	0.001425	0.000922	38.60	90.26	22.91
4.9	0	0.000012	0.001713	0.001297	0.000923	35.86	89.65	22.21
5.0	0	0.000011	0.001582	0.001169	0.000924	33.11	88.93	21.54
5.1	0	0.000011	0.001450	0.001040	0.000925	30.36	88.10	20.92
5.2	0	0.000010	0.001318	0.000911	0.000926	27.59	87.11	20.33
5.3	0	0.000009	0.001185	0.000782	0.000927	24.81	85.92	19.76
5.4	0	0.000008	0.001052	0.000653	0.000928	22.02	84.47	19.23
5.5	0	0.000007	0.000919	0.000525	0.000928	19.23	82.67	18.73
5.6	0	0.000007	0.000785	0.000396	0.000929	16.44	80.36	18.25
5.7	0	0.000006	0.000652	0.000270	0.000930	13.64	77.31	17.79
5.8	0	0.000005	0.000518	0.000151	0.000930	10.85	73.11	17.36
5.9	0	0.000005	0.000385	0.000062	0.000931	8.07	67.00	16.95
6.0	0	0.000004	0.000255	0.000025	0.000932	5.34	57.43	16.56
6.1	0	0.000003	0.000136	0.000013	0.000932	2.84	41.83	16.23
6.2	0	0.000003	0.000055	0.000008	0.000932	1.16	22.70	16.01
6.3	0	0.000004	0.000025	0.000005	0.000932	0.51	11.50	15.91
6.4	0	0.000004	0.000014	0.000004	0.000932	0.28	6.67	15.88
6.5	0	0.000004	0.000009	0.000003	0.000932	0.18	4.37	15.87
6.6	0	0.000003	0.000006	0.000002	0.000932	0.13	3.10	15.87
6.7	0	0.000003	0.000004	0.000002	0.000933	0.09	2.32	15.87
6.8	0	0.000003	0.000003	0.000001	0.000933	0.07	1.81	15.88
6.9	0	0.000002	0.000003	0.000001	0.000934	0.06	1.44	15.88
7.0	0	0.000002	0.000002	0.000001	0.000934	0.05	1.18	15.88
7.1	0	0.000002	0.000002	0.000001	0.000934	0.04	0.98	15.89
7.2	0	0.000001	0.000002	0.000001	0.000934	0.03	0.82	15.89
7.3	0	0.000001	0.000001	0.000001	0.000935	0.03	0.70	15.89
7.4	0	0.000001	0.000001	0.000001	0.000935	0.02	0.60	15.89
7.5	0	0.000001	0.000001	0	0.000935	0.02	0.52	15.89
7.6	0	0.000001	0.000001	0	0.000935	0.02	0.45	15.89
7.7	0	0.000001	0.000001	0	0.000935	0.02	0.39	15.90

