ALGAL BIOTECHNOLOGY FOR FUEL APPLICATIONS

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Algal Biotechnology for Fuel Applications

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Algal Biotechnology for Fuel Applications

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CONTENTS

PREFACE

Algae are a solution to reduce carbon emissions, especially in today's world where the global climate has become important. The United Nations and the European Union suggested that algae can be used in this regard. With the genetic engineering done in the past, it has been observed that algae can be reproduced with synthetic DNA. It is even said that algae will evolve into a separate life form from other living things. Our book offers a wide range of environment-friendly algae technologies that reduce harmful emissions. In future editions, criticism from valuable readers will allow us to further develop new issues.

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CHAPTER 1

Introduction

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Abstract: The purpose of writing this book is to justify the production of biofuels from algae to minimize the emissions of fossil fuel technologies to reduce their environmental effects. Moreover, the use of algae, to reduce the amount of CO_2 emissions from the global CO_2 cycle is an alternative to existing biomass conversion technologies. The book covers the most efficient algae-to-oil conversion technologies, fuel characterization, and their reflection on different technologies. It is our hope that the topics here will not only help the scientific community for a more thorough understanding of alternatives to fossil fuels but also the civil society at large as well as policymakers at national and international level.

Keywords: Algae, Algae to oil, Biofuel production, Energy Consumption, Harvesting, Species.

INTRODUCTION

Many algae conversion technologies can convert raw bio materials to liquid biofuels (Fig. **1**). Liquid biofuels are preferred mostly in the transportation industry and many of these technologies produce various intermediates during biomass to liquid fuel conversation (Fig. **2**) [1 - 24].

Industry actors, definitions, and the current status of the biomass process are given in Figs. (**3** - **5**) [1 - 24].

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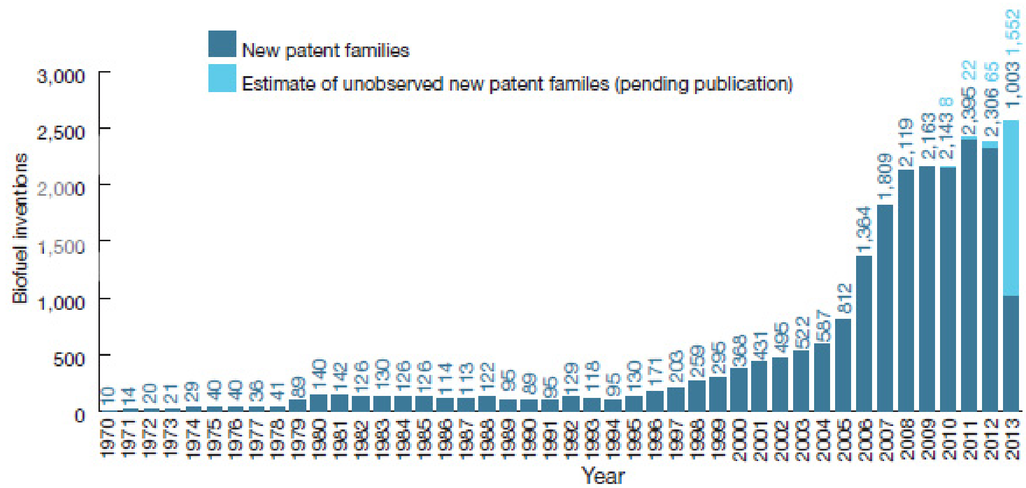

Fig. (1). Patented biofuel technologies [25].

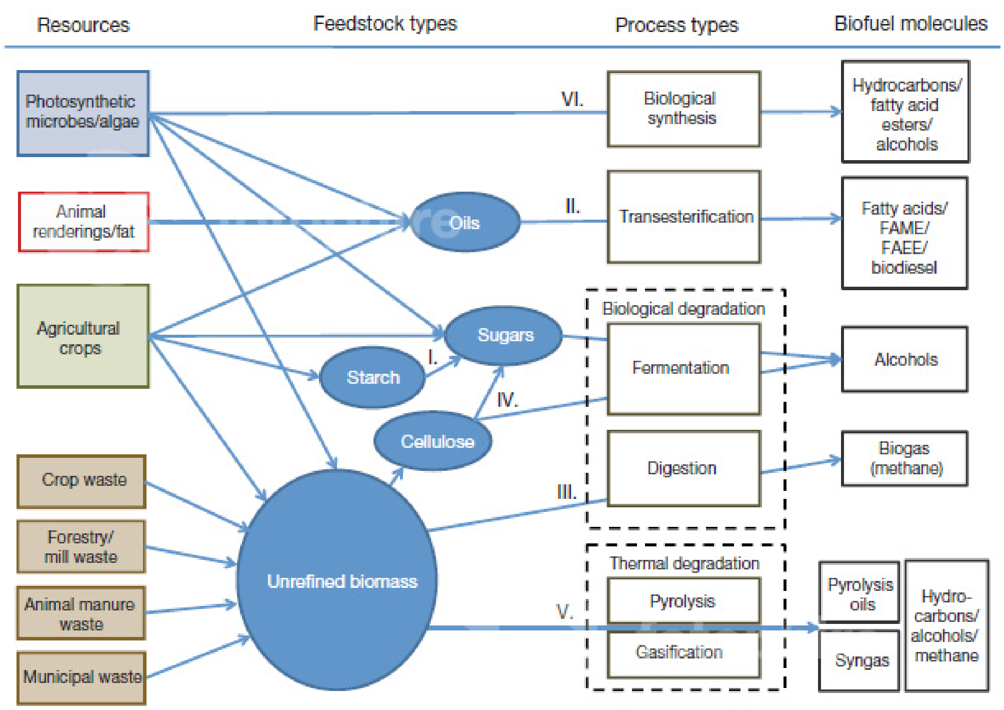

Fig. (2). Biofuel pathways [25].

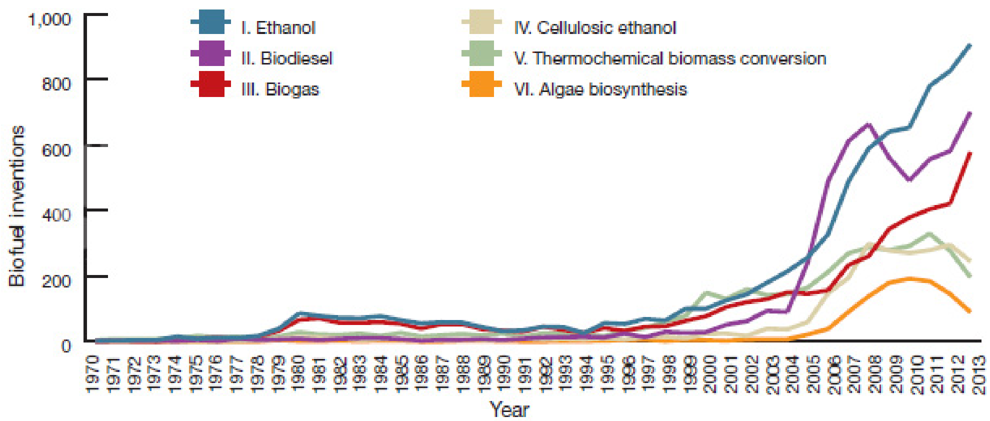

Fig. (3). Biofuel inventions [25].

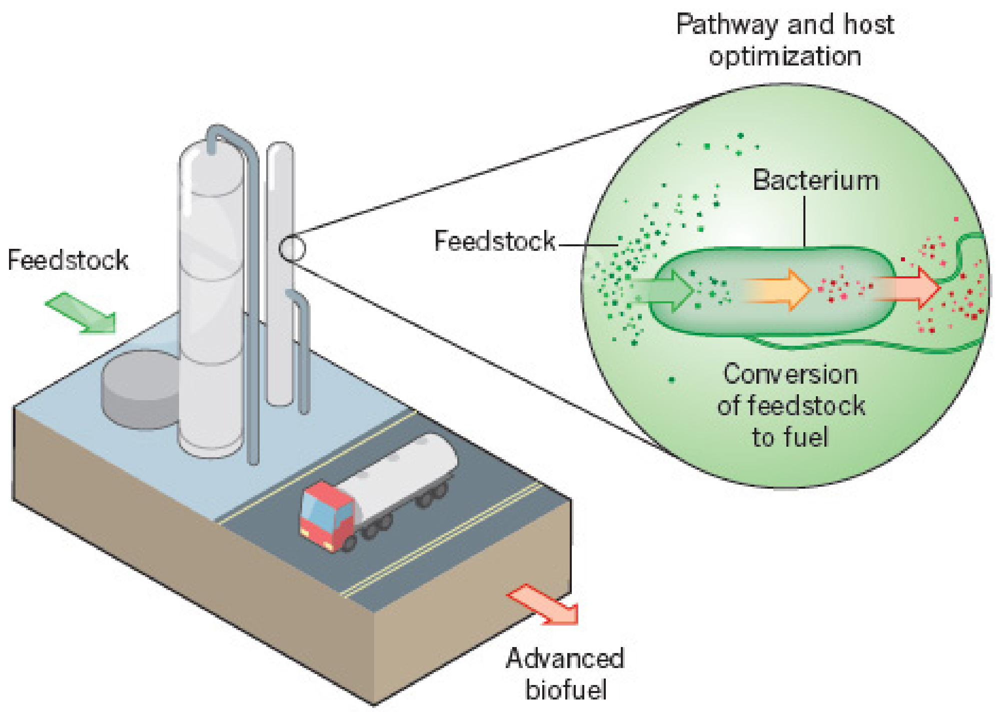

Fig. (4). Advanced biofuel technology basic definition [26].

CHAPTER 2

Anaerobic Algal Biotechnology

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Abstract: Biogas is produced with an anaerobic method, which involves live digestion of biomass in an oxygen-free environment. The second part of our book gives information about algae technology of the anaerobic process, which produces biogas by a biological process using animal fertilizers, food waste, and bioenergy products. In general, biogas can be used to produce heat and electricity, and its addition to the natural gas network is even considered as a vehicle fuel. It consists of 30-40% CO_2 as content, 45-65% CH_4. Conversion of CH_4, which is 20 times more harmful than CO_2 as a greenhouse gas, into energy is essential for the protection of environmental impact. In this sense, the burning of biogas emerges as a greenhouse gas reduction strategy.

Keywords: Algae, Algae to oil, Biofuel production, Energy Consumption, Harvesting, Species.

INTRODUCTION

In anaerobic digestion, which is a complex biochemical reaction that is carried out in several steps by the algae in an oxygen-free environment, the products are carbon dioxide and methane, biogas occurs from their mixture (Table **1**) [1 - 29].

In multiple stages, proteins, fats, and carbohydrates turn into water-soluble amino acids, fat subordinates, and sugars (Fig. **1**). The general composition of biogas is presented in Table **2**. The stages of biogas production from algae are hydrolysis, acidogenesis, acetogenesis, and methanogenesis. It is assumed that these stages combine acidogenesis and acetogenesis. In digesting the algae in an oxygen-free environment, all four steps take place inside the reactor. Biogas production takes place almost at the end of stage 3 [1 - 29].

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Table 1. Elemental biogas composition [8].

