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Thermal Treatment of Construction Waste: A Waste Management Approach in Malaysia

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ABSTRACT

Thermal treatment of waste materials is identified as one of the potential methods in waste management practice. The method is currently implemented in Malaysia for municipal solid waste and it is believed that thermal treatment processes are suitable too for certain types of construction waste materials. Therefore, this study aimed to identify the chemical properties of construction waste materials in terms of moisture content, volatile matter, ash content and fixed carbon through proximate analysis to determine the possible construction waste materials that can be included in thermal treatment processes. The findings of the proximate analysis showed that wood waste recorded 85.11% volatile matter with 1.28% ash content, while plastic waste recorded 90.19% volatile matter with 7.50% ash content. It was understood that the higher the percentage of volatile matter in a particular material, the longer the combustion process, hence, the higher the heating value might be generated. For that reason, wood and plastic waste from the construction industry could be a great source for thermal treatment processes and heat energy generation since both materials are highly volatile matter with relatively low ash content or residuals. The minimal residuals could preserve our landfill space and lessen the environmental impacts.

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1. Introduction

Since independence, the Malaysian construction industry has undergone numerous changes in terms of projects granted, and it is now regarded as one of the crucial industries that contribute to the expansion of the national economy. However, this industry also generates the most solid waste (Hasmori et al., 2020). The strong demand for residential and commercial growth produces numerous building wastes which causes various environmental impacts. Currently, in the Malaysian scenario, most of the construction wastes are disposed of in an open landfill in the form of mixed waste. Only metal waste is separated and recycled with a recycling rate of 95%. Metal is highly valued in the construction industry because of its scrap purchasing value and the existence of easily accessible metal waste management facilities (Maniam, 2019). Commonly, construction waste materials can be managed through several waste management methods. One of them is through thermal treatment processes. However, this method is not widely explored in the Malaysian region, particularly for construction waste, due to the minimal number of waste incinerators with emission control systems and sufficient studies on construction waste material's suitability for thermal treatment processes. Therefore, this study aimed to identify potential construction waste materials that can be included in thermal treatment processes as an effort to minimise the amount of waste materials getting disposed of in landfills while preserving natural resources and mitigating the environmental impacts. There are several facilities in association with the thermal treatment processes. Among them are incinerators, landfill disposal facilities and leachate treatment plant facilities. Landfill disposal and leachate treatment facilities are closely integrated with thermal treatment processes to ensure the safe and environmentally responsible disposal of by-products, such as fly ash and bottom ash, generated during incineration.

1.1 Incineration and Landfill Disposal Facilities in Malaysia

Incineration is considered one of the viable methods for managing solid waste, particularly in countries facing challenges such as limited landfill space, high waste generation rates and increasing environmental concerns. The process involves the controlled combustion of waste materials at high temperatures, typically between 850°C and 1,100°C, to convert them into ash, flue gas and heat energy. Modern incineration facilities often incorporate waste-to-energy (WTE) technology, where the heat produced during combustion is captured and used to generate steam, which drives turbines to produce electricity (Turconi et al., 2011).

As of recent years, Malaysia operates four small-scale incinerators for municipal solid waste management, located in Kedah (1), Perak (1) and Pahang (2) (SW Corporation, 2019). Beyond these small facilities, the government has shown increasing interest in developing large-scale WTE incineration plants, especially in major urban centers like Kuala Lumpur. The proposed Taman Beringin WTE Plant, for instance, is designed to process approximately 1,200 tonnes of waste per day, significantly reducing the amount of waste directed to landfills while simultaneously generating renewable energy (Taib et al., 2017). However, effective emission control systems are crucial to ensure that the incineration process does not negatively impact air quality or public health (Khan et al., 2021).

