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Energy Consumption and Carbon Calculations of Microalgae Biodiesel

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***Abstract*—**At present, the severe oil crisis and greenhouse effect are booming, which is a growing worry for China. Over a long period of study, choosing the development of biological diesel is a feasible way in the desertification region in China. With considering the adaptability of Micro-algae in desertification region and analyzing energy consumption and carbon calculations of Micro-algae biodiesel produced by JJ company , this paper, make the microalgae our optimal choice to develop biological diesel in china's desertification region.

***Keywords*—**Biodiesel, Microalgae, Energy Consumption, Carbon Calculations

I. Introduction

CHINA is already one of the largest countries in energy consumption and carbon dioxide emissions. Therefore it is of great strategic meaning for China to enhance its oil security by utilising its exsiting materials to produce alternative liquid fuel, that is, biodiesel on a large scale[1]. In addition, the impact that desertification has had on China in general, is undeniable. It will become even more severe and wide as the environment gets more and more worse. "The Third Communique on the desertification situation in China " released by China's Forestry Administration indicated that China's desertification regions have already added up to 2.6362 million square kilometers, accounting for 27.46% of China’s total land area until the year 2004. For above reasons, it has become crucial to use existing technology to find the suitable material for producing biodiesel to develop desert areas which suffer water shortage and arable land scarcity.

This paper gives an analysis framework map of biodiesel produced from microalgae and a systematic collection of all material and energy input and output data throughout the life cycle of microalgae biodiesel production. To illustrate these ,this paper also evaluates the life cycle of JJ company's biodiesel production system with an annual output of 120 tons and gives emphasis to studying its environmental impacts and resource consumption during various stages of the life cycle.

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II. An Introduction of Microalgae

Microalgae is a kind of aquatic phytoplankton and they can effectively use sunlight to convert water and carbon dioxide into bio-energy [2]. Besides, the earth have rich microalgae resources with more than 200,000 types , which provides a wide range of raw material resources for studying and developing biodiesel [3].Furthermore, microalgae is an energy crop ,so there are not any other raw materials of biodiesel could compared with it.

A. High Efficient Photosynthesis and Short Growth Cycle

Because of high efficiency of photosynthesis, the number of microalgae can become as much as twice by three to five days time. In addition, some species of microalgae can even be harvested twice per day. So the output per unit area of the microalgae is the output of grains ten times even hundreds of times.

B. High Oil Content

Microalgae contains twenty to seventy percent of oil which is far more than most terrestrial plants. As an illustration, table 1 lists the oil content and oil output per hectare of several commonly-used raw materials for biodiesel. As a result, we can find that the oil output of microalgae is much higher than other crops through comparison.

C. Small Area of Occupation by Microalgae

Large-scale cultivation of microalgae just requires a small area of land. Certainly, this character has remarkable significance because the country, which have a large population and a wide coverage of desertification regions , needs more land for producing grains. Microalgae, without a doubt, becomes one of the most ideal biodiesel materials. What's more , it is estimated that the demand for diesel in China will reach to 140 million tons [4]. Assuming that the demand for diesel in China are fully satisfied in 2010, it compares in Table I . the land area requirements by several raw materials of biodiesel. The characteristics of microalgae are vastly different for the reasons of different species and cultivation methods of microalgae. In order to give a clear description, microalgae in Table 1 refers to Chlorella which is the raw material for JJ company's 120 tons of biodiesel annually. Through comparisons above, given that microalgae has many advantages as short growth cycle, small area requirement and high oil content .Owing to all characteristics of microalgae , it is concluded that microalgae is the best choice for developing biodiesel in the desertification region.

TABLE I
CONTRAST OF MATERIAL PROPERTIES

Name	Growth Circle[5]	Annual Output (t/ hectare)	Oil Content[6] (%)	Oil Output (t/ hectare)	The demand for land (thousand millions hectares)	the percentage in the total arable land
high oil corn	70-140 days	7.49	7-10	0.75	1.87	153 %
soybean	90-140 days	1.59	15-20	0.32	4.40	361 %
castor-oil	1-2 years	3.02	58-75	2.27	0.62	50.8%
rapeseed	150 -240 days	1.80	37.5-46.3	0.83	1.68	138%
palm	5-10 years	4.45	About 50	2.23	0.63	51.6%
shiny-leaved yellowhorn	3 -5 years	22.6	30-36	8.14	0.17	13.9%
Microalgae	1 -2 days	225	54	121	0.01	0.82%

The growth cycle refers to the duration from the breeding to the fruit ripening. It varies from area to area, considering different climates, lights and water condition.