Basic Components	Biogas Composition (%)
Carbon dioxide (CO_2)	30-40
Methane (CH_4)	45-65
Ammonia (NH_3)	0-1
Hydrogen sulfide (H_2S)	0.3-3
Nitrogen (N_2)	0-5
Moisture (H_2O)	0-10
Oxygen (O_2)	0-2

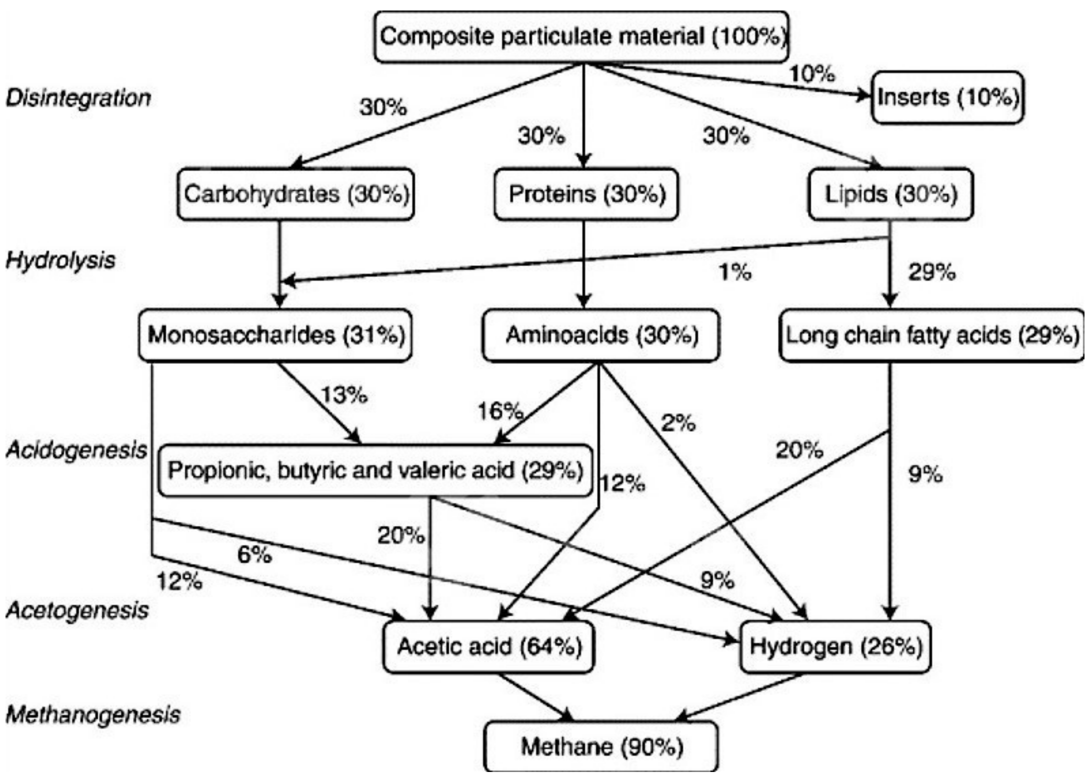

Fig. (1). Primary anaerobic digestion steps [8].

Step 1: Hydrolysis

In hydrolysis, the first step of the anaerobic process, the organic structure with a sizeable polymeric structure breaks down into simpler molecules such as amino acids, carbohydrates, fats, proteins, fatty acids, and simple sugars.

The major hydrolysis products are acetate and hydrogen. In the next process, methanogenic bacteria come into play. Methanogenic bacteria are expected to be large enough to convert the disrupted molecule into methane (Fig. **2** and Table **2**) [1 - 29].

Step 2: Fermentation or Acidogenesis

Other types of biomass break down after hydrolysis break down into simpler compounds during the acidogenesis phase. In an acidic environment, CO_2, H_2, ammonia, H_2S, alcohols, volatile fatty acids, carbonic acids, and by-products are formed. Biomass, which cannot reach sufficient size for methane production, reacts with the acetogenesis bacteria in the environment for the next stage [1 - 29].

Step 3: Acetogenesis

Acetogenesis bacteria use organic molecules of level 2 as energy and carbon source from acetate. CO_2, acetic acid, and H_2 are the essential ingredients for methane production in other products [1 - 29].

Step 4: Methanogenesis

In methanogenesis (the last stage of anaerobic digestion), methanogenic bacteria produce by-products from acidogenesis and hydrolysis, such as methane from products of steps 3 [1 - 29].

The two main reactions known at this stage are the use of carbon dioxide and acetic acid as reactants for the production of methane. From products, methane and CO_2 can turn into water. The primary known CH_4 raw material at this stage is acetic acid [1 - 29].

While CO_2 can be converted to methane and water by the reaction, the primary mechanism for forming methane in methanogenesis is acetic acid. This pathway creates two main products of anaerobic digestion, methane, and CO_2. It is observed that anaerobic digestion technology is applied in three categories [1 - 29].

- Dry continuous system: It is a system based on vertical or horizontal flow reactors working with 15-45% dry matter.
- Wet continuous system: technology in which raw material containing more than 20% dry matter is processed in continuously stirred tanks [1 - 29].
- Dry intermittent operation: These are systems where dry matter solids with 28-50% are processed at stages such as multi-stage irritants and filtration. The final product is used as a fertilizer [1 - 29].

CHAPTER 3

Thermal Liquefaction Based Algal Biotechnology

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Abstract: Large amounts of residues are obtained after lipid extraction when producing biodiesel from microalgae. From these residues, animal feed or bioethanol production may be obtained. Another alternative biofuel that can be obtained from microalgae biomass residues is bio-oil from pyrolysis or hydrothermal processes. Out of these, microalgae for biofuel production stand out due to the high thermal value of Algal biomass of around 24 MJ / kg. The organic components of the biological mass can be thermally decomposed in the production of fuel by thermochemical applications, such as direct combustion, gasification, pyrolysis, and liquefaction. With the hydrothermal liquefaction process, microalgae are converted into liquid crude oil with or without a catalyst. The reaction takes place at 280-370 °C and 10-25 MPa pressure on wet biomass in water. Biological oil production by hydrothermal liquefaction method from microalgae has gained considerable attention in recent years. Compared to the biodiesel obtained mainly due to the lipid content, hydrothermal liquefaction converts not only the lipid content but also carbohydrates and proteins.

Keywords: Algae, Algae to oil, Biofuel production, Catalytic process, Liquefaction.

INTRODUCTION

The purpose of converting biomass into liquid fuels is to use biomass that is difficult to use, has low energy contents, and takes up much space. The production of oils allows them to be stored, used directly, and pumped in combustion furnaces or used to obtain certain chemicals and fuels. As the essential product is liquid, the word liquefaction has been accepted to describe this process. A hydrothermal conversion process is a process involving water at high pressures and temperatures. Although high-temperature water (HTW) indicates that the liquid water is below the critical pressure and temperature

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(374.1 °C, 221 bar), over this point, it becomes a highly compressible liquid called supercritical water (SCW). An advantage of hydrothermal treatment for biomass is that hot water can act as a catalyst, a solvent, or a catalyst precursor. While many biomass compounds (*e.g.*, cellulose, lignin) are insoluble in ambient conditions, most are readily soluble in supercritical water (SCW) or HTW. The hydrothermal treatment has unique advantages for wet biomass related to both engineering (*e.g.*, higher energy efficiency) and chemistry (*e.g.*, rapid hydrolysis). The most crucial advantage of hydrothermal conversion is that hydrothermal treatment eliminates the need for feed water drying and removal [1 - 50].

Hydrothermal liquefaction is one of the thermochemical processes used to convert biomass into liquid products with high-energy content. It is generally performed under subcritical water conditions, an organic liquid called bio-oil, and high pressures are obtained (Fig. **1**). The hydrothermal liquefaction process resembles the way fossil fuels are formed. Nevertheless, fossil fuels are formed by the exposure of biomass underground with high pressures and temperatures for many years, while hydrothermal liquefaction results in liquid fuel in much shorter times in hours, even minutes. The fact that water is environmentally friendly and a unique solvent, the process can be applied to wet biomass, and therefore the biomass is not necessarily dried. It can be performed with high-energy efficiency, making hydrothermal liquefaction attractive and at much lower temperatures than pyrolysis. The goal of hydrothermal liquefaction is to obtain a commercial fossil fuel with high enthalpy density after the conversion of biomass. The essential point of the process is the risk and cost of using high pressure [1 - 50].

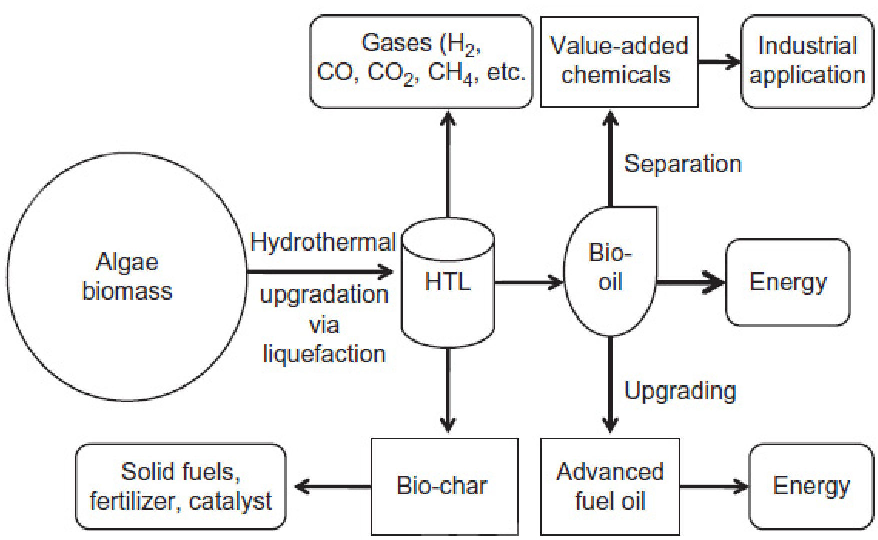

Fig. (1). A typical hydrothermal liquefaction process of algae.

There are also different types of production methods of algae to oil in current technology (Figs. **2** and **3**).

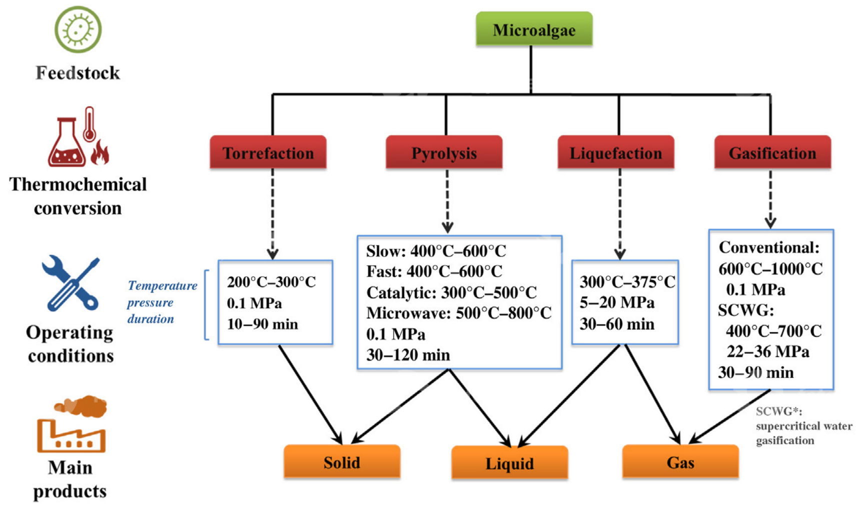

Fig. (2). Various techniques are used for algae to oil technologies [51].

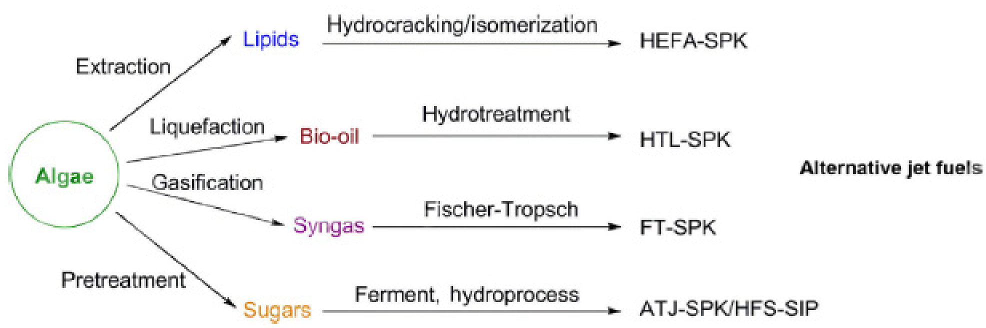

Fig. (3). Algae to Jet fuel pathway (HEFA-SPK: Hydro-processed Esters and Fatty Acids-Synthetic Paraffinic Kerosene, HTL-SPK: Hydrothermal processed-Synthetic Paraffinic Kerosene, FT-SPK: Fischer Tropsch processed-Synthetic Paraffinic Kerosene, ATJ-SPK/HFS-SIP: Alcohol to Jet Synthetic Paraffinic Kerosene/ Hydroprocessed Fermented Sugars to Synthetic Isoparaffins) [52].