One of the main advantages of incineration is its ability to reduce the volume of waste by up to 90%, significantly extending the lifespan of existing landfill sites. Moreover, incineration contributes to Malaysia's energy mix, aligning with national policies that promote renewable energy and circular economy practices (Sulaiman et al., 2007). Despite its benefits, incineration in Malaysia faces several challenges. High capital investment and operational costs are significant barriers to the widespread adoption of advanced incineration technology. Public opposition is also a persistent issue, with concerns over air pollution, the release of hazardous substances such as dioxins, furans and particulate matter and the potential health impacts on nearby communities. As a result, any expansion of incineration facilities requires strict regulatory oversight, continuous emissions monitoring and transparent public engagement to address environmental and social concerns (Sulaiman et al., 2007). To ensure the sustainability and efficiency of incineration, proper waste segregation at the source is essential. Waste with high moisture or organic content reduces combustion efficiency and increases the risk of incomplete burning and pollutant emissions. Therefore, public education, source separation programs and technological upgrades are necessary to maximize the benefits of incineration as part of Malaysia's integrated solid waste management strategy.

In terms of landfill operation, solid waste acceptance into the landfill is controlled according to the types of waste that are brought by the armroll trucks, open lorries and compactors. The landfill itself is divided into several types, such as sanitary, secured and inert landfills, based on the types of waste that are generated in Malaysia (Shadi et al., 2020). In sanitary and secured landfill, leachate formation and collection are often a concern to avoid contamination of the soil and groundwater supply (Siddique et al., 2022). This leachate collection facility is not applicable for inert landfills since an inert landfill is known as an open landfill system that permits the disposal of non-hazardous and non-leachable waste materials. At the moment, construction waste as a part of solid waste generation in Malaysia is being allowed for disposal at inert landfills located throughout the Klang Valley. There are a few landfills in operation around the Klang Valley, such as Sungai Kertas inert landfill, Kuang inert landfill, Dengkil inert landfill, Jeram sanitary landfill and Sabak Bernam sanitary landfill, with a total solid waste acceptance of about 8,000 tonnes daily (SW Corporation, 2019).

1.2 Leachate Treatment Plant Facilities in Malaysia

The level of leachate formation, particularly in a landfill, is based on several factors such as changes in climate, types of waste material, presence of heavy compounds in disposed waste materials, level of humidity and presence of oxygen (Ashraf et al., 2019). The standard pH value of leachate is between pH 6 and pH 9. It is also added that this liquid-formed leachate contained some threatening compounds such as copper, chromium, nickel, lead, sulphate and arsenic, particularly from the construction industry, which might pollute the environment (Chin et al., 2020; Manoharan et al., 2021; Sealey et al., 2001). To overcome this issue, the government (some of the facilities were constructed by private licenced operators) has constructed a leachate treatment plant facility to collect the formed leachate through a specific channel and treat it before the leachate is released into the environment. However, the leachate collection facilities are only widely implemented in secured and sanitary landfills, whereby these landfills have proven records in accepting hazardous solid waste materials. There are possibilities for inert landfill, to be included with certain amounts of waste materials that are made up of inorganic compounds during the manufacturing stages. These inorganic compounds are capable of impacting the environment similarly to the waste materials that are disposed of in sanitary and secured landfills. For example, construction waste in Malaysia is acceptable in the inert landfill for open waste disposal (Mah et al., 2018). It was studied that waste materials from the construction site that were brought into the landfill by the armroll truck possibly contained some inorganic compounds that are leachable and impactful to the environment (Molla et al., 2021).

2. Proximate Analysis

Proximate analysis, in general, focuses on the chemical composition of a material in terms of moisture content, volatile matter, ash content and fixed carbon. The output of the proximate analysis is used for assessing the quality of the material for thermal treatment and as a substitution for non-renewable sources (Jauhara et al., 2018). The construction waste samples for the proximate analysis in this study were collected from a construction site located in Klang Valley, Malaysia. Among the collected waste samples were concrete, brick and block, plastic, wood, soil and aggregate and mechanical and electrical (PVC pipes and electrical fixtures). The collected waste samples were tested through the proximate analysis at the Malaysian Nuclear Agency, Bangi. In determining the percentage of moisture content, volatile matter, ash content and fixed carbon in a material, several formulas are associated (Kwaghger et al. (2017). The formulas can be referred to in the section 2.1.4 below.

