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Co-gasification of almond shell and microalgae in a fluidized bed gasifier

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Abstract - One of the main technologies for utilising biomass to produce high-quality gas is biomass gasification. Because of the depletion of fossil fuels and the worsening environmental issues, biomass energy is a significant alternative energy source. In this study, a 10 kW bubbling fluidized bed gasifier was used to co-gasify almond shell and microalgal biomass in order to evaluate the effects of gasification temperature, equivalence ratio, feedstock mixing ratio, and steam injection on syngas, components, tar content, lower heating value. The microalgal and almond shell were torrefied to boost the heating values prior to feeding into the gasifier. The ash content of microalgal torrefied pellets is discovered to be significantly higher than that of almond shell torrefied pellets. The extreme higher amount of ash may result in sintering and agglomeration during gasification, despite the fact that ash compositions might work as catalysts to speed up the gasification reaction. The results of the aforementioned co-gasification studies demonstrate that CO and CO2 contents rise with rising ER, whereas CH4 and H2 exhibit the opposite tendency. H2, and CH4 levels decline and then slightly increase as the microalgal torrefied pellet's mixing ratio is increased, however CO and LHV contents increase and subsequently decrease. Steam injection can boost H2 and CO2 yields while lowering CH4 and CO yields as well as LHV. As compared to the gasification of almond shell torrefied pellet, it can be shown that the microalgal torrefied pellet produces more gasification products due to its high ash concentration.

Keywords: Co-gasification, Fluidized bed, Torrefaction, Microalgae, almond shell.

I. INTRODUCTION

A thermochemical process called "biomass gasification" transforms biomass into producer gas that contains gaseous species. In instance, steam fluidized bed gasification creates a fuel gas with a large amount of methane and carbon dioxide, as well as hydrogen and carbon monoxide [1]. The technology for gasifying lignocellulosic biomass to create renewable fuels and chemicals is moderately advanced [2]. When biomass is partially burned, a process called gasification creates valuable gases that can either be used as a direct fuel source or upgraded to more value liquid fuels and chemicals [3]. To understand the impact of raising the biomass feeding ratio on the operation of an IGCC plant, Long and Wang [4] recently researched the cogasification of coal and biomass. They concluded that the cogasification process is more efficient than a single gasification operation. The direct gasification of biomass in a commercial atmospheric CFB gasifier built by the Foster Wheeler Energia Oy, Finland, has also been successfully tested by the Lahden Lampovoima Oy Kymijarvi power plant gasification project [5]. Moreover, co-gasification of several fuels has been demonstrated to be practical [6]. Nonetheless, microalgae have long been acknowledged as a viable biomass resource for the creation of energy [7]. Nevertheless, to increase the fuel quality before using it as a fuel, crumbled microalgae must first undergo pelletization and torrefaction. The fuel grade of torrefied microalgae is comparable to that of coal [8]. Thus, the objective of this investigation is to expand the utilization of microalgae as fuels. Several studies then looked into how various factors, including as temperature, feed concentration, and residence period, affected SCWG (RT). Many investigations into the thermochemical conversion of almond residue have been conducted. In a fluidized bed reactor, Rapagna and Latif looked into the steam gasification of almond shell [9]. Investigated were the effects of temperature and particle size on product yield. The impact of temperature on the SCWG of agricultural leftovers, such as hazelnut, walnut, and almond shells. The product's gas content increased as a result of the temperature rising. Trona and dolomite were also included as alkali and alkaline earth metal (AAEM) catalysts, which helped to increase the overall gas and hydrogen production. During catalytic and non-catalytic experiments, the maximal hydrogen yields were 4.41 and 7.09 mmol/g, respectively [10]. The noncatalytic SCWG of several agricultural wastes, such as almond shell, walnut shell, and wheat straw, at temperatures between 400ºC and 440ºC. At 440ºC, a maximum hydrogen output of 4.1 mmol/g was recorded [11]. For a better conversion of biomass into gaseous products, a variety of catalysts have been used [12]. Among them, Nickel as metallic catalyst and some alkali catalysts have been broadly used. Nevertheless, there are some challenges in the application of Ni-based catalysts such as rapid deactivation, coke formation and contamination within the interactions between biomass content and the metal which results in lower selectivity and stability.

