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Research Progress on Algae Biomass Resources Conversion

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Abstract

With the global fossil energy exhausting, seeking renewable energy sources is extremely urgent. Currently, algae biomass resources research gets more and more attention. In this article the research of algae biomass energy conversion was described, and the development of biodiesel fuel technologies was reported, which was expected to provide reference for future development and utilization of algae biomass resources.

Keywords

Algae biomass resources; biodiesel fuel; high value-added chemicals

Introduction

Currently, most of the world's energy production comes from fossil fuels. But fossil fuels are limited while human's demand for them is increasing. According to the report of International Energy Outlook released in 2011 by Electronic Industries Alliance, from 2009 to 2035, energy consumption is expected to increase 50% in the global market, in which fossil fuels account for 90% [1].While human consumption of fossil energy will be increasingly exhausted. There are also environmental problems: Environmental pollution caused by the extraction of fossil fuels and the destruction of the ecological balance caused by the burning of fossil fuels.

Plants are the converter and the collector of the sunshine, which play an irreplaceable role in carbon cycle [2]. Plants convert solar energy into chemical energy through carbon cycle, which will be released through biochemical reactions of humans and other biological organisms. But today's atmospheric environment is seriously damaged due to the excessive burning of the fuels. Therefore, looking for renewable resources to replace fossil fuels is urgent. Meanwhile, biomass energy is the most promising alternative resource to replace fossil fuels and other chemicals [3, 4].

At present, there are many studies on the conversion of biomass into energy. Biomass energy comes mainly from plants including terrestrial plants and aquatic plants. The research on terrestrial plants is comparatively mature because it is carried out relatively early. Straw is used as raw material to replace fossil fuels by producing clean energy – biogas, which is one of the comparatively mature biomass conversion technologies. However, when using terrestrial plants to generatediesel oil and high valuable chemicals, the product is complex, which contains lactonesubstance, organic acid, ketone, cyclopentenone, phenolic substance, furan, long-chain alkane and other substances [5]. The structure of cellulose and lignin is stable and the content of cellulose and lignin is large in the terrestrial plants, which needs pretreatment to be converted into raw sugar in the process of transformation. But utilizing the crops rich in starch may lead to the problem of striving for land against the farmer and affecting food security. As a result, people are turning their eyes to aquatic plants.

As the typical representative of aquatic plants – seaweed is one of relativelyideal biomassalternative resources. First of all, seaweed has a high rate of photosynthesis. Compared with terrestrial plants, seaweed has higher yields. Secondly, seaweed is grown in seawater and does not occupy fresh water and land resources [6]. However, with the development of seafood aquiculture industry, various environmental problems are becoming more and more serious, such as excessive nutrient salt leading to the deterioration of water body, plankton boom, red tide and other environmental problems. These problems can not only lead to the diseases of aquiculture organisms, but also destroy the ecological balance. In this case, purifyingthe cultivation environment has become an urgent problem to be solved, which is the key whether the development of aquaculture can be sustainable or not. Therefore, large seaweeds (such as kelp, eucheuma, asparagus and gulfweed) are urgently needed to absorb and use nutrient salt in the aquiculture environment to clean up it, which can increase the economic interests of the aquiculture system, reduce the aquiculture pollution to the environment and maintain the sustainable development of aquaculture. In addition, seaweed has the function of biological nitrogen fixation. As an autotroph that is capable of photosynthesis, seaweed can control greenhouse gases. Therefore, the study of using seaweed resources is imperative [7].

1. Conversion of seaweed biomass into biodiesel

Renewable sources such as wind, solar and geothermal energy are stable sources of energy.But electricity can be generated only from these sources. To obtain fuel energy, energy can only be converted from biomass or other renewable energy sources (such as hydrogen). At present, conversion of biomass energy through biomass hydrothermal liquefaction has been studied a lot. Hydrothermal liquefaction is also a kind of bionic test. This idea is derived from biological hypothesis accepted by everyone: The oil, gas and coal in the nature are formed by millions of years of high temperature and high pressure thermo-chemical conversion (TCC) after organic remains are buried in the ground. As a result, people get inspired by TCC to use hydrothermal liquefaction technology. TCC is a process of modifying biomass under high temperature, high pressure and anoxic condition, in which long chain organics and polymers can be converted into short chain organics, such as fuel gas and diesel. TCC includes direct liquefaction, hydrothermal liquefaction and high temperature pyrolysis [8]. In addition to hydrothermal liquefaction for obtaining oil and fat of the seaweed, biodiesel can be prepared by extraction of separation, ester exchange and other technologies.