The water used in the hydrothermal liquefaction process is an environmentally friendly and unique solvent; this process can be applied to wet biomass; it is performed with high energy efficiency at lower temperatures than pyrolysis. Water, which is the most critical solvent in nature, has very different properties in the above-critical conditions. Water cannot only dissolve organic compounds under normal conditions; it can also dissolve organic compounds under critical conditions. Under normal conditions, while the water has a high dielectric

CHAPTER 4

Biodiesel Production from Algae Oil

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Abstract: In this study, biodiesel production was investigated by the transesterification reaction from algae oil. For biodiesel production, the oil obtained from Chlorella protothecoides type algae grown in freshwater with 5% thermal water was added to fully automated closed-loop system high-tech pyramid photobioreactors and adapted for oil production, which had a low acid value (0.23 mg KOH/g). Because of this, base catalyst transesterification was applied. For the transesterification reaction, 99.7% purity of methyl alcohol as alcohol and 99.9% purity of potassium hydroxide (KOH) was used as a catalyst. In order to determine the most suitable conditions for the production of biodiesel from algae oil, a series of laboratory-scale preliminary experiments have been carried out. As a result of the optimization studies, the 6:1 methyl alcohol/oil molar ratio, the use of KOH up to 0.75% of the oil by mass, the reaction temperature of 60 °C, and the reaction time of 60 minutes were determined as the most suitable conditions for biodiesel production. Under these conditions, 96.4% methyl ester yield was obtained, and kinematic viscosity and density values of the final biodiesel product were measured as 4.493 mm^2/s and 882 kg/m^3. As a result of the physical and chemical analysis of the produced biodiesel, it has been determined that it has an ester content of over 96% and that the free and total glycerol content with methanol, mono-, di- and tri-glyceride is well below the maximum values specified in the EN 14214 and ASTM 6751 biodiesel standards. However, properties such as viscosity, density, flash point, cetane number, acid value, sulfur and water content were found to be compatible with the specified standards. In addition, besides having the standard fuel properties of the produced biodiesel, its high cetane number (57) and good cold filter clogging point (-11 ºC), makes it an important alternative diesel engine fuel.

Keywords: Algae oil, Biodiesel fuel properties, Transesterification.

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INTRODUCTION

Algae Oil Characterization And Fatty Acid Distribution

Algae have oil contents with different compositions depending on the species types. Some species were identified to have suitable fatty acid values. In the same way, some algae have more components of fatty acids due to their dry masses. Microalgae can grow in different conditions, even in the availability of fewer nutrients. They are best to be chosen for cultivation. The collection of samples needs care so that the entire biofuel contents could be obtained through careful handling of the instruments. The growth is also affected by different environmental factors that are not explicitly known for every region, so the process needs increasing attention accordingly [1].

The algae oil used for biodiesel production in the study was obtained from a commercial company (Soley Biotechnology, Istanbul, Turkey). The seaweed oil used was obtained from Chlorella protothecoides algae, grown in fresh water with 5% thermal water, and in fully automated closed-loop system high-tech pyramid photobioreactors adapted to produce heterotrophs and oils (Fig. **1** and Table **1**).

Fig. (1). Algae oil is produced from biodiesel.

Table 1. Some properties of algae oil.

Properties	Unit	Algae Oil	Pretreated Algae Oil
Density (15 ºC)	kg/m^3	917	914
Cinematic Viscosity (40 ºC)	mm^2/s	36,8	33,6
Acidity Value	mgKOH/g	0,29	0,23
Moisture Content	ppm	742,6	228
Calorific Value	kJ/kg	39,287	39,370

Some properties were analyzed before algae oil was converted to biodiesel. In the analyses made, it has been determined that seaweed oil has high water content, viscosity, and density values. To reduce the water content of algae oil, the sample oil was taken into a beaker after being filtered and preheated by mixing it with a magnetic stirrer for 2 hours at a temperature (above 1100 ºC) above the boiling point of water. In the preheating process, after the oil was rested in a suitable environment, the same parameters were analyzed again. In Table **1**, some properties of the moss oil used in biodiesel production before and after pretreatment are given. When Table **1** is examined, it is seen that there is a significant decrease in the water content, especially after the seaweed oil has been subjected to a preheating and filtering process. The viscosity of algae oil appears to be too high to use as a fuel in diesel engines. In order for vegetable and animal oils to be used as an alternative fuel in diesel engines, it is necessary to reduce the viscosities that are too high compared to oil-based diesel fuel (diesel oil). For this purpose, dilution, microemulsion forming, pyrolysis, and transesterification methods are used. In the dilution method, the oil is diluted by mixing with a certain amount of diesel fuel. The mixture improves the viscosity, evaporation, and spraying properties of the fuel, depending on the diesel fuel ratio. In microemulsion generation, the oil is intended to form microemulsions with short-chain alcohols such as methanol, ethanol, or 1-butanol. The microemulsion is the equilibrium distribution of optically isotropic liquid microstructures with sizes between 1-150 nm, which is formed by the combination of two ordinarily non-mixing liquids and one or more active substances. In the pyrolysis method, fat molecules are broken down into smaller molecules in an oxygen-free environment at high temperatures. Pyrolysis process: It is divided into three parts; such as hydrocracking, catalytic cracking, and thermal cracking. The amount of product produced depends on the method used and the reaction parameters. With this method, although the fuel properties of the oils are similar to the diesel fuel properties, the high energy consumption is the most crucial disadvantage. Transesterification is the re-esterification reaction of fatty acids (vegetable oils, domestic waste oils, animal fats) with alcohol (methanol, ethanol, *etc.*)

CHAPTER 5

Algal Biodiesel Chemical Characterization

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Abstract: Algae have been produced or evaluated as a nutritional supplement in animal husbandry, rather than as an alternative energy source for many years. As a result of biomass energy research, which has accelerated in recent years with the impact of rising oil prices, algae have started to be seen as a promising energy source. Despite being successful in laboratory research, pilot, and small-scale experiments, also called third-generation biofuel technologies and aiming to use many algae species in nature as an energy source, the desired yield cannot be obtained if ideal processes cannot be created in large-scale local productions. In general, algae may contain about 15-77% fat although the volume varies by species. Compared to other oil plants, their high oil content and growth efficiency make algae attractive for biodiesel and biogas production. The production of these fuels from algae has the potential to respond to the increasing global energy need and, in part, to contribute to the prevention of global warming by converting more than enough carbon dioxide in the atmosphere into efficient products through photosynthesis.

Keywords: Algal biodiesel, Chemical Characterization, Environmental issues, Oil quality.

INTRODUCTION

One of the advantages of using algae as raw materials for biofuels is that different types of fuels can be produced through it. In addition to biodiesel and biogas, algae have properties that can meet our needs for ethanol, bio-jet fuel, bio-gasoline, or other fuel. Biodiesel is a diesel fuel derived from plant or animal lipids (oils or fats). Studies show that some algae species contain more than 80% of their total dry weight fat. Algae cells have large-scale biomass production capacities, as they are grown in an aqueous suspension medium in pools and photobioreactors with water, CO_2, and dissolved nutrients. Fats produced from

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algae can be converted into biodiesel for later use in automobiles. In Fig. (**1**), biodiesel and various biofuels are obtained as a result of the extraction of oil from algae that was established next to the power plant and grown by using wastewater such as agricultural or sewage.

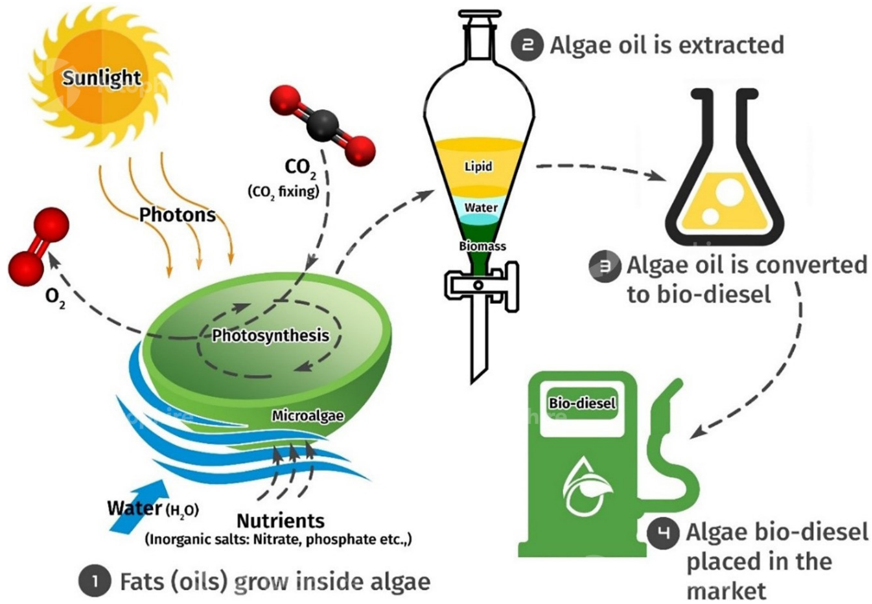

Fig. (1). Flowchart for biotechnology [1].

ALGAE OIL AND ITS PROPERTIES

Due to the quality and quantity of oil produced from algae; the nutrients in the environment vary depending on CO_2, water, light intensity, pH, and temperature. Minerals and vitamins, which are very useful for health, are high in algae oil. Algae oil, which is mostly preferred in the cosmetics industry, is also useful for general health. Algae oil is very effective in the study of thyroids, regeneration of tissues, and acceleration of metabolism. The usage area of moss oil is extensive. However, it is generally preferred for body’s beauty. The reason is that the minerals and vitamins contained in algae oil meet the body's needs. Also, as a result of the rapid consumption of fossil fuels in recent years, the pollution of the atmosphere at the same speed and the increase of the effects of greenhouse gases have increased the demand for alternative energy sources. As a result of the studies, the idea that algae oil will be an alternative source of fossil fuels has been strengthened. In addition, fuels such as biodiesel, bio-jet fuel, bio-gasoline, biobutanol, bioethanol, and methane were obtained from algae oils, and it was determined that their fuel properties are suitable (Table **1**) [2].

Table 1. Mandates, targets, and policies of selected countries [2].

Biodiesel and Ethanol	Policies	Country
Obligation by 2030 (% energy), 30% biofuel supply	-	Finland
5% ethanol	To produce ethanol approved feedstocks, biofuels' policy expands	India
25% biodiesel (%vol.) by 2036 and 32% ethanol	-	Thailand
10% biodiesel, 12% ethanol (%vol.)	-	Argentina
10% renewable energy by 2020 (T) in transport with 7% for conventional biofuels (% energy)	In 2030, a Provisional agreement for 14% renewable energy in transport	European Union
Low carbon Fuel Standard in Oregon and California	by 2022 136 billion L.	USA
10% biodiesel (%vol.) and 27% ethanol	RenovaBio signed into law, by 2028 10% GHG reduction	Brazil
10% ethanol (%vol.)	To extend nationwide distribution in 2020, 10% ethanol was mandated	China

Some properties are analyzed before algae oil is converted to biodiesel. In the analyses made, it has been determined that algae oil has high acid value, viscosity, and density values and partially contains water. To reduce the water content of algae oil, the sample oil is first passed through a filter. Then, it is taken to a beaker and subjected to preheating by mixing it with a magnetic stirrer for 2 hours at a temperature over 100 ^{o}C (at 110 ^{o}C), which is the boiling point of the water. After the preheating process, the oil is rested in a suitable environment and then the acid value, viscosity, density, and water content parameters are analyzed again. In Table **2**, some properties of the moss oil used in biodiesel production before and after pretreatment are given [2].

Table 2. Some properties of algae oil.

