



## Research article

# Turning trash into treasure: Torrefaction of mixed waste for improved fuel properties. A case study of metropolitan city

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## ABSTRACT

Solid waste management is one of the biggest challenges of the current era. The combustible fractions in the waste stream turn out to be a good energy source if converted into refuse-derived fuel. Researchers worldwide are successfully converting it into fuel. However, certain challenges are associated with its application in gasifiers, boilers, etc. to co-fire it with coal. These include high moisture content, low calorific value, and difficulty to transport and store. The present study proposed torrefaction as a pretreatment of the waste by heating it in the range of 200 °C–300 °C in the absence of oxygen at atmospheric pressure. The combustible fraction from the waste stream consisting of wood, textile, paper, carton, and plastics termed as mixed waste was collected and torrefied at 225 °C, 250 °C, 275 °C, and 300 °C for 15 and 30 min each. It was observed that the mass yield and energy yield decreased to 45% and 62.96% respectively, but the energy yield tended to increase by the ratio of 1.39. Proximate analysis showed that the moisture content and volatile matter decreased for torrefied samples, whereas the ash content and fixed carbon content increased. Similarly, the elemental analysis revealed that the carbon content increased around 23% compared to raw samples with torrefaction contrary to hydrogen and oxygen, which decreased. Moreover, the higher heating value (HHV) of the torrefied samples increased around 1.3 times as compared to the raw sample. This pretreatment can serve as an effective solution to the current challenges and enhance refuse-derived fuel's fuel properties.

## 1. Introduction

As the population undergoes exponential growth, the quantity of generated municipal solid waste also escalates. It puts an immense

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burden on the environment and sustainable development [1]. Currently, developing countries are disposing of a massive quantity of their waste in landfills, contaminating the soil, atmosphere, and nearby water bodies, including underground water resources [2]. The

### Nomenclature

C	Carbon
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
H	Hydrogen
H <sub>2</sub> O	Water
HHV <sub>r</sub>	Higher heating value of raw sample
HHV <sub>t</sub>	Higher heating value of torrefied sample
ISWM	Integrated solid waste management
M <sub>r</sub>	Mass of raw sample
M <sub>t</sub>	Mass of torrefied sample
MJ/kg	Megajoule per kilogram
N	Nitrogen
OH	Hydroxyl
RDF	Refuse derived fuel
S	Sulfur
TGA	Thermogravimetric Analysis

integrated solid waste management (ISWM) approach intends to devise a waste management system that optimizes the recovery of all the material as well as energy from the entire waste stream. It incorporates diverse outlooks aligned with the goals of sustainable development in terms of environment enhancement, economic viewpoint, and societal norms to eradicate the bleak impacts of improper solid waste management systems and designs [2,3]. The generated waste comprises of a large quantity of combustible fractions, including plastics, biomass, paper, carton, textile etc. The utilization of combustible waste in energy production is becoming popular among developing countries [3]. It positively impacts the environment in terms of less space requirement for landfills with extending the lifetime of the landfill sites [4]. It also helps in culminating the energy crisis of the developing countries by reducing their dependency on conventional energy sources. Different types of feedstocks have been used to determine the system efficiency [5]. The mixed municipal waste originating from diverse sources i.e., residential dwellings, commercial and industrial localities comprise multiple categories like fossil-based organic material (plastic, petroleum products, etc.), biogenic materials (wood, paper, garden waste, etc.), putrescible organic waste (food waste, animal waste, etc.) and a combustible fraction (textile waste, food packaging, etc.). Each of the categories has its significance in terms of waste-to-energy conversion scenario [4,5]. The use of municipal solid waste is also employed in the form of refuse derived fuel (RDF) to overcome the energy demand, which is the fuel made up of a combustible fraction of municipal solid waste. The respective waste is segregated from other categories of waste, then it undergoes a shredding process, after that it is compacted or densified and then it is employed in different kind of furnaces and boilers as the fuel to fulfill energy demands [5]. The process of RDF formation and its densification breeds in the foreseeable characteristics of the fuel with enhanced calorific value which makes it more desirable for the researchers and policy makers as compared to the biomass-based fuel [4]. It can be produced by combining diverse waste forms to vary composition and so the high energy yielding group can be employed based on the local waste availability it would include cow dung, rice husk, different forms of plastics, etc. [2,3]. Different ratios of waste are combined particularly the combustible fraction as per need. Although it poses a viable solution to the waste management sector in terms of energy production, but certain challenges are associated with its large-scale use [6]. These include high hydrogen gas yield in the syngas produced in the gasifiers and low calorific value of the feedstock. The low fuel quality due to high moisture content and volatile matter content also creates a barrier to using it as a direct feedstock or co-firing it with coal in different gasifiers, boilers, or furnaces [7]. Moreover, the high moisture content makes it hygroscopic which compel high energy consumption for drying purpose impacting overall systems energy efficiency. Furthermore, due to high moisture content, the bulk density of the waste tends to lower in turn lowering the quality of fuel and its energy content. Moreover, the high carbon/oxygen ratio accompanied by these reasons makes it a less viable resource by impacting the calorific value. High carbon content is desired for good quality fuel, but municipal solid waste has a high carbon to oxygen (C/O) ratio and comparatively low carbon content resulting in low calorific value [6,7]. Torrefaction is a pretreatment technique used to upgrade the fuel properties of the waste which can be further used for energy production and as the feedstock to direct fire or co-fire with coal [8]. It is also known as high-temperature drying and low-temperature pyrolysis due to the conditions required to run the methodology. It is typically carried out at temperature range of about 200 °C–300 °C in the absence of oxygen at atmospheric pressure for residence time ranging from 5 min to 60 min [8]. It usually enhances the calorific value and the carbon content of the raw waste and transforms it into fine-quality fuel [9,10]. The torrefaction technique is generally applied on biomass till date different feedstocks and their composites were investigated at different conditions varying time and temperature and so the best conditions are optimized. Wood is the feedstock mostly investigated to optimize the conditions to use with coal [8]. The torrefaction of RDF results not only in improved calorific value but the grindability of the fuel as drying of the waste makes it brittle in nature reducing the extensive need of energy to employ it as fuel and overall improving system efficiency by not only enhancing

