Synergistic Effect of Co-utilization of Coal and Biomass Char: An Overview

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Abstract: Global concerns on impact of greenhouse gases emission, mostly released from coal-fired power plant, and the depletion of fossil fuel particularly coal, has led the production of electricity from alternatives resources such as co-utilization technologies. Previous studies proved that the co-utilization of coal and biomass/biomass chars has significantly reduced the emission of greenhouse gases either during the pyrolysis, combustion or gasification process in laboratories, pilots as well as in the industrial scales. Interestingly, most of the studies reported the presence of synergistic effect during the co-utilization processes particularly between coal and biomass char while some are not. Biomass chars were found to have porous and highly disorder carbon structure and belong to the class of most reactive carbon material, resulting to be more reactive than those hard coal and lignite. Up to date, microwave assisted pyrolysis is one of the best and latest techniques employed to produce better quality of biomass chars and it is also reduce the processing cost. Lot of works has been done regarding on the existence of synergistic effects during its co-utilization. However, the knowledge is limited to thermal and product characteristics so far. Even so, the specific reasons behind its existence are yet to understand well. Therefore, in this paper, the emphasis will be given on the synergistic effects on emission characteristics of co-utilization of coal and biomass chars so that it can be apply in energy-based industries to help in reduction of the greenhouse gases emission.

Keywords: Coal, Biomass chars, Synergistic effects, Microwave assisted pyrolysis.

1. Introduction
Energy demand increases over the year especially in developed and developing countries. Between 1971 and 2014, world total primary energy supply (TPES) was multiplied by almost 2.5 times. In which, oil remained the dominant fuel in 2014; nonetheless fell from 44% to 31%. Meanwhile, coal natural gas and nuclear was increased from 26–29%, 16–21%, and 1–5%, respectively. As for Asia, coal remains by far the main energy source, supplying more than half (54%) of its main energy demand compared to 29% globally in 2014 followed by oil (21%), biofuels (13%), and natural gas (8%). According to the International Energy Agency (IEA) 2016, the significant utilisation of coal in Asia is partly explained by the use of coal in power generation where in 2014, coal represented 67% of the electricity mix versus 41% globally [1].

Coal is black or dark brown solid type of fossil fuel. It is combustible, sedimentary, organic rock, which is composed mainly of carbon (C), hydrogen (H), oxygen (O), and volatile matters. As stated above, it was a dominant fuel in global power generation where it full power generation cost are below...
than oil, gas or renewables [2]. In comparison to other type of fossil fuels, coal has more than 100 years reserves globally based on 2015 production [3]. This is the main reason for coal being widely used as dominant fuel in power generation plants. However, coal is the dirtiest among fossil fuels since it emitting excessive greenhouse gases such as SOx, NOx and CO2 during its utilization for power generation. Increasing concerns on the adverse effect of the emissions arising from coal conversion technologies on the environmental and gradually depletion of the fossil fuel reserves had led to global initiatives on using renewable and other opportunity resources to meet the future energy demands in a sustainable manner. Biomass has been reported to be the most promising alternative resources that is renewable which promoted the significant reduction of greenhouse gases emission during its co-utilization with coal as well as potentially to the replacement of fossil fuels.

2. Co-utilization of coal and biomass
Co-utilization is a promising thermochemical conversion way to utilize the abundant biomass residues and wastes into cleaner energy products for reducing the consumption of the fossil fuel particularly coal. The most highlighted one is the impact on the emission of greenhouse gases i.e. SOx, NOx, CO2, volatile organic compound (VOC) and poly-aromatic hydrocarbon (PAH) which largely released from their formation during incomplete combustion. As compared to coal, there was proved that co-firing or gasification of coal and biomass results in a reduction in the emission of the latter. It is believe that the competitive char burnout contributed in the reduction of NOx, while the reduction of SO2 can be explained by sulphur fixation in the ash due to the increase in potassium and calcium from biomass. Also, biomass contains virtually has no sulphur, therefore, SO2 emissions are reduced in direct proportion to the coal replacement [4,5]. Co-firing may also reduce fuel costs, minimize waste and reduce soil and water pollution, depending upon chemical composition of the biomass used [6].

2.1. Environmental impact of co-utilization of coal and biomass
According to Tillman, 2000 [7], almost all demonstrations of co-firing shown a significant reduction on emission of SOx, NOx and CO2. In his study, he found that the NOx reduction is typically disproportionate to the co-firing percentage on a heat-input basis, and result from the fuel volatility. In addition, co-firing also provides for significant reduction in fossil CO2 emission. Demirbas, 2003 [6] stated that the benefits of co-firing include the reduction in CO2 emission from the combustion of fossil fuels, the reduction of SO2 formation through a reduction in fuel. To reduce greenhouse gas emission, the pressure is on conventional coal fired utilities to burn renewable fuels such a waste product or energy crop-derived biomass fuels, as a lowest cost option for reducing greenhouse emission. The impacts of co-firing of coal with biomass residues could substantially contribute to reduction in CO2 emission from the power generation sector. Co-firing has a larger potential contribution to CO2 reduction than the most other options for the power sector. In addition, Dayton, 2002 [8] stated biomass usually has lower sulphur content than coal. Therefore, the co-firing results in a reduction of SOx emission because of a displacement of sulphur in the fuel blend. Similar reduction also observed for NOx emission because the nitrogen content of the co-fired fuel generally lower than the nitrogen content of coal. Based on the previous studies, similar findings reported the positive reduction of greenhouse gases emission done by co-utilization of coal and biomass [9–11] as well as the most effective ways in reduction of the excessive biomass wastes i.e. oil palm biomass and municipal waste in Malaysia.