Recently, some researchers investigate the effect of carbonaceous materials such as biochar and hydrochar on the thermochemical conversions of biomass [13]. Tested the biochar derived from pyrolysis of wheat straw, rice husk and cotton stalk as a catalyst and catalyst support. Enhancement in hydrogen production was observed due to the porosity of the biochar and its mineral content [14]. studied the effect of the pyrolysis derived algal biochar as a catalyst on the hydrogen production from pyrolysis of macroalgae. Total gas and hydrogen production were favored by the addition of biochar [15]. In the previous study of the authors, algal hydrochar as a solid residue of the SCWG used as a catalyst for its own process which resulted in the higher hydrogen yield [16]. All experiments were carried out in a 10 kW bubbling fluidized bed gasifier to investigate cogasification of the microalgal torrefied pellet and and almond shell torrefied pellet. The effects of gasification temperature, equivalence ratio (ER), feedstock mixing ratio and steam injection on syngas compositions, the lower heating value (LHV), and tar content were analyzed to understand the feasibility of employing microalgae as the gasification feedstock.

II. RELATED WORK

A. Almond shell

For co-gasification, the Almond shell and Microalgae are used. The biomass used was almond shells, which represent an abundant agricultural sub-product in regions of moderate climate. It was shown below in Fig.1. The dust present in almond shells was washed with water and dried in sunlight for 4 days and also dried in an oven to remove moisture after it was sieved to 400µm.The ultimate and proximate analysis of palm kernel shell was shown in Table 1.

Fig.1. Almond shell

B. Microalgae

The microalgae were produced in algae ponds. Drying process that dissipated after an initial period of drying at 60 °C in an outdoor furnace. Most of the solid pieces were particles between 4.7 and 9.5 mm in size; therefore, this size range was used in the gasification process. The ultimate and proximate analysis of Microalgae was shown in Table 1.

Fig.2. Microalgae

Table 1
Proximate and ultimate analysis of fuel.

Property	Microalgae	Almond shell
Moisture content (wt%)	11.81	03.98
Proximate analysis (wt%, dry basis)		
Volatile matter	12.20	72.87
Fixed carbon	04.30	21.30
Ash content	07.64	01.68
Ultimate analysis (wt%, dry basis)		
C	48.86	49.83
H	07.37	06.03
N	10.87	00.80
S	00.66	00.36
O (by difference)	25.56	41.01
Higher heating value, HHV (MJ/kg)	19.30	44.05

III. THE PROPOSED MECHANISM

The experiments were carried out in a 10 kW bubbling fluidized bed gasification system including the gasification chamber with a windbox, the feeding system, the air supply system, and the syngas treatment section. Fig. 3 shows the flow diagram of the bubbling fluidized bed gasifier employed in this study. The gasification chamber, with a diameter of 7.6 cm in the bed region, 19.8 cm in the freeboard region, and a total high of 1.9 m, was constructed of 6 mm SUS310 stainless steel covered with ceramic fiber to limit heat loss. A cylindrical windbox with a conical bottom, 30 cm in height and 7.6 cm in diameter, connected to the air supplied line was fabricated of 6 mm stainless steel. The air pre-heated by an electric heater was served as the fluidization gas through a perforated plate distributor of 2 mm stainless steel with an open area ratio of 2%. The gasification chamber is kept at the operating temperature by means of the electric heating system covered the bed region. The feeding of the feedstock into the gasifier at the position above the sand bed was carried out continuously. The two-stage feeding system includes a hopper with two pneumatic knife gate valves to block air, and a screw feeder is connected to the gasifier. The syngas leaving the gasifier entered a cyclone for the primary cleaning. Ash and unburned char dropped from the cyclone into a sealed vessel for removal.. The components of the syngas, such as CO, CO_2, H_2, and CH_4 were analyzed by employing an Agilent 7890A gas chromatograph (off-line) during the steady state operation. syngas exited from the cyclone and passed to a wet scrubber, then was discharged via the stack after a combustor.