heating values but also diminish the mechanical strength required to grind it in furnaces and boilers [9]. The torrefaction also eliminates the moisture content along with the enhancement of carbon content in the fuel making it hydrophobic in nature which facilitates its transportation and storage while preserving it from microbial degradation [10]. Researchers have optimized the time and temperature for torrefaction of different types of biomasses and developed the mechanism to co-fire it along with coal to curtail detrimental environmental impacts associated with coal burning. It not only retrenches the adverse environmental impacts, but it also serves the purpose of generating clean energy [10,11]. So, the improved energy content of the torrefied RDF as compared to the raw RDF along with the upgraded behavior proves torrefaction to be the promising technique to fully recover the material and energy content of the mixed waste. The objective of this study was to utilize torrefaction as a pretreatment of municipal solid waste as RDF feed stock. Since municipal solid waste is not considered suitable as RDF feed stock due to its characteristics, this pretreatment was explored to enhance the calorific value and fuel properties of the municipal solid waste.

## 2. Materials and methods

Only combustible fractions of the waste stream were required for current study. The sample was collected from a facility in Lahore, Pakistan, where waste comes from different socio-economic regions. The waste fractions were characterized, the results of which are shown in Fig. 1. The sample consisted of 30% wood and bagasse, 40% paper and tetrapak, 20% textile waste and 10% plastics, particularly wrappers and termed as mixed waste.

The stepwise methodology of the study is presented in Fig. 2.

After sample collection, the waste was dried under atmospheric conditions. Next, the waste was shredded into 4 mm particle size using a laboratory-scale shredder. The shredded sample was homogenized and torrefied. The experimental setup for torrefaction consists of a stainless-steel tube furnace called torrefactor made by Pakistan Council of Scientific and Industrial Research (PCSIR) model TF-1102. Its length was 22 inches and internal diameter was about 1.26 inches. 10 g shredded and homogenized sample was loaded into the torrefactor. Torrefaction was carried out in the absence of oxygen which was achieved by continuous purging of nitrogen gas in the torrefactor at the rate of 1L/min. The waste was torrefied at four different temperatures (225 °C, 250 °C, 275 °C, and 300 °C) for 15 min and 30 min residence time. Finally, the raw sample and 8 other samples were prepared for analysis. Following are the details of samples prepared after torrefaction.

A1: 225 °C for 15 min A2: 225 °C for 30 min.

B1: 250 °C for 15 min B2: 250 °C for 30 min.

C1: 275 °C for 15 min C2: 275 °C for 30 min.

D1: 300 °C for 15 min D2: 300 °C for 30 min.