1.1 Preparation of biodiesel through hydrothermal liquefaction of microalgae

Hydrothermal liquefaction is a technology of broad application prospect: By hydrothermal liquefaction, high moisture waste biomass can be converted into energy intensive biocrude, which can be directly burned as fuel or refined into transport-level fuel. Therefore, There are many reports on the intermediate stage research of converting seaweed biomass into primary biocrude. Biomass diesel is a kind of black viscous crude oil that produces energy 30 ~ 38 mJ per kilogram. The subsequent stages include carrying produced biodiesel into a conventional crude oil refinery for mixed treatment or separation treatment with crude oil to reduce the end discharge of the entire product line in the refining process. Treatment of upgrading crude oil or supercritical catalysis is also carried out to crack and distill the biodiesel via hydrogenation treatment, while the study of subsequent refining treatment is relatively few [9-11]. If crude oil is burned directly without further treatment, the production of biocrude can't be utilized efficiently and nitrogen oxides will be produced to pollute the air. Back in the 1970s and 1980s, Pittsburgh Energy Research Center has studied the conversion of biomass into biodiesel first. Recently, the center has made an upgrade research on hydrothermal liquefaction with commercial purpose [12].

High-energy seaweed, especially microalgae is rich in lipids, which is a potential source of biofuel. Lipids in seaweed can be converted into hydrocarbon high-energy fuel to provide energy source for motor vehicles. Water thermal cracking of the seaweed is researched by a group led by professor Minowa of Japanese Tsubaka energy and environment national institute at the earliest, which lays the foundation of producing biomass crude oil based on microalgae as raw material [13-16]. In addition, high oil production of microalgae is an indisputable fact, whose oil production has exceeded that of the best oil crops [17,18]. Therefore, there are more and more reports on the production of biodiesel by water thermal cracking of microalgae gradually. Johnson [19] has carried out the study of converting is ochrysis into crude bio-oil through hydrothermal reaction in reaction kettle by controlling temperature (250 ~ 350 ℃) and reaction time (from a few seconds to a few hours). Biller [20] has studied the conversion of nannochloropsis into biofuel by microwave hydrothermal treatment, which shows that: The reaction temperature can be reduced with addition of 0. 1 mol/L NaCl when nannochloropsis is used as raw material. Higher quality of crude oil can be obtained with microwave hydrothermal method and ash content is reduced from 26% to 5%. Solvent extraction is used to recover crude oil. Abundant N, P and other nutrient substances can be recycled from the water phase. Vardon [21] takes high humidity waste as raw material, making comparative study among spiral seaweed, pig manure and anaerobic digestion sludge. In the research, biocrude obtained from the three materials all shows a similar high heat value (32 ~ 35 mJ/kg), high total nitrogen and oxygen content (19% ~ 23%). But production of biocrude of the three materials is different from each other: Production of biocrude of anaerobic digestion sludge is the least of 9. 4% and that of spiral seaweed is the most of 33%. Biomass conversion route and biomass raw materials lead to different physical and chemical properties of biocrude: The molecular weight and distribution of boiling point of the biocrude through high temperature pyrolysis is lower than that of the biocrude through water thermal cracking; The molecular weight and distribution of boiling point of the scenedesmus containing high lignin and cellulose is higher than that of spiral seaweed in the same condition of water thermal cracking. Energy consumption varies from each other: In the condition that the seaweed biomass is the raw material with same humidity of 80%, energy consumption of water thermal cracking is lower than that of slow high temperature pyrolysis because the latter needs to evaporate water. In addition, the study also finds that the disadvantage of biocrude is that it has more impurity atoms. So it is necessary to upgrade the biocrude further more. Talukder and others [22] have studied the preparation of lipid and lactic acid. With 5% sulfuric acid as catalyst, nannochloropsis is taken as raw material. The reaction is carried out for 1 hour under the condition of 120℃. Then lipid is extracted and separated from hydrolysis product under the condition of 40℃ and 200 r/min using hexane as extractant. Among the product, the yield of sugar (including xylose and glucose) can reach 64.3%. After removing lipid, the rest product is processed through neutralizing treatment as culture medium for fermentation to produce lactic acid. Garcia and others [23] have studied the microalgae Desmodesmus sp. as raw materials. In the condition of 175 ~ 450℃ temperature range and 0 ~ 60 min time range, reaction is carried out in the intermittent reaction system. After optimization of the reaction condition, production of grease can reach 75% under the condition of 375℃ and 5 min. Energy density of the obtained grease is 22 ~ 36 mJ/kg. Levine and others [24] obtain biodiesel through two-stage process: The first stage, , molecule inside lipid hydrolysis occurs in subcritical water when wet seaweed has the humidity of 80% under the hydrothermal condition of 250℃ for 15 ~ 60 min. Then cluster cells become solids that are easy to filter toretain the lipid. And a sterile and developmental nutrition aqueous solution is formed. The second step, wet fat solids rich in acid produce biodiesel in the form of fatty acid ethyl ester(FAEEs) in supercritical water and ethanol [ethanol/solid is 2 ~ 8 (W/W)]. Grease recovery rate could reach 77% ~ 90%.