Annual output per unit = annual output/ cultivated area. These data are gained through calculating relevant information from China Agricultural Network, China Business Information Network, etc.

The oil content of crops are closely related to climate , moisture conditions, planting methods and crop species. Oil outputs are gained through calculating the maximum of oil content.

The arable areas of China is 1.82574 billions Mu in 2009

III. ANALYSIS FRAMEWORK

The analysis framework of microalgae biodiesel, which concludes the energy consumption and carbon calculations, is a systematic process. This process from the beginning of microalgae selection and large-scale production to the end of biodiesel consumption . In order to facilitate the study, the analysis framework is simplified into four phases: (1) phase of microalgae cultivation (2) phase of microalgae collection, storage and transportation (3) phase of biodiesel production (4) phase of biodiesel transportation and consumption. As an illustration, Fig.1 shows the energy consumption and carbon calculations of analysis framework of Microalgae biodiesel.

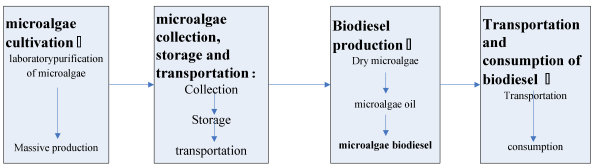

Fig.1 analysis framework of Microalgae biodiesel

As shown in Table Ⅱ below, it is the analysis that the raw material inputs, energy consumption and emissions are included in this four phases showed in Fig .1. In Table II, we only consider electricity consumption of the equipments and fuels consumption within microalgae collection, storage and transportation process without taking into account the energy consumption and emissions of the equipments and vehicles in their life-cycle. Besides ,the consumption during the biodiesel production phase includes methanol, electricity, catalysts, and fuel. Through the microalgae production process, Not only the CO_2 is absorbed , but also the O_2 is created in the photosynthesis of microalgae. Certainly, the CO_2 and a few other gases are produced in the all phases of biodiesel life cycle.

TABLE II
UNITS FOR MAGNETIC PROPERTIES

	Microalgae cultivation	microalgae collection, storage and transportation	Biodiesel production	Transportation and consumption of biodiesel
Consumption of raw materials	Chlorella, Culture medium (elements such as N, P and so on), CO2		Methanol, hydrogen, catalyst	
energy consumption	Electricity, coal	Electricity, petroleum	Electricity, petroleum, coal	Petroleum
emissions	CO_2、O_2	CO_2	CO_2	CO_2

IV. STUDY OBJECTS AND INDICATORS DESCRIPTION

This paper selected 120 tons annual production of microalgae biodiesel by JJ company as the study object and the species of microalgae is chlorella which grown in the freshwater lakes, rivers, reservoirs of Ordos City. And then it continuously produces the high-oil algae by adopting the full-enclosed reactor loop production process which is light energy self-supporting type. As far as is known, each light reactor produces 50 tons of suspensions per day, which contains 1.5 Kg of dry material per ton and 54% of oil and the annual oil output of each light reactor is 12.15 tons per provided that it works 300 days a year. In our project, the whole line with a total of 10 sets of light reactors thus can produce 120 tons of oil annually. To simplify the calculation, it is analyzed on the basis of energy consumed and environmental impacts caused by the system to produce 1t of the biodiesel, and as such, the system's functional unit is 1t biodiesel .

Evaluation indicators include energy consumption and emissions, of which energy consumption was measured by the

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consumption of standard coal, and emissions contain such as HC, CO, PM_{10}, NOx, SOx, and CO_2. In all of these, the amount of CO_2 is the key indicator of the carbon calculations.