### 2.1. Analytical methods

The following analysis was carried out using prepared samples as per the details given below.

#### i. Process efficiency parameters of torrefaction process:

There are four important parameters i.e., weight loss, mass yield, energy yield, and energy density. These all were calculated as follow.

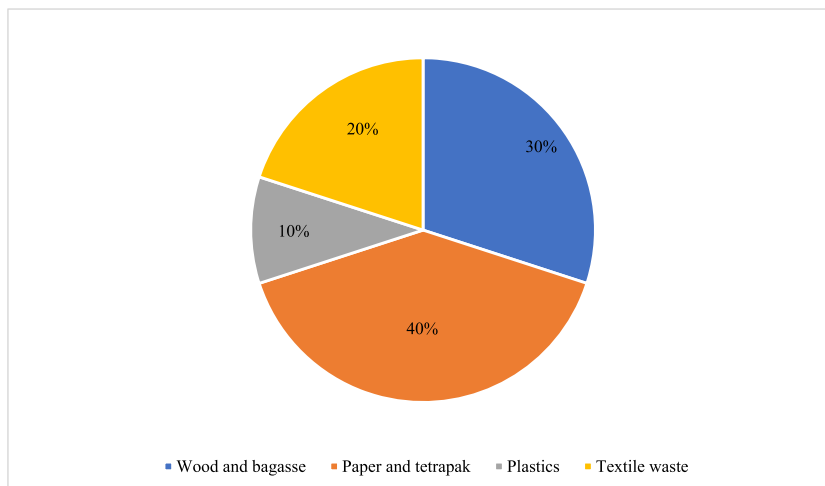


Fig. 1. Composition percentage of sample.



Fig. 2. Stepwise methodology.

$$\text{a) } \text{Weight loss} = \frac{M_r - M_t}{M_r} \times 100\% \quad (1)$$

$$\text{b) } \text{Mass Yield (MY)} = \frac{M_t}{M_r} \times 100 \quad (2)$$

where;

$M_r$  = Mass of raw sample.

$M_t$  = Mass of torrefied sample.

$$\text{c) } \text{Energy Yield (EY)} = \text{Mass yield} \times \frac{HHV_t}{HHV_r} \quad (3)$$

where;

$HHV_r$  = Higher heating value of raw sample.

$HHV_t$  = Higher heating value of torrefied sample.

$$\text{d) } \text{Energy Density} = \frac{EY}{MY} \quad (4)$$

#### ii. Proximate Analysis:

Proximate analysis was carried out to determine the gross characteristics of the samples. The moisture content, volatile content, and ash content were determined by ASTM D-3173, ASTM D-3175, and ASTM D-3174 methods, respectively. The fixed carbon was calculated using the following formula [12].

$$\text{Fixed Carbon} = 100 - \text{Moisture Content} - \text{Volatile matter content} - \text{Ash content} \quad (5)$$

#### iii. Ultimate Analysis:

The carbon, hydrogen, nitrogen, and Sulfur were analyzed by Elementar Analysensysteme GmbH – vario MICRO CHNS Elemental Analyzer (serial number 15095076), and oxygen content was determined by subtracting the sum of (C, H, N, and AC %) from 100.

#### iv. Calorific Value:

The Gross Calorific Value or HHV was determined as per ASTM – D – 5865 07a by Digital Bomb Calorimeter.

#### v. Thermogravimetric Analysis:

The thermogravimetric analysis was carried out using thermogravimetric analyzer LECO TGA-701 by ASTM – D 5142-04 method to determine the combustion behavior of samples.

**Table 1**

Process efficiency parameters of torrefaction.

Sample	Weight Loss (%)	Mass Yield (%)	Energy Yield (%)	Energy Density
Raw	0	100	100	–
A1	17 ± 0.8 <sup>a</sup>	83 ± 0.5	94.0 ± 0.6	1.13 ± 0.7
A2	23.7 ± 1.1	76.3 ± 0.8	93.8 ± 0.6	1.21 ± 0.6
B1	28.3 ± 0.4	71.7 ± 0.6	110.5 ± 0.5	1.54 ± 0.3
B2	31 ± 0.8	69 ± 1.0	107.6 ± 0.7	1.55 ± 0.8
C1	41 ± 0.6	59.6 ± 0.7	98.21 ± 1.0	1.64 ± 0.6
C2	43 ± 1.2	57 ± 0.3	97.02 ± 1.2	1.70 ± 0.9
D1	52 ± 1.0	48.5 ± 1.0	86.83 ± 1.1	1.79 ± 0.8
D2	55 ± 1.3	45 ± 1.1	83 ± 0.9	1.84 ± 0.8

<sup>a</sup> ±Standard Deviation (SD).

