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Analysis of microalgae pellets combustion in a circulating fluidized-bed

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Abstract. Microalgae are expected to become an important source of high-value products with several applications in a large number of areas of biotechnology and, especially, in biofuels production. The increasing interest in microalgae as a source of biofuel (so-called third generation biofuel) is due to the several advantages. The objective of this study was to investigate combustion characteristics of microalgae (*Oscillatoria* sp.) pellets burnt in a circulating fluidized-bed (CFB) in terms of sample temperature profiles, ignition time, ignition temperature, devolatilization time and the burnout time. Spherical 10-mm microalgae pellets were tested at temperature of 850°C in a 12-kW bench-scale CFB combustor.

1 Introduction

Fossil fuels provide around 79% of world energy supply [1]. In countries such as China, Australia and Poland, coal is the primary source of power generation. However, coal combustion results in emission of CO_2 to atmosphere which is probably the main cause of global warming. Therefore, other biomass or alternative fuel solutions are needed, including microalgae. There is a growing number of works devoted to combustion [2-6], pyrolysis [7-9] and gasification [10-12] of biofuels.

Microalgae are expected to become an important source of high-value products with several applications in a large number of areas of biotechnology (such as cosmetics, pharmacy and food) and, especially, in biofuels production. The increasing interest in microalgae as a source of biofuel (so-called third generation biofuel) is due to the several advantages that it offers over terrestrial oil crops. These advantages include: high growth rate, an all-the-year-round production, high efficiency in CO_2 capture, the use of wastewater as a source of nutrients, the elimination of the need for herbicides or pesticides, and their possible cultivation in brackish water or non-arable land, resulting in a minimisation of the associated environmental impact. Microalgae can be farmed in fresh water or marine water and thus are not in competition with production of food crops [6-8, 13, 14].

Direct combustion is a thermochemical technique used to burn biomass in the presence of excess air. In the process, photosynthetically stored chemical energy in the biomass is converted into hot gases [13]. Typically, combustion takes place inside a boiler, furnace or

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in a steam turbine at a temperature around 850 °C. The combustion process accepts various types of biomass, but the moisture content should be less than 50%. The heat produced from the combustion process does not have suitable options for storage; hence it is best utilized immediately. The cost of energy production from direct combustion is slightly higher as the biomass requires pretreatment, such as dehydrating, cutting and crushing, prior to the process. One of the simplest approaches in the literature for microalgae biomass utilization is combined heat and power production [13].

Circulating fluidized-bed (CFB) boilers are ideal for efficient power generation. They are capable of firing a broad variety of solid biomass fuels in small combined heat and power plants and large utility power plants. CFB combustion technology is increasingly becoming the market-leading technology used in the large-scale utility power sector firing a broad range of solid biomass fuels, due to its well-known benefits such as fuel flexibility, high efficiency, availability, and reliability. However, detailed knowledge of biomass specifications and full understanding of their variability of supply are paramount to design boilers with the highest efficiency and availability, and to operate them in the most economical way [15].

Microalgae biomass conversion technologies are classified in two different types such as biochemical conversion and thermochemical conversion (Figure 1). Combustion, gasification and pyrolysis are widely used thermal processes which can be used to convert dried algae to energy and fuels [16]. Most of the thermochemical processing studies on algae are based on thermogravimetric experiments on pyrolysis [7,9], gasification [7,11] and combustion [6,7].

Once you have produced the algae in many processes it's dried to a powder before it can be used in the processes to produce liquid fuels. In some cases this will not be done on site, therefore the algae powder will need to be transported. This is where small scale pellet plants come into play. To reduce the transportation costs of algae it can be pelleted. Algae pellets will also flow much better through the process hoppers etc than powder which can bridge and lead to a halt in the liquid fuel production process [17].

However, little is known about the behaviour of microalgae in the combustion process in CFB boilers. The objective of this study was to investigate combustion characteristics of microalgae pellets burnt in a circulating fluidized-bed.

