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# Unlocking the Energy Potential of Temple Waste and Coconut Fiber through Refuse-Derived Fuel Production toward Sustainable Energy

I Made Wahyu Wijaya[1*], I Gusti Ngurah Made Wiratama[2], I Kadek Ardi Putra[2], Ni Putu Cempaka Dharmadewi Atmaja[3]

[1] Regional and Rural Planning Study Program, Postgraduate Program, Universitas Mahasaraswati Denpasar, Jalan Kamboja No. 11A, Denpasar, Bali, 80233, Indonesia

[2] Environmental Engineering Study Program, Faculty of Engineering, Universitas Mahasaraswati Denpasar, Jalan Kamboja No. 11A, Denpasar, Bali, 80233, Indonesia

[3] Management Study Program, Faculty of Economic and Business, Universitas Mahasaraswati Denpasar, Jalan Kamboja No. 11A, Denpasar, Bali, 80233, Indonesia

* Corresponding author's e-mail: wijaya@unmas.ac.id

## ABSTRACT

Organic temple waste has the potential to be used as biomass-based fuel, with a 90% composition of biodegradable waste consisting of leaves, flowers, fruit, and food scraps. To minimize environmental impact, proper management efforts are necessary to handle the temple waste and produce a valuable product. An alternative method for dealing with organic waste includes producing fuel from biomass which is refuse-derived fuel (RDF). This would not only create a new product for waste wages but also prevent them from ending up as waste in the landfill. The current research aimed to investigate the characteristics of organic temple waste and coconut fiber as RDF material and its potential to replace coal use. The RDF was produced from temple waste using leaf and flower components combined with coconut fiber as the primary ingredients. The material was dried, ground, and produced into powder form before it was analyzed in terms of its characteristics. RDF made from temple waste has best result among coconut fibre and the both mixture with above 4800 kcal/kg. It belongs to class 2 solid fuels based on their characteristics, according to the National Standard for biomass-based fuel. Furthermore, the RDF still needs to be improved for industrial scale and requirement. Product durability test has shown good result for the temple waste material comparing with coconut fibre and coal. The study showed that temple waste and coconut fibre are promising to be processed into RDF as coal substitution in the combustion process.

**Keywords:** temple waste, coconut fiber, refuse-derived fuel, energy, recycling.

## INTRODUCTION

Bali is known for having traditions and a culture that are still vibrant and thriving. Bali's Hindu religious community has a range of traditions for commemorating holy occasions and celebrations. The Hindus offer the means of livelihood before the Lord or the ancestors at religious ceremonies. This is an expression of thanks to the God for everything he has done for the Hindus community (Balachander, 2015; Yüksel, Arıcı, Krajčík, Civan, & Karabay, 2021). The offering consists of flowers, leaves, straw, and other natural things possessed by those who wish to offer them to God. After the celebration, the majority of the pay will be disbursed to family members, with the remainder being discarded. One of the immediate consequences of religious celebrations is waste. The temple waste is mostly formed of organic materials, although not all of them degrade rapidly and readily, such as bamboo, hard leaves, and coconut fruits and skins. As a result, collected and unsorted waste directly dumped into the environment and will also cause environmental impacts, such as odours, disruption of environmental aesthetics, and a reduction in land capacity for waste disposal (Wahyu Wijaya, 2019; I. M. W. W. Wijaya et al., 2021; Yadav, Juneja, & Chauhan, 2015; Yadav, Singh, Juneja, & Chauhan, 2018). In addition to the land area, the remaining waste, such as that dropped in the river or the residue of religious ceremonies held on the beach, frequently ends up off the shore.