The microalgal torrefied pellet and almond shell torrefied pellet with a diameter of 6 mm, and a length of 10 mm were used as feeding fuels. The feedstock was firstly pelletized by a flat die pellet mill. Afterwards, the pellet was torrefied at 250°C for 1 h. The proximate and ultimate analyses of fuels are listed in Table 1. Silica sand was employed as the bed material in this study and the mean size of the sand was 0.437 mm in diameter with a minimum fluidization velocity of 18.9 cm/s.

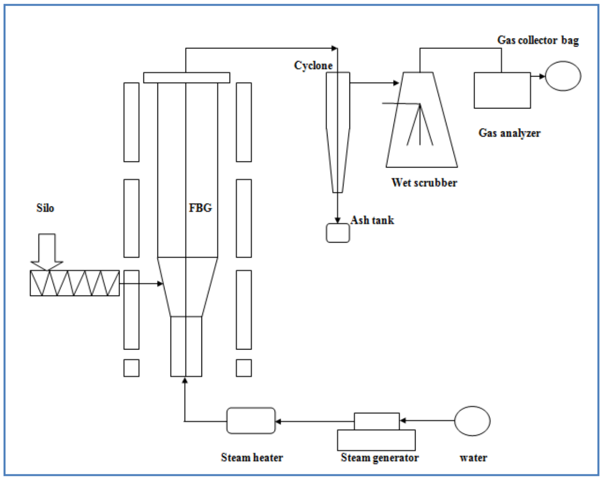
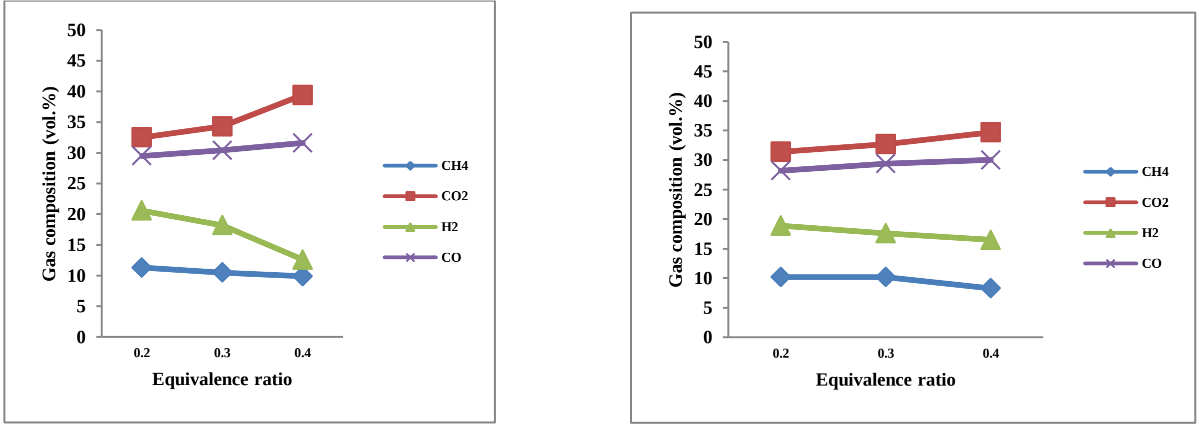


Fig.3.Scheme of the experimental system

IV. PERFORMANCE EVALUATION

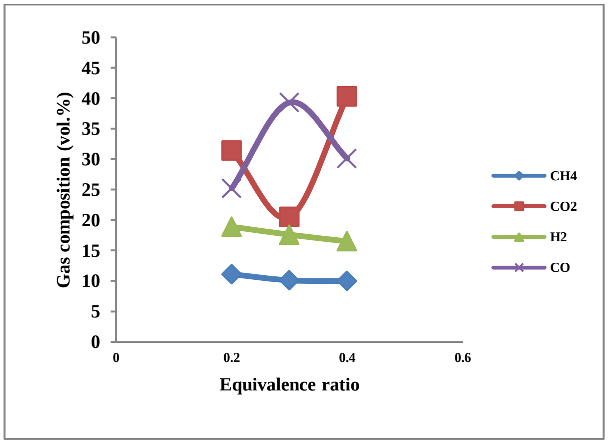
A. Effect of ER and gasification temperature

For co-gasification, torrefied pellets from almond shells and microalgae were combined. The microalgal torrefied pellet was mixed at 20 weight percent, 30 weight percent, and 50 weight percent. Fig. 4 shows the effect of ER on the syngas composition form co-gasification at 700°C.