### 3. Results

#### 3.1. Efficiency parameters of torrefaction process

The process efficiency parameters for the torrefaction are shown in Table 1. It indicates the samples' mass yield, energy yield, and energy density before and after the torrefaction process. It can be seen that the weight reduction was observed with an increase in torrefaction time and temperature. It decreases to about 55% of the original weight for D2 (maximum time and temperature for torrefaction). The mass yield also shows a decreasing trend with the increase in temperature and time up to 45%.

#### 3.2. Characterization of prepared samples

The samples were characterized through proximate and ultimate analysis. Table 2 shows the comparison between raw samples and torrefied samples. Proximate analysis shows that the samples' moisture content and volatile matter content tend to decrease with the rise in temperature and time of torrefaction. The moisture content reduces from 7.7% of the raw sample to 0.9% of the D2 sample. Similarly, the volatile matter content decreases from 79.67% of the raw sample to 65.11% of D2 [13]. In contrast, ash content tends to increase with the rise in temperature and time of torrefaction. It shows a rise from 3.8% of the raw sample to 7.7% of D1 and D2. The ultimate analysis shows that the carbon content tends to increase for torrefied samples with the rise in temperature, while for the raw sample, carbon content was 51.16%, and for D2, it became 74.02%. The hydrogen content depicts a unique behavior. For raw sample, it was 5.38%, but then it began to increase till B2, where samples are torrefied at 250 °C for 30 min. As the torrefaction temperature increases further, it tends to decrease; finally, at D2 it becomes 5.39%. At the same time, the other elements including nitrogen, sulfur, and oxygen tend to decrease with increasing torrefaction temperature and time. For the raw sample, the nitrogen, sulfur, and oxygen were 1.99%, 0.36% and 41.10% respectively. After torrefaction, these tend to decrease and finally reached 1.66%, 0.32%, and 18.56% for nitrogen, sulfur, and oxygen respectively.

#### 3.3. Calorific value

It can be observed that the HHV of the raw sample is less than compared to the torrefied sample. In the proposed study, two residence times were considered at which samples were torrefied at different temperatures. Fig. 3 shows the relation between calorific values and the samples produced at different temperatures and varied residence time. It was revealed that the HHV increases as the time and temperature of torrefaction increases. The maximum calorific value of 28.9 MJ/kg was achieved at maximum temperature i. e., 300 °C torrefied for 30 min. As time increased, the calorific value also showed a surge from 15.65 to 28.9 MJ/kg.

#### 3.4. Thermogravimetric analysis

Fig. 4 shows the trend of the sample's weight loss (%) with an increase in temperature. The temperature range to study the behavior of samples as fuel was between 200 °C to 800 °C based on the specification of the instrument used for the raw sample, the moisture decreased from 94% to 3.9%. The torrefied samples exhibited weight reduction of 6.2% for A1, 6.9% for A2, 7.8% for B1, 8.5% for B2, 9.7% for C1, 10.4% for C2, 12.1% for D1 and 14.1% D2 respectively when the temperature is increased from 200 °C to 800 °C. The