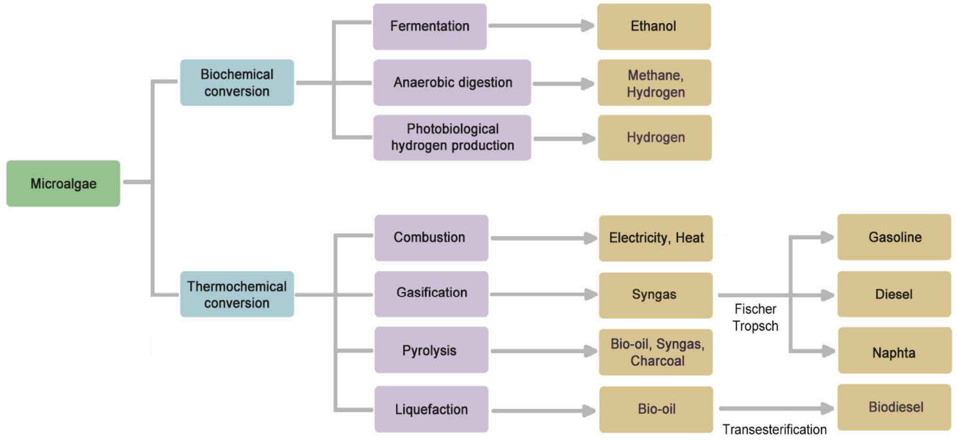

Fig. 1. Microalgae biomass conversion processes.

2 Experimental

2.1 Tested microalgae

Properties of microalgae (*Oscillatoria* sp.), including proximate and elemental analyses and higher heating value (HHV) are listed in Table 1. The proximate analysis showed volatiles (mainly organic) of 72.3 wt% in microalgae. The HHV of microalgae was 15.86 MJ/kg. The elemental analysis showed that the tested biomass mainly consisted of carbon and oxygen.

Table 1. Proximate and ultimate analyses of microalgae.

Proximate analysis (dry basis)	
Moisture content , wt %	4.4
Volatiles content, wt %	72.3
Ash content, wt %	8.9
Fixed carbon, wt %	14.4
HHV, MJ/kg	15.86
Ultimate analysis (dry basis)	
Carbon, wt %	37.7
Hydrogen, wt %	5.5
Nitrogen, wt %	4.7
Sulphur, wt %	0.46
Oxygen*, wt %	38.34

*calculated by difference

2.2 Laboratory method of algae pelletization

Figure 2 displays a flow diagram that demonstrates how the microalgae pellets were produced. The first stage involved drying algae feedstock. In the second stage, the fuel was milled in a laboratory mill. In the third stage, the milled fuel was sifted by passing it through a series of standard sieves with sizes decreasing to 0.1 mm. The sifted fuel was mixed with potato starch as a binder (approximately 8% by weight) and water in the fourth stage.

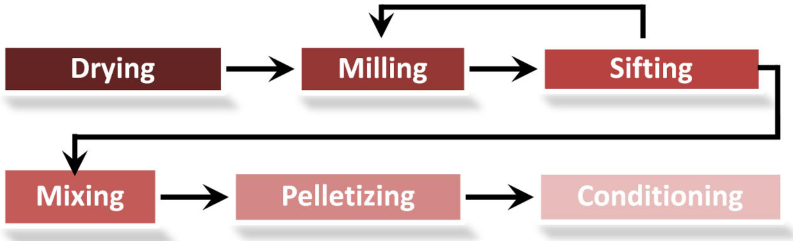

Fig. 2. Flow diagram of biomass pellet production [3].

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In the fifth stage, the mixture was compacted using a hydraulic stamping press, which gave the pellet its spherical shape. Figure 3 illustrates system for forming pellets. The last stage involved conditioning the pellets to remove moisture. Figure 4 shows the physical appearance of the microalgae pellet.

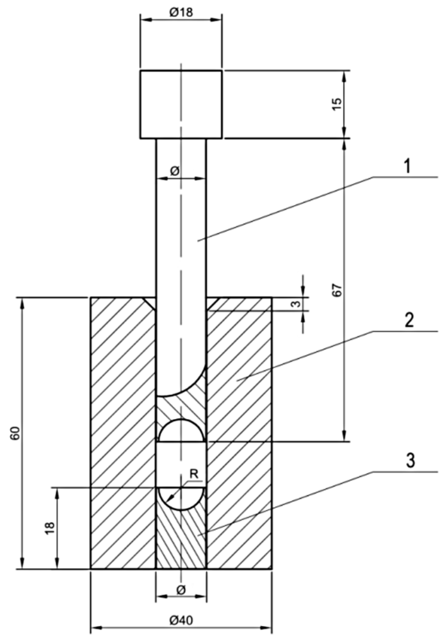

Fig. 3. Scheme of construction unit for biomass pellet formation: 1-upper punch, 2-matrix, and 3-lower punch [3].