7.8	0	0.000001	0.000001	0	0.000935	0.01	0.35	15.90
7.9	0	0.000001	0.000001	0	0.000935	0.01	0.31	15.90
8.0	0	0	0.000001	0	0.000935	0.01	0.27	15.90
8.1	0	0	0	0	0.000935	0.01	0.25	15.90
8.2	0	0	0	0	0.000936	0.01	0.22	15.90
8.3	0	0	0	0	0.000936	0.01	0.20	15.90
8.4	0	0	0	0	0.000936	0.01	0.18	15.90
8.5	0	0	0	0	0.000936	0.01	0.16	15.90
8.6	0	0	0	0	0.000936	0.01	0.15	15.90
8.7	0	0	0	0	0.000936	0.01	0.14	15.90
8.8	0	0	0	0	0.000936	0	0.13	15.90
8.9	0	0	0	0	0.000936	0	0.12	15.90
9.0	0	0	0	0	0.000936	0	0.11	15.90
9.1	0	0	0	0	0.000936	0	0.10	15.90
9.2	0	0	0	0	0.000936	0	0.09	15.90
9.3	0	0	0	0	0.000936	0	0.09	15.90
9.4	0	0	0	0	0.000936	0	0.08	15.90
9.5	0	0	0	0	0.000936	0	0.07	15.90
9.6	0	0	0	0	0.000936	0	0.07	15.90
9.7	0	0	0	0	0.000936	0	0.07	15.90
9.8	0	0	0	0	0.000936	0	0.06	15.90
9.9	0	0	0	0	0.000936	0	0.06	15.90
10.0	0	0	0	0	0.000936	0	0.05	15.90
10.1	0	0	0	0	0.000936	0	0.05	15.90
10.2	0	0	0	0	0.000936	0	0.05	15.90
10.3	0	0	0	0	0.000936	0	0.05	15.90
10.4	0	0	0	0	0.000936	0	0.04	15.90
10.5	0	0	0	0	0.000936	0	0.04	15.90
10.6	0	0	0	0	0.000936	0	0.04	15.90
10.7	0	0	0	0	0.000936	0	0.04	15.90
10.8	0	0	0	0	0.000936	0	0.04	15.90
10.9	0	0	0	0	0.000936	0	0.03	15.90
11.0	0	0	0	0	0.000936	0	0.03	15.90
11.1	0	0	0	0	0.000936	0	0.03	15.90
11.2	0	0	0	0	0.000936	0	0.03	15.90
11.3	0	0	0	0	0.000936	0	0.03	15.90
11.4	0	0	0	0	0.000936	0	0.03	15.90
11.5	0	0	0	0	0.000936	0	0.03	15.90
11.6	0	0	0	0	0.000936	0	0.02	15.90
11.7	0	0	0	0	0.000936	0	0.02	15.90
11.8	0	0	0	0	0.000936	0	0.02	15.90
11.9	0	0	0	0	0.000936	0	0.02	15.90
12.0	0	0	0	0	0.000936	0	0.02	15.90

12.1	0	0	0	0	0.000936	0	0.02	15.90
12.2	0	0	0	0	0.000936	0	0.02	15.90
12.3	0	0	0	0	0.000936	0	0.02	15.90
12.4	0	0	0	0	0.000936	0	0.02	15.90
12.5	0	0	0	0	0.000936	0	0.02	15.90
12.6	0	0	0	0	0.000936	0	0.02	15.90
12.7	0	0	0	0	0.000936	0	0.02	15.90
12.8	0	0	0	0	0.000936	0	0.01	15.90
12.9	0	0	0	0	0.000936	0	0.01	15.90
13.0	0	0	0	0	0.000936	0	0.01	15.90
13.1	0	0	0	0	0.000936	0	0.01	15.90
13.2	0	0	0	0	0.000936	0	0.01	15.90
13.3	0	0	0	0	0.000936	0	0.01	15.90
13.4	0	0	0	0	0.000936	0	0.01	15.90
13.5	0	0	0	0	0.000936	0	0.01	15.90
13.6	0	0	0	0	0.000936	0	0.01	15.90
13.7	0	0	0	0	0.000936	0	0.01	15.90
13.8	0	0	0	0	0.000936	0	0.01	15.90
13.9	0	0	0	0	0.000936	0	0.01	15.90
14.0	0	0	0	0	0.000936	0	0.01	15.90
14.1	0	0	0	0	0.000936	0	0.01	15.90
14.2	0	0	0	0	0.000936	0	0.01	15.90
14.3	0	0	0	0	0.000936	0	0.01	15.90
14.4	0	0	0	0	0.000936	0	0.01	15.90
14.5	0	0	0	0	0.000936	0	0.01	15.90
14.6	0	0	0	0	0.000936	0	0.01	15.90
14.7	0	0	0	0	0.000936	0	0.01	15.90
14.8	0	0	0	0	0.000936	0	0.01	15.90
14.9	0	0	0	0	0.000936	0	0.01	15.90
15.0	0	0	0	0	0.000936	0	0.01	15.90
15.1	0	0	0	0	0.000936	0	0.01	15.90
15.2	0	0	0	0	0.000936	0	0.01	15.90
15.3	0	0	0	0	0.000936	0	0.01	15.90
15.4	0	0	0	0	0.000936	0	0.01	15.90
15.5	0	0	0	0	0.000936	0	0.01	15.90
15.6	0	0	0	0	0.000936	0	0.01	15.90
15.7	0	0	0	0	0.000936	0	0.01	15.90
15.8	0	0	0	0	0.000936	0	0.01	15.90
15.9	0	0	0	0	0.000936	0	0.01	15.90
16.0	0	0	0	0	0.000936	0	0.01	15.90
16.1	0	0	0	0	0.000936	0	0.01	15.90
16.2	0	0	0	0	0.000936	0	0.01	15.90
16.3	0	0	0	0	0.000936	0	0.01	15.90