2.1 Materials and Methods

2.1.1 Sample Preparation

The sample preparation was carried out in accordance with the American Society for Testing and Materials (ASTM) standards, specifically for determining moisture content (ASTM E949-88), volatile matter (ASTM E897-88), ash content (ASTM E830-87) and fixed carbon (ASTM D 3172-07a) (Darmawan et al., 2021). Waste samples collected from construction sites were first crushed into smaller pieces using a grinder, as shown in Figure 1, to achieve the preferred powder or small solid form for testing. According to ASTM requirements, each sample needed to weigh at least three grams. Crushing the samples made it easier to adjust the weight compared to using larger, solid pieces. The grinder was cleaned with an air compressor after each use to remove any leftover material from the previous sample and to prevent it from mixing with the new batch. This process was repeated for all waste samples to ensure they were adequately prepared for testing. Upon sample crushing, the required number of crucibles and lids were arranged in the sample tray. The crucibles and lids were washed thoroughly to avoid contamination from the previous samples or third-party agents. Each waste sample was represented with three crucibles and lids. Three sets of crucibles were used instead of one to obtain a more accurate result, which will be divided by three to obtain an average value. The crucibles and lids were then weighed and the values were recorded. After recording the weight of the crucible and lid, the crucible was placed on the weighing machine and added with +/- 3.00 grams of crushed waste sample.

2.1.2 Moisture Content

After the sample preparation process, the crucibles were arranged on the sample tray and brought to the Memmert thermal oven. The Memmert thermal oven was pre-heated at 107°C according to ASTM standards for identifying the moisture content of prepared samples.

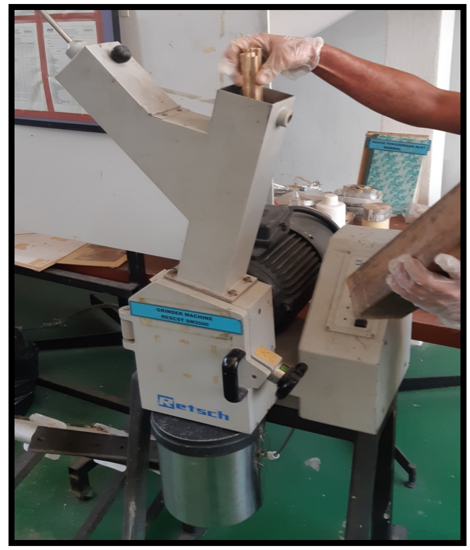

Figure 1 Inserting a waste sample into the grinder machine model SM2000

At 107°C, the samples were placed into the oven (Figure 2) and the timer was set for one hour. In identifying the moisture content, the crucibles were not covered with lids and the temperature was set constant at 107°C for one hour. After one hour, the Memmert thermal oven was switched off and the sample tray was taken out for the cooling process. The samples were cooled down for 15 minutes at room temperature before being sent to the weighing area.

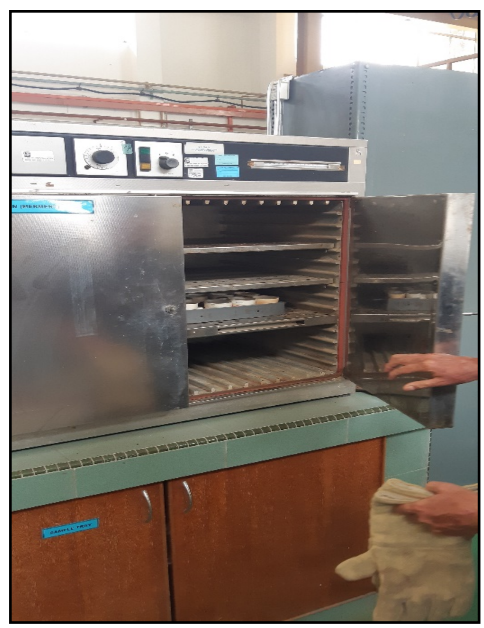

Figure 2 The Memmert thermal oven with waste samples

A desiccator is commonly used in thermal studies to restrict the influence of external moisture on the oven-heated sample during the cooling down process. However, the desiccator available during the laboratory session was small and only fit for one crucible at a time. Therefore, the samples were cooled down at open room temperature. After 15 minutes cooled down, the samples and crucibles were weighed and the readings were recorded to calculate the percentage of moisture content.