Fig. 4. Spherical microalgae pellet (d = 10 mm).

2.3 CFB combustor and experimental procedures

Microalgae pellets combustion tests were conducted in a 12-kW bench-scale CFB combustor shown schematically in Figure 5. The facility consists of a combustion chamber (1), a cyclone (2), a downcomer (3) and a loop seal (4). The electrically-heated rectangular combustion chamber (riser), 680×75×35 mm, is the main component of the unit. Silica sand (particles smaller than 400 μm) to a mass of 0.3 kg constituted the inert bed. A rotameter (15) controlled the supply of air to the preheater (8). During combustion tests, the superficial gas velocity was kept at a constant level of about 5 m/s. The temperature was held at 850 °C by means of a microprocessor controller (11). S-type thermocouples (T1–T3) measured the temperature at three different levels inside the combustion chamber with an accuracy of ±2 °C.

A single microalgae pellet (5) was introduced into the combustion chamber and positioned stationary in the bed. To measure the temperatures in the centre and at the surface

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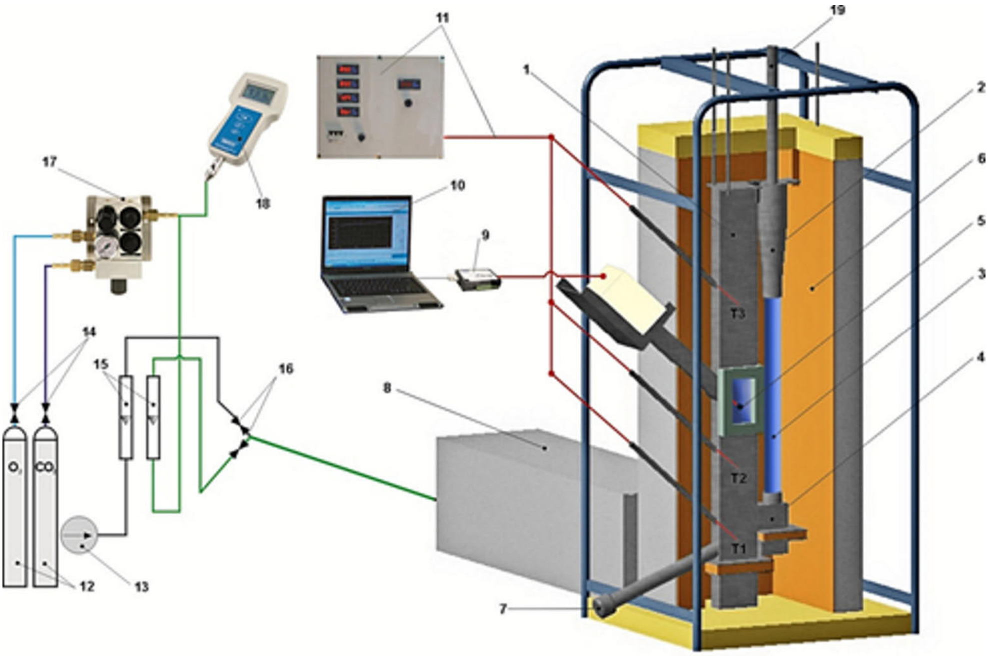
of the biomass sample a special stand was constructed. It provided a support for two S-type thermocouples.



Fig,.5. Schematic diagram of the experimental apparatus [4]

1-combustion chamber, 2-cyclone, 3-downcomer, 4-loop seal, 5-biomass particle, 6-insulation, 7-drain valve, 8-preheater, 9- card, 10-computer, 11-temperature control system, 12-gas cylinders, 13-air compressor, 14-pressure regulators, 15-rotameters, 16-valves, 17-mixer, 18-gas analyser, 19-ventilation duct, T1–T3-S-type thermocouples

The tip of the first thermocouple was located inside the particle, while the second thermocouple measured the surface temperature and served as a basket in which the microalgae pellet was placed. The thermocouples were connected via a card (9) to a computer (10) in order to record the temperature measurements.

