

WASTE TO ENERGY: INVESTIGATION OF CHARACTERISTICS AND THERMAL BEHAVIORS OF WASTES

Nguyen Hong Nam*, Khuong Duy Anh, Le Gia Thanh Truc
University of Science and Technology of Hanoi - VAST

ABSTRACT

Wastes from agro-industrial activities as well as municipal wastes can become a potential source for advanced energy conversion technologies. Due to differences in the nature of waste sources, existing knowledge regarding the characteristics and thermal behaviors of wastes is still very limited. This study aimed to investigate the characteristics and thermal behaviors of three types of waste: bagasse, textile and plastic wastes. Results showed that these wastes had a high potential for use in energy conversion technologies. Plastic waste had the highest value for volatile matter and calorific value. Meanwhile, bagasse and textile wastes had a very low ash content, suitable for thermal processes. TGA-DTG analysis showed that the thermal decomposition of bagasse and textile wastes were relatively similar, expressed in three stages: dehydration, volatile matter decomposition, and char oxidation. However, for plastic waste, the thermal behavior was primarily composed of decomposition of volatile matter and polyene chains. These results provide important information for the simulation and design of advanced energy systems using diverse sources of wastes.

Keywords: Wastes; bagasse; textile; plastic; proximate analysis; thermogravimetric analysis.

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RÁC THẢI THÀNH NĂNG LƯỢNG: NGHIÊN CỨU ĐẶC TÍNH VÀ HÀNH VI NHIỆT CỦA RÁC THẢI

Nguyễn Hồng Nam*, Khuong Duy Anh, Lê Gia Thanh TrúC
Trường Đại học Khoa học và Công nghệ Hà Nội - Viện Hàn Lâm Khoa học và Công nghệ Việt Nam

TÓM TẮT

Rác thải từ các hoạt động nông – công nghiệp và rác thải sinh hoạt có thể trở thành nguồn nguyên liệu tiềm năng cho các công nghệ chuyển hóa năng lượng tiên tiến. Do sự khác biệt lớn về bản chất của các nguồn thải, hiểu biết hiện có về đặc tính và hành vi nhiệt của rác thải vẫn còn rất hạn chế. Nghiên cứu hướng tới mục tiêu xác định các đặc tính và hành vi nhiệt của ba loại rác thải: bã mía, vải vụn và nhựa. Kết quả phân tích cho thấy các rác thải này có tiềm năng cao để sử dụng cho các công nghệ chuyển đổi năng lượng. Nhựa có giá trị cao nhất về hàm lượng chất bốc và nhiệt trị. Trong khi đó, bã mía và vải vụn có hàm lượng tro rất ít, phù hợp cho các quá trình nhiệt hóa. Phân tích nhiệt TGA-DTG cho thấy sự phân hủy nhiệt của bã mía và vải vụn tương đối giống nhau, thể hiện qua ba giai đoạn: giai đoạn khử hơi nước, giai đoạn phân hủy hàm lượng chất bốc và giai đoạn oxi hóa than. Tuy nhiên, đối với nhựa, sự phân hủy nhiệt được cấu thành chủ yếu từ sự phân hủy chất bốc và các chuỗi polyene. Các kết quả này mang lại những thông tin quan trọng cho việc mô phỏng và thiết kế các hệ thống chuyển hóa năng lượng tiên tiến sử dụng các nguồn rác thải đa dạng.

Từ khóa: Rác thải; bã mía; vải vụn; nhựa; phân tích đặc tính; phân tích nhiệt vĩ mô.

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* Corresponding author. Email: Nguyen-hong.nam@usth.edu.vn

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1. Introduction

Agricultural, industrial and municipal activities in Vietnam currently generate large amounts of wastes. According to the Vietnam Environment Administration, the municipal solid wastes increase between 10 and 16% annually [1]. The current total amount of solid wastes in Vietnam is more than 30 million tons, of which only 10% is collected for reuse or recycling. The huge quantities of wastes that are not properly treated are causing many hazard problems to the environment [1]. Therefore, making use of these wastes as a source of feedstock for various advanced energy conversion technologies, such as gasification or co-combustion, is one of the first priorities for sustainable development of the country.