V. ENERGY CONSUMPTION AND CARBON CALCULATIONS

A. Analysis of Energy Consumption and Emissions in Microalgae Cultivation Phase

At present, the fast growing microalgae oil content is usually only 10% to 20%, but this microalgae is so difficult to reap if it is no bigger than 10 micrometers . On the contrary, the another microalgae grows very slowly if it contains more than 60% of oil. Therefore, it is the must way to make a project of the microalgae species optimization in order to select this species with three benefits such as fast growing, high oil content and easy harvest.

Consequently, the principles of selecting microalgae, as raw material to produce biodiesel ,can not only be confined to species selecting, accessibility of species and adaptability, but also need to analysis the potentiality of cultivating and consider whether the science and technology can be utilized in industrial production. Microalgae selecting and cultivating principles are listed in Table III.

TABLE III
MICROALGAE SELECTING AND CULTIVATING PRINCIPLES

Core segments	Principles
Microalgae breed selection	adaptability, easy accessibility; adapt to local climate and environment
Cultivating condition	great potential of Microalgae breed : balance the relation between fast growing and high oil content choice of autograph and heterotrophy：autotroph can make full use of light energy and CO_2 but with low cell concentration and high separation cost; heterotrophy can make relative high cell concentration and easy to separate nutrient, growth factor, precursor, temperature, beginning PH and inoculums size will all affect the oil content of Microalgae

As microalgae species, chlorella ,which is from fresh lakes, rivers and water pool in Ordos, Inner Mongolia, is selected by JJ Company. Besides, this company cultivates them by adapting autotrophism with light energy which can make the oil content reach as high as 52%.

In the paper analyses, for the reason of uncertainty of chlorella on the CO_2 absorption rate, the experience value is adopted ,that is, accumulation of 1 mg of dry material through photosynthesis by chlorella requires 1mol (1.8mg)CO_2[7]. Each light reactor produces 50 tons of suspensions during a single day and night with 1.5 Kg / t of dry material. So the annual dry material produced by Chlorella draws 50 t/d × 1.5 Kg/t × 300 d = 22500Kg = 22.5t, and each light reactor annual CO_2 consumption volume draws 22.5 t × 1.8 = 40.5t. The production process produces a lot of oxygen. It will produce about 1200 kilograms of oxygen as producing 1,000 kilograms of algae powder.

In addition , only N element and P element, as two major elements in the Medium, are considered in the paper analyses. Since all the culture solution will be attributable to farmland as fertilizer at last, the element content absorbed by chlorella is only calculated. The elemental analysis of chlorella is shown in TableⅣ.

TABLE IV
THE ELEMENTAL ANALYSIS OF CHLORELLA (DRY CELLS WEIGH)

[C]	[H]	[O]	[N]	[P]	the others
48.9%	6.8%	31.3%	6.9%	1.2%	4.9%

Electricity consumption mainly includes two parts. One is the electricity consumption by the full-enclosed photo-reactor system which is running with an average power of 1.1KW and can realize the on-line control of temperature, pH, CO_2 concentration, water cycle, stirring, centrifugation and so on in the process of cultivation while the power of the system operation does not include centrifugal equipment operation in this phase. The other part is the electricity consumption by the light source. In the system, each set of full-enclosed system contains 20 incandescent tubes with power of 40W each. Thus, the electricity average power by each set of full-enclosed system draws 1.1 KW +0.04 KW × 20 = 1.9KW . The annual electricity consumption draws 1.9 KW × 24 h/d × 300d = 13680 KW • h. The entire supply of electricity is from coal power plants.

The phase study is limited to the raw materials and the energy consumption from the full closed photo-reactor ,expect from the laboratory purification of microalgae. Based on the above analysis, in Table Ⅸ the results of energy consumption and emissions in the microalgae production phase are presented.

B. Analysis of Energy Consumption in Collection, Storage and Transportation Phase of Microalgae

Due to the output of each full-enclosed light reactor system is limited, the consumption is negligible in the storage period of the microalgae. Therefore, calculation mainly include the electrical energy consumption of centrifugation and drying in the microalgae harvesting process ,and fossil energy consumption and environmental emissions of the vehicle in the transportation phase, not counting the energy consumption and environmental emissions of equipments and vehicles in their own life-cycle.