Properties	Unit	Algae Oil	Pretreated Algae Oil
Density (at 15 ^{o}C)	kg/m^3	915	913
Kinematic viscosity (40 ^{o}C)	mm^2/s	35,6	32,4
Acidity value	mg KOH/g	0,28	0,22
Water content	ppm	734,7	220

When Table **2** is examined, it is seen that there is a significant decrease in the water content, especially after the seaweed oil has been subjected to a preheating and filtering process. The viscosity of algae oil appears to be too high to be used

CHAPTER 6

Microbial Fuel Cells (MFCs) Technology

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Abstract: The purpose of this book chapter is to provide general information regarding microbial fuel cell (MFC) systems, an important type of fuel cell of environmentally friendly energy conversion systems as an alternative to fossil fuel technologies. Besides, it is one of the main motivations of this study to include the academic literature on microbial fuel cells, which is a very popular field of study in recent years. In this context, the history, principles, and different approaches of MFCs are discussed. After that, the materials (anode, cathode, membrane, *etc*.) that make up the system are examined. Finally, different types of microbial fuel cells that can be varied by material design are discussed and presented.

Keywords: Energy, MFC materials, Microbial fuel cell, Single-chamber MFC, Two-chamber MFC.

INTRODUCTION

The fuel cell is a clean, high-efficiency energy technology that does not remove waste materials that cause environmental pollution. Fuel cells are devices that continuously convert the chemical energy of a fuel (hydrogen-rich gas mixture from hydrogen) and an oxidizer (oxygen of air) into electricity and heat form. In other words, it is an electrochemical structure (galvanic cell) that converts the free energy of a chemical reaction into electrical energy. The fuel cell has a high fuel conversion efficiency ranging from 40% to 70%, depending on the thermal value of the fuel [1].

Fuel cells are similar to accumulators or batteries. Both convert chemical energy directly into electricity. It is stored in the accumulator before the use of chemical energy, while the fuel cell can generate electricity as long as energy is supplied from external sources. The principle of operation of fuel cells is the chemical reaction, which is the opposite of water electrolysis. In a fuel cell, gaseous fuels

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(hydrogen) are sent by the anode and oxidizing gases (oxygen) by the cathode. Oxidation reactions at the anode occur at the cathode and reduction reactions occur at the cathode. As a result of the total reaction, water and heat are produced as a product [2]. In the electrolysis reaction, when a direct current is applied to the water, it decomposes in proportional volumes to oxygen and hydrogen. Since electric energy is decomposed into water components when applied, it is taken logically if the process is arranged in the opposite direction, that is when water and heat are obtained as a result of the reaction of oxygen and hydrogen [1 - 3].

Instead of pure hydrogen, hydrocarbons can be used in the fuel cell. However, it is not preferred because it reduces efficiency. The general display of a typical fuel cell is shown in Fig. (**1**).

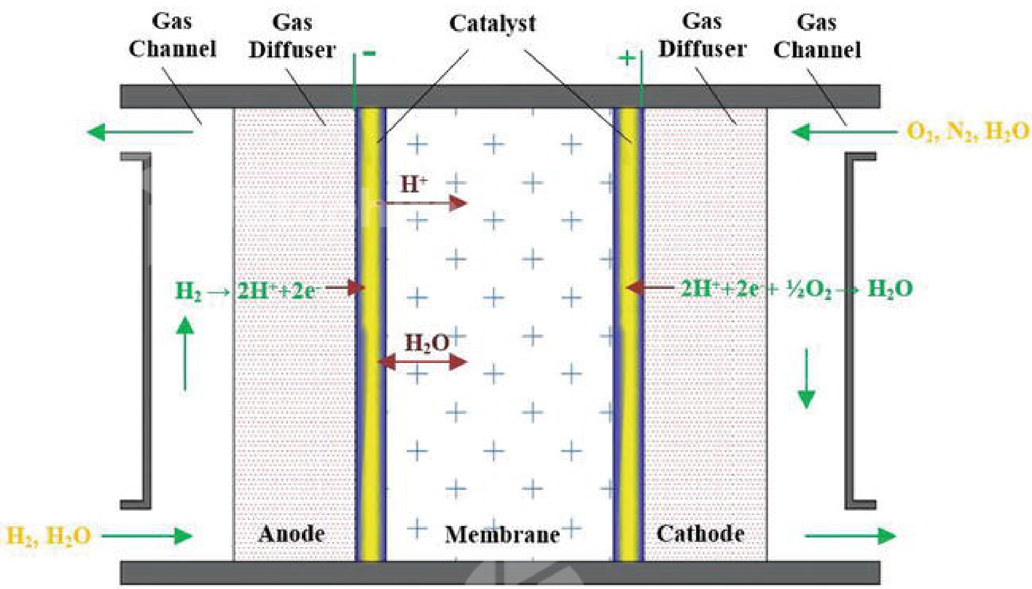

Fig. (1). A typical PEM (Polymer electrolyte membrane) fuel cell [4, 5].

Considering that fossil fuels are consumed day by day, it is necessary to find and use alternative energy sources. Therefore, electrical energy production from renewable energy sources is the most preferred method. Recently, the most emphasized alternative energy source is Microbial Fuel Cells (MFCs). The principle of the MFC, in its purest form, is to convert chemical energy contained in organic waste into electrical energy with the help of microorganisms.

Microbial Fuel Cells (MFCs)

Electric energy production from microorganisms was not a new idea but was first introduced by Botanical professor MC Potter at Durham University in 1911. In this study, he stated that electricity production is the result of the activities of microorganisms, and the electrical effect is affected by temperature, food source, and the number of active microorganisms available. In the study, it was reported between the maximum of 0.3-0.5 V electricity generation. Assuming that people will meet their energy needs from such systems in the future, he established a single microbial fuel cell but did not have a broad knowledge of bacterial metabolism [6].

No significant work has been carried out until the early 1980s. During this time, with the realization that electricity is a significant power source, Young *et al.* (1966), using intensive studies on MFC, used microorganisms for the production and removal of electrochemical products. As a result, they made three types of biochemical fuel cells [7]. In the late 1980s, Benotto proposed the reduction and oxidation process that takes place in microorganisms, which is still valid today with many studies [8].

In 2004, the relationship between electricity generation and wastewater treatment was demonstrated using MFCs, and it was shown that domestic wastewater could be treated at the application scale when generating electrical energy. A first lab-scale MFC prototype was developed by Bruce Logan and showed that when bacteria are fed with microbial nutrients, such as glucose acetate, or organic compounds in wastewater, energy is produced [9].

MFC technology is a promising sustainable energy source that can use organic materials, and generate electrical energy, recently through microorganisms [10, 11]. One of the reasons why MFC systems are regarded as renewable energy sources is that they are carbon-neutral, that is, they release only stable carbon into the atmosphere as a result of oxidation of organic materials [12]. MFC can also be considered an electrochemical hybrid system because they are a system that combines microbial and electrochemical processes [10]. In short, MFCs are bioelectrochemical reactors that convert chemical energy in organic compounds into electrical energy through catabolic reactions of microorganisms under anaerobic conditions. In MFC, dissolved organic materials are converted into electrical energy by bioelectrochemical means, that is, by the catalytic reaction of microorganisms [13].

In a study, Varol and Uğurlu (2016) investigated the use of *Spirulina platensis*, a blue-green alga, as a renewable energy source in discrete and semi-discrete systems. In intermittent studies, by reducing 89-93% of volatile solids, a solids

CHAPTER 7

Algae Cultivation in Different Systems

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Abstract: Since algae are simple organisms that contain chlorophyll, they can be found anywhere on earth where they can use light for photosynthesis. Although pool-type open systems are generally used, closed photobioreactors are also used in the cultivation of algae. The low investment and operating costs of the outdoor pools made the system preferable in the industry. However, the difficulty of controlling the production conditions and the risk of contamination appears as the disadvantages of the system. It is necessary to compare fundamental aspects such as effective use of light in large-scale culture systems, temperature, hydrodynamic balance in algae culture, and maintaining the continuity of the culture. The ideal growth of each algae species takes place in culture media with its specific conditions. For example, Spirulina grows best at high pH and bicarbonate concentration, Chlorella in nutrient-rich media, and Dunaliella salina at very high salinity.

Keywords: Fuel from Algae oil, Photobioreactor, Open-closed pond systems.

INTRODUCTION

Microalgae absorb solar energy under phototrophic growth conditions. Microalgae absorb carbon dioxide from nutrients in aquatic life and the air. The most important factor affecting microalgae's production efficiency is reactor selection. Outdoor pools are systems that require large areas and are used in industrial activities due to the low capital and investment cost. Temperature control in these systems is difficult due to seasonal and daily fluctuations. Fluctuations in temperature, poor light intensity, dissolved oxygen concentration, and the effect of pH can limit the growth parameters of microalgae. With low biomass productivity (0.1-1.5 g/L), the formation of unwanted species and operational weakness make system control difficult.

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Open systems consist of different structures such as large and shallow circular pools, algae pools. Circular and agitated ponds revolving around the central shaft are the earliest known algae growing tanks. These systems are designed to be 10.000 m^2 due to the difficulty of constructing the larger mixer.

The most common system used for microalgae production is algae ponds. These systems are designed in the form of oval-shaped and closed-loop circulation channels, in the range of 0.2-0.5 meters, to be mixed with an impeller to ensure homogeneity. Algae ponds can be made of fiberglass, concrete, or membranes.

Chlorella and spirulina are the most commonly grown microalgae species in open systems. When considering microalgae cultivation in open systems, many parameters such as land cost, the biology of microalgae, nutrients and water in the system, final product to be formed and local climatic conditions should be considered [1, 2].

OPEN POND SYSTEMS

Production in the open system is completely open to nature, depending on the climatic conditions of the region where the product is made. Open systems are shallow open-channel raceway pool systems where the water depth is not less than 15cm and not more than 25cm; circulation is provided by paddle mixers [1, 2]. In the production of the open-air system, factors such as temperature, lighting, evaporation, and water loss cannot be intervened. Nutrients such as nitrogen, phosphorus, and carbon can be partially controlled. The amount of carbon can be determined by measuring the acidity of water. Due to disadvantages such as being impure (mixed with other species), being directly affected by external factors, and being unhygienic, the waste of Spirulina, which is produced in the open system, increases, and the productivity decreases. These negativities directly affect the production costs [1, 3]. In addition, labor costs in the production in open systems are quite high. The main reason for the use of open systems is that the initial establishment costs are quite low, the seasonal cycle can be caught, the production can be started quickly, and the product can be purchased early. In addition, such production systems are preferred and made in hot regions where seasonal values do not change much, water is abundant, production will not be affected much [4, 5]. The quality standard of the product obtained as a result of the products made in open systems varies according to the seasonal conditions and differences of the day [1, 6, 7]. This brings together more than one quality classification. As a result of this classification, the usage area of the product changes. Therefore, the value decreases depending on the quality class of the product [8]. The yield of the products made in the open system is not certain and varies in a wide range [9]. This creates uncertainty in the production. In order to eliminate these negativities and reduce risks, the number of production pools and systems in open systems is increased (Fig. **1**). Parallel to this increase, personnel, energy, land, and consumption expenses also increase [10, 11]. Another important factor in Spirulina production in open systems is that the ponds are open to poultry, reptiles, amphibians, rodents, and other regional wildlife species and visitors. The biggest problem that cannot be dealt with in open-type production systems is flies and aquatic insects, and their destruction and removal are carried out with pesticides. The use of pesticides also creates a toxic effect. It is not as easy as it seems to eliminate this toxicity. The use of such chemicals and drugs causes significant losses in products to be used as human food but also poses some risks. At this point, the point to be considered is that the product to be offered for human consumption should first of all be purified from bacteria that cause disease and transmitted to animals and possibly toxic substances that have been used. This purification process brings additional workmanship and chemical applications to the product. In these applications, it causes various concerns in terms of consumability, as well as spoiling the quality, organic structure, and naturalness of the product [7, 12 - 15].

Fig. (1). Algae production in pools and ponds.