The *Tri Hita Karana* is a concept of balance and harmony between God, man, and the environment in Hinduism. Religious festivals are one of the realizations of the *Tri Hita Karana* concept, in which people offer offerings or methods of compensation to God as a form of appreciation to the Lord for providing diverse natural resources to meet requirements (Putu, Adi, Suarna, & Windia, 2015). However, if the leftover waste interferes with environmental sustainability, society will suffer. Some of the efforts made to handle temple waste in the pure region include waste (Juneja, Chauhan, & Yadav, 2015; Temple, 2017) collection by hygiene personnel and transportation to landfills. The municipal recovery facility has completed the composting of organic waste generated by the rest of the employees. Organic waste, on the other hand, has the potential to be used as biomass fuel. According to Wijaya et al. (I.M. Wijaya, Wiratama, Putra, & Aris, 2023), the composition of biodegradable waste remains dominated by organic waste (90%), which includes leaves, flowers, fruit, and food scraps, with paper and plastic accounting for the remainder. To avoid having an impact on the environment and society, the rate of monthly waste and remaining wages must be followed by suitable management efforts. However, the current processing efforts, namely the compost, have not been able to tackle the problem optimally. Thus, converting biodegradable waste into biomass fuels could be an alternative method to reduce waste accumulation.

Some recycling techniques were conducted previously to reduce the amount temple waste, especially flower waste in the environment. Other recycling was including vermicomposting, bioethanol, charcoal, etc. Jain (Jain, 2016a) has successfully applied vermicomposting by using discarded flowers. An interesting finding was done by Khammee and colleagues (Khammee, Unpaprom, Buochareon, & Ramaraj, 2019a). By applying the concept of waste to energy, recycling of *Tagetas erecta* into biofuel has been conducted. It could be a rich source of sugars from the flower waste which can be potentially converted into bioethanol. Bogale (Bogale, 2017a) presented another approach in recycling the discarded flowers in Ethiopia. Ethiopia is the second largest flower exporter in Africa. The flower waste was converted into biochar through the pyrolysis process. The information on waste composition is useful in determining the way to manage the waste. Several previous studies have carried out temple waste management, such as recycling flower waste into compost through the vermicomposting technique (Jain, 2016b; Samadhiya, Pradesh, & Pradesh, 2017), biofuel materials (Khammee, Unpaprom, Buochareon, & Ramaraj, 2019b), biochar (Bogale, 2017b) natural dyes (Singh et al., 2017), and natural fertilizers (Anvitha, Sushmitha, Rajeev, & Mathew, 2015).

Alternative methods for dealing with organic waste in general include the production of fuel from biomass. Bricks made from pyrolysis or refuse-derived fuel (RDF), both of which can be burned as fuel, are the possible outcomes of the processing of biomass (Chavando, Silva, Tarelho, Cardoso, & Eusébio, 2022; Widyatmoko, Sintorini, Suswantoro, Sinaga, & Aliyah, 2021). The combustion of steam and brick, as well as other businesses that include a burning process, are some of the prospective users of biomass fuels. Other potential users of biomass fuels include steam processes, steam power plants, and the combustion of steam and brick. With this utilization, it will give a fresh cycle for the month's remaining waste wages to not end up as a bulk in the landfill but rather create a new product that is useful and even worth selling (Shehata et al., 2022). This will prevent the salaries from ending up as waste in the landfill. In addition, the potential for the leftover waste in Bali is great due to the fact that there are approximately 5000 temples and 3 million Hindu people who consume the means of remuneration every time. The purpose of current research is to investigate the characteristic of organic temple waste and coconut fibre as RDF material and its potential to substitute the use of coal.

## METHOD

The RDF was produced from temple waste using leaf and flower components combined with coconut fiber as the primary ingredients. The components of the highest wage residual waste are the foliage and flowers. However, coconut fibers derived from the coconut fruit, which is also used in a variety of repair methods, but its composition is challenging due to the hard structure of the fruit and skin. According to the research conducted by Wijaya et al. (Made et al., 2021), the remaining waste was dumped around the temple during ceremonies.

