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An Innovative Renewable Energy Application for Algae and Fecal Sludge in the Combusted Boiler System

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Abstract: Biomass is a composition of various types of waste materials that can be utilized as useful form of energy. However this new kind of energy hasn't met its full potential in production of energy especially electricity generation due to its lower performance in terms of thermal efficiency. Algae and microalgae have been treated as the source of bio-fuel and some algae also used in fermentation for bio-gas and other phase of energy. In this paper we selected the freshwater microalgae "Chlorella Vulgaris" as the main material and mixture with fecal sludge. We used the mixture as biomass fuel and combusted in the boiler system to analysis its heating performance. We found out the mixture material combusted in the boiler system, the outlet gas temperature is up to 700 ℃and the emission gas components are in a trend with time serious. The results in this paper will be used as a reference material for microalgae multi-oriental energy application and biomass composition proximate and ultimate research development in the future.

***Keywords:** Biomass Energy, Microlgae, Fecal Sludge, Renewable Energy*

1. Introduction

Since industrial revolution in 19th century, the artificial activities and modern industry with a huge quant usage of fossil fuel and emission of carbon dioxide into atmosphere had increased rapidly in 20th century, which it also related within the phenomena such as global warming and climate change. After the oil crisis in 1970s, scientists search for an alternative energy source and developing innovated technology to reduce the usage of fossil fuel and carbon dioxide emission [1]. Renewable energy seems to become the solution for the situation, and it includes hydropower, wind, solar, ocean (OTECs, wave, current, tide, etc.) and biomass energy. Biomass had been used since the mankind discovered fire and biomass energy has the mature technology and mostly using in the developing countries, such as in Africa and Asia using it for cooking and heating in daily life and the ratio might up to one-third in total energy supply [2]. Furthermore, biomass energy has the advantages with the flexibility and convinces, it also contributes 10% energy supply till today.

Biomass includes a board range of biomaterials, such as wood, agricultural waste, energy grease, food industry waste, and algae (microalgae/ macro algae). Biomass energy could be used directly or converted into different phase for advanced energy device, engine or combustion boiler system, that as known as biofuel [3]. The 1st generation of biofuel extracts the oil crop or animal grease as the main material, which it has fully commercialized and developed by using convectional technology [4]. The debate of "food versus fuel" had been raised after food crisis in 2008, the concept for producing biofuel starting to investigate the material without competing feedstock, the 2nd generation biofuel is fermented plant lignin, hemicellulose and cellulose and transforms into bioethanol [5]. However, the scientists search for an alternative material and with great potential and promising application. Algae have been considered as the 3rd generation biofuel, with lipid, protein and cellulose as the components, and no competition with food crop feedstock and land usage.

Microalgae and its Application

The concept using algae as biomass energy material researches started in 1978 till 1996, U.S. Department of Energy's Office of Fuels Development funded a project that is called ASP, Aquatic Species Project. The ASP aimed to develop the microalgae technology by using the waste carbon dioxide from power plant, to produce transportation fuel, select the potential microalgae strains and design the portal type of photo-bioreactor. Japan government (NEDO) also funded the project for carbon dioxide fixation and photo-bioreactor design, which used the Chlorella. sp as the main material. The programs established the fundamental principles such as, the basic design for photo-bioreactor, promising strain for lipid production (Table 1.) and open pond aquaculture system [6].

***Table 1**. Lipid content dry biomass of various species of microalgae*

Microalgae Species	Lipid(%dry weight)
Monallanthus salina	>20
Nannochloropsis sp.(fresh water)	20-35
Nannochloropsis sp.(sea water)	31-68
Neochloris oleoabundans	35-54
Botryococcus braunii	25-75
Chlorella sp.	28-32
Crypthecodinium cohnii	20
Cylindrotheca sp.	16-37
Dunaliella primolecta	23
Isochrysis sp.	25-33
Nitzschia sp.	45-47
Phaeodactylum tricornutum	20-30

[7~13]

In recent studies, the using microalga as other main purpose to biomass energy overcomes the low performance and increases the efficiency with certain transformation. In purpose of improving the efficiency effectively and cost down properly, those algae needed to be treated or pretreated before used in energy system or transform into other energy phase, such as syn-gas or liquidized. However, the algal biodiesel production has shown that lipid extraction and that might over use chemicals could jeopardize the environment and cause the energy waste during harvesting procedures. Some studies use the fermentation as the main approach, which is anaerobic reaction with a biological process in which sugars such as glucose, fructose, and sucrose are converted into cellular energy and thereby produce ethanol and carbon dioxide as metabolic waste products. Anaerobic digestion is a spontaneous process mediated by micro-organisms converting biomass into biogas, but it still needs more developed [14].