CHAPTER 8

Use of Microbial Fuel Cells (MFCs) in Food Industry Wastewater Treatment

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Abstract: Since MFC degrades simple carbohydrates *i.e.* glucose, acetate, and butyrate, and countless organic substances such as pig wastewater, domestic wastewater, and manure sludge waste, the biochemical energy generated by the catalytic reactions of microorganisms and converts the waste produced into energy. It promises a sustainable wastewater treatment to balance the operating cost. This chapter is a review of the advantages of microbial fuel cell treatment of food industry wastewater, which creates high organic pollution in the industrial field.

Keywords: Food industry wastewater, Industrial wastewater treatment, Microbial fuel cell.

INTRODUCTION

Rivers, groundwater strata, and groundwater are particularly contaminated by humanitarian actions such as energy and food production. This pollution occurs when large amounts of foreign and harmful substances or substances that cannot be removed by natural cleaning are mixed into water, and this mixing makes the water unusable. More than 10 million children die before their 5th birthday each year. Four million of these children die before turning a month old and 2 million from diarrhea. This current situation necessitates the purification of water from pathogens for its sustainable use. Today, 300-500 million tons of heavy metals, solvents, toxic waste, and other waste materials accumulate every year due to industrial activities. Others break down to form non-toxic compounds. Industries based on organic raw materials such as the food production industry are the sectors that contribute the most to the organic pollution problem. The food industry in developing countries produces more than 50% of organic water pollutants. The water supply, sewerage, and wastewater systems require energy

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for the extraction, distribution, collection, treatment, and disposal of water. Traditionally, water supply systems rely on surface water resources, large distribution systems, and the mixing of treated wastewater. Today, additional energy input is needed to meet the increasing water demand and to protect human and environmental health [1].

It is known from the literature and managerial experiences that 25-40% of the operating costs in a conventional wastewater treatment plant result from energy consumption. This value varies between approximately 0.2-2.1 kW-hour per m^3 of treated wastewater. Typically, in a conventional wastewater treatment plant, the main contributors to energy consumption are mixed fluid aeration (55-70%), primary and secondary settling by sludge pumping (15.6%), and sludge dewatering (7%) [2].

Today, by using microbial fuel cells for the treatment of wastewater with limited use for biogas production with high concentrations of nitrogen and sulfur, the wastewater treatment will be carried out under anaerobic conditions, while electrical energy will be obtained directly. The system, which can be operated with high loading rates under anaerobic conditions, will be treated without ventilation, which corresponds to almost half of the energy needed for the treatment, as mentioned above, and electrical energy will be obtained directly from the chemical energy stored in organic matter. As there is only CO_2 output as a result of wastewater treatment, there is no need for an additional gas treatment unit [3].

COMPONENTS OF MFC

Many different types of MFC reactors have been used in studies carried out so far.; These are generally two-compartment, H-type MFC reactors, U-tube MFC reactors, tubeless MFC reactors, sediment-type MFC reactors, and single-compartment MFC. The H-type MFC reactor consists of two flasks, usually in the form of an H, combined with a tube containing a membrane that separates the anode and cathode from each other. Separators are usually in the form of a cation exchange membrane or salt bridge such as Nafion or Ultrex. The point that should be taken into consideration in designs is that the membrane allows protons to pass while not allowing the passage of food or the electron acceptor in the cathode compartment. Accordingly, MFC; consists of anode, cathode, and selectively permeable proton exchange membrane [4].

Anode Cell

An anode material should be: biocompatible, suitable mechanical strength, low internal resistance, high conductivity, high surface area, porosity, non-corrosive, non-clogging by bacteria, cheap, easily manufactured, chemically inert, and scalable in larger sizes. The most important of these features is that it must have electrical conductivity, unlike other biofilm reactors. Also, the bacteria must be able to attach to the material and provide a good electrical connection. There are many anode materials used in MFCs. Materials such as plain graphite, graphite plate, carbon paper felt or foam, mesh vitreous carbon (RVC), graphite granules, graphite rods, graphite fibers, graphite fiber brushes, and anode due to their stability, high conductivity, and high specific surface area in a microbial graft mixture are being used [5, 6].

The use of carbon-based electrodes has long been proven and enabled the production of carbon in a large number of analytical and industrial applications due to its high efficiency in heterogeneous electron transfer kinetics [5, 6].

Cathode Cell

The cathode material is another factor that limits power generation in MFCs and significantly affects performance. Different cathode materials were used in the studies according to the reactor and wastewater type. In addition to the use of graphite-based materials, it can also be used as an anode electrode [9]. In the cathode section; A three-phase reaction occurs: solid (cathode electrode), gas (electrons, protons, and all of the oxygen), and liquid (catholyte). Ferricyanide $[Fe(CN)_6]$ has a very popular use as an experimental electron acceptor in MFC systems due to its good performance. Oxygen is the most suitable electron acceptor for MFC due to its high oxidation potential, low cost, sustainability, and no chemical waste generation [3, 7 - 9].

PROTON SELECTIVE MEMBRANE

MFCs are divided into two according to the presence of membrane in MFCs. The presence of the membrane is not mandatory [3].

Proton conductive membranes are MFC components that physically separate the anode and cathode compartments and allow the passage of protons to the cathode to generate electrical current, and ensure that the mixtures in the cathode and anode compartments do not mix. These membranes must be permeable to allow proton passage from the anode to cathode. The most widely used membrane type in proton selective systems is the Nafion membrane [3].

ELECTRICTY FORMATION IN MFCS

Obtaining electrical energy from an MFC is possible only if the reaction taking place is thermodynamically suitable. The total cell electromotive force of the

CHAPTER 9

Development of Algae Oil Production With Ecological Engineering

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Abstract: It is well known that the use of algae-based fuels is not widespread as they do not meet the necessary fuel standards. The amount of oil products obtained from traditional biomass sources exceeds that obtained from algae. However, ecology can provide more assistance in increasing the current efficiency of oil production from algae. Depending on the species, effective results can be obtained through the production of fatty acids and biofuels. The amount of fuel produced by a single species should be weighted against the amount of oil produced by a combination of species. The presence of genetic diversity, particularly in two types of algae mixtures, is unavoidable in order to improve the quality of fuel produced. The lipid obtained under genetically diverse population is highlighted in this study.

Keywords: Biodiesel quality, Ecological science, Fatty acid, Genetic diversity, Mixed algae.

INTRODUCTION

Humans, like all living things, require energy. As a result, humans have changed their lifestyles for years in search of energy resources, waged wars, and even changed their industries based on energy production. The most significant advantage of algae over traditional biomass sources is that they can be grown ubiquitously and it is relatively easy to separate the fatty acids produced from the biomass. The fatty acid methyl ester is a well-known product during the esterification process of fatty acids extracted from algae biomass. The different

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types of acid compositions and fatty acids determine the quality of algae biomass. Innovative technologies, such as the hydrothermal liquefaction method, can be used to determine the conversion efficiency of wet algae biomass to crude oil [1].

The fact that the biomass with a fat-to-acid ratio is generally low in the whole mass is a significant bottleneck. The primary reason for this is that living organisms consume energy and store some products while producing fatty acids.

Using genetic engineering technologies, more than one algal strain can improve both the quality and quantity of biofuel produced. Such genetic manipulations can also reduce the increasing cost and constraints in fatty acid production.

FINDINGS

A scenario for oil production by mixed algae is depicted in Fig. (**1**) [2], showing the life cycle greenhouse gas emissions for biofuels produced from algae cultures grown with treated wastewater. Carbon emissions are due to the use of electricity when the water is pumped out of the system after the algae have grown. The high concentration of algae biomass is an important outcome of this life cycle study. In other words, mixed algae harvest more efficiently. It has been determined that an environment with minimal chemical inputs during algae cultivation without the use of electricity can only be produced under conditions such as precipitation and clumping. However, the cultivation of algae in a large precipitation tank will cost additional infrastructure. However, the carbon emission effect of this setup on the cost was not considered such as the cost of dewatering (*i.e.*, 50.2 g CO_2 eq/MJ). Drying was thought to be accomplished through centrifugation and heating. The steam of coal plants can be used for heating. The sunlight can also be used to dry the algae. However, considering the intensity of the sunlight during the time of processing, such drying should be weighed against time and space. Improving the tools such as pumps, and centrifuges has a significant impact on system cost [2]. When three different algae species were combined and supplemented with 5% $MgCl_2$, $ZnCl_2$, and NaH_2PO_3 for fuel production the oil production increased by 6.3%, 16.2%, and 0.71%, respectively [3].

The importance of algae mixtures for the production of high oil content was also emphasized in other studies. Bio-oil produced by mixing 15 different algae species can be converted into biodiesel at 60% efficiency and while 96% of nutrient removal was also achieved [4]. In addition, another study showed the increased yield of methane by mixed algae in household waste using biogas technology [5]. A study using CO_2 conversion of *Chlorella vulgaris* and *Scenedesmus obliquus* species to be 14.9% and 13.85% when CO_2 feeding rates were 140.91 and 129.82 mg/L per day, respectively. The same study found that the mixture of *Scenedesmus obliquus* and *Chlorella pyrenoidosa* has the greatest potential (biomass production up to 20%, CO_2 conversion at 10%) for biomass production and CO_2 conversion compared to other species. In conclusion, it is predicted that liquefaction is an ideal technology for the production of fuel from algae [6]. The rate of lipid removal was shown to increase ten-fold at a temperature range of 80−140 ºC for 12 minutes using the hydrothermal wave process and mixed algae cultures combined with an alternative electroflotation method produced the best algae-growing environment [7].

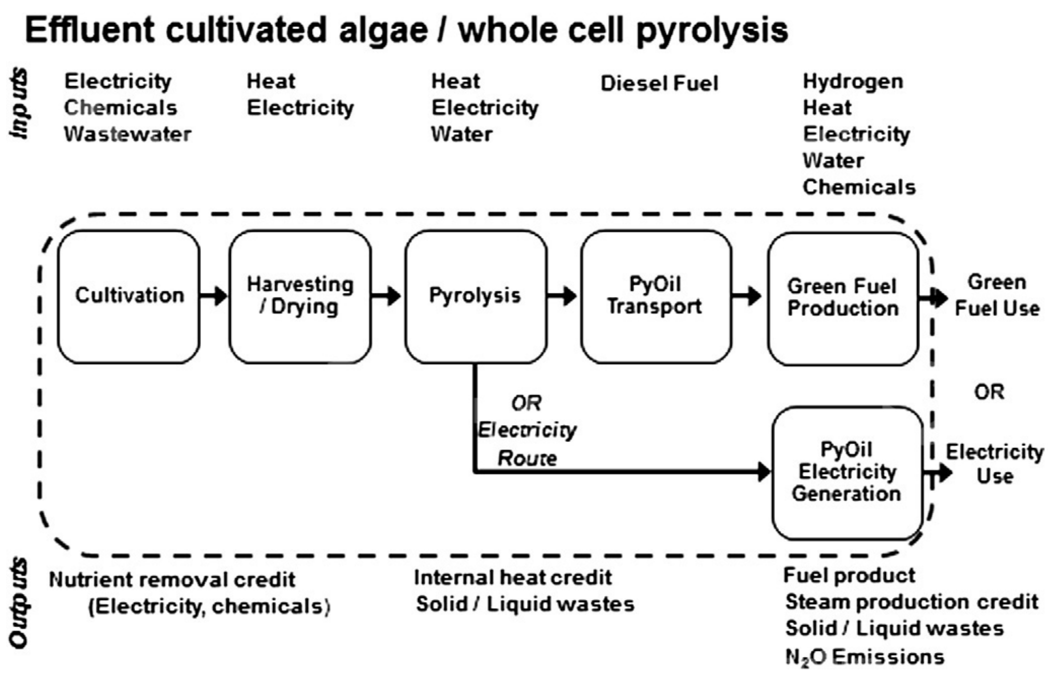

Fig. (1). The stages envisioned during an algae fuel production [2].

CONCLUSION

The evaluation of algae-based biofuel in terms of environmental engineering is summarized below.