## Tools and material

In the waste collection, some 100 L polypropylene (PP) sacks were used to collect the waste and bring to the separation site. The equipment used during the waste collection and measurement, included a 4×6 m plastic tarp for separation base, a density box with a size of 1×1×0.5 meters or 0.5 m$^3$ for density analysis, a Wei Heng WH-A08 digital scale to weigh the waste, and data sheet. All temple waste was moved to the RDF processing place. The temple waste was dried through direct sunlight in 4 days on a plastic sheet.

## Waste sorting

The purpose of waste disposal is to remove non-organic garbage that could interfere with the RDF production process. The refuse from the workplace has been sampled and analysed based on various categories, including flower, leaf, metal, plastic, wood, headband, and food waste. For the production of RDF, leaf waste, flower waste, and coconut sable refuse are utilized. This waste is selected due to its low water content, which makes it easy to dry.

## Briquette production

Biomass briquettes are made using a press machine to print biomass into a pellet shape with a length of 5–10 cm and a diameter of 1 cm. The dried temple waste then proceeds to some machines to produce the RDF. A chaft cutter machine (MCC) series 6-200 with GC-200 Engine and 6.5 horsepower (hp) was used to grind the


**Figure 1.** RDF material samples

temple waste into smaller pieces of about 2–3 cm. Afterwards, a milling machine FFC 23 with GX 270 engine and 9 hp worked to produce finer temple waste form. The temple waste powder was then pressed into pellet form by using a vertical pellet press machine SLD 150 MPK with JF 180 engine. In this study, the RDF material involved mixing temple waste with coconut fibre with the aim to increase the calorific value. The prepared samples are shown below in Figure 1. The variations used in this briquette mixture are:

- C1 – 100% temple waste;
- C2 – 75% temple waste + 25% coconut fiber;
- C3 – 50% temple waste + 50% coconut fiber;
- C4 – 25% temple waste + 75% coconut fiber;
- C5 – 100% coconut fiber.

### Characteristic analysis

RDF is a type of fuel produced from municipal solid waste (MSW) or other forms of waste. It is processed to remove non-combustible substances and used as a renewable energy source in a variety of industries. The physical properties of RDF can vary based on the composition of the refuse used and the processing techniques employed.

The RDFs were prepared and analyzed for their moisture, ash content, organic content, and caloric value. The result of caloric value was converted into electrical power potential and $CO_2$ equivalent to define its potential as an energy alternative. Water content was determined by drying a certain amount of waste in an electrical oven at 103 ± 5 °C for one hour until the constant weight was achieved. Water content, dried material, ash content, organic content, volatile, and carbon content were analyzed with gravimetry according to Method Analysis by Association of Efficial Agriculture Chemist. Nitrogen was measured by using semimicro Kjeldhal method, meanwhile phosphorus and calcium were measured by using spectrophotometry and atomic absorption spectroscopy (AAS). The caloric value was measured using a Gallenkamp Ballistic Bomb Calorimeter. Each sample was weighed into the steel capsule at 0.50 g. To contact the capsule, a 10 cm-long cotton thread was tied to the thermocouple. The device was sealed and charged with up to 30 atoms of oxygen. The bomb was activated by pressing the ignition button, causing the sample to burn in an excess of oxygen. The thermocouple and galvanometer equipment were used to measure the greatest temperature rise in the bomb (Awulu & Audu, 2018).

## RESULT AND DISCUSSION

RDF is typically manufactured as small, uniformly sized granules or fluff. Pellets are cylindrical or disc-shaped, whereas fluff refers to irregularly shaped, pulverized, and compacted waste. This biomass briquette is in the shape of a tube with a length of about 5 cm, a diameter of 0.5 cm, and a brown color. The biomass mass of the briquette is 10 grams, with a type mass of 10.19 gr/cm$^3$. Physically, this product appears to have fibers that may come from coconut leaf fibers or coconut sable fibers. Such fibers can strengthen the briquette structure so that it is denser and not easily fragile. The research by Wijaya et al. [8, 9] mentioned that the average monthly waste of one religious activity in Pura, Bali, reached 292.36 kg ± 2.48 with a type mass of 63.56 ± 5.83 kg/m$^3$ and was dominated by leaf and flower garbage (79.38%).