(a) Mixing ratio of microalgal torrefied pellet = 20 % (b) Mixing ratio of microalgal torrefied pellet = 30 %

The same tendency of varying syngas composition at various mixing ratios is shown in Fig. 4 (a and b). The contents of CO and CO_2 rise as ER rises, but CH_4 and H_2 exhibit the opposite trend. Also, CO_2 content is always greater than CO content. The higher ER value equates to introducing more oxygen into the gasifier, enhancing the oxidation (combustion) reaction and CO_2 production for the same reason as mentioned previously.



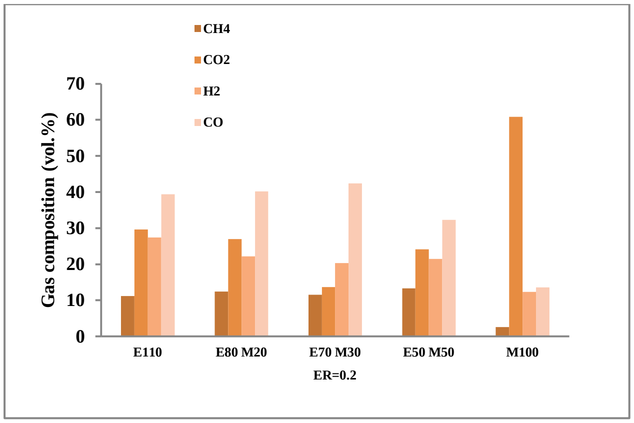
(c) Mixing ratio of microalgal torrefied pellet = 50 %

Fig. 4. Effect of ER on syngas composition from co-gasification at 700ºC.

However, CO and CO_2 contents in Fig. 4(c) show the different results. Although CO_2 exhibits the opposite trend, CO first rises and then falls. Because of the greater ash content, it is hypothesised that raising the microalgal torrefied pellet mixing ratio at lower gasification temperatures may have an impact on the syngas production.

B. Effect of mixing ratio

Fig. 5 shows the effect of mixing ratio on syngas composition for co-gasification at 800ºC with different ER.



The codes are represented in the figures as a mixture of microalgal and almond shell torrefied pellets. For instance, E80M20 denotes a mixture of 20% microalgal torrefied pellet (M) and 80% almond shell torrefied pellet (E), whereas M100 denotes the use of exclusively microalgal torrefied pellet (M) as the feeding fuel. The similar guidelines apply to other codes.

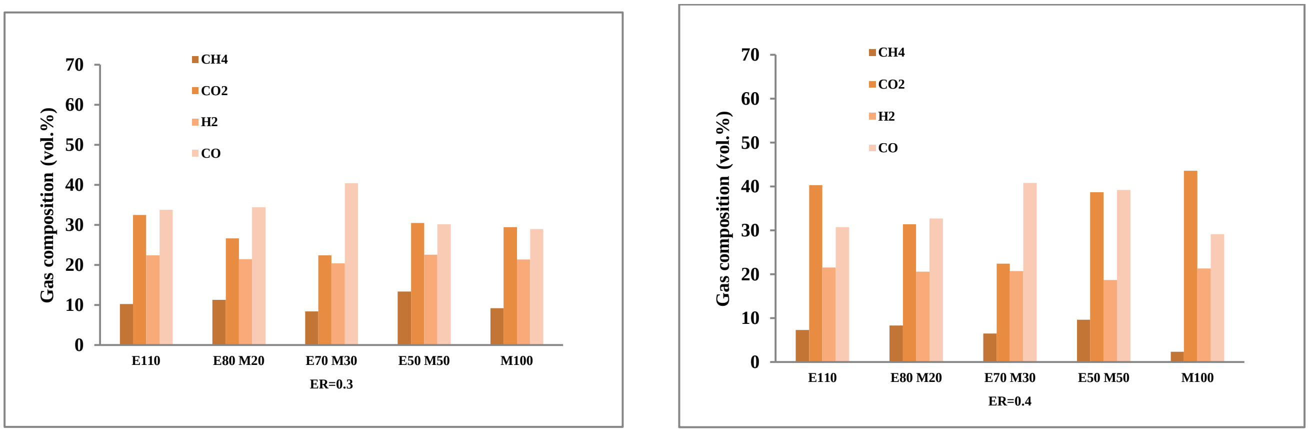


Fig. 5. Effect of mixing ratio of microalgal torrefied pellet on syngas composition from co-gasification at 800ºC.