1. C16-C18 methyl esters of algal lipid are easily and quickly decomposed and dissolved.
2. The biofuel is biodegradable and non-toxic as 99.6% of the biodiesel derived from canola was decomposed in about 21 days.
3. The biofuel is environmentally friendly and is a renewable energy source, and it can be produced using local resources.
4. Unlike diesel, biofuel does not contribute to the accumulation of CO_2 in the

CHAPTER 10

Microalgae Culture

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Abstract: Energy is becoming one of the most expensive production inputs nowadays. Energy reserves are starting to run out and their polluting effects have been seen around the world. Therefore, there is an urgent need for renewable energy sources instead of fossil fuels. One of these energy sources is algae biomass, which is seen as promising for biofuel production.

Keywords: Algae Biomass, Biodiesel, Lipid Production, Microalgal Biotechnology.

INTRODUCTION

Algae are aquatic, using solar energy, oxygen-producing photosynthetic autotrophs that are unicellular, colonial, or are constructed of filaments or composed of simple tissues [1]. Microalgae contain valuable metabolites which can be utilized in biofuels, health supplements, pharmaceuticals, and cosmetics [2]. They also have applications in wastewater treatment and atmospheric CO_2 mitigation. Microalgae produce a wide range of bioproducts, including polysaccharides, lipids, pigments, proteins, vitamins, and bioactive compounds [3]. The interest in microalgae as a renewable and sustainable feedstock for biofuel production has inspired a new focus in biorefinery. Growth enhancement techniques and genetic engineering may be used to improve their potential as a future source of renewable bioproducts. First, the cultivation of microalgae does not need much land as compared to that of *terraneous* plants [4] and biodiesel produced from microalgae will not compromise the production of food and other products derived from crops. Second, microalgae grow extremely rapidly and many algal species are rich in oils [5]. Today, studies conducted in many countries to increase the production of microalgal oil are aimed at obtaining high amounts of oil with biomass efficiency, and success is being achieved in cost

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analysis studies. In recent years, the use of microalgal biomass to obtain biofuel has become increasingly important [6]. The properties of biodiesel obtained from microalgae seem to be similar to those obtained from oilseed crops and fossil fuels. However, biodiesel from microalgae is considered to be an environmentally friendly and sustainable fuel for the future [7]. Unfortunately, the cost associated with producing biodiesel from microalgae is relatively high; therefore, the question rises as to why are microalgae a source of biomass? Microalgae are considered to be the most efficient biological system using solar energy and inorganic compounds for the production of organic compounds *via* photosynthesis. Algae are plants that have a simple reproductive system, do not have vascular bundles, and the entire biomass can be harvested and utilized. **a.** Algae are considered to be a very efficient biological system for harvesting solar energy for the production of organic compounds *via* the photosynthetic process. **b.** Algae are non-vascular plants, lacking (usually) complex reproductive organs, making the entire biomass available for harvest and use. **c.** Many species of algae can be cultivated to produce commercially- valuable compounds, such as proteins, carbohydrates, lipids, and pigments [8]. d. Algae are microorganisms having a simple cell division cycle, enabling them to complete their cell cycle within a few hours and can be made a genetic selection and strain screening relatively quick and easy. They also undergo much rapid growth and production processes than other crops. **e.** Infertile soils where land cultivation cannot be done can be utilized for microalgae production using seawater or brackish water. **f.** With microalgae production in shallow ponds, protein, and other metabolites can be obtained without concreting the soil, and algae production can be carried out in different models, from simple systems to fully automatic systems, depending on the degree of use of technology [9]. Pawar [10] reports that autotrophic cultivation of microalgae can offer a reliable solution for future energy security in addition to sequestration of carbon dioxide (CO_2). However, the economics of the biodiesel production process mainly depends on the capital as well as operating costs of the photobioreactors (PBRs) and dewatering units which are the major hurdle in the successful implementation of the algal biofuel mission. The laboratory studies have revealed important aspects of microalgae growth kinetics under various conditions and the data can be used as a basis to design an optimal largescale process. The growth of microalgae in the PBR depends on various factors, and the complete process is complex and needs complete monitoring of pH, gas sparging time, dissolved oxygen (O_2) level, biomass concentration, the temperature of the culture media, and so on. The role of nutrient media (composition and micronutrients) also plays a crucial role in determining maximum growth. Microalgae production in ponds, and open system, has both advantages and disadvantages compared to production in closed systems, tubular or panel photo-bioreactors (PBR).

CULTIVATION OF ALGAE IN PONDS

Constructing ponds for microalgae production can be considered cheaper than building closed systems; production costs may vary according to countries and raw material. It is important that the inner surface of the pond is smooth and easy to clean, and that there are no areas where there is no aeration in the pools. Another important issue is that there is no toxic substance released from the inner surface of the pond to the water.

The biggest advantage of these open ponds (Fig. **1**) is their simplicity, resulting in low production costs and low operating costs [11]. With paddlewheels providing the flow, algae are kept suspended in the water and are circulated back to the surface on a regular frequency. The ponds are usually kept shallow because the algae need to be exposed to sunlight, and sunlight can only penetrate the pond water to a limited depth [12].

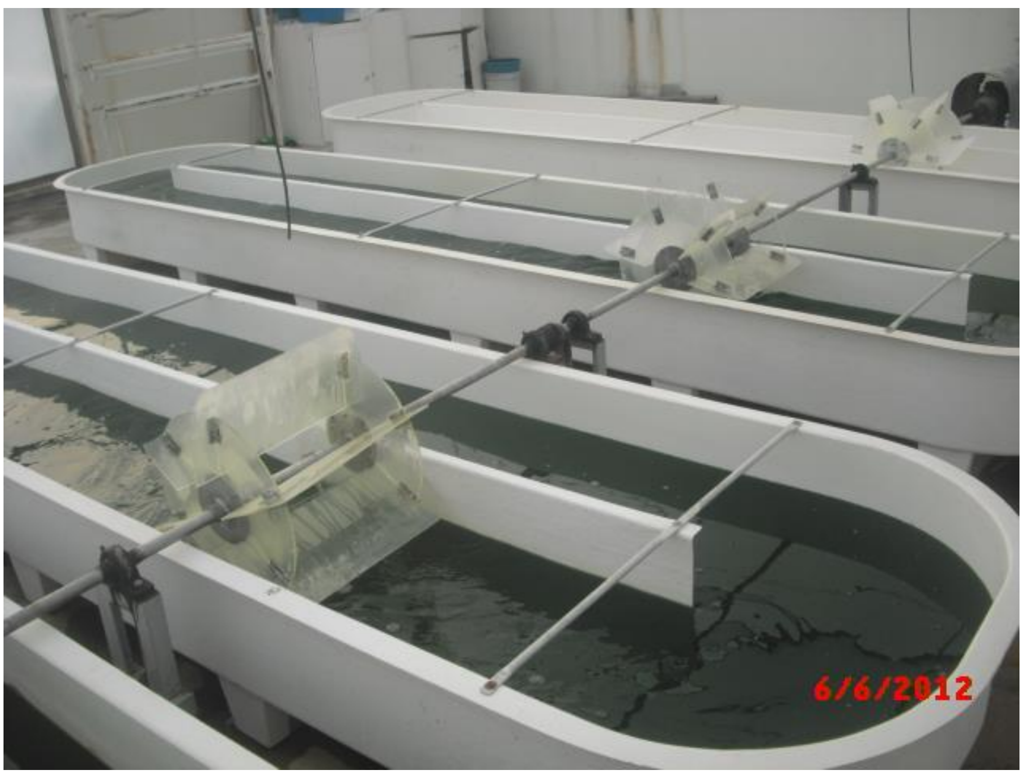

Fig. (1). Algae ponds in Cukurova University.

CHAPTER 11

Different Species of Algae

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Abstract: The oil yield of many microalgae species varies. Therefore, the selection of algae species is important. Features that are effective in selecting the appropriate species for algae production are growth and productivity, minimum contamination, and easy harvesting. However, the percentages of carbohydrate, fat, and protein in the structure of algae provide preliminary information about the oil yield to be obtained from that algae species.

Keywords: Algae types, Biofuel production, Macro-algae.

INTRODUCTION

In 1969, Whittaker classified blue-green algae into 5 different kingdoms, which is applicable till date. Algae are from the monera kingdom. Cyanophyta species belong to the Eubacteria kingdom in the Procaryota group in the triple classification system. Cyanophyceae species are morphologically divided into four orders. These are:

1: Chroococcales

2: Oscillatoriales

3: Nostocales

4: Stigonematales.

In the following sections, information about the parameters to be considered in determining algae species and the general classification of algae species are given.

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KEY FEATURES FOR DETERMINING ALG SPECIES

Generally, when determining algae species, physical determinations are made of the places where they are collected. These are the sea, ocean, river, *etc.*, along with the properties of water. Major parameters include pH, temperature, electrical conductivity, light transmittance, dissolved oxygen, and salinity.

Temperature

Different species live at different temperature values. Temperature, seasons, geographic location, water area, depth of water affect the absorbed solar energy and the amount of molten material.

pH

It is vital in terms of the pH value in aquatic environments, which is between 6-10. The variety and density of blue-green algae increase at high pH (low alkaline environment). However, exceptionally, some species live in 4-4.5 pH. So, this value can be taken as a lower limit for blue-green algae. Living in low pH values, blue-green algae can be used as a competitive agent where nitrogen fixation is possible.

Dissolved Oxygen (mg/l)

The dissolved oxygen value in the water, which is directly related to the living creatures in the water, determines the quality of the water and the value of the amount of oxygen used by living things. The amount of oxygen dissolved in water is determined by salinity, water temperature, and biological factors occurring in water.

Electrical Conductivity (μS/cm)

1 cm^3 of the solution at 25 °C is the opposite of its resistance in ohms and its value is determined by solids dissolved in water.

Salinity (%)

Salinity is the amount of salt content dissolved in water. The total density of water content can also be expressed as salinity. pH and density change the salinity.

ALGAE SPECIES

Chroococcus turgidus

Cells can be easily distinguished by the large dark granules they contain (Fig. **1**).

They are found as single cells, or often in groups of 2 to 4 cells, rarely 8 cells. Cells are round or ellipsoid-shaped. The unsheathed length is 8–32 µm, and the sheathed is 13-25 µm. They live planktonically. They float freely in the body of water. Their gelatinous or mucous matrix sheath is colorless. Their colors are blue-green, yellowish, or olive green [1 - 87].

Fig. (1). *Chroococcus turgidus* (scaled with 10 µm) [88].

There are fuel recovery studies on this species [88, 89].

Chroococcus limneticus

It is generally in the form of a plate. Cells are free-floating and can be found in groups of 4-32. Cells are blue-green, olive green, or yellowish. It is 6-12 µm without sheath, 8-14 µm in size if it is sheathed, and is colorless (Fig. **2**) [9, 20, 21, 30, 77, 82, 90 - 131]. There are fuel recovery studies on this species [93].

Fig. (2). *Chroococcus limneticus* (scaled with 10 µm) [132].

CHAPTER 12

Lipid Production in Microalgae

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Abstract: Microalgae, which are considered to be the living group that uses water and solar energy most effectively, have attracted the attention of researchers. Researches on efficient production of microalgae from starter cultures in the laboratory environment to outdoor ponds and photobioreactors continue in many countries. In addition to the known microalgae species, studies to search for new microalgae species that are rich in nutrient content and ease of production are ongoing. Of course, the researches also include more economical algae production studies. Algae and algae produced as larval food in aquaculture can be used as food support, as well as in the production of nutraceuticals and pharmaceuticals, like food coloring, soil fertilizer, and plant diseases. Algal oils and algal biomass have been gaining interest in renewable energy sources, especially in recent years, and studies in this area continue. The implementation of all these issues is based on well-known algal physiology and the realization of successful algae cultures.

Keywords: Algae Biomass, Biodiesel, Lipid Production, Microalgal Biotechnology.

INTRODUCTION

Energy is becoming one of the most expensive production inputs nowadays. Energy reserves are starting to run out and their polluting effects have been seen around the world. Therefore, there is an urgent need for renewable energies instead of fossil fuels. One of these energy sources is algae biomass, which is seen as promising for biofuel production.