The density of RDF can vary depending on the processing methods and waste materials employed. Pelletized RDF typically has a greater density than fuzz RDF. The density of RDF is between 300 and 600 kg/m$^3$. Typically, RDF granules have a uniform particle size, which ensures efficient combustion. The specific particle size distribution can vary based on the end-use application requirements.

According to the Bali Province Statistic Institute 2023, the total number of Hindu public places of worship on Bali Island is 4836. If estimated, then on every single day of religious ceremonies, each public ceremony would potentially produce 1413.29 tons of artisanal waste with a composition of leaves and flowers of 1121.43 tons. The Hindu community on Bali Island has many religious ceremonial holidays that are carried out in the temple so it has a huge potential for waste to be exploited. RDF must meet general quality requirements in order to be utilized safely and effectively (Sarc & Lorber, 2013), such as:

- well-defined calorific value
- low chlorine content
- quality-controlled composition (few impurities)
- defined grain size
- defined bulk density.
- availability of sufficient quantities meeting required specifications.

The result of RDF characteristics are shown on the Table 1.

**Table 1.** RDF characteristic for each samples

| No | Parameter | Unit | Samples | | | | |
|---|---|---|---|---|---|---|---|
| | | | C1 | C2 | C3 | C4 | C5 |
| 1 | Water content | % | 13.83 | 9.88 | 12.88 | 12.00 | 12.98 |
| 2 | Dried content | % | 86.17 | 90.12 | 87.11 | 87.99 | 87.01 |
| 3 | Ash | % | 5.63 | 14.09 | 9.68 | 5.81 | 8.30 |
| 4 | Organic mater | % | 94.37 | 85.91 | 90.32 | 94.18 | 91.69 |
| 5 | Volatile | % | 67.24 | 59.33 | 64.68 | 69.08 | 62.86 |
| 6 | Carbon (’C) | % | 13.30 | 16.69 | 12.76 | 13.09 | 15.84 |
| 7 | Nitrogen (N) | % | 0.72 | 1.87 | 1.08 | 0.74 | 1.56 |
| 8 | Phosphorus (P) | % | 0.66 | 0.91 | 0.77 | 0.70 | 0.91 |
| 9 | Calcium (Ca) | % | 4.49 | 4.17 | 4.81 | 5.49 | 4.44 |
| 10 | Gross energy | kcal/kg | 4556.8 | 4558.1 | 4186.4 | 4418.3 | 3761.8 |

## Water content

The results of laboratory tests of the biomass breakdown characteristics of waste revealed that the water content of all the samples that have been tested was below 15%. The lowest water content of 9.88% pertains to bulk samples with a composition of 100% waste. The water content has met the requirements for solid fuel in accordance with SNI 8966: 2021 on solid fuel, which is less than 15%. The drying of biomass briquettes in this study was still done in a natural fashion under sunlight for 4 days. The use of more sophisticated dryers will be able to lower the water level on the biomass bridge. The study of Fadila et al. (Fadila Rania, Gede Eka Lesmana, & Maulana, 2019; Rania, Lesmana, & Maulana, 2019) also conducted drying with sunlight for 7 days with an average water content of RDF material of 5.56%. The moisture content of RDF is a crucial factor affecting its combustibility. Depending on the processing procedures and storage conditions, the moisture content of RDF typically ranges between 10% and 30%. High moisture content in RDF can impair the overall combustion efficiency. Water requires energy to evaporate, which absorbs heat during the combustion process. As a result, a larger portion of the energy derived from RDF is utilized for dehydrating and vaporizing the moisture, rather than directly contributing to the combustion process. This reduces the overall energy output and combustion efficiency.