**Table 2**  
Characterization of collected waste samples.

Sample	Proximate Analysis				Ultimate Analysis				
	Moisture content (%)	Volatile matter contents (%)	Ash content (%)	Fixed carbon content (%)	C (%)	H (%)	N (%)	S (%)	O (%)
Raw	7.7 ± 0.6 <sup>a</sup>	79.67 ± 0.4	3.8 ± 0.4	8.83 ± 0.8	51.16 ± 1.1	5.38 ± 0.6	1.99 ± 1.4	0.36 ± 0.4	41.10 ± 0.8
A1	4.8 ± 0.4	79.66 ± 0.6	4.8 ± 0.3	10.74 ± 0.6	54.07 ± 0.8	5.41 ± 0.9	1.99 ± 1.0	0.36 ± 0.5	38.17 ± 0.9
A2	3.8 ± 0.4	77.75 ± 0.6	4.8 ± 0.9	13.65 ± 0.7	56.04 ± 1.3	5.50 ± 0.9	1.96 ± 0.8	0.36 ± 0.4	36.14 ± 1.4
B1	2.9 ± 0.6	78.65 ± 0.8	5.8 ± 1.0	12.65 ± 0.8	59.14 ± 1.1	5.51 ± 1.3	1.94 ± 1.3	0.36 ± 0.4	33.05 ± 1.6
B2	1.9 ± 0.5	77.71 ± 0.9	5.8 ± 1.2	14.59 ± 0.3	62.18 ± 0.8	5.51 ± 1.1	1.94 ± 1.3	0.36 ± 0.4	30.01 ± 0.9
C1	1.9 ± 0.8	71.88 ± 1.0	5.8 ± 0.8	20.42 ± 0.6	63.92 ± 1.4	5.50 ± 0.5	1.82 ± 1.0	0.34 ± 0.5	28.42 ± 1.1
C2	1.9 ± 0.8	70.91 ± 0.6	6.7 ± 1.1	20.40 ± 0.9	67.02 ± 0.6	5.40 ± 0.8	1.79 ± 0.8	0.34 ± 0.4	25.45 ± 1.1
D1	1.9 ± 0.6	68.97 ± 0.5	7.7 ± 0.3	21.43 ± 0.6	71.18 ± 0.7	5.40 ± 0.6	1.74 ± 0.9	0.33 ± 0.3	21.34 ± 0.8
D2	0.9 ± 0.7	65.11 ± 0.3	7.7 ± 0.8	26.29 ± 0.7	74.02 ± 0.8	5.39 ± 0.6	1.66 ± 0.8	0.32 ± 0.3	18.56 ± 0.6

<sup>a</sup> ±Standard Deviation (SD).

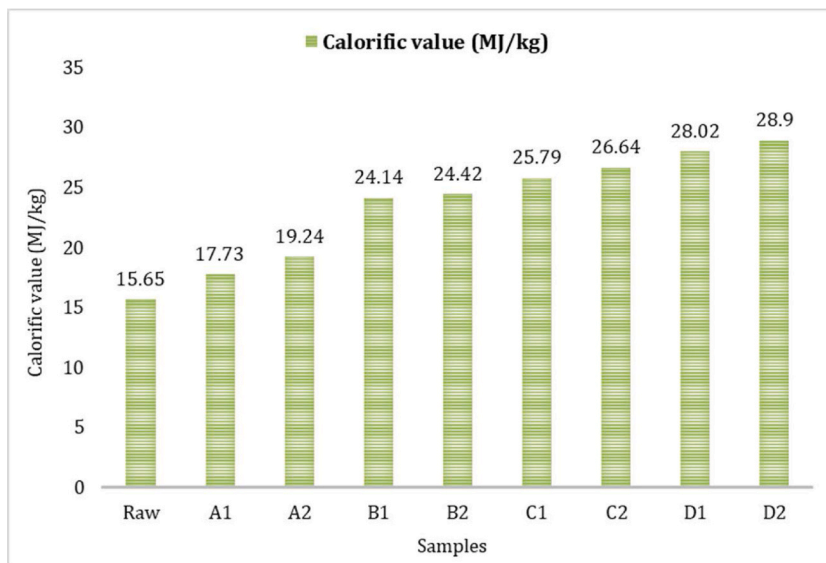


Fig. 3. Calorific values of samples.

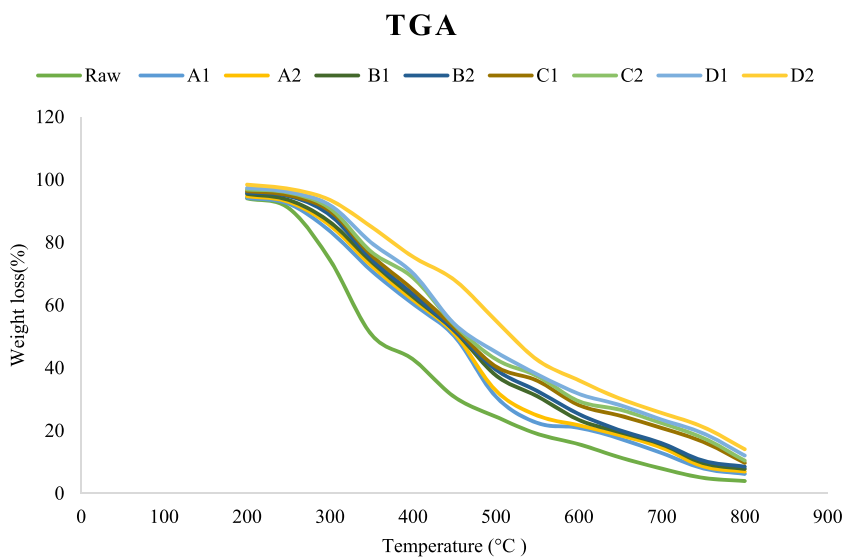


Fig. 4. The thermogravimetric analysis of all samples.

average temperature range at which torrefied samples exhibit 50% weight loss was 450–500 °C.