2.1.3 Volatile Matter

The procedure was then continued to the next stage to identify the percentage of volatile matter. The same crucibles with balance of waste samples from the moisture content analysis were used in this stage. However, in this stage, the crucibles were covered with lids before being placed into the box furnace for 10 min. The box furnace was pre-heated at 950°C before the placement of the sample tray for the analysis. Upon reaching 950°C, the box furnace cover was lifted and the sample tray was immediately placed (Figure 3). However, the timer was not set since opening and closing of the box furnace cover affected the internal accumulated temperature with the external room temperature. Therefore, the timer was set once the box furnace temperature rose to 950°C. After 10 min, the sample tray was retrieved from the box furnace using a sample trolley and cooled down for 15 min at room temperature before being weighed. The weight of samples, crucibles and lids were recorded to calculate the percentage of volatile matter.

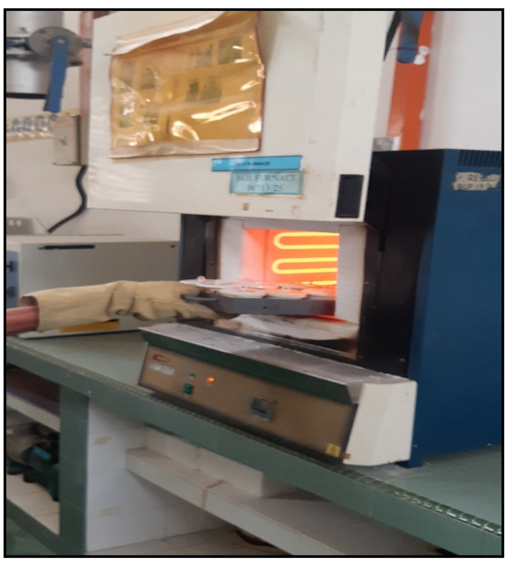

Figure 3 Box furnace with sample tray

2.1.4 Ash Content and Fixed Carbon

Then, the process continued with the last stage in identifying the percentage of ash content. In this stage, the process was almost the same as volatile matter but the box furnace was pre-heated at 750°C. The crucibles in the sample tray were exposed without being covered by lids. The timer was set for one hour after the temperature rose back to 750°C once the sample tray was located in the box furnace. After one hour, the box furnace was switched off and the sample tray was retrieved using the sample trolley. Then, the sample tray was cooled down for 15 min and the samples and crucibles were weighed and recorded. Using the formulas below (1)-(3), the recorded values were utilised to determine the percentage of moisture content, volatile matter and ash content. Obtained percentage of moisture content, volatile matter and ash content was applied to the fixed carbon formula (4) to complete the proximate analysis.

$$M = \frac{(C + S\ \text{after heating}) - (C)}{(C + S\ \text{before heating}) - (C)} \times 100 \qquad (1)$$

$$V = \frac{(C + L + S\ \text{before heating}) - (C + L + S\ \text{after heating})}{(C + L + S\ \text{before heating}) - (C + L)} \times 100 \qquad (2)$$

$$A = \frac{(C + S\ \text{after heating}) - (C)}{(C + S\ \text{before heating}) - (C)} \times 100 \qquad (3)$$

$$F = 100 - M - V - A \qquad (4)$$

Where;
C = Weight of Crucible (g)
S = Weight of Sample (g)
L = Weight of Lid (g)
F = Percentage of Fixed Carbon (%)
M = Percentage of Mositure Content (%)
V = Percentage of Volatile Matter (%)
A = Percentage of Ash Content (%)

3. Result and Discussion

Table 1 shows the outcome of the proximate analysis. The moisture content of the wood waste was found to be the highest (8.05%) in Table 1, with other building waste components in the same category ranging between 0.72% and 1.89%. About volatile matter, plastic had the highest reading (90.19%), followed by wood (85.11%), concrete (8.09%), brick and block (5.23%), mechanical and electrical (56.02%) and soil and aggregate (4.50%). In terms of ash content, the top five waste components were brick and block (91.60%), soil and aggregate (88.74%), concrete (87.46%), mechanical and electrical (36.43%), plastic (7.50%) and wood (1.28%), while for the fixed carbon, the highest value was recorded by mechanical and electrical (6.89%), followed by wood (5.56%) and soil and aggregate (5.01%). The rest of the waste components were in between 1.60% and 3.51%.