Two principal energy conversion lines are being applied: biochemical conversion processes, e.g. digestion and fermentation technologies, and thermochemical conversion, e.g. combustion, pyrolysis, and gasification technologies. Amongst these two lines, thermochemical conversion technologies are much more widely used, considering their flexibility for various purposes, such as heat and power production, or fuel production, etc.

In order to design/select the appropriate thermal conversion technology, a deep understanding of the characteristics of wastes and their thermal behaviors are crucial [2]. To determine the characteristics of wastes for energy purposes, the proximate analysis was proven to be the most suitable technique [3]. Proximate analysis is used for investigating the distribution of the waste in moisture, volatile matter, fixed carbon and ash content when it is heated under specified conditions. Meanwhile, the thermal behaviors determined by the thermogravimetric analysis – differential thermal analysis (TGA-DTG) can give valuable information about thermal

stability and decomposition based on the mass loss, as well as the rate of reactivity [4].

Numerous studies of characteristics and thermal behaviors have been conducted on various types of waste, for instance, pyrolysis and gasification of corn wastes [5], woody biomass, oat straw, dried citrus waste [6] as well as food waste [7]; co-pyrolysis of raw/terrified wood and coal blends [8]; pyrolysis of paper waste [9], [10]; combustion on wood pellet and sawdust [11] and municipal waste [12], [13]; gasification of rice husk [14], bagasse [15] and municipal solid waste [16]. Nevertheless, due to the wide variation in the nature of different waste sources, the existing data regarding municipal, agricultural and industrial wastes is still very small and fragmented. Moreover, as wastes are highly heterogeneous, the determination of thermal behaviors using a classic TGA-DTG technique - in which only a few milligrams of sample are used for measurement – cannot give a precise result.

The aim of this study, thus, was to determine the characteristics and the thermal behaviors of three types of waste: bagasse, textile, and plastic, which respectively represent agricultural, industrial and municipal wastes. A macro-thermogravimetric system, in which a much more important amount of sample could be measured, was used to take into account the heterogeneity of the wastes studied.

2. Material and method

2.1. Sample preparation

Bagasse and textile wastes were collected from the factories, and plastics were collected from the landfill in the Northeast regions of Vietnam. All those wastes have been pre-treated to ensure the reliability of the experimental results. Samples were cut into pieces with the size below 0.5 mm (Figure 1). Distilled water was used to clean impurities from the materials. Samples were stored into closed boxes for further experiments.



Figure 1. Bagasse, textile and plastic wastes

2.2. Experimental setup

The experiments were carried out at the University of Science and Technology of Hanoi. Each step of the experimental procedure (Figure 2) was explained in details in sections below.

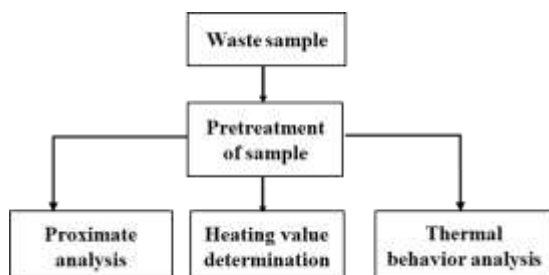


Figure 2. Experimental procedure

2.2.1. Proximate analysis

The proximate analysis of the wastes was carried out in the oven Memmert UNB 300 (Figure 3) for moisture content determination and the Furnace Nabertherm LT 24/12/P330 (Figure 4) for volatile, ash and fixed-carbon content determination.