Fig. 5 shows the weight loss (%) per minute using derivative thermogravimetry (DTG). The DTG curve for the raw sample showed a higher peak compared to the torrefied samples, where a gradual decrease in peak heights was observed. This indicates better and smooth combustion. For the raw sample, the peak was at 5.6, and for the torrefied sample (D2) it was at 3.04. The temperature range for observed peaks lies between 300 °C - 450 °C.

### 3.5. Ignition temperature and volume reduction

Fig. 6 shows the relation between the degree of torrefaction and ignition temperatures. The ignition temperature was determined by using TGA profiles of the fuel. It reveals that as the torrefaction conditions become severe for RDF, the ignition temperature shows an increasing trend. It hikes from 300 °C to 460 °C for mixed waste RDF.

Fig. 7 compares the volume reduction of raw samples and torrefied samples. It was observed that as the degree of severity of torrefaction increases the volume reduction also tends to increase.

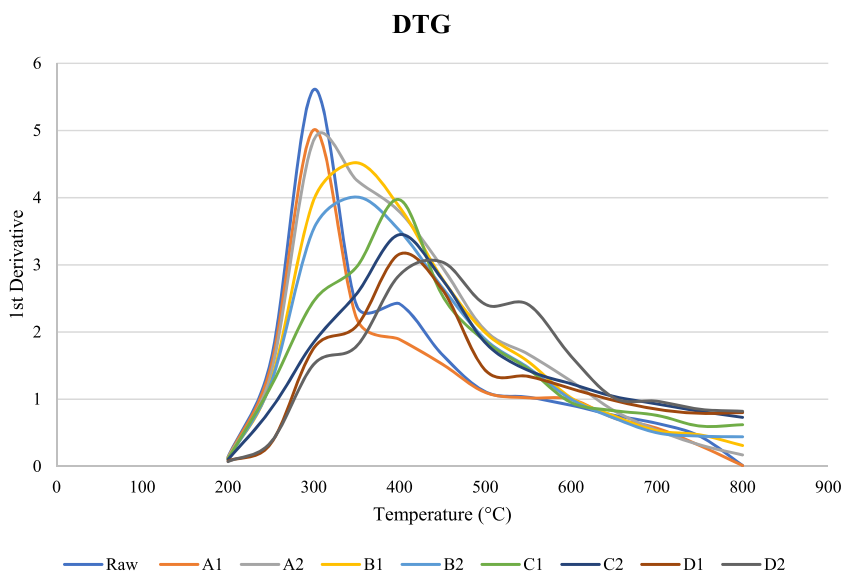


Fig. 5. The DTG of samples.

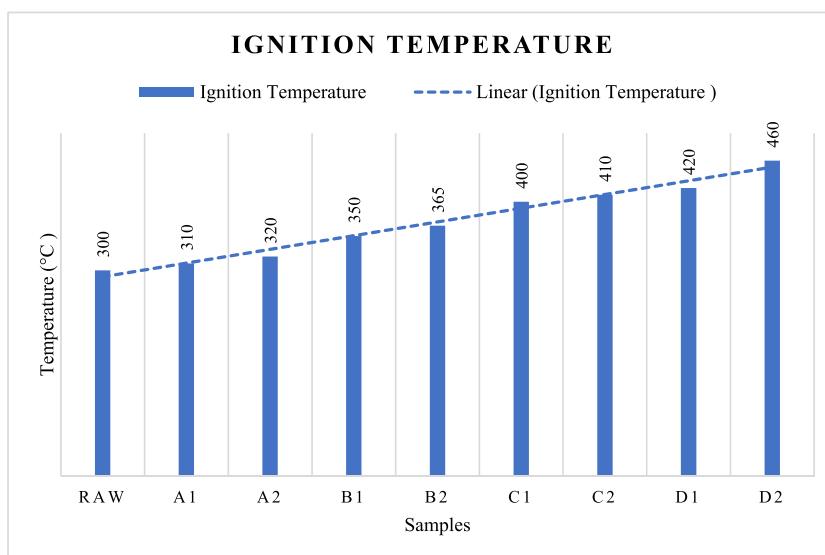


Fig. 6. Comparison of Ignition temperatures of raw and torrefied RDF.