The co-utilization of coal and biomass is an interesting way to solve the environmental problems particularly on greenhouse gases emission. As a consequence from this field of study, a number of studies has been carried out to understand the combustion characteristics and its behaviour during co-utilization processes under thermogravimetric analyser (TGA). Most interestingly, there are few number of studies has been reported the existence of synergistic effect in the co-utilization of coal and biomass [12–20] while others are not [21–27].

3. Synergistic effect of co-utilization of coal and biomass char
The studies on co-utilization of biomass char and coal are relatively new field all over the world. Co-utilization of biomass char in existing coal-fired power plants may result to environmental, technical, and economical benefits. Combustion reactivity assessment by thermogravimetric analysis (TGA) technique has been reported in literature for either coal [28–30] or biomass fuels [31–33], but there
exist a few comparison studies [34,35] and even less concerning about coal-biomass char blends [36,37].

According to Kastanaki & Vamvuka 2006 [38], biomass char were generally more reactive than those of hard coal and lignite based on their finding. In addition, biomass chars were found to have porous and highly disorder structure and belong to the class of most reactive carbon materials. The porosity within the chars causes more accessible of the reactive gas to active site resulting in the very good combustion reactivity. Biomass chars production is derived from pyrolysis process where the biomass is decomposed by heating in oxygen free or oxygen-limited environment. Pyrolysis has been used commercially for the wide production including bio-gas and bio-oil. Lot of technologies also has been invented to meet the desired i.e. muffle furnace [39], fixed bed furnace [40], and drop tube furnace (DTG) [41] in effort to investigate the biomass chars characteristics. However, microwave assisted pyrolysis reaction is one of the latest technique employed for pyrolysis reaction nowadays. Its benefits will reduce processing cost, produce better product quality and reduce hazard to human, environment and enhance quality of life [42].

3.1. Synergistic effects

The unexpected finding was discovered by previous studies claimed that there was the existence of synergistic effects during co-utilization of coal and biomass chars. However, not all studies discovered the same synergistic effects output as previous studies i.e. combustion reactivity, weight lost, thermal stability, and de-volatilization. Meanwhile, some of studies claimed there was lack and even no synergistic effect reported. By far, basically, the observed synergistic effects of co-utilization of primary and secondary fuels can be divided into three categories; thermal characteristics, product characteristics and emission characteristic. Summary of previous studies on synergistic effects by co-utilization of coal and biomass chars are shown in Table 1.

Table 1. Summary of previous studies on synergistic effects by co-utilization of coal and biomass char

| Author(s) | Feedstock | Method & Conditions | Remarks |
|-----------|-----------|---------------------|---------|
| Lu, Lee, Chen, & Lin, 2013 [19] | Biomass – Torrefied C. japonica wood (char). Coal – Australian’s anthracite coal. | Thermogravimetric analysis (co-pyrolysis reaction) – Heating rate (20 °C/min), Temperature range (25–800 °C), inert air condition (N₂ influenced, 100 cc/min) | Synergies observed – weight percentage |
| Sahu, Sarkar, Chakraborty, & Adak, 2010 [43] | Biomass – Pyrolyzed Saw dust & rice husk (char). Coal – Indian’s coal | Thermogravimetric analysis (co-combustion reaction) – Heating rate (10 °C/min), Temperature range (ambient up to 750 °C), air flow rate (50 ml/min) | Synergies observed (lack) – improvement of reactivity in major combustion zone. – Blends containing less than 50% are better performing. |
| Gil et al., 2012 [44] | Biomass – Torrefied pine sawdust (char). Coal – Anthracite (AC), semianthracite (HVN), high-volatile bituminous (DAB, M6N and NZ) | Thermo-balance (oxy-fuel combustion reaction) – Heating rate (2, 3, & 5 K/min), Temperature range (room to 1273 K), air flow rate (50 NmL/min, 30 %O₂ and 70 %CO₂) | No synergies observed |
| Kastanaki & Vamvuka | Biomass – Cotton, | Thermogravimetric | Synergies observed – |
2006 [38]

| Year   | Source                  | Methodology                                                                 |
|--------|-------------------------|-----------------------------------------------------------------------------|
| 2006   | forest residues, olive  | analysis (co-combustion reaction) - Heating rate (10 °C/min), Temperature   |
|        | kernel, & wood chars.   | range (25–850 °C), air flow rate (45 mL/min)                               |
|        | Coal – Lignite          | combustion performance of the blends showed some deviation from the        |
|        |                         | expected weighted average of the constituents chars.                       |

Idris, 2014 [42]

| Year   | Source                  | Methodology                                                                 |
|--------|-------------------------|-----------------------------------------------------------------------------|
| 2014   | Biomass – EFB, PKS,     | Thermogravimetric analysis (co-combustion reaction) – Heating rate (20 °C   |
|        | PMF chars (microwave    | /min).                                                                      |
|        | irradiation)            | Synergies observed – improved coal reactivity.                               |
|        | Coal – Mukah            | – Low burnout temperature.                                                   |
|        | Balingian               |                                                                             |

4. Conclusion

It can be seen that, a lot of efforts have been done in order to understand the existence of the synergistic effects and behaviour of the combustion characteristics during co-utilization of coal and biomass/biomass char so that it can be apply beneficially in energy-based industry. By far, the works on synergistic effect during co-utilization is limited only to the investigation on thermal and product characteristics. Details works focusing on emission characteristics which might be related with the existence of the synergistic effect is yet to be explore. Therefore, further studies are very much needed to be conducted.

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