In the oven Memmert UNB 300, the air gets warmed in a preheated chamber by both convection and fan-circulation ovens, enters the chamber through ventilation slots. The oven fan provides a larger amount of air throughput and a more intensive horizontal forced circulation compared to natural convection. The air valve is in charge of controlling the rate of air change (Figure 3).

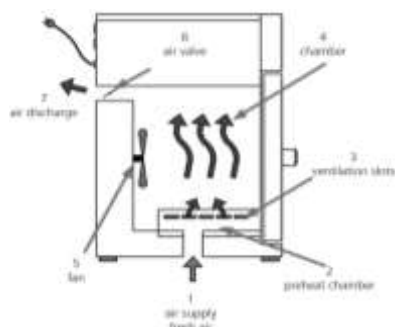


Figure 3. Memmert UNB 300

Meanwhile, the furnace Nabertherm LT 24/12/P330 is embedded with ceramic muffle heated from four sides, which provides high resistance to aggressive gases and vapors. The chamber is equipped with an over-temperature limiter to protect the furnace and load. The gas inlet system is mounted on the furnace for reactive gases with a shut-off valve and flow meter with a regulator valve and a pipe. The exhausted pipe is connected to the chimney of the furnace (Figure 4).

The moisture content (M) is calculated as follows:

$$M = \frac{m_2 - m_3}{m_2 - m_1} * 100\% \quad (1)$$

where m_1 , m_2 , m_3 are respectively the mass of the empty container, the mass of the container with the sample before analysis, the mass of the container with the sample after analysis.

For determining the volatile matter, the muffle furnace was heated up from ambient temperature to 900 °C, at which the sample was kept for 7 minutes. The volatile matter (V) is then given by:

$$V = \left(\frac{m_2 - m_3}{m_2 - m_1} * 100\% - M \right) * \frac{100}{100 - M} \quad (2)$$

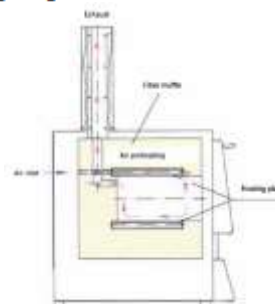


Figure 4. Furnace- Nabertherm L24/12/P330

The ash content is determined when the sample was heated from ambient temperature to 550°C and until getting a constant mass. The ash content (A) is then given by:

$$A = \frac{m_3 - m_1}{m_2 - m_1} * 100 * \frac{100}{100 - M} \quad (3)$$

The fixed-carbon content (FC) is determined by difference:

$$FC = 100 - M - V - A \quad (4)$$

2.2.2. Heating value determination

The higher heating value was evaluated by the Parr 6200 Calorimeter (Figure 5).

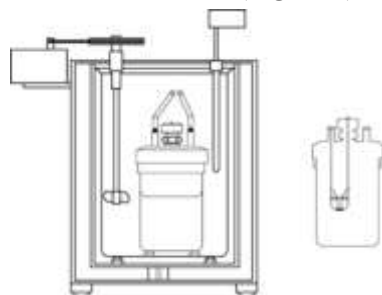


Figure 5. Parr 6200 Calorimeter

An electronic thermometer, with a specially designed thermistor sensor sealed in a stainless-steel probe, measures precisely the temperature. The thermal jacket is provided by a circulating water system driven by a high capacity pump, which keeps a continuous forced flow around the sides and bottom of the bucket chamber. Its temperature is maintained for isoperibol operation. About 0.1 mg of sample is prepared for the Parr 1108P Oxygen Bomb. The bomb furnished with the calorimeter will safely burn samples, liberating up to 8000 calories per charge, using automatic oxygen charging pressures up to 40 atm.

2.2.3. Thermal behaviors analysis

The TGA-DTG analysis for the determination of thermal behaviors of wastes was done in a new macro-thermogravimetric reactor (Figure 6). The reactor is composed of a ceramic tube

with 111 cm length and 7.5 cm internal diameter. It is placed in an electrical furnace having three independently controlled heating zones to keep the uniform temperature.