Ignition time and devolatilization time were measured by stopwatch with an accuracy of 0.1 s. The intraparticle temperature, the surface temperature, ignition time and devolatilization time were measured simultaneously.

Video and digital cameras were used to record the combustion process of microalgae pellets.

Spherical 10-mm microalgae pellets were tested at temperature of 850°C in the air atmosphere.

3 Results and discussion

Each biomass sample introduced to the combustion chamber undergoes several characteristic stages namely:

a) heating and drying,
b) ignition of volatiles,
c) combustion of volatiles,
d) combustion of remaining char.

Almost all solid fuels experience these processes but the duration of each process depends on fuel type and its composition (moisture and volatile matter contents, total carbon content), temperature in the combustion chamber, heating rate and oxidizing atmosphere [4].

Figure 6 shows pictures of a microalgae pellet burning in a circulating fluidized bed. The first stage is heating and drying (Fig. 6a). After rapid heating, the ignition of volatiles follows. The ignition time (τ_i) was 2 s for microalgae pellets. Burning volatiles form a distinctive long flame (Fig. 6c). The average volatiles combustion time was 32 s. The last stage is combustion of char (Fig. 6d).

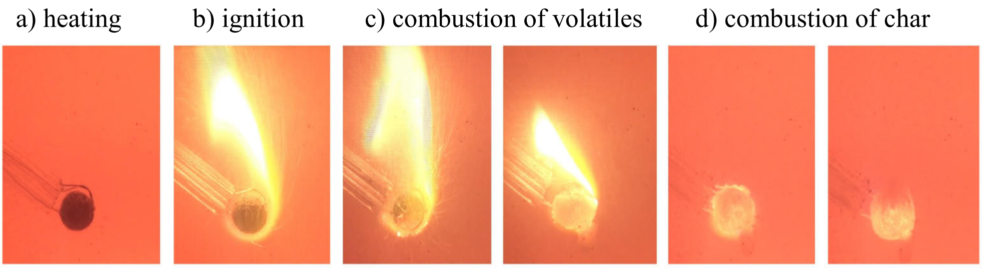


Fig. 6. Visualisation of microalgae pellet in CFBC in air.

Figure 7 shows temperatures measured at the surface and in the centre of microalgae pellet burned at 850 °C in CFB. The average ignition temperature of microalgae pellets was determined to be 308 °C in the air atmosphere. When the flame approaches its point of extinction, the surface temperature reaches its maximum value. The maximum surface temperature was approximately 1100 °C. In the next stage, i.e. char combustion, the centre temperature was higher than the surface temperature. The maximum centre temperature was approximately 1000 °C. The burnout time (τ_b) of microalgae pellet was approximately 138 s.

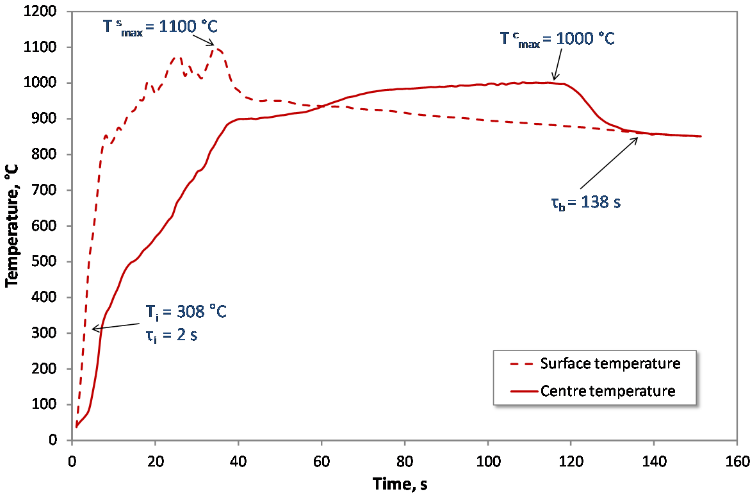


Fig. 7. Temperature profiles for microalgae pellet during combustion in CFB.

The comparison of temperature profiles for 10-mm microalgae pellet and wheat straw pellet is shown in Figure 8. In both cases, after an initial delay, the centre temperature exceeds the surface temperature and is approximately 100°C higher during the course of combustion. The temperature profiles for both pellets are similar. However, the combustion process of wheat straw pellet proceeded at slightly higher temperatures and was shorter in time compared to

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combustion of microalgae pellet. The burnout time of wheat straw pellet is approximately 42% shorter than that for microalgae pellet.