1.2 Preparation of oil through hydrothermal liquefaction of seaweed

In addition to microalgae, there are also studies on the conversion of biomass into biocrude from large seaweeds as raw materials. Elliott and others [25] add wet large seaweed mud into continuous reaction device for hydrothermal reaction. The seaweed mud with a humidity of 78.3% can convert 58.8% of the carbon into gravity - separable crude oil products at a supercritical condition of 350℃ and 20 MPa. And the mud can combine with catalytic hydrothermal vaporization (CHG) for water purification of HTL by-products and the recovery of fuel gas from water-soluble organic matters. In this whole process, conversion rate of liquid and gas fuel products from large seaweeds is high. Besides, there are also a small amount of organic matters remaining in aqueous solution.

1.3 Other preparation methods of oil

In addition to hydrolysis of hydrothermal liquefaction to produce biomass oil, there are also reports on conversion of biomass into biocrude oil in other methods. Martin and others [26] have studied ways to get bioethanol and biodiesel from seaweed at the same time. First, seaweed is separated to seaweed oil, seaweed starch and protein. Seaweed oil is converted into biodiesel through either of two methods, which are enzyme catalysis and base catalysis. And seaweed starch is converted into bioethanol. In the optimal condition, 60% biomass diesel, 30% starch and 10% protein are obtained. And fuel ethanol can be produced by the obtained starch through fermentation and dehydration. In addition, the study shows that the quality of biodiesel produced by the conversion of enzyme catalysis is relatively high. Ahmad and others [27] separate biodiesel from microalgae by ester exchange method. And the extraction of different kinds of microalgae shows that different microalgae have the production rate of 92%. But biodiesel prepared through this method has many impurities.

2. Prospective

At present, the conversion of seaweed into the resources needed by people has achieved remarkable results, which makes it possible to alleviate the environmental ecological problems such as resource depletion and environmental pollution.

However, the problems existing in the conversion of seaweed biomass have limited scale industrial application. The main problems are: ①The raw materials are complex. So the most of obtained products are of low purity, which need to be separated and purified to improve the purity of the products. ②The conversion technology is not mature. The technology is still in the experimental stage, which still needs constantly optimization of the conversion process route. Therefore, it is necessary to continuously optimize the utilization and conversion of biomass by reducing cost, reducing pollution and improving product quality to prepare for the industrialization of this technology.

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