#### 4. Discussion

The results reveal that the slight increase in temperature in the torrefaction process facilitates the release of moisture content, which causes the mass yield to decrease [11]. As the temperature increases, carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), and other organic gases are released along with moisture content, due to which the mass yield tends to reduce to half of the original mass at maximum temperature (300 °C) and residence time (30 min). Hence, the mass loss at higher temperatures was greater than at lower temperatures [14]. Energy yield also shows a similar decreasing trend due to the loss of some energy-lean components. It is the amount of energy retained in the feedstock after torrefaction [15] that is a ratio between the mass yield and HHV of the raw and torrefied sample [16]. The rate of decrease in energy yield was lower compared to mass yield [17]. The reason is that the HHV values tend to increase for torrefied samples with the temperature increase. At the same time, the mass yield tends to decrease. Hence, the ratio between them does not decrease compared to mass yield [18]. However, the energy density tends to increase up to 1.39 as the temperature and time of torrefaction increase due to the retention of energy rich components of solid waste. Energy density is considered as the fuel property of combustible material [19]. It is the amount of chemical energy present in the fuel per unit volume [20]. It is desired that the energy density must exceed 1 to achieve the energy gain required [21]. Hence, the energy density can fulfill

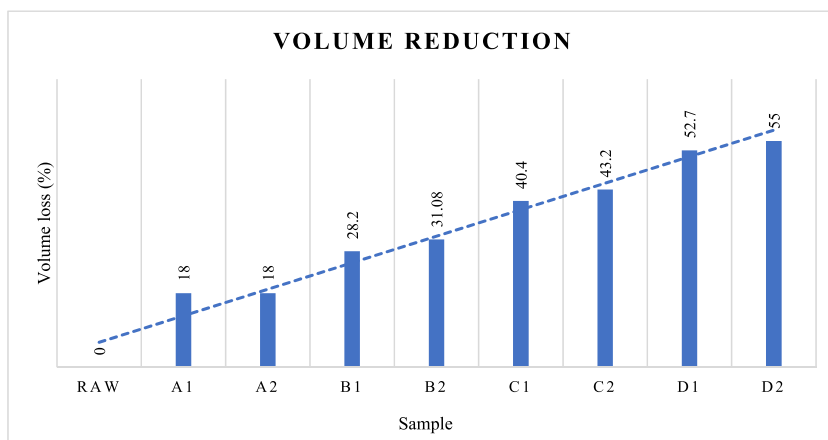


Fig. 7. Volume reduction after the process of torrefaction.

the energy requirement as revealed in the current study.

The torrefaction as pretreatment causes a massive reduction in the waste's moisture content, mainly due to the removal of hydroxyl groups (OH) [22]. This hinders the hydrogen bonding with the surrounding water molecules giving a hydrophobic nature to the torrefied waste [23]. Reduced moisture makes the torrefied waste appropriate for almost all types of energy conversion processes like gasification [10]. The reason for volatile matter reduction is the loss of extractives and devolatilization, removing CO, H<sub>2</sub>O, etc. It can be observed that the volatile matter decreases faster between 250 °C–275 °C, and then it becomes slow. The same trend was observed for torrefied samples by different researchers [24]. The high volatile matter content impedes the steady combustion process and dissipates the fuel which not only decreases the process efficiency but also downturns the calorific value of the fuel [25]. The removal of moisture content along with the volatile matter results in high ash and fixed carbon in the samples. As the sample undergoes mass loss and at high-temperature torrefaction, it loses its volatility, so the ash tends to increase [25,26]. The fixed carbon increases mainly due to the loss of oxygen-related gases. Moreover, the torrefaction process enhances the carbonization of the compounds by increasing carbon content [12].

The elemental analysis depicts that the increased carbon and decreased hydrogen and oxygen are of great significance in enhancing the calorific value of torrefied waste [27].

The HHV of the samples in this study was compared to the sub-bituminous coal, which is approximately 23.9 MJ/kg, and other forms of coal, like lignite, which is around 17.4 MJ/kg [28]. The decrease in oxygen content leads to the enrichment of elemental carbon in the torrefied sample resulting in a hike in calorific value [29]. The high temperature and high residence time facilitate the complete release of volatile organic compounds, due to which calorific value increases [30].