Studies in microalgal biotechnology continue with modern biotechnology studies as well as traditional biotechnology studies. While genetic engineering researches are being carried out in microalgal lipid production, studies on the physiology of algae are also continuing. It is aimed to increase lipid production by creating

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stress in algae cells with different stress sources. Generally, with nitrogen deficiency in the environment, lipid enhancement studies are carried out in algal biomass.

Biodiesel can be produced from oils or lipids obtained from a variety of sources. Triglycerides, the major form of dietary lipid in fats and oils, are considered to be the main component essential for the production of biodiesel. The commonly used sources of fats for the production of biodiesel include pure vegetable oil, animal fats, and waste cooking oils. However, recently microalgae have been considered to be a potential source for biodiesel production because they can be harvested daily. Microalgae can multiply rapidly by dividing and can often grow over a wide temperature range and the oil content they produce can be very high (up to 80% of the dry weight) when compared to other traditional feedstocks.

Algae can be cultured in non-agricultural land, with high photosynthetic activity, harvested throughout the year with high biomass production. High lipid from algae is possible by reducing some elements of growth conditions from the nutrient medium. It is known that different nutrient sources and concentrations affect the growth and physiology of microalgae cells [1]. When nitrogen in the environment is reduced, lipid content increases while the amount of biomass decreases [2]. Production of protein is favored during periods of nitrogen sufficiency with limited carbohydrate synthesis; carbohydrates accumulate and protein production decreases whereas lipids usually increase [3, 4].

Our aim in our studies on microalgal lipids for more than ten years has been to carry out research to provide biomass with high lipid content for biodiesel that countries will need in the near or distant future.

We first carried out our studies to increase the microalgal lipid content in the laboratory conditions, then we tried the best results we achieved in outdoor photobioreactors and ponds.

The effect of nitrogen deficiency on the growth and lipid content of microalga *Isochrysis affinis galbana* in two photobioreactors was studied at the algal biotechnology outdoor unit. In this study, *Isochrysis affinis galbana* were cultured in two reactors: flat panel photobioreactors with different light paths (1, 3, 5, 7, and 10 cm) and tubular photobioreactors, with 50% nitrogen reduction and 20% inoculation densities. Biomass, lipid, and protein ratios were determined. The highest lipid content of 33.13% was obtained from *I. aff. galbana* with 12.11% protein in flat panel photobioreactors with 50% nitrogen reduction and 10 cm light path, and a 0.991 gL^{-1} biomass rate was obtained (Figs. **1** and **2**). The highest optical density was found in the 10 cm light path flat panel photobioreactor with a 50% nitrogen reduction [5].

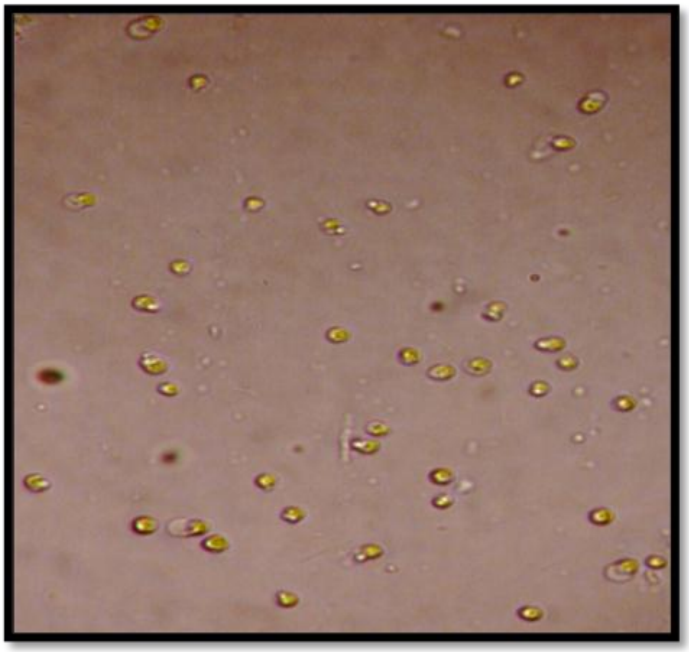

Fig. (1). Microalga *Isochrysis affinis galbana* (x40).

Fig. (2). *Isochrysis aff. galbana* cultures in tubular and flat-panel photobioreactors.

In the other study, we carried out, the effect of nitrogen limitation on the cell density, biomass, chlorophyll *a*, total carotene, protein, and lipid content of microalga *Phaeodactylum tricornutum* (Bohlin), Bacillariophyceae, cultured in photobioreactors outdoor was investigated. *Phaeodactylum tricornutum* (Fig. **3**) was cultivated in an appropriate medium as the control group, at the same time, it was cultured in a medium in which nitrogen was reduced to 50%. At the end of the study, it was determined that 35.04% lipid with 0.980±0.02 gL^{-1} biomass and

CHAPTER 13

The Science of Catalysts in Algae Oil Production

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Abstract: CO_2, which is a gas produced as a result of combustion, has an important share in greenhouse gases such as SO_x, CO, and NO_x and causes global warming. As biodiesel produced from algae converts CO_2 within the biological carbon cycle, it accelerates the carbon cycle, as a result of which the greenhouse gas effect decreases. C16-C18 methyl esters in biodiesel whose degradability feature resembles dextrose (sugar) do not show any negative microbiological affect up to 10000 mg/L, they decompose rapidly in nature. 40% of diesel in water and 95% of biodiesel in 28 days can be degraded. In the production of biodiesel, catalysts that break the triglyceride bonds allow the esters to become free.

Keywords: Biocarbon cycle, Biodiesel production, Catalyst types, Greenhouse gases.

HOMOGEN CATALYSTS

Catalyst and reactant are present in the same phase in homogeneous reactions. They are in the form of base, acid, or liquid enzyme solutions. Generally, HCl and sulfuric acid (H_2SO_4) are used as homogeneous catalysts in the acidic transesterification reaction. Potassium hydroxide (KOH) and sodium hydroxide (NaOH) are used in the alkali transesterification reaction. Lipase enzyme in liquid form used in the transesterification reaction is a homogeneous enzyme catalyst. The temperature is high in the presence of acidic catalysts. The water in the environment negatively affects the reaction. The catalyst in the same homogeneous environment with glycerin is separated together, it cannot be recovered, and the water in the environment affects the reaction negatively. The temperature is high in the presence of acidic catalysts. The environment is strongly acidic because the equipment and materials used are resistant to pressure

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and corrosion and must be made of expensive materials. Cost increases and creates danger for the user. A base catalyst is 4000 times faster than an acidic catalyst. Alkaline catalysts are less corrosive than acids. Free fatty acid and moisture content are the main criteria affecting basic transesterification. With the hydrolysis of oils, fatty acids become free in the presence of water. However, under these conditions, when esterification is not performed, free fatty acids cause the formation of soap by depleting the basic catalyst by the reaction. Free fatty acid content should be less than 4% in a basic catalyzed reaction. Homogeneous enzyme catalysts in liquid lipase form are used in transesterification reactions. Aqueous enzyme solutions with stabilizers such as benzoate prevent microbial growth such as sorbitol and glycerol. Homogeneous catalysts take place in more suitable reaction environments. Their selectivity is high. Some of the disadvantages of homogeneous catalysts can be overcome by using a heterogeneous catalyst. There are many studies on the algae to oil process using various homogenous catalysts [1 - 10]. Various basic homogeneous catalyst reactions are summarized in Figs. (**1** - **7**).

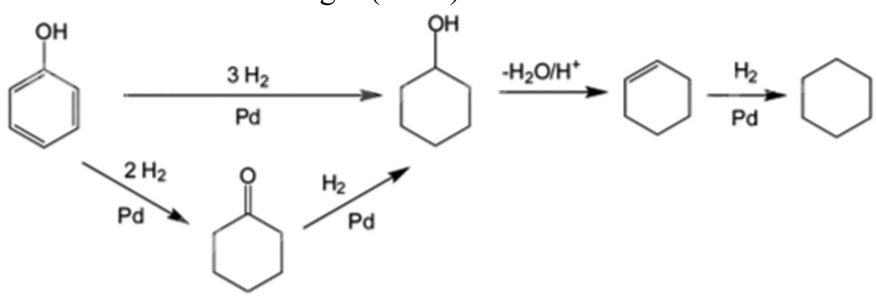

Fig. (1). Phenol hydrodeoxygenation over Pd/C catalyst [8].

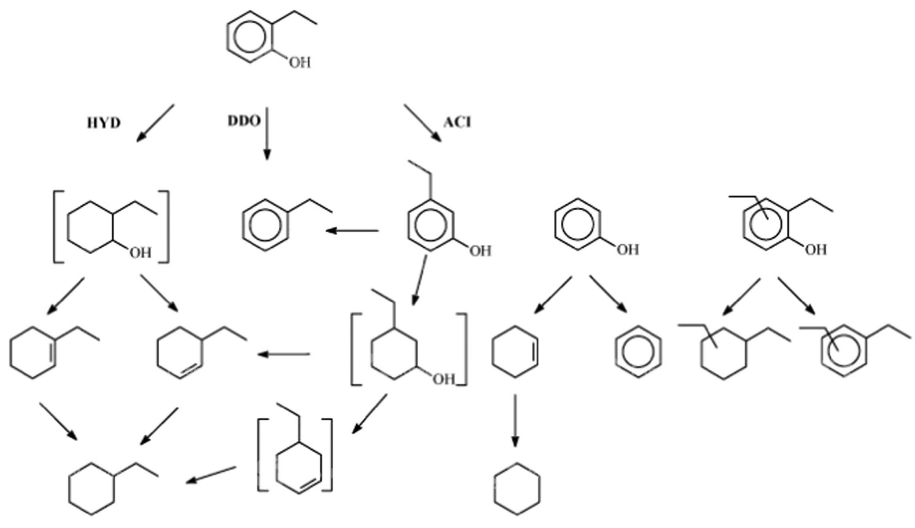

Fig. (2). 2-ethylphenol transformation over sulfided Mo-based catalysts [8].

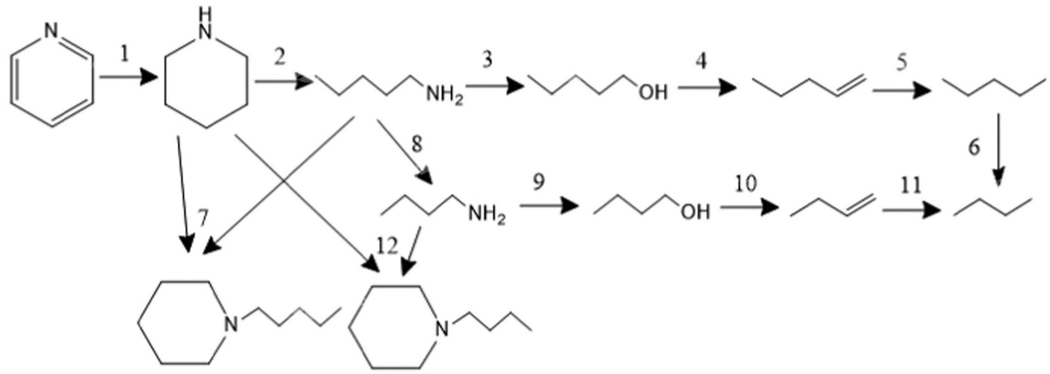

Fig. (3). Pyridine hydrodenitrogenation mechanism [8].