The average parameters during 10-mm pellets combustion in a circulating fluidized-bed are shown in Table 2.

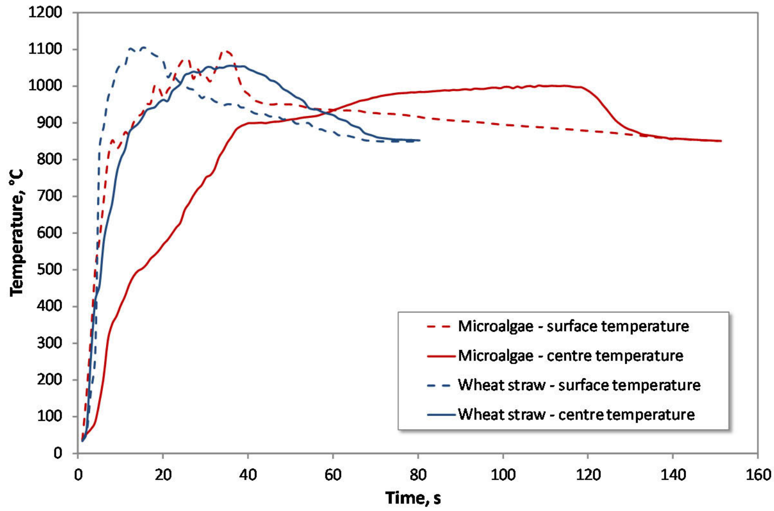

Fig. 8. Comparison of temperature profiles for microalgae pellet and wheat straw pellet during combustion in CFB.

Table 2. Average parameters during 10-mm pellets combustion in CFB at 850 °C.

Fuel	**Microalgae**	**Wheat straw** [19]	**Salix viminalis** [19]	**Bituminous coal** [19]
Ignition time, τ_i, s	2	< 1	< 1	3
Ignition temperature, T_i, °C	308	260	280	370
Maximum surface temperature, T^s_{max}, °C	1100	1150	1140	1070
Maximum centre temperature, T^c_{max}, °C	1000	1020	1030	1080
Volatiles combustion time, s	32	18	24	50
Burnout time, s	140	80	90	580

Generally, the ignition temperature decreases with an increase in volatile matter content. The comparison of the volatiles combustion time and burnout time is shown in Figure 9 and 10, respectively. The volatiles combustion time depends on the volatiles content in fuel and the density of pellet. The burnout time depends on the carbon content in fuel and the density of pellet.

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Fig. 9. Comparison of devolatilization time for 10-mm pellets in CFBC

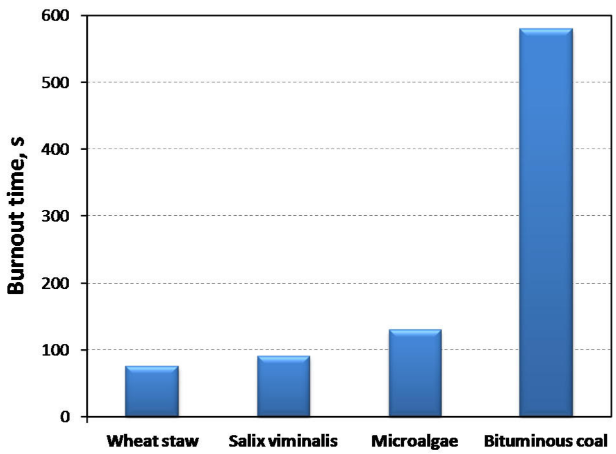

Fig. 10. Comparison of burnout time for 10-mm pellets in a circulating fluidized bed.

4 Conclusions

Spherical microalgae pellets were burned in a laboratory-scale CFB combustor at 850 °C. The higher heating value of microalgae (*Oscillatoria* sp.) was 15.86 MJ/kg. The average ignition temperature and ignition time of microalgae pellets were 308 °C and 2 s, respectively. The average volatiles combustion time and burnout time of microalgae pellet were 32 s and 138 s, respectively. The results of this experimental research show that the microalgae pellets can be successfully burned as an alternative fuel in circulating fluidized bed boilers.

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