Figure 5(a-c) shows that as the mixing ratio of the microalgal torrefied pellet is increased, H_2 and CH_4 initially decrease and then slightly increase (M). On the other hand, CO_2 exhibits the opposite behaviour, increasing first and then decreasing. As a result, increasing CO yield by adding the right quantity of microalgal torrefied pellets.

C. Heating value of syngas

The heat of water vaporisation is subtracted from the higher heating value to get the lower heating value (LHV), sometimes referred to as the net calorific value (HHV). LHV is typically employed in practical situations and serves as a syngas quality indicator.

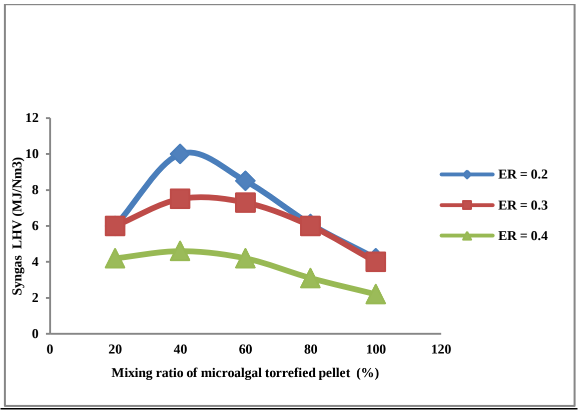


Fig. 6. Effect of mixing ratio of microalgal torrefied pellet on syngas LHV (gasification temperature = 800°C).

The effect of the microalgal torrefied pellet's mixing ratio on the lower heating value of syngas with various ER at 800°C is shown in Fig. 6. As the mixing ratio of the microalgal torrefied pellet is increased, LHV initially rises and then falls. As a result, the LHV was dominated by the CO concentration. Moreover, feeding 30% of the torrefied microalgal pellet results in the greatest LHV.

D. Effect of steam injection

In order to understand the effect of the steam injection on syngas and LHV, the gasification test was carried out with injecting 0.86 kg/h of 128 °C steam at ER = 0.3.

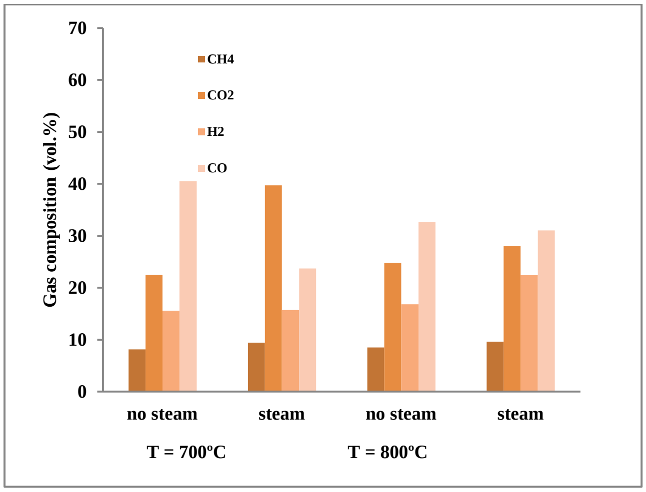


Fig. 7. Effect of steam injection on syngas composition (ER = 0.3, mixing ratio of microalgal torrefied pellet = 50%).

According to Fig. 7, adding steam increases H_2 and CO_2 yields while lowering CH_4 and CO yields. It is believed that adding steam improves methane reforming ($CH_4 + 2H_2 \rightarrow CO_2 + 4H_2$), water-gas shift reaction ($CO + H_2 \rightarrow CO_2 + 2H_2$), and char decomposition, especially around 700°C. Because adding steam lowers the bed temperature, the water gas reaction ($C + H_2 \rightarrow CO + H_2$) is not immediately apparent at 800ºC. On the other hand, it is also clear that at lower temperatures, the gasification process was dominated by the water-gas shift reaction, which is why adding steam causes a significant increase in CO_2.