Biomass utilization is the trend for biomass energy related applications, thermochemical conversion is considered one of the promising routes, and these processes include gasification, pyrolysis, liquefaction and combustion. Combustion is high temperature chemical reaction between fuel and oxidant, and converted fuel to energy in the form of heat in the gas phase. Recently the microalgae energy-related researches focus on pyrolysis, such as bio-diesel. However, only a few studies about the microalgae in combustion behaviors, and mostly studied the Chlorella species. These studies analyzed the microalgae in different oxygen concentrations and N_2/O_2 ratio in thermogravimtric analysis (TGA) [15] [16]. In 2014, the Lopez-Gonzalez reported [17] that a microalga (Chlorella. vulgaris, Nannochloropsis gaditana and Scenedesmus almeriensis kinetic and analyzed in TGA-MS-DSC) is potential biomass for combustion application. In previous study, we analyze the two different microalgae in TGA and calorific meter, the calorie values from Chlorella V. and Spirulina are over 5000 Kcal/Kg, which is higher than most of the biomass materials, such as wood waste or crop stein and the TGA result shows that decreased rapidly after the temperature reached 300 °C and 80% of the sample had been burned out after 900 °C [18]. In this study, we used the Chlorella V. mixed with fecal sludge to combust in the boiler system to analysis the heating value to be generated and the its heating behavior in the boiler system with time serious.

Material and Method

Microalgae have been studied for decades, and used in energy application depends on its property and composition. The chemical composition will be important for using in energy related researches. However, we also have to consider the quantity and potential in biomass energy. Therefore, in this study we selected Chlorella V,, that has been used in multi-applications and well known by the general consumers. Recently, Chlorella V. also is chosen as the raw material for produce bio-diesel or carbon fixation with its high growth rate, rich in lipid cell and the ability to synthesis long chain fatty acid. In this study, we mixed the Chlorella V. powder with fecal sludge (sample size under 2.5mm), also as known as night soil sludge that contain feces and urine, which is collected from Kyushu local area.

***Fig 1**. Microalgae (Chlorella V.) Powder Samples from Taiwan Chlorella Manufacturing Company*

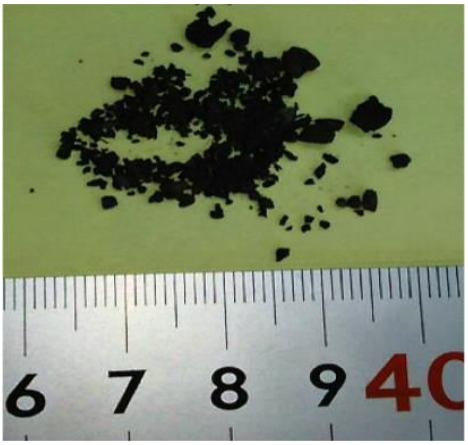

***Fig 2**. Fecal Sludge*

The calorific value analysis method covers the determination of the gross calorific value of a prepared analysis sample of solid forms of biomass by the bomb calorimeter method. The calorific value, or heat of combustion, is a measure of the energy available from the microalgae. Calorific value is determined in this method by burning a weighed analysis sample in an oxygen bomb calorimeter under controlled conditions.

***Fig 3**. Calorific Meter, SHIMADZU Corp., model: CA-4J*

The structure of the combustion system as shown in Fig 4, the furnace has an inner cylinder and outer casing, which is called bi-cylindrical structure. The procedures as fellow:

1. Preheating the burner until the temperature reached 500℃.
2. Supplying the fuel and air into the combustor.
3. Burner stopped after temperature reached 800℃.
4. After the heating temperature is stable (over 800℃), which start to analyze gas components.

Temperature is measured in 4 places, ch1, ch2, ch3, ch4, and also sampling the gas components.

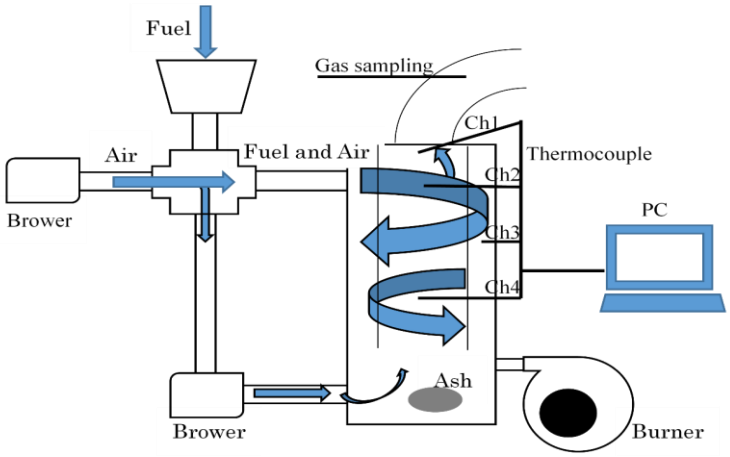

***Fig 4**. Combustion System Illustration Diagram*

Results and Discussions

The atmosphere and sample condition as shown in Table 2., the water content and Calorific Value are the test from the mixed sample. The Chlorella V. calorific value is over 5000 Kcal/KG [18], and the water content is near 0%. The mixed sample due to fecal sludge lowers the heating value and raised the water content.