## Ash content

The ash content of all samples is in the range of 5–15%, with 100% pure waste samples having the highest ash content, which is 14.09%. This ash content is lower than the optimal ash level in coal for combustion, which is 25–30%. The presence of ash indicates the mineral content of a material, so the higher the level of ash, the higher the mineral content and the lower the content of carbon. This shows that the material structure is becoming increasingly heterogeneous. The high mineral content of a material can inhibit the combustion process, so the lower the ash levels, the better the material for combustion is (Aich, Behera, Nandi, & Bhattacharya, 2020; Behera, Nandi, & Bhattacharya, 2019; Wang et al., 2021). After combustion, RDF contains ash residues. The amount of ash depends on the waste composition and the efficiency of pre-processing processes. Typically, the ash content of RDF ranges from 10% to 30%.

## Volatile value

Volatile values (flying substances) on all samples were above 50%. The value is higher than the percentage of coal flying material for combustion, which is 26.75% (Aich et al., 2020). Increased content of volatile substances can improve combustion performance, but very high volatility values will interfere with the burning process due to increased production of exhaust gases (Liu, Chen, & Wei, 2015). The volatility of RDF can affect its combustibility. In general, a higher volatile content facilitates ignition and improves combustion characteristics. However, excessive volatile matter can also contribute to increased emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs). For efficient and environmentally friendly combustion, it is essential to discover the optimal proportion of volatile substances (Vamvuka, Esser, & Marinakis, 2023). According to studies, the volatile value of RDF can vary based on the composition of the used refuse materials. The RDF from municipal solid waste (MSW) typically possesses a volatile value between 70 and 85 percent. This is because MSW contains organic materials, such as paper, cardboard, plastics, and biomass.

### Carbon content

The carbon content of all samples was in the range of 12–17% and was below the optimal content for good combustion, which is 33.3% according to Aich et al. (Aich et al., 2020). The decrease of the carbon content is a factor in reducing the calorific value and combustion efficiency (Shangdiar, Lin, Cheng, Chou, & Wu, 2021). The carbon content of RDF can vary based on the composition of the used waste materials and the processing techniques employed. RDF derived from MSW typically contains a substantial quantity of carbon, as it consists of a variety of carbon-rich materials. Alternatively, the carbon content of the RDF produced from industrial waste or biomass residues can vary depending on the waste stream. Carbon content is an essential metric for evaluating the energy potential of RDF. Carbon-rich substances have a higher calorific value and can increase the fuel's energy content (Nowak, 2023). Consequently, higher carbon content results in an increase in energy production during combustion.

### Calorific value

The calorific values for all samples have exceeded 4000 kcal/kg, except the mixture of pure temple waste with coconut fiber (25%) had the lowest calorie value of 3700 kcal/kg. The composition of 100% temple waste and 100% coconut fiber has a calorific value that is not much different, namely 4880 kcal/kg. The calorific value increases along with fixed carbon and volatile matter; hence, the amount of carbon is a factor affecting the calorific value of the material (Boumanchar et al., 2017). The results showed higher calorific value comparing with the previous research which was focused on the drying method that was natural drying RDF with 3311.7 kcal/kg and 2912.7 kcal/kg (I.M. Wijaya et al., 2023). RDF has a comparatively high calorific value, a measurement of its energy content. It can range between 15 and 25 megajoules per kilogram (MJ/kg), depending on the composition of waste and the eradication of non-combustible materials during processing. The calorific value of RDF can vary depending on a number of variables, such as the composition of the waste materials used to generate it and the processing techniques employed (Longo, Cellura, & Girardi, 2020; Özkan, Işık, Günkaya, Özkan, & Banar, 2019). Municipal solid waste (MSW), industrial waste, and biomass residues have varying calorific values. The calorific value of the RDF derived from MSW is typically between 8 and 20 megajoules per kilogram (MJ/kg), or 3,400 and 8,500 British thermal units per pound (BTU/lb). It is essential to observe, however, that the calorific value can vary significantly depending on the composition and characteristics of the waste stream (Ganesh, Vignesh, & Kumar, 2013). Carbon content influences the calorific value of RDF, as carbon-rich materials tend to have higher thermal values. Moisture content, volatile content, and the presence of inorganic materials or contaminants are additional variables that can impact the calorific value.