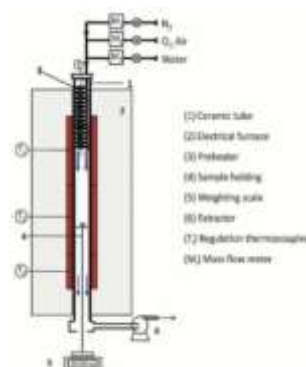


Figure 6. Macro-thermogravimetric reactor

A mixture of high purity N₂ and O₂, controlled by mass flowmeters was used as the reaction environment. The experiment was carried out under atmospheric conditions. The reactor was heated from the ambient temperature to 800°C at a heating rate of 10 °Cmin⁻¹. 700mg sample was put on the ceramic stick and brought up to the desired place inside the reactor. Three measurements on each sample were carried out and the average value was calculated. The acceptable precision is 0.1%.

3. Results and discussion

3.1. Proximate analysis

Results of the proximate analysis are given in Table 1.

Table 1. Proximate analysis of bagasse, textile, and plastic wastes

Sample	Moisture (% wt)	Proximate analysis (% wt, db)			HHV (MJkg ⁻¹ , db)
		V	A	FC	
Bagasse	9.34	84.08	0.70	15.22	16.45
Textile	5.21	89.19	1.90	8.91	20.41
Plastic	0.00	94.06	5.94	0.00	35.28

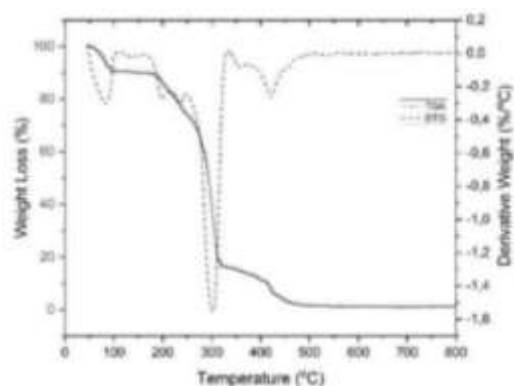
V: Volatile matter, A: Ash content, FC: Fixed-carbon content, HHV: Higher heating value, db: dry basis

It can be seen that the ash content of bagasse has the lowest value (0.70%), which is nearly 3 times lower than that of textile (1.90%) and 8 times lower than that of plastic (5.94%). The presence of low ash content in the feedstock is appropriate for thermochemical conversion processes because ash content may act as a heat sink, which reduces the process efficiency as well as sensible heat available for the reactions [17]. All three materials have high volatile content, ranging from 84.08 to 91.90%, which contributes to the material's ease of burning. The heating value of bagasse, textile, and plastic wastes is respectively 16.45, 20.45 and 35.28 MJkg⁻¹,

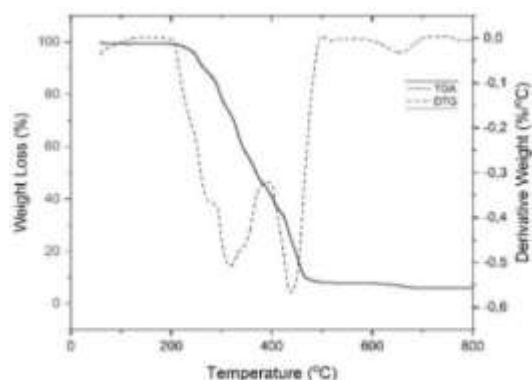
which is directly proportional to the volatile matter. Regarding the fixed carbon, there were high gaps between these values of three samples, with the range from 0% for plastic waste to 15.22% for bagasse.