Fom the results, the main focus was given to the ash content and volatile matter of the waste materials in determining the suitability of materials for thermal treatment processes. When a waste material possesses high ash content, it might lead to abnormal combustion and environmental pollution. The abnormal combustion significantly reduces the calorific value generation, which causes the material not to be suitable for thermal treatment processes.

Table 1 Outcome of the Proximate Analysis

Component of Waste	Elements			
	Moisture Content (%)	Volatile Matter (%)	Ash (%)	Fixed Carbon (%)
Concrete	0.94	8.09	87.46	3.51
Brick and Block	0.99	5.23	91.60	2.16
Plastic	0.72	90.19	7.50	1.60
Wood	8.05	85.11	1.28	5.56
Soil and Aggregate	1.89	4.50	88.74	5.01
Mechanical and Electrical	0.72	56.02	36.43	6.89

In terms of volatile matter, volatiles have a major influence on the ignition and combustion of waste material in the thermal treatment facility. When a material shows a high concentration of volatile matter, it is generally made up of more hydrocarbons that influence the duration of the combustion process. The longer the combustion process of waste material, the higher the calorific value it might generate in waste to heat energy conversion (Zhang et al., 2020). Therefore, Bajracharya et al. (2016) suggested that rather than landfilling a waste material, heat energy extraction from it can be useful for various purposes such as electricity generation and substitution for high fuel consumption industries. Hence, from the results in Table 1, it can be concluded that plastic and wood waste from the construction industry are suitable for thermal treatment. This is because they have a very high percentage of volatile matter and a very low percentage of ash content in terms of their chemical characteristics. The analysis conducted by Saad and Williams (2016) on mixed plastic waste from the construction industry also proved the capability of plastic waste for thermal treatment, whereby the material recorded 99.02% of volatile matters, while for wood waste, Zevenhoven (2001) stated 80% of volatile matters with minimal amount of ash content. The ash content should be disposed of appropriately as they are made up of bottom ash and fly ash which contain hazardous and leachable elements. The bottom ash should be deposited in sanitary landfills while fly ash in secured landfill facilities with a leachate collection system. Bottom ash is typically generated in the combustion chamber and is relatively easy to collect for disposal. In contrast, fly ash is carried along with the flue gas and requires a bag filter system for effective collection. To manage hazardous gases that pass through the system, a semi-dry spray neutraliser and activated carbon adsorbent are employed. This combination is highly effective in adsorbing toxic gases and heavy metals, ensuring that only clean air is released into the environment. Additionally, the system requires periodic water cleaning, with the resulting wastewater directed to a leachate treatment plant for proper treatment and disposal (Hamidinasab & Nabavi-Pelesaraei, 2025).

4. Conclusion

Waste management practice through the integration of various methods might effectively recover the waste materials in a vast amount rather than focusing on a single landfilling method as currently practised by the Malaysian construction industry for most of the construction wastes except for metal waste. Even though landfilling is a part of the waste management system in Malaysia, it should be considered as the final option since landfill method possesses disadvantages to nature in terms of environmental degradation and depletion of natural resources. The addition of thermal treatment method in the waste management practice, apart from reuse and recycling methods, could reduce a portion of waste materials from getting disposed of in landfills. Moreover, with further study, the generated heat energy from the thermal treatment processes could be a great source of electricity generation through steam production as renewable energy. The Malaysian government could consider the thermal treatment method for construction waste by providing sufficient facilities such as incinerators and emission control systems since it is proven that wood waste and plastic waste from the construction industry are well suited for waste combustion.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

Author Contribution

E.M. and N.O. contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

Data Availability

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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