Several parameters of the RDF granules are also compared to Indonesia National Standard (SNI) 8966: 2021 on Solid Fitting Fuel. Table 2 provides a comparison of the RDF test results analyzed in this study. On the basis of this comparison, the RDF pellets in this study belonged to class 2 solid fuels, according to their characteristics. It meets the fuel categories for class 1,

**Table 2.** Comparison of RDF quality between the samples and SNI

| Parameter | Unit | Temple waste RDF | SNI | | |
|---|---|---|---|---|---|
| | | | Class 1 | Class 2 | Class 3 |
| Diameter | mm | 10 | 6–10 | 6–12 | 6–12 |
| Length | mm | 10–50 | 3.15–40 | 3.15–40 | 3.15–40 |
| Moisture | % | <15 | <15 | <20 | <25 |
| Ash | % | 5–15 | <15 | <20 | <25 |
| Volatile value | % | 50–70 | <65 | <70 | <75 |
| Carbon content | % | 12–17 | >15 | >10 | >5 |
| Calorific value | kcal/kg | 3700–4600 | 4777 | 3583 | 2389 |

including levels of flying matter, carbon levels, and calorie values.

Obviously, the RDF quality improvement must continue in order to attain RDF fuel class 1. Multiple efforts are required to satisfy these quality standards, including: (1) Increase drying procedures to reduce the moisture content of RDF pellets. The storage of pellets will also affect pellet quality, necessitating a dry storage area, protection from rain, and protection from soil and air moisture. (2) Enhanced sorting procedures to reduce the amount of contaminants that may be involved in the pelletization process. (3) Addition of other combustible materials to achieve a calorific content of 5,000 kcal/kg. Additional materials can be obtained from waste generated by other industry activities, thereby making this an endeavour to process waste.

## RDF product test

The RDF product test includes the quality and durability of the product when it will be used by the user. The product test in this study includes combustion rate, storage durability, and temperature durability.

### *Combustion rate*

The combustion rate of refuse-derived fuel (RDF) is an important parameter that affects the efficacy and performance of RDF combustion processes. Components such as waste material composition, particle size and shape, moisture or volatile matter, as well as combustion conditions such as temperature and oxygen availability influence it. Due to its homogenous particle size and controlled composition, RDF generally has a moderate to high combustion rate. Non-combustible substances or contaminants, such as inorganic substances or high levels of moisture, can hinder the process and reduce the overall rate. Proper fuel preparation, including size reduction and homogenization, is crucial for optimizing the combustion rate of RDF (Sarc & Lorber, 2013).

Controlling the conditions of combustion, such as sustaining the proper temperature and supplying enough oxygen can further increase the rate of combustion. In the applications requiring rapid and efficient energy release, such as industrial boilers and waste-to-energy plants, the combustion rate is essential. Understanding and optimizing the rate of combustion maximizes energy recovery and reduces environmental impacts. For more information on the RDF combustion rate and its specific characteristics, academic databases and targeted literature searches can yield research papers, scientific articles, and literature reviews.

In this combustion process, coconut fiber is more easily burned than RDF pellets, briquettes, and coal products. Coconut fibre takes 9 minutes to burn in the form of coal, but RDF pellets take 29 minutes longer. The briquette burning process takes 39 minutes, and the coal burning takes 20 minutes. The combustion process becomes lengthy because the burning does not spread rapidly from one briquette to another briquette or pellet to pellet, so the combustion process is longer. The combustion test is shown in Figure 2.

