Jurnal
Teknologi

Full Paper

# MICROWAVE PYROLYSIS ASSISTED WITH CARBON BASED ABSORBENT: AN OVERVIEW

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**Article history**
Received
*28 November 2014*
Received in revised form
*01 April 2015*
Accepted
*11 May 2015*

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**Abstract**

Over recent years, there has been an explosive growth of interest in the development of novel gel-phase materials based on small molecules. It has been recognised that an effective gelator should possess functional groups that interact with each other via temporal associative forces. This process leads to the formation of supramolecular polymer-like structures, which then aggregated further hence, gelating the solvent. Supramolecular interactions between building blocks that enable gel formation include hydrogen bonds, interactions, solvatophobic effects and van der Waals forces.

*Keywords*: Microwave, pyrolysis, microwave absorber, carbon, microwave pyrolysis



## 1.0 INTRODUCTION

Microwave (MW) technology has received great attention due to its application in thermo-chemical treatment of waste material including scrap tires, biomass, sewage sludge, wheat straw and others. This technology is considered at the early stage of development since it started about twenty years ago. In comparison to direct combustion and gasification as a thermo-chemical process, pyrolysis has attracted the most attention in dealing with waste material because the process works under an inert atmosphere with the absence of oxygen. This situation provides a safe working condition. Thus, pyrolysis became the most favourable process to work under MW irradiation. Microwave pyrolysis (MWP) has gained rapid attention by researchers in dealing with waste management [1].

As compared to conventional pyrolysis (CP), the MWP is better because it can eliminate or totally reduce the heat transfer resistance found in CP process due to the MW ability that allows the penetration of waste materials and deposition of energy [2, 3]. Thus, heat is generated throughout the volume of the waste materials in which, produces uniform and rapid sample heating. Besides that, MWP gives a higher heating efficiency and heating rate resulting in a greater time saving.

Most of waste materials are poor receptors of microwave energy. This situation leads to the application of microwave absorber (MWA) during MW pyrolysis process. Without MWA, it is impossible to achieve the temperature necessary to carry out the pyrolysis. This is because MWA absorbs MW energy and transfers it to the poor MW absorbing material. Furthermore, it has been found out that the microwave absorber does influence the product yielded from the MWP process. This review paper presents the studies completed by previous researchers regarding the MWP with the presence of the MWA.

## 2.0 MICROWAVE PYROLYSIS (MWP) OF WASTE MATERIALS

Zhou et al. [4] have carried out an experimental work involving the MWP of corn and wheat straw. It was found that the maximum amount of product produced were solids, followed by liquid and finally gas phase with a ratio close to 1:1:1 due to a very small difference between them. The result gained for the microwave power consumption was 668 W with a final pyrolysis temperature of 600°C.

Huang et al. [5] has concluded that the most suitable microwave power for microwave induced pyrolysis for rice straw was 300W since higher the MW power leads to unstable reaction while an an MW power below 300W resulted in a poor reactivity. From this study, ahigh content of hydrogen gas (50.76 vol%) was produced from the MW induced pyrolysis. Besides that, Huang et al. [6] also reported that 55% hydrogen gas could be recovered from rice straw by applying the MW induced pyrolysis process.

Based on previous researchers, it was found that MWP is a good alternative for the waste treatment process. However, an additional absorber during the process would help to produce better results in terms of yield, radiation time and also cost saving.

## 3.0 APPLICATION OF CARBON BASED MATERIAL AS MW ABSORBER IN MICROWAVE PYROLYSIS (MWP)

### 3.1 Silicon Carbide (SiC)

Silicon Carbide (SiC). Borges et al. [7] have used corn stover and wood sawdust in the study of fast microwave assisted pyrolysis of biomass using microwave absorbent. 500g of SiC (act as MWA) were placed in the base of quartz reactor to form an absorbent bed layer. It was found that the application of microwave absorbent improved the heating rate of biomass, which indirectly led to fast pyrolysis condition. It was reported that a higher bio oil yield were observed with the presence of SiC absorber instead of MWP alone. The yield of bio-oil from wood sawdust was 65% while the yield of bio-oil from corn stover was 64%.