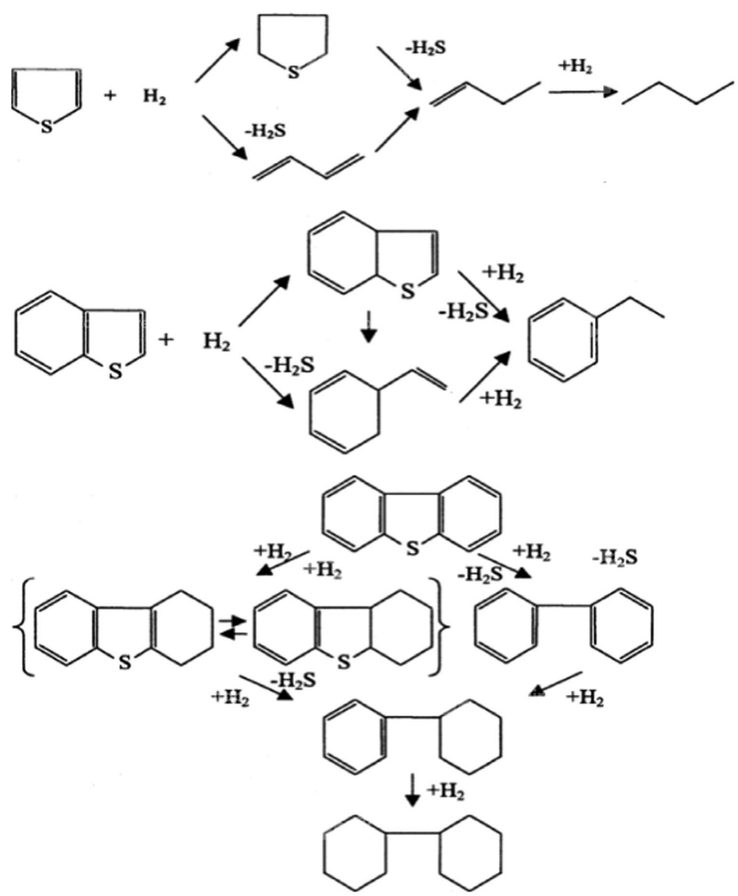

Fig. (4). Benzothiophene, thiophene, and dibenzothiophene desulfurization [8].

CHAPTER 14

Economical Fundamentals for Algae to Fuel Technology

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Abstract: This chapter provides basic economic information that readers will need during the operation phase before establishing any algae business. The subject has been reinforced with simple examples.

Keywords: Capital recovery factor, Engineering economy basics, Present value factor.

LIFETIME COST CALCULATION OF ASSETS

The lifetime cost of an asset is the analysis of the initial purchase, scrap, operating, labor, material, interest, insurance, depreciation, and tax costs of an investment (equipment, plant, and/or service) throughout its life. The reliability of the lifetime cost calculation of the asset also depends on the good evaluation of economic data and making healthy predictions for the future.

In order to calculate the cost of the product, economic factors such as what will be inflation in the future, how much interest and fuel costs will increase must be estimated close to the truth. The future cost depends on the estimated life of the investment as well as economic pressures and political decisions. As a result, the lifetime cost calculation is quantitative and just an estimate. The parameters required for its calculation usually depend on the structural theories and the skill and experience of decision-making mechanisms. For the lifetime cost calculation to be reliable, expert experience or literature should be consulted on this subject. Lifetime cost calculation is usually made on a uil basis. Definition of Present

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Value Factor and Capital Recovery Factor concepts is needed in calculating lifetime cost every year [1 - 17].

PRESENT VALUE FACTOR

Let's assume that you borrow 100 $ with 25% interest per year. At the end of a year, the interest rate of 100 $ becomes 25 $. The sum of the debt and interest received is as follows:

$100 \times (1 + 0.25) = 125$ $

At the end of the second year, total debt will be

$100 \times (1 + 0.25) \times (1 + 0.25) = 100 \times (1+ 0.25)^2 = 156.25$ $

Total debt amount after n years (the value of 100 $ after n years) would be

$100 \times (1 + 0.25)^n$

It can be calculated from the formula. Each year the total value of money increases by a factor of (1 + 0.25). If the annual interest rate is i, the total value TV (value of money over time) of money in n years with the present value of money PV would be,

$$TV = PV \times (1 + i)^n \quad \textbf{(1)}$$

If n years after Equation 1, the present value of the money whose total value will be TV is PV then,

$$PV = TV / (1 + i)^n \quad \textbf{(2)}$$

In other words, the value of the money whose present value will be ND decreases by (1 + i) -n factor for each past year. This factor is also called the Present Value Factor [1 - 17].

$$PVF = (1 + i)^{-n} \quad \textbf{(3)}$$

CAPITAL RECOVERY FACTOR

Let's calculate how much money we can borrow with 25% interest, provided that we pay 100 $ at the end of each year and pay the whole in 3 years. The present value of 100 $ we will pay at the end of the first year would be,

$100 / (1 + 0.25) = 80$ $

The present value of 100 $ we will pay at the end of the second and third year, respectively would be,

$100 / (1 + 0.25)^2 = 64$ $

$100 / (1 + 0.25)^3 = 51.2$ $

In that case, the total money we can receive in 3 years, provided that we pay 100 $ at the end of each year, is 80 + 64 + 51.2 = 195.2 $.

The present value of the money we can receive with a maturity of n years provided that we pay the Annual interest rate (AIR) amount at the end of each year at the annual interest rate,

$$PV = AIR \sum_{m=1}^{n} \frac{1}{(1+i)^m} \quad \textbf{(4)}$$

This is the present value of the money received in n years, provided that they pay an equal AIR amount at the end of each year.

When

$PV = AIR \sum_{m=1}^{n} \frac{1}{(1+i)^m} = \frac{1-(1+i)^{-n}}{i}$ in this expression, its current value is PV the amount that is paid in n equal intervals

$$PV = AIR \left[\frac{i}{1-(1+i)^{-n}}\right] \quad \textbf{(5)}$$

will be, the $\left[\frac{i}{1-(1+i)^{-n}}\right]$

The capital Recovery Factor in this expression is called the CRF.

$$GKF = i / 1 - (1 + i)^{-n} \quad \textbf{(6)}$$

For the detailed explanation example -1 is given [18 - 36].

Example-1:

If we borrowed 100 $ at equal intervals over 10 years with an annual interest of

CHAPTER 15

Closing Remarks

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Abstract: In order to better evaluate the water potential of our world, we will now take a look at the various aquatic products that have had a significant impact on the biotech industry, from research materials to nutritional additives.

Keywords: Biofuel from marine creatures, Biofuel production, Mechanical pressing process, Microalgae, Oil extraction, Solvent extraction.

INTRODUCTION

The process of combining water and sunlight by the plant and turning it into matter and oxygen is called photosynthesis. Photosynthesis, also known as carbon dioxide digestion, usually occurs in the green leaves of plants in lamellar structures called chloroplasts. With the help of sunlight, about 3 liters of oxygen per hour is produced per kilogram of a healthy green leaf. This phenomenon, which provides an energy flow of about 16 W, is obtained from a 1 m^2 leaf area. One of the most fundamental phenomena that occurs in nature and that plants interact with light in photosynthesis. In terms of the formation of nutrients, fuel, and the production of atmospheric oxygen, all living things are closely dependent on this event. A leaf area of 15-30 m^2 is required to produce the oxygen that a person needs for 24 hours. Calculations show that in an average climate zone, a large tree can only provide the oxygen consumed by an adult in a year [1 - 7].

It is known that the energy given by the sun to the world is approximately $1.5x10^{18}$ kWh/year and this issue is 10000 times greater than the total energy con-

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sumed in the world. Approximately 0.1% of this energy coming to the surface of the earth is converted into biomass by photosynthesis and stored. This is approximately 10 times more than the total energy used in the world. The average photosynthesis efficiency given above increases 0.5-1.3% in temperate regions and 0.5-2.5% in semi-tropical regions. In order to give an idea about the energy of biomass formed as a result of photosynthesis, it would be sufficient to say that this is equal to the power ($9x10^7$ MW) of a 100000 times larger nuclear power station [6, 8, 11].

For example, the total energy amount per one hectare area parallel to 40o is 1.47 x 10^{13} calories. If all of this energy was to be converted into carbohydrates, a yield of 2000 tons per hectare could be achieved. However, 43% of the total sunlight falling on the earth's surface is effective rays with photosynthesis. For willow and hybrid poplar, which can yield 10 tons of dry matter per hectare, 159 W of sunlight falls per m^2 and the plant can absorb 0.30-0.41% of it. In Thailand, where 186 W of sunlight falls per m^2, the amount of solar energy absorbed by green algae increases to 4.90%, and accordingly, the dry matter yield reaches 164 tons/ha per year. While the gas production range for algae species is 380-550 kg volatile matter per liter, the average gas production is 460 l / kg-UM [6, 8 -11].

Solid fermented fertilizers are used in algae production. The use of fermented fertilizer is the method of placing dry or green leaves in a pit with a filter-bed, reusing the bottom-filtered water in the reactor feed material, and storing the above dry matter for use. This fermented fertilizer contains bacteria heavily and is suitable for composting plant materials. During anaerobic fermentation, the nutritional value is not lost, and especially vitamin B12 is synthesized during this period. It is rich in protein. This material is dried under the sun or in a dryer. In this type of use, drying the fermented manure by using the produced biogas increases the total system efficiency. However, high temperatures should be avoided in order not to spoil the vitamin structure. This dried material is laid and can be used as an additive in animal feed or as fish feed after the venom is removed. The demilitarized fermented fertilizer is rich in nutrients and trace elements and can be used in algae production [12 - 16].

Microalgae

Microalgae, which is one of the sources of biomass energy, is also an important ecological cycle element. Blue, red, green, *etc.* microalgae production in colors is the most effective and economical way to convert solar energy into biomass [17 - 21].

Microalgae are used in the feed, food, cosmetic and pharmaceutical industries as well as in biotechnological production. Recently, it has been used in biofuel production [17 - 21].

Algae can be grown abundantly in much smaller plots. In addition, algae do not require special conditions such as fresh water and fertile soil and can be harvested many times a year. Algae can grow practically, wherever there is sufficient light. Some of them are also grown in saltwater [17 - 21].

Algae can grow indoors or outdoors under suitable conditions. Open systems include pools, channels, waterfalls, natural water environments, *etc.* systems. Closed systems consist of photobioreactors. The basic principle in this type of reactor design is to reduce the light path and thus increase the amount of light reaching each cell. In addition, there must be functions that increase gas exchange, provide the optimum amount of light to the cells, and create a good mixture. The necessary conditions for the production of microalgae are given in Table **1** [17 - 21].

Microalgae are much more advantageous than soy and corn plants for biodiesel production. Table **2** shows the comparison of microalgae and some other biodiesel sources [17 - 21].

Table 1. Production conditions for microalgae.

Parameters	Boundary Values	Optimum Conditions
Temperature (ºC)	16-27	18-24
Saltiness (g/I)	12-40	20-24
Light density (Ix)	1000-10000	2500-5000
Lightness time (Morning: m night h)	-	16:8 minimum 24:0 maximum
pH	7-9	8.2-8.7

Table 2. Comparison of some biodiesel sources.

Plant	Oil Yield (I/ha)	Needed Area (Mha)*	Percentage of the Harvested Area*
Corn	172	1540	864
Soybean	446	594	326
Rape	1190	223	122
Jatropha	1892	140	77
Coconut	2689	99	54
Palm	5950	45	24

SUBJECT INDEX

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Hüseyin KARACA

Hüseyin Karaca graduated as a chemical engineer from Ankara University of Turkey in 1990. He earned his MSc degree from Inonu University in 1993. He was awarded a PhD degree in chemical engineering from Ankara University in 1998. During this period, he worked as a research assistant in Inonu University. He has 32 international articles, 67 national and international papers and 22 national projects. He is currently working as a professor in the department of chemical engineering at Inonu University. His research interests are coal science and technology, liquefaction, energy technologies, biomass and kinetics.

Cemil KOYUNOĞLU

Dr. Cemil Koyunoğlu started his academic life with his teacher, professor Hüseyin Karaca during his last semester of BSc in 2007. Later, as soon as he graduated, he started his co-founder carrier between 2007-2010 by establishing İnönü-Pal internationally accredited fuel oil testing laboratory. He took his first staff in the Department of Energy Systems Engineering at Yalova University in 2010 and started his Ph.D. program at the Istanbul Technical University Energy Institute in 2011. He continued his research assistant position between 2012 and 2017 at the Istanbul Technical University Energy Institute. He went to the USA for his Ph.D. studies between 2015-2016. He graduated in 2021 with his Ph.D. To date, he has presented a number of papers and different presentations at many international energy congresses on clean coal and fuel technologies. He continues with Yalova University Energy Systems Engineering Department as doctoral research and teaching assistant position with his own "CML" equation and "C" constant for energy efficient studies".