16.4	0	0	0	0	0.000936	0	0.01	15.90
16.5	0	0	0	0	0.000936	0	0.01	15.90
16.6	0	0	0	0	0.000936	0	0	15.90
16.7	0	0	0	0	0.000936	0	0	15.90
16.8	0	0	0	0	0.000936	0	0	15.90
16.9	0	0	0	0	0.000936	0	0	15.90
17.0	0	0	0	0	0.000936	0	0	15.90
17.1	0	0	0	0	0.000936	0	0	15.90
17.2	0	0	0	0	0.000936	0	0	15.90
17.3	0	0	0	0	0.000936	0	0	15.90
17.4	0	0	0	0	0.000936	0	0	15.90
17.5	0	0	0	0	0.000936	0	0	15.90
17.6	0	0	0	0	0.000936	0	0	15.90
17.7	0	0	0	0	0.000936	0	0	15.90
17.8	0	0	0	0	0.000936	0	0	15.90
17.9	0	0	0	0	0.000936	0	0	15.90
18.0	0	0	0	0	0.000936	0	0	15.90
18.1	0	0	0	0	0.000936	0	0	15.90
18.2	0	0	0	0	0.000936	0	0	15.90
18.3	0	0	0	0	0.000936	0	0	15.90
18.4	0	0	0	0	0.000936	0	0	15.90
18.5	0	0	0	0	0.000936	0	0	15.90
18.6	0	0	0	0	0.000936	0	0	15.90
18.7	0	0	0	0	0.000936	0	0	15.90
18.8	0	0	0	0	0.000936	0	0	15.90
18.9	0	0	0	0	0.000936	0	0	15.90
19.0	0	0	0	0	0.000936	0	0	15.90
19.1	0	0	0	0	0.000936	0	0	15.90
19.2	0	0	0	0	0.000936	0	0	15.90
19.3	0	0	0	0	0.000936	0	0	15.90
19.4	0	0	0	0	0.000936	0	0	15.90
19.5	0	0	0	0	0.000936	0	0	15.90
19.6	0	0	0	0	0.000936	0	0	15.90
19.7	0	0	0	0	0.000936	0	0	15.90
19.8	0	0	0	0	0.000936	0	0	15.90
19.9	0	0	0	0	0.000936	0	0	15.90
20.0	0	0	0	0	0.000936	0	0	15.90
20.1	0	0	0	0	0.000936	0	0	15.90
20.2	0	0	0	0	0.000936	0	0	15.90
20.3	0	0	0	0	0.000936	0	0	15.90
20.4	0	0	0	0	0.000936	0	0	15.90
20.5	0	0	0	0	0.000936	0	0	15.90
20.6	0	0	0	0	0.000936	0	0	15.90