JJ company, with adoption of serializing industrial centrifugation collection, achieves to make collecting rate of biomass from inoculums reach 70% or above which turns into dry powder after drying process. And the production may last more than 150 days per year. Fig.2 demonstrates the flow chart for microalgae collecting and extracting through centrifugation.

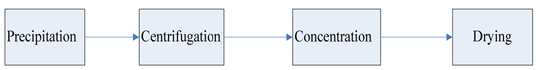

Fig. 2 the flow chart for microalgae collecting and extracting through centrifugation

Each set of full-enclosed light reactor system is calculated as 6.6 KW × 3.5 h/d × 300 d +11KW × 1 h/d * 300 d= 10230 KW • h on the basis of 6.6 KW of average centrifugal power with 3.5h of average running time per day and of 11 KW of average drying power with 1h of average running time per day.

Provided that the transportation radius from microalgae production areas to biodiesel plant is 15km and that a load of 1 ton vehicle is used to transport microalgae in one round trip per day, in Table Ⅸthe data of energy consumption and emissions during phases of microalgae collection, storage and transportation is presented. The emission coefficient is from the current domestic internal combustion engine emission levels (as the TableⅤ shows).

TABLE V
DOMESTIC PHYSICAL PROPERTIES OF GASOLINE AND THE INTERNAL COMBUSTION ENGINE EMISSION COEFFICIENT [8]

Unit of fuel consumption by road transportation	Density	Emission coefficient /g*km^{-1}					
		HC	CO	PM_{10}	NO_x	SOx	CO_2
0.0706 L/(t•km)	0.72 kg/L	1.0	8.6	0.1	2.8	2.6	170

C. Analysis of Energy Consumption and Emissions in Biodiesel Production Phase

Microalgae lipid can be obtained through fracturing, extracting and refining dry thalli. And the detailed flow chart for microalgae oil producing stage is demonstrated in Fig 3.

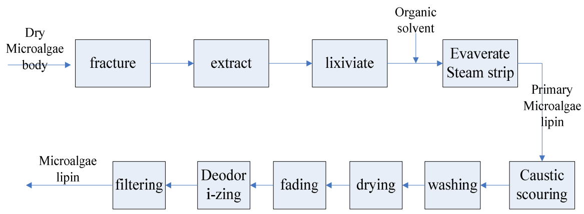

Fig.3 Flow chart for producing microalgae oil stage

Currently biodiesel is mainly produced in chemical method which is to mix animal and plant fats with alcohols such as methanol or ethanol in the condition of acid or alkaline catalysts with high temperature (230 - 250 ℃) in the transesterification reaction by which the corresponding fatty acid methyl esters or ethyl esters come into being. Then biodiesel is formed after the process of washing and drying. Methanol or ethanol in the process can be recycled. In the end ,there may be about 10% of glycerol as by-product from the production process. In addition, the production equipment is the same as the general oil production equipments. Fig 4 is the flow chart for the production of microalgae biodiesel.

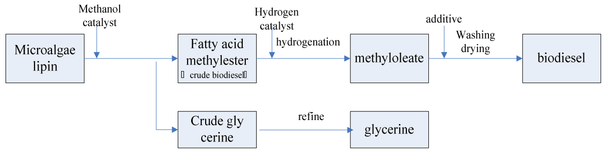

Fig. 4 Flow chart for stage of producing microalgae oil

The raw material input and the energy consumption are the primary considerations in the phase of biodiesel production. The Table Ⅵshows the required amount of raw materials and energy consumption for producing one ton of biodiesel. However, the consumption of additives and water has been omitted since it is of a very small amount.

TABLE VI
AMOUNTS OF RAW MATERIALS AND ENERGY CONSUMPTION REQUIRED FOR THE PRODUCING ONE TON OF BIODIESEL

Cost Items	Amounts required
1. raw materials	
Dry Chlorella	1.86t
Hydrogen gas (under standard conditions)	30 m^3
Methanol	0.14t
Three-way Catalysts	0.001t(negligible)
Solid multi-phase base	0.009t(negligible)
RE additive	0.001t(negligible)
Other additives	0.003t(negligible)
2. Fuel and power	
water	25 m^3 (negligible)
electricity	90 kw. H
Coal (steam, thermal energy)	0.27t

TableⅦ above shows energy consumption of methanol and hydrogen for producing 1ton of biodiesel of which the hydrogen with 99.8% purity is produced through Chinese-made electrolytic cell SDJ2500-50 [9] with the electrical energy consumption of 5.1(KW • h)/m^3. Therefore the total electrical energy consumption is 153 KW•h in order to produce 30 m^3 of hydrogen.