***Table 2**. The atmosphere and sample condition during the combustion experiment*

Atmospheric Temp(℃)	Atmospheric Pressure(Pa)	Water Supply Temp(℃)	Humidity(%)
7.8	102.3	8.5	72.4
Fuel Type		Water Content(%)	Calorific Value (Kcal/KG)
Microalgae (*Chlorella. V*) + Fecal Sludge		10.30%	4435.2

The combustion system is stable after temperature reached 800℃, we analyzed the gas emission in 5 times in different timing as shown in Fig 5., to construct a time serious.

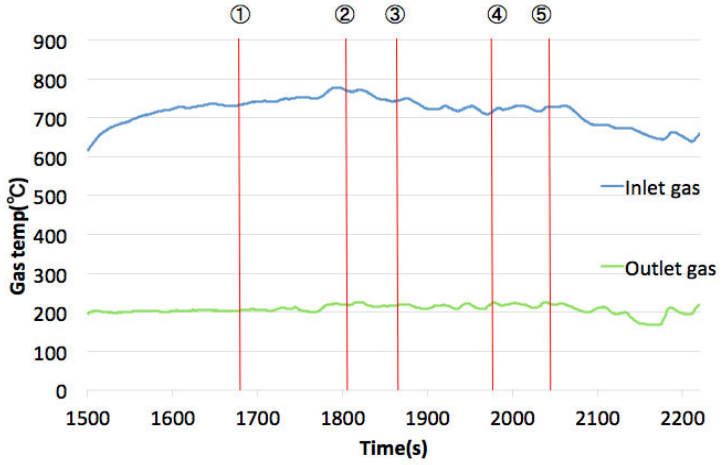

***Fig 5**. Gas sampling time serious*

The concentration changes of gas emission have shown in Table 3. The concentration changes in O2 and CO have the same trend increasing with time, but in NO, NOx shows in the other way, that decreasing with time. The microalgae are composed with cellulose, protein, and fatty acid. Also carbon plays an important role in the photosynthesis effect, the carbon is the main component in Chlorella V.. CO and CO2 increase more and cause NO and NOx reducing. (Fig.6)

***Table 3**. List of gas emission concentration in combustion system time serious*

	O_2 (%)	CO_2 (%)	CO (ppm)	NO (ppm)	NO_x (ppm)	SO_2 (ppm)
1	8.9	9.4	1.0	36.0	91.0	0.5
2	7.6	11.8	37.0	40.0	96.3	1.5
3	8.7	10.6	39.0	36.5	93.5	1.5
4	9.1	10.2	50.0	31.0	85.9	2.5
5	12.1	7.4	72.0	25.0	76.4	3.5

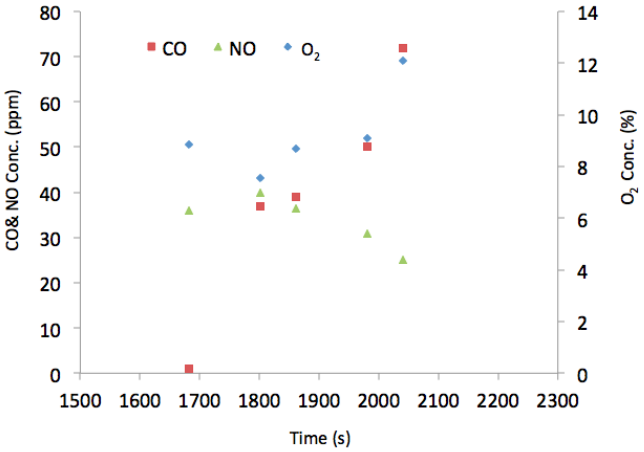

***Fig 6**. Time serious of CO vs. NO vs. O_2 in the combustion system*

Conclusions

We analyzed Chlorella V. mixed with fecal sludge sample for its calorific value and heat performance in the combustion system:

- Chlorella V. obtains higher calorific value than fecal sludge.
- CO and CO_2 concentration increase with time.
- However NO and NOx decrease with time, perhaps the amount of carbon atom, competing for oxygen.

In Taiwan, and some other Southern Asian countries have the euphotic effects in the lakes, ponds or dams. Algae not only damage the ecosystem in the aquatic area and also become a waste treatment issue. In this study, we analyzed calorific value mixed microalgae and fecal sludge. Algae can provide higher energy than fecal sludge, and with NOx and COx emission concentration have totally different trends with time. Its behavior could use to simulate to combine microalgae with sludge for further studies. Algae and biomass energy related technologies still have a huge space for improvement and microalgae related researches would be even better optimized in the near future.

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