20.7	0	0	0	0	0.000936	0	0	15.90
20.8	0	0	0	0	0.000936	0	0	15.90
20.9	0	0	0	0	0.000936	0	0	15.90
21.0	0	0	0	0	0.000936	0	0	15.90
21.1	0	0	0	0	0.000936	0	0	15.90
21.2	0	0	0	0	0.000936	0	0	15.90
21.3	0	0	0	0	0.000936	0	0	15.90
21.4	0	0	0	0	0.000936	0	0	15.90
21.5	0	0	0	0	0.000936	0	0	15.90
21.6	0	0	0	0	0.000936	0	0	15.90
21.7	0	0	0	0	0.000936	0	0	15.90
21.8	0	0	0	0	0.000936	0	0	15.90
21.9	0	0	0	0	0.000936	0	0	15.90
22.0	0	0	0	0	0.000936	0	0	15.90
22.1	0	0	0	0	0.000936	0	0	15.90
22.2	0	0	0	0	0.000936	0	0	15.90
22.3	0	0	0	0	0.000936	0	0	15.90
22.4	0	0	0	0	0.000936	0	0	15.90
22.5	0	0	0	0	0.000936	0	0	15.90
22.6	0	0	0	0	0.000936	0	0	15.90
22.7	0	0	0	0	0.000936	0	0	15.90
22.8	0	0	0	0	0.000936	0	0	15.90
22.9	0	0	0	0	0.000936	0	0	15.90
23.0	0	0	0	0	0.000936	0	0	15.90
23.1	0	0	0	0	0.000936	0	0	15.90
23.2	0	0	0	0	0.000936	0	0	15.90
23.3	0	0	0	0	0.000936	0	0	15.90
23.4	0	0	0	0	0.000936	0	0	15.90
23.5	0	0	0	0	0.000936	0	0	15.90
23.6	0	0	0	0	0.000936	0	0	15.90
23.7	0	0	0	0	0.000936	0	0	15.90
23.8	0	0	0	0	0.000936	0	0	15.90
23.9	0	0	0	0	0.000936	0	0	15.90
24.0	0	0	0	0	0.000936	0	0	15.90
24.1	0	0	0	0	0.000936	0	0	15.90
24.2	0	0	0	0	0.000936	0	0	15.90
24.3	0	0	0	0	0.000936	0	0	15.90
24.4	0	0	0	0	0.000936	0	0	15.90
24.5	0	0	0	0	0.000936	0	0	15.90
24.6	0	0	0	0	0.000936	0	0	15.90
24.7	0	0	0	0	0.000936	0	0	15.90
24.8	0	0	0	0	0.000936	0	0	15.90
24.9	0	0	0	0	0.000936	0	0	15.90

25.0	0	0	0	0	0.000936	0	0	15.90

Appendix G: T-106 Data

Table 14: T-106 Vapor Stream Water Composition Data

kW	Water Mass Fraction	Water Composition (mg/kg biodiesel)
1	0.00401791	4017.91
2	0.0038067	3806.7
3	0.00356645	3566.45
4	0.00329579	3295.79
5	0.00299344	2993.44
6	0.00265824	2658.24
7	0.00228906	2289.06
8	0.00188532	1885.32
9	0.00144723	1447.23
10	0.00097804	978.04
11	0.00049184	491.84
12	6.99E-05	69.929
13	3.85E-06	3.8521
14	1.05E-06	1.0531
15	5.00E-07	0.50044
16	2.95E-07	0.29504
17	1.91E-07	0.19122
18	1.29E-07	0.12931
19	8.85E-08	0.088505
20	5.99E-08	0.059898
21	3.93E-08	0.039258
22	2.51E-08	0.025053
23	1.91E-08	0.019075
24	2.05E-08	0.020548
25	2.49E-08	0.024879
26	3.05E-08	0.030468
27	3.68E-08	0.036808
28	4.37E-08	0.043687
29	5.09E-08	0.050947
30	5.85E-08	0.058463

Table 15: T-106 Vapor Stream Composition Data

	Conc.				
kw	water	methanol	glycerol	sulfuric acid	biodiesel
1	0.001055915	0.379641464	0.077148508	0.00210167	0.540