TABLE VII
ENERGY CONSUMPTION OF METHANOL AND HYDROGEN PER UNIT

	the unit energy consumption	
	Coal	electricity
Methanol [10] (kg)	199kg	0.04 KW·h
Hydrogen (m^3)		5.1KW·h

Based on the above analysis, the results of energy consumption and emissions in the phase of biodiesel production are obtained as shown in TableⅨ.

D. Analysis of Energy Consumption during Phase of Biodiesel Transportation and Consumption

Provided that the average transportation radius from biodiesel plant to its final consumers is 300km and that the emission coefficient is from the current domestic internal combustion engine emission levels (as shown in Table V), ,as a result, the total fuel consumption is 0.031t which is 0.0706 L/(t•km) × 300 km × 2 × 0.72 Kg/L =31Kg= 0.031t during the transportation.

Supposing that all the biodiesel is consumed though combustion, Table Ⅷshows the emission coefficient of biodiesel combustion.

Based on the above analysis, in Table Ⅸ the results of energy consumption and emissions in the transportation and consumption phase of biodiesel are presented.

TABLE VIII
EMISSION COEFFICIENTS OF BIODIESEL AND FOSSIL DIESEL[11]

label	Emission coefficient /g*kg^{-1}					
	HC	CO	PM_{10}	NO_x	SOx	CO_2
B100	0.009	0.333	0.498	2.394	0.323	2926
fossil diesel	0.029	0.628	0.958	4.788	10.77	3181

VI. RESULTS

Table IX shows the energy consumption and emissions of microalgae biodiesel in its life cycle. In order to simplify the comparison, energy consumptions have been converted into standard coal.

TABLE IX
ENERGY CONSUMPTION AND EMISSIONS IN THE LIFE CYCLE OF 1T BIODIESEL

Phases	Item	consumption amount	standard coal equivalent (t)	Emission coefficient /g*kg^{-1} HC	CO	PM_{10}	NO_x	SOx	CO_2
microalgae cultivation phase	Electrical energy	1125 KW·h	0.405	0.074	0.443	0.813	4.851	4.551	1250
	Medium	N 0.128t	0.418	0.074	0.548	0.664	4.602	4.130	1324
		P 0.022t	0.034	0.002	0.018	0.009	0.106	0.062	35.226
	CO2	3.333t							
collection, storage and transportation phases of microalgae	Electrical energy	842.0 KW·h	0.303	0.055	0.332	0.608	3.628	3.404	935.0
	Gasoline	0.038t	0.059	0.741	6.371	0.074	2.074	1.926	125.9
biodiesel production phase	Electrical energy	95.14 KW·h	0.034	0.006	0.037	0.068	0.407	0.382	105.0
	Coal	0.47t	0.47	0.086	0.515	0.944	5.631	5.283	1451
biodiesel transportation and consumption phase	B100	1t	0	0.009	0.333	0.498	2.394	0.323	2926
	Gasoline	0.031t	0.048	0.6	5.16	0.06	1.68	1.56	102