### *Storage durability*

The potential of refuse-derived fuel (RDF) to maintain its quality and properties over an extended period of time in a controlled environment is due to its stored durability. It entails evaluating how well RDF retains its energy content, physical properties, and overall stability during storage. Moisture control, temperature control, air circulation, contaminant control, and storage infrastructure all impact the durability of stored RDF. Controlling moisture is essential for minimizing moisture ingress and preserving the integrity of RDF. Temperature regulation is essential for preventing deterioration processes, while air circulation helps prevent condensation and spontaneous combustion.

The presence of contaminants, such as non-combustible materials, metals, or glass, can reduce the durability of stored RDF and lead to equipment damage or operational issues. During RDF production, proper sifting and screening can

**Table 3.** Started burning time

| No | Parameter | Material | | |
|---|---|---|---|---|
| | | Temple waste | Coconut fibre | Coal |
| 1 | Combustion process | Started in 29 minutes<br>Temperature: 160 °C | Started in 9 minutes<br>Temperature: 180 °C | Started in 39 minutes<br>Temperature: 220 °C |

**Figure 2**. Product combustion and durability test

reduce the presence of contaminants and increase their durability in storage. Infrastructure for storing RDF, such as appropriate flooring, drainage systems, fire prevention measures, and adequate space for equipment manoeuvrability, is essential for guaranteeing its durability. Monitoring RDF on a regular basis is necessary to detect degradation or changes in its properties over time. This may entail periodic sampling and analysis of RDF samples in order to evaluate variables such as moisture content, energy content, and physical properties. By implementing appropriate storage practices and maintaining suitable storage conditions, stored RDF can be optimized, ensuring that its quality and energy content remain suitable for combustion or other uses.

### *Temperature durability*

The durability of refuse-derived fuel (RDF) products is crucial for their use in combustion or energy recovery systems. It entails evaluating how well RDF maintains its physical integrity, energy content, and other important properties throughout its lifecycle as a fuel product. Particle size and homogeneity, structural integrity, moisture content control, contaminant control, and packaging and storage all influence the durability of RDF. Particle size and homogeneity facilitate uniform combustion and handling, whereas structural integrity measures the resistance of RDF to fracture, fragmentation, or degradation during handling and transportation. High moisture levels can lead to fungal growth, decomposition of organic components, and a decrease in energy content, making moisture control essential for preserving the desired moisture level. Controlling contaminants reduces their presence, resulting in a more durable and consistent fuel product. The durability of the product is seen in how resistant the briquette product is to fire by measuring the temperature within a certain period of time. The rate of product change is the prevalence of the change in a given period of time. The durability of the product can be seen in Figure 3.

Packaging and storage are essential for the preservation of RDF products, protecting them from moisture, contamination, and physical damage during transport. Ensuring appropriate manufacturing processes, quality control measures, and adherence to pertinent standards and specifications improves the durability of RDF products, ensuring that they retain their desired properties, such as energy content and combustion characteristics, throughout their lifecycle. Regular quality checks and monitoring of RDF products, such as sampling and analysis, assist in assessing their durability and identifying deviations or issues that may impact performance. This enables corrective measures to be taken to preserve product integrity and maximize utilization efficiency.