Zhao et al. [8] has designed an MW reactor in order to investigate the MW pyrolysis of wheat straw. The usage of SiC as MWA with hot air did affect the heating rate at different of MW power. By using hot air of 200°C at 900W power, the temperature reached up to 1000°C and it provided a heating rate of 60°C/min. Without the presence of hot air, the heating rate decreased as the MW power decreased. The bio-oil yield was 25wt% at 400W of MW power while at 500W and 600W of MW power, the bio-oil produced was 31wt%. Whereas, the concentrations of syngas increased when the temperature increased.

Zhang et al. [9] has carried out a study on MWP of printed circuit board. 20g of SiC was used as MWA during MWP process. MW power used was 350W, 500W and 600W with 20 minutes radiation time. The authors have concluded that this study has proved the suitable process for fast pyrolysis of printed circuit board. Liquid products contains large amount of phenolic coumpound and bisiphenol A and Glass fibre and metals could easily recovered from the solid. The liquid products can be used in waste-to-energy facilities.

### 3.2 Char

Char is one of the well-known microwave receptor during MW heating process. A study on the effects of char as a microwave absorber has been carried out by Salema and Ani [10]. In this research work, two types of oil palm biomass have been used; oil palm fiber (OPF) and oil palm shell (OPS). Seven different levels of MW power were applied; 100W, 180W 300W 450W, 600W, 850W and 1000W. The three ratios of biomass to MWA used were 1:0.25, 1:0.5, and 1:1. The maximum product yielded was obtained at the ratio of 1:0.5 for both OPF and OPS. From the results obtained, it was concluded that bio-oil yielded greatly influenced by the application of MWA. Besides that, it was also reported that application of MWA helps the MW to work at low power input.

Dominguez et al. [2] used char from pyrolysis process of sewage sludge at 1000°C temperature to produce bio-syngas with low concentration of $CO_2$ and $CH_4$. There were two types of sludges used in this study; wet and dry sewage sludges. In order to explore the possible influence of the addition of char on the pyrolysis, the experiments in the electrical furnace were also conducted in the presence of char. This study has shown that MWP can be a good alternative option for sewage sludge disposal. As compared to conventional pyrolysis, MWP produced more gas with higher concentration of syngas and less char.

Beneroso et al. [11] carried out a study on influence of the microwave absorbent and moisture content on the microwave pyrolysis of an organic municipal solid waste. This study also used char from pyrolysis process as MWA. The three absorbent-to-waste ratio used in this study were 0.2:1, 0.4:1 and 1:1. The presence of a microwave absorbent is important to carry out the pyrolysis process and from this study, it was reported that minimum absorbent-to-waste ratio of 0.2:1 has been found needed to induce pyrolysis. Lower ratio gave a higher concentration and production of syngas. Application of MWA leads to production of rich syngas ($CO + H_2$) fraction with a low microwave power.

### 3.3 Activated Carbon

Activated carbon that was used by Zubairu et al.[12] was a coconut based activated carbon (3mm particle size) in their study of the effect of stirrer speed on microwave pyrolysis process of oil palm shell biomass. 25%, 50% and 75% MWA were applied in this study. It was found that as the amount of MWA and speed of stirrer increased, bio-oil product decreased. Salema and Ani [1] also used coconut based activated carbon (1-2 mm particle size) in their research regarding the MWP of palm shell biomass assisted overhead stirrer. Results gained shows that ratio of biomass to carbon of 1:0.5 gave the highest bio-oil yield and phenol content in bio-oil at 500 °C MWP temperature.

Bu et al. [13] produced phenol and phenolics from lignocellulosic biomass by using MWP method. Activated carbon (GAC 830 PLUS) was used as an absorber. This type GAC 830 PLUS is an acid washed, high purity granular activated carbon produced by steam activation of selected grades of coal. Amount of esters produced by MWP by using activated carbon as absorber was higher as compared to MWP alone. The ratio of the MWA to biomass that produced highest concentration of phenolics (66.9 %) and phenols (38.9 %) was 3:1, at 589K MWP temperature with 8 minutes retention time.

Zhang et al. [14] have studied the characterization of nitrogen (N2) transformation during MWP process of sewage sludge [14]. In this study, activated carbon was used as MW receptors. This activated carbon (ca. 2.5g) was mixed with 24g of dried sludge (0% moisture) before microwave heating process. The main nitrogenous gas produced during MWP process were $NH_3$ and HCN with the maximum yield of $NH_3$ occurred at 700°C while HCN maximum yield occurs at 800°C pyrolysis temperature.