3.2. Thermal behavior analysis

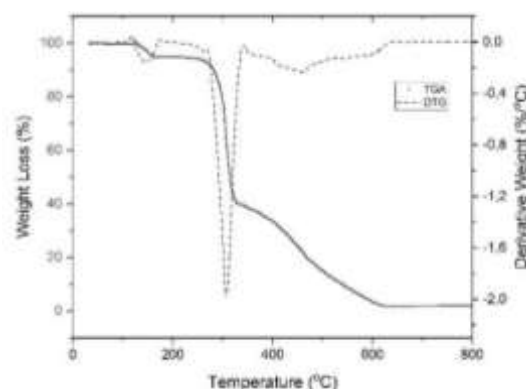
The TGA-DTG curves of three wastes were presented in Figure 6. The first endotherm peak in bagasse and textile wastes corresponded to the removal of moisture and loss of light volatile compounds below 200 °C. For plastic wastes, this phenomenon was not observed. The decomposition of plastic occurred at a temperature range of 202 – 500 °C, while that of bagasse and textile wastes occurred at 180 – 470 °C, and 200 – 600 °C, respectively. The second endotherm peak temperature of bagasse happened at 301 °C, followed by that of textile (307 °C) and plastic (317 °C) wastes, with decomposition intensities of 1.5%/°C, 2.0%/°C, and 0.5%/°C respectively.



(a) Bagasse waste



(b) Plastic waste



(c) Textile waste

Figure 6. TGA-DTG of different wastes

This can be attributed to the decomposition of hemicellulose, cellulose and lignin, leading to the formation of char. These components frequently degrade at a very similar temperature ranges, therefore, they have the overlapping endotherms [18]. For plastic waste, this endotherm peak was attributed to the elimination of HCl molecules leaving behind longer polyene chains. For textile waste, this may be related to the formation of volatile products such as ketones, aldehydes or ethers from the char crosslinking reactions and the cellulose, hemicellulose, lignin disintegration.

The third thermal decomposition peak of bagasse happened at 420 °C, followed by that of textile (453 °C) and plastic (437 °C) wastes, with decomposition intensities of 0.3%/°C, 0.2%/°C, and 0.55%/°C respectively. For bagasse waste, this peak corresponded to the char oxidation process, where the carbon amount in the char reacted with oxygen, leaving at the end a small amount of ash content. For plastic waste, this corresponded to the thermal degradation of the polyene sequences occurred during this stage yielding volatile aromatic and aliphatic compounds. For textile waste, this peak is due to char decomposition which is formed amid the stage of a fast weight reduction [19]. The TGA-DTG profiles of these wastes were summarized in Table 2.

Table 2. DTG-TGA profile

Waste	First endotherm		Second endotherm		Third endotherm	
	PT (°C)	DI (%/°C)	PT (°C)	DI (%/°C)	PT (°C)	DI (%/°C)
Bagasse	45.55	7.43	46.87	0.09	1.96	0.77
Textile	68.78	4.56	26.17	0.45	0.80	0.29
Plastic	67.59	4.65	27.27	0.45	0.83	0.30

PT: Peak temperature, DI: Decomposition intensity

4. Conclusion

This study aims to investigate the characteristics and thermal behaviors of three types of waste: bagasse, textile and plastic wastes. The results contribute directly to the design and simulation of advanced technology converting waste to energy, such as pyrolysis or gasification, with the objective of limiting environmental issues.

The pyrolysis properties of three types of waste: bagasse, plastic, and textile have been investigated. All three types of waste have high potential for energy conversion technologies based on their heating values and proximate results. Plastic waste had the highest value of volatile matter content and heating value. Meanwhile, bagasse had a small amount of ash which is suitable for thermochemical processes. The TGA-DTG analysis showed that the degradation of bagasse and textile had a relatively similar trend. The thermal degradation of those two wastes was demonstrated by a three-stage reaction: dehydration stage, volatile decomposition stage and char oxidation stage. Meanwhile, for plastic waste, the dehydration stage was not performed and the final stage was the consequence of the polyene chains decomposition. The results of thermal behavior and characteristics of bagasse, textile and plastic wastes can be used to help engineers in the design of thermal systems using these wastes.

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