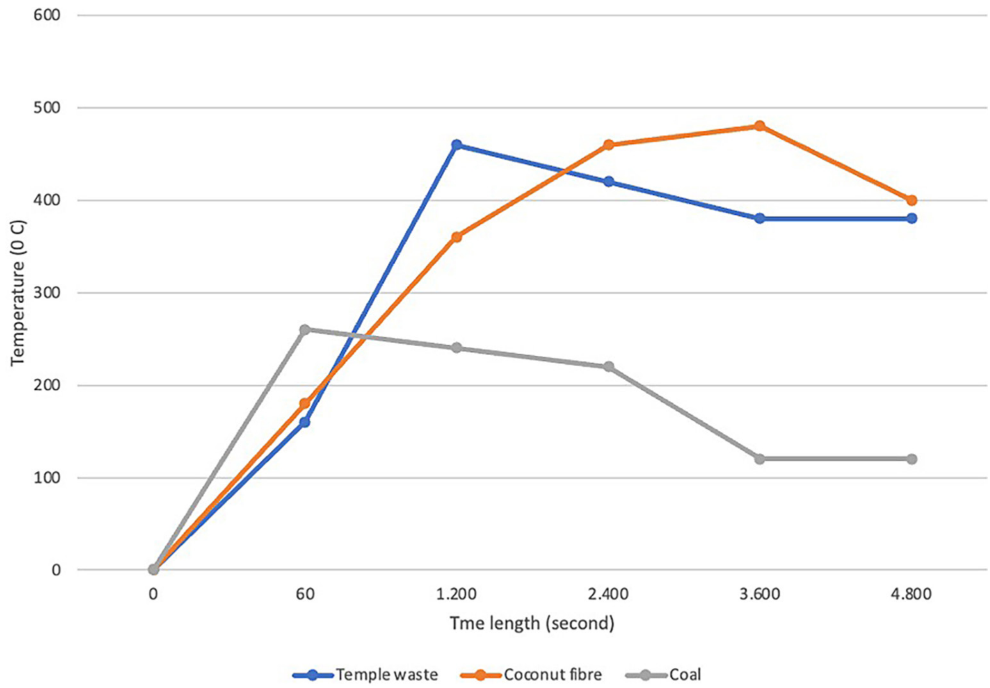


**Figure 3.** The temperature of RDF according to the burning time

The following is an explanation based on this observation.

1. Once coal is detected in the coconut fiber and RDF pellet products, the briquette product begins with a temperature of 160 °C in the first minute, while the cacao fiber reaches 180 °C in the first minute.
2. After 20 minutes of incineration, the temperature of coconut fiber increases to 360 °C, whereas the temperature of RDF pellets reaches 460 °C. This indicates that briquette anthracite is hotter than coconut fibers at the 20-minute mark. RDF pellet coal distributes more slowly than coconut fiber and generates more heat; 240 °C applies to both briquettes and coal.
3. At the forty-minute mark, the temperature of the coconut fiber decreases and the material is completely consumed, so 200 grams are added. This results in a rise in the temperature of coconut fiber. With a temperature decline to 420 °C, RDF coal pellets continue to be resistant. The temperature of the briquette drops by up to 120 °C. The temperature of the briquette also decreased, while the temperature of the coal remained constant.
4. At the 60-minute mark, the RDF pellets retained their heat despite experiencing a decline due to the absence of pellet additions. While coconut fiber coal has diminished and exhausted its supply, 200 grams of coconut fiber have been added. This resulted in a 480 °C increase in the rear of the coconut fiber. Without re-adding the material, the temperature of the RDF granules dropped to 380 °C. It is also encountered by briquette and coal products when there is a drop in temperature.
5. A re-measurement was performed at the 80-minute mark, when the temperature of the RDF pellets remained stable at 380 °C, while the temperature of the coconut coal had dropped to 400 °C and had already turned to charcoal. Temperatures dropped for coal and coal-based products as well.

## CONCLUSIONS

The RDF made from temple waste has best result among coconut fibre and the mixture of both with above 4800 kcal/kg. It is belonged to class 2 solid fuels based on their characteristics according to the National Standard for biomass-based fuel. Furthermore, the RDF is still needs to be improved for industrial scale and requirement. Product durability test has shown good result for the temple waste material comparing with coconut fibre and coal. The study shown that temple waste and coconut fibre are promising to be processed into RDF as coal substitution in the combustion process. Other combustible materials from organic waste could be also used to increase the quality of RDF in the further study.

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