2	0.000882774	0.318375105	0.076781351	0.002470211	0.601
3	0.000726052	0.262745367	0.074359801	0.002857892	0.659
4	0.000586926	0.213202126	0.07006256	0.003261208	0.713
5	0.000465296	0.169768244	0.064146439	0.00367687	0.762
6	0.000360328	0.132158056	0.056924243	0.004101974	0.806
7	0.000270629	0.099870308	0.048721941	0.004532641	0.847
8	0.000194614	0.072379281	0.039857338	0.004962531	0.883
9	0.000130680	0.049101659	0.030607639	0.005378911	0.915
10	0.000077480	0.029551031	0.021203929	0.005754906	0.943
11	0.000034357	0.013434355	0.011744301	0.006008936	0.969
12	0.000004382	0.00179475	0.002294246	0.005658941	0.990
13	0.000000236	9.8521E-05	0.000145372	0.003240835	0.997
14	0.000000064	2.69481E-05	4.01951E-05	0.001887833	0.998
15	0.000000030	1.27979E-05	1.91612E-05	0.00123644	0.999
16	0.000000018	7.53577E-06	1.13293E-05	0.000875592	0.999
17	0.000000012	4.87582E-06	7.37015E-06	0.000646523	0.999
18	0.000000008	3.28921E-06	5.00848E-06	0.000485758	1.000
19	0.000000005	2.24345E-06	3.45186E-06	0.000364066	1.000
20	0.000000004	1.50983E-06	2.36008E-06	0.000266461	1.000
21	0.000000002	9.80077E-07	1.57291E-06	0.000185457	1.000
22	0.000000002	6.13813E-07	1.03494E-06	0.000120466	1.000
23	0.000000001	4.49891E-07	8.34242E-07	8.40346E-05	1.000
24	0.000000001	4.56315E-07	9.72982E-07	7.30768E-05	1.000
25	0.000000002	5.17041E-07	1.26494E-06	6.81973E-05	1.000
26	0.000000002	5.95493E-07	1.62789E-06	6.46023E-05	1.000
27	0.000000002	6.81549E-07	2.02687E-06	6.13766E-05	1.000
28	0.000000003	7.71763E-07	2.44322E-06	5.83406E-05	1.000
29	0.000000003	8.64785E-07	2.86508E-06	5.54591E-05	1.000
30	0.000000004	9.59754E-07	3.28389E-06	5.2732E-05	1.000
31	0.000000004	1.05636E-06	3.69469E-06	5.01551E-05	1.000
32	0.000000005	1.15436E-06	4.09429E-06	4.77315E-05	1.000
33	0.000000005	1.25377E-06	4.48174E-06	4.54619E-05	1.000
34	0.000000006	1.35455E-06	4.85626E-06	4.33356E-05	1.000
35	0.000000006	1.45679E-06	5.21924E-06	4.13525E-05	1.000
36	0.000000007	1.56026E-06	5.57012E-06	3.9492E-05	1.000
37	0.000000007	1.66542E-06	5.91182E-06	3.77573E-05	1.000
38	0.000000008	1.77216E-06	6.24534E-06	3.61394E-05	1.000
39	0.000000008	1.88059E-06	6.57075E-06	3.4628E-05	1.000
40	0.000000009	1.99158E-06	6.89413E-06	3.32115E-05	1.000
41	0.000000009	2.10449E-06	7.21324E-06	3.18916E-05	1.000
42	0.000000010	2.21958E-06	7.52993E-06	3.0659E-05	1.000

43	0.000000010	2.33706E-06	7.84558E-06	2.94988E-05	1.000
44	0.000000011	2.45656E-06	8.15953E-06	2.84082E-05	1.000
45	0.000000012	2.57803E-06	8.47241E-06	2.73794E-05	1.000
46	0.000000012	2.70149E-06	8.78503E-06	2.64085E-05	1.000
47	0.000000013	2.82707E-06	9.09773E-06	2.54923E-05	1.000
48	0.000000013	2.95472E-06	9.41121E-06	2.46262E-05	1.000
49	0.000000014	3.08438E-06	9.72615E-06	2.38059E-05	1.000
50	0.000000015	3.21619E-06	1.00425E-05	2.30295E-05	1.000