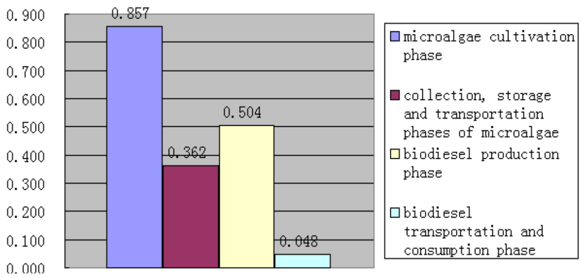

Fig.5 Energy consumption in the life cycle of producing1t biodiesel

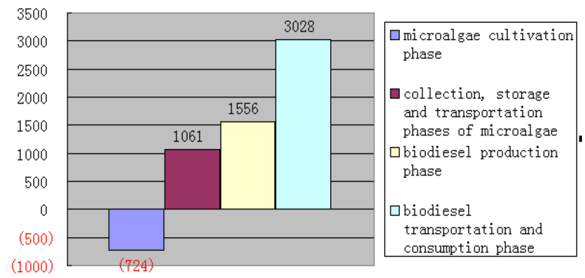

Fig.6 CO2 emissions in the life cycle of producing 1t biodiesel

From the Fig.5, it is concluded that most energy consumption lies in the microalgae production phase due to largely use of artificial light sources and consumption of culture medium by completely closed photo-reactor power followed by the phase of biodiesel production and collection, storage and transportation phases of microalgae in which centrifugation and drying of microalgae take larger proportion of energy consumption. From Fig.6, it can be concluded that most of CO_2 is discharged in the biodiesel transportation and consumption phase mainly due to the combustion of the biodiesel. In microalgae production phase the CO_2 emissions is negative since microalgae grows in the solar energy self-supporting way and absorbed a lot of CO_2. The above analysis indicates that the energy consumption and emissions of micro-algal biodiesel in the life still have room for improvement. Given the non-renewable nature of the diesel, the conclusion is that, the microalgae is the best choice for the desertification areas to develop biodiesel .

VII. Conclusion

1) Compared with other normal energy crops, the microalgae are outweighed by the benefits of high oil content, small area requirement and short growth cycle. In addition, microalgae is very suitable for the development of vast desertification areas in China..
2) According to the construction of microalgae biodiesel consumption-CO2 analysis framework map and the systematic collection of the framework chart of material, energy input and output data, it is concluded that the technical difficulties are species selection and massive production of microalgae. the microalgae cultivation phase determines the amount of energy consumption. Besides, the method of microalgae biodiesel production by JJ Company has some reference meanings for the desertification areas in China to develop biodiesel.
3) From the amount of energy consumption analysis and carbon calculations on microalgae biodiesel of JJ Company, the conclusion is that, microalgae biodiesel has positive effects on reducing the energy consumption and the emissions of CO_2 and other gases. Particularly, microalgae can absorb a lot of CO_2 in their production phase, and the fact gives strong good reasons to Chinese government to develop biodiesel in the vast desertification areas.

References

[1] ChinaEnergyNetwork..http://www.china5e.net/news/newpower/200301/200301190015.html.
[2] Chen Feng,Jiang Xue. Microalgal Biotechnology[M]. China Light Industry Press, 1999.9,pp.21
[3] Chen Feng,Jiang Xue. Microalgal Biotechnology[M]. China Light Industry Press, 1999.9,pp.34
[4] ChinaBusinessNetwork.http://www.chinaccm.com/C4/C401/C40101/news/20070709/12221 1.asp.
[5] China Agriculture Information Network- Crop cultivation in China Information Network. http://zzys.agri.gov.cn/nongqing.asp.
[6] Google Scholar. http://scholar.google.cn
[7] Oswald WJ. Macromodel for outdoor algae mass production[A].In: Borowitzka Ma (ed). Micro-algae Biotechnology[M]:Cambridge : Cambridge University Press ,1990.357～394.
[8] Zou Zhi-ping,Ma Xiao-qian.Life cycle assessment on the solar thermal power generation [J]. Renewable Energy.2004, NO.2:12-15.
[9] Li.Zhong-lai.Preparation of hydrogen and hemical applications[J]. Small Nitrogenous Fertilizer Design Technology.2004,Vol.25,NO.4:45-50
[10] Wu.Peng-ming. Analysis on Investment of 300 kt/a Methanol Plant[J]. Techno-Economics in Petrochemicals. 2003 , 19(2) : 22～35 .
[11] HU Zhi-yuan,TAN Pi-qiang,LOU Di-ming.Study on Greenhouse Gases Emission Characteristic of Diesel Car Engine Fueled with Biodiesel Fuel[J].Chinese Internal Combustion Engine Engineering, 2009.4 Vol.30, NO.2:11-19.

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