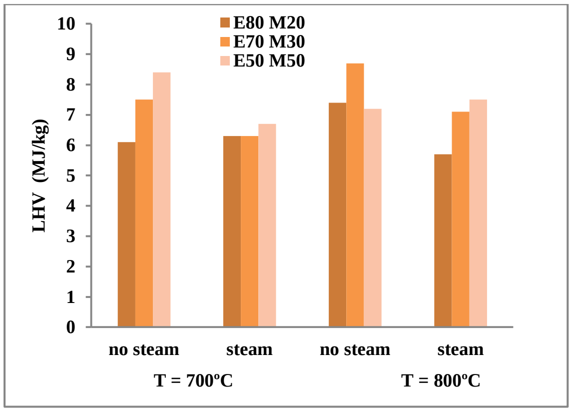


Fig.8. Effect of steam injection on syngas LHV (ER = 0.3).

Fig. 8 depicts the impact of steam injection on LHV. It was discovered that adding steam to the system reduced the LHV. As was already indicated, this is explained by the fact that after injecting steam, a significant amount of CO_2 rises. Moreover, the possibility of feedstock and bed material agglomeration is increased by steam injection. The yield of syngas would be impacted.

E. Tar contents

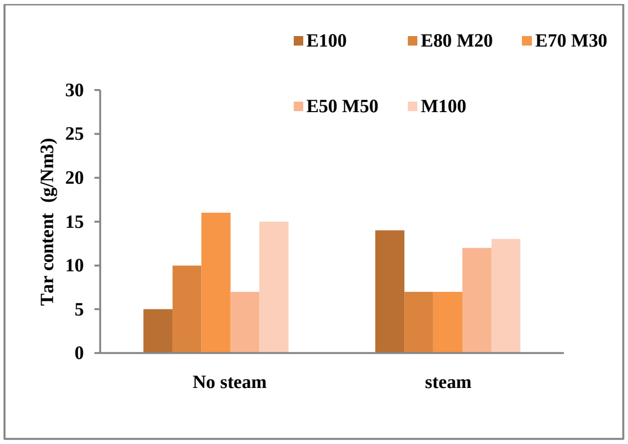


Fig. 9. Effect of steam injection on tar content from co-gasification (gasification temperature = 800°C, ER = 0.3).

Any organic molecules in syngas formed from biomass with a molecular weight greater than benzene are referred to as tar. Fig. 9 depicts the impact of steam injection on the tar content. According to Fig. 7, the steam injection can lessen the tar content of the microalgal torrefied pellet at a lower mixing ratio. It is suggested that adding a little bit of ash to the steam can help remove more tar. Nonetheless, the tar content would rise if agglomeration due to ash compounds combined with steam took place. At E50M50 in Fig. 7, the outcomes brought on by agglomeration can be found.

V. CONCLUSION

In order to research the effects of different operation parameters on the syngas, the microalgal torrefied pellet and almond shell torrefied pellet were co-gasified in a 10 kW bubbling fluidized bed gasification system. The ash concentration of microalgal torrefied pellets is discovered to be significantly higher than that of the majority of almond shell. The extreme higher amount of ash in the microalgal torrefied pellet may promote sintering and agglomeration during gasification, despite the fact that ash compositions can act as catalysts to accelerate the gasification reaction.

The results of the aforementioned co-gasification studies demonstrate that CO and CO_2 contents rise with rising ER, whereas CH_4 and H_2 exhibit the opposite tendency. Steam injection boosts H_2 and CO_2 yields while lowering LHV, CH_4 and CO yields. Tar concentration could be decreased by adding a little bit of ash to steam. As a result, the gasification products are impacted by the microalgal torrefied pellet's high ash content. It may be inferred that increasing CO production and LHV without adding steam is possible by adding the right amount of microalgal torrefied pellet.

According to the study, the microalgal torrefied pellets have a high ash concentration that dominates the gasification products, and the results reveal a different trend from the gasification of almond shell. However, additional research may be required to understand the significance of the high-content ash in microalgae during gasification in the near future if the use of microalgae as solid biomass fuels is to be expanded.

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