It has been observed in the relevant studies that RDF undergoes degradation in the range of 200 °C–600 °C depending on the feedstock being used to produce RDF [31]. If the significant constituent is lignocellulosic material, then it would show maximum degradation in the range of 200 °C–400 °C [32]. Whereas if the dominant constituent is plastic, 400 °C–600 °C is the usual range of degradation [33]. The thermal stability of plastics is high compared to other materials, so it requires a high temperature for degradation [34]. In the proposed study, the torrefied samples are more thermally stable than the raw sample due to the enhanced characteristics i.e., more crystalline, and hydrophobic nature.

The peaks at 200 °C–400 °C show the decomposition of paper, textile, and organic material in the samples. As the temperature increases above 400 °C, the peaks show the degradation of plastics and other polymers, if present. The torrefied samples showed comparative curves, which indicate better and smoother combustion behavior and greater energy density [35].

The ignition temperature is the lowest temperature at which the fuel starts combustion without any extrinsic source. The ignition temperature of raw waste is less compared to torrefied waste. The reason is the presence of volatile matter content. As in MSW the volatile matter content is highest due to which the ignition starts earlier, while in torrefied samples, the volatile matter content is less and inert content is high due to which the ignition takes time and starts at a higher temperature [36,37].

The torrefaction is also known as the high-temperature drying, which causes evaporation accompanied by the release of volatile gases which cause mass loss and densify the samples causing their volume to decrease [38]. At large scale, this system works effectively for wastes which contain low moisture content. However, this system becomes very expensive if the waste contains higher moisture content. Moreover, decreasing mass yield is also a major concern for commercial purposes. It demands more input to give the desired turnout. Hence, there is a need to explore the system thoroughly for commercial utility as well.

## 5. Conclusion

The study demonstrates that torrefaction can be an effective pretreatment method for improving the fuel properties of mixed waste used as a feedstock for RDF. The torrefaction process significantly reduced moisture contents and volatile matter and increased fixed carbon and energy density with increasing torrefaction temperatures and residence times.



The findings suggest that torrefied mixed waste can be a viable fuel option for use in gasifiers or co-firing with coal, as it has improved combustion characteristics and energy potential compared to untreated mixed waste. The study provides valuable insights into the potential of torrefaction as a sustainable waste management solution and a viable method to recover energy.

Further research and testing on the economic and environmental feasibility of implementing torrefaction on a larger scale would be necessary to evaluate its potential as a practical waste-to-energy solution. However, the results of this study provide a promising outlook for using torrefaction as an effective means of treating mixed waste and enhancing its fuel properties.

### Data availability

1. Sharing research data helps other researchers evaluate your findings, build on your work and to increase trust in your article. We encourage all our authors to make as much of their data publicly available as reasonably possible. Please note that your response to the following questions regarding the public data availability and the reasons for potentially not making data available will be available alongside your article upon publication.

**Response:** No

2. Sharing research data helps other researchers evaluate your findings, build on your work and to increase trust in your article. We encourage all our authors to make as much of their data publicly available as reasonably possible. Please note that your response to the following questions regarding the public data availability and the reasons for potentially not making data available will be available alongside your article upon publication.

Has data associated with your study been deposited into a publicly available repository?

**Response:** Data will be made available on request.

### Ethical declaration

Review and/or approval by an ethics committee was not needed for this study because this study does not involve any living organism.

### CRedit authorship contribution statement

**Muhammad Umar Farooq:** Writing – original draft, Data curation, Conceptualization. **Khadija Sadiq:** Writing – review & editing, Formal analysis, Data curation. **Mehwish Anis:** Writing – review & editing, Methodology, Formal analysis. **Ghulam Hussain:** Writing – review & editing, Formal analysis. **Muhammad Usman:** Writing – review & editing, Resources. **Yasser Fouad:** Writing – review & editing, Funding acquisition. **M.A. Mujtaba:** Writing – review & editing, Software, Resources. **H. Fayaz:** Writing – review & editing, Funding acquisition. **A.S. Silitonga:** Writing – review & editing.

### Declaration of competing interest

I on the behalf of the all authors, declare that there is no conflict of interest and all the elements of the submission are also in compliance with the journal publishing ethics. We did not use AI and AI-assisted technologies for this research paper. By submitting this manuscript, the authors agreed that the copyright for their article should be transferred to this journal if the article is accepted for publication. The work contained within the research paper is our original contribution and has not been published anywhere.

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