Zuo et al. [15] have studied the importance of microwave receptor during MWP of sewage sludge [15]. Four different microwave absorber were used in this study; graphite (G, 1mm × 1mm), columned active carbon (AC 10mm height × 3mm i.d.), pulverous silicon carbide (SiC) and char produced from another MWP process. The authors have concluded that by comparing these four microwave absorbers, activated carbon was the most suitable MWA in order to produce syngas ($H_2$ + CO) from sewage sludge.

Tian et al. [16] have designed a microwave melting reactor in order to prepare a glass-ceramic from sewage sludge. Microwave has been chosen as the heating equipment in this study. However, sewage sludge is known as a poor receptor of microwave energy. The authors have overcome this problem with a design of double-layer microwave melting reactor structure which can improve the microwave absorption of sewage sludge by filling up the absorption layer with activated carbon since it is a good microwave receptor. Glass–ceramics based on $CaO–Al_2O_3–SiO_2$ system was successfully developed in this research.

A study on dry reforming of methane has been carried out by Fidalgo et al. [17] in 2008. In this study, coconut shell based activated carbon with particle size range of 0.5mm to 2mm has been used as microwave absorber. Two sets of experiments have been done in which, one of them was run without MWA while the other one was run by using an absorber. It was reported that the most ideal temperature for this study was 700°C – 800°C. Based on the results reported, it was proven that usage of activated carbon as MWA has increased the conversion of $CH_4$ and $CO_2$ instead of the MW heating without using MWA. It was concluded that this MW-assisted dry reforming could increase the conversion of $CH_4$ and $CO_2$ up to 100% for a long period of time under suitable operating condition. Same activated carbon were used in another study of producing hydrogen ($H_2$) gas from methane ($CH_4$) by using MW pyrolysis process and also electric furnace [18]. The experiment was carried out at 800°C with 65 minutes radiation time. It was found that better results were given by the experimental that was carried out by using MW pyrolysis with activated carbon MWA as compared to experiment done by electric furnace.

### 3.4 Graphite

Graphite. Tian et al. [19] have used graphite as MWA in their study to produce bio-oil from sewage sludge. Usage of MW power below than 400W gave a maximum bio-oil yield (49.8wt.%) with 6 minute radiation time. Amount of PAHs produced also negligible with sulphur and nitrogen remained as solid at this condition. 600W – 800W of microwave power caused a reduction in bio-oil yield and increment in gas production. Bio-oil yield was 11.7wt.% while the gas yield was 51.8wt.%. Higher microwave power which were 1000W – 1200W lead to constant production of bio oil which was 7wt.% with increasing of gas yield from 56.9wt.% to the maximum of 60.2wt.% and solid yield decreased from 35.9wt.% to 32.6wt.% when maximum temperature increased from 1040°C to 1200°C. Overall, the authors have concluded that 400W of microwave power was the optimum condition for resources and energy recovery from sludge.

The 5g of graphite were homogenously mixed with 20g of urea in the study of MW pyrolysis of urea [20]. Experimental works were carried out by using classic heating and microwave heating methods. It was found that the yield produced by using MW heating method was higher as compared to yield produced by using classic heating. The selectivity of products and reaction rate also increased with the presence of graphite as MWA.

## 4.0 SUMMARY

In a nutshell, the application of carbon based material as an absorbent in microwave pyrolysis process can increase the temperature of sample material. This situation contributes to low power microwave usage which indirectly leads to energy saving. Besides that, products such as pyrolytic liquid, solid and gas yield will also be influenced by MWA. Although many studies have been carried out regarding microwave pyrolysis process with or without microwave absorbent, none of them particularly studied on the microwave pyrolysis of automotive paint sludge (APS). Thus, the authors will carry out a study on this APS since paint waste generated are rapidly increasing.

## Acknowledgement

The authors gratefully acknowledge Ministry of Education Malaysia for FRGS grant 600-RMI/FRGS5/3(90/2014), Faculty of Chemical Engineering and Universiti Teknologi MARA (UiTM).

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