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Regional Case Study

Potential Waste from Temporary Shelters in the Area of Universitas Pertamina as Raw Materials of Refuse Derived Fuel (RDF)

Betanti Ridhosari[1]*, I Wayan Koko Suryawan[1], Ari Rahman[1], Ardhan Ardianto[1], Nurulbaiti Listyendah Zahra[1]
[1] Department of Environmental Engineering, Faculty of Infrastructure Planning, Universitas Pertamina, South Jakarta, 12220, Indonesia
* Corresponding Author, email: betanti.ridhosari@universitaspertamina.ac.id

Abstract.
Universitas Pertamina has a strong vision in the energy field and is developing environmentally friendly infrastructure and management, including waste management. Considering these efforts, 'waste-to-energy' is an interesting concept to be developed. The practical application of this concept is exemplified by refuse-derived fuel (RDF). This research aimed to analyze the potential of waste from Universitas Pertamina's temporary shelter as raw materials for RDF and identify the potential energy that can be produced. This research began by measuring the generation and composition of waste. Each type of waste is identified for water content, ash content, and calorific value. These findings were used to identify which waste types could serve as RDF raw materials. The water content analysis showed that, except for food waste, all waste types met RDF standards. All waste types also met the RDF ash content standards. The calorific value analysis showed that plastic waste had the highest heating value at 45.6 MJ/kg, followed by rubber waste (40.1 MJ/kg) and styrofoam (35.0 MJ/kg). Calculations for waste generation potential and heating value indicated a total potential calorific value reached 9,895.1 MJ/day. With this significant potential, Universitas Pertamina has the opportunity to develop innovative waste management, especially in producing RDF.

Keywords: Refuse derived fuel (RDF); water content; ash content; calorific value; waste-to-energy.

1. Introduction

Higher education is closely aligned with its role as articulated in the three pillars: education, research, and community services, all focusing on sustainable development. Universities should contribute to environmental sustainability by adopting effective environmental management systems that mitigate the adverse environmental effects of campus activities and enhance the efficiency of their various systems, including transportation, infrastructure, energy, and utilities (Abubakar et al., 2016). Universitas Pertamina has a strong vision in the energy sector. Universitas Pertamina aspires to be a global institution in innovation and entrepreneurship in technology and business, focusing on energy.

One potential for energy utilization within the campus environment is using waste as a new renewable energy source. Within its campus infrastructure and facilities development framework, Universitas Pertamina actively promotes a green campus program that prioritizes environmental management efficiency, including solid waste management. It shows that its waste management effort aligns with the larger goal of minimizing environmental impacts. The management of waste generation stands out as a critical factor that must be addressed to achieve sustainable infrastructure (Zen et al., 2016).

The waste composition at Universitas Pertamina encompasses various materials, ranging from food waste, leaves, PET bottles, styrofoam, plastic waste, paper, glass, metals, and more (Ridhosari & Rahman, 2020). Regrettably, much of this generated waste reaches final disposal sites (TPA), where most still adhere to open dumping or controlled landfill systems. The application of these systems has environmental side effects, primarily concerning land requirements, water pollution from leachate, air pollution, and a decline in the community's standard of living. Hence, exploring waste management strategies that incorporate energy recovery as a proactive and sustainable solution becomes imperative.

Energy recovery from waste can be achieved by producing RDF through pellets, briquettes, or powder tailored to specific needs. Processing waste into RDF is a proactive step in providing solid fuel for cement and power generation (Longo et al., 2020). Based on a life cycle assessment (LCA) of cement production that was found in the studies by Tun et al. (2021), Stafford et al. (2016), and Kosajan et al. (2020), the cement industry requires RDF to support the reduction of fossil fuel usage and greenhouse gas emissions. However, Indonesia's current RDF production from waste processing must sustain cement production (Ummatin et al., 2017). Sustainable urban waste management and supporting environmentally friendly industrial processes are the responsibilities of all levels of society. Waste processing, which mainly focuses on downstream waste management, should shift to the source of waste (source reduction). One potential source of waste in this regard is public facilities like the area of Universitas Pertamina.

An analysis of the waste utilization potential from the higher education sector was conducted at Rajamangala University of Technology Isan, Surin Campus, with a low heating value reaching 29 MJ/kg, exceeding the RDF quality standards from Italy, and surpassing previous data reported in studies from China and Korea (Weerasak & Sanongraj, 2015). This analysis indicates that waste from higher education institutions can also be turned into RDF. RDF is valuable for reducing waste's water content, increasing the resulting product's calorific value, reducing leachate production, converting waste into energy, recovering waste, and decreasing pollutant emissions into the environment (Weerasak & Sanongraj, 2015). RDF is an alternative fuel produced from waste materials with a high energy content. Therefore, this research focused on Universitas Pertamina due to the minimal research in Indonesia that has explored the potential of converting waste generated into RDF across all areas of a higher education institution. Previously, Institut Teknologi Bandung had processed cafeteria waste using a bio-drying process, potentially producing RDF as raw materials in cement industry combustion (Chaerul & Fakhrunnisa, 2020). However, that initiative was limited to cafeteria waste and all the mixed waste into RDF without a detailed analysis based on waste types. The production of RDF from waste requires selecting the appropriate waste composition to achieve a high calorific value. Therefore, a detailed and comprehensive study of the waste composition at Universitas Pertamina is imperative before implementation. This research seeks to contribute valuable insights to enhance the references and foster innovation in waste management at higher educational institutions.

On this basis, the objectives of this research are as follows: 1) to identify the potential waste available at Universitas Pertamina's Temporary Shelter as raw materials for RDF and 2) to estimate the total calorific energy for each waste composition present at the temporary shelter.

2. Methods

This research commenced by measuring waste generation and composition in the area of Universitas Pertamina. Subsequently, each type of waste was assessed using several parameters, including water content, ash content, and calorific value. Based on the measurements, the total calorific value was estimated by considering the quantity of each waste type generated. It was conducted to identify which type of waste holds the highest potential value.

2.1. Measurement of Waste Generation and Composition in the Area of Universitas Pertamina

The study's waste generation and composition measurements were conducted through load count analysis over eight days. The measurement followed the guidelines of SNI 19-3964-1994, which specify the methods for sampling and measuring urban waste generation and composition. The equipment for this measurement included a 20 cm x 20 cm x 100 cm sample volume measurement tool equipped with a height scale, digital scales, a logbook, writing instruments, a measuring tape, and personal protective equipment such as gloves and masks.

Waste generation and composition measurement took place at a temporary shelter within the area of Universitas Pertamina. The selection of temporary shelters as the sampling location represents the waste characteristics generated by stakeholders within the area of Universitas Pertamina. It includes the campus area of Universitas Pertamina, the building of Persatuan Wanita Patra (PWP), the building of Pertamina Corporate University (PCU), the office building of Pertamina Foundation (PF), the building of Pertamina Simprug Residence (PSR), and others.

2.2. Measurement of Water Content, Ash Content, and Calorific Value

This study's waste characterization involved measuring water and ash content, adhering to established gravimetric principles. The water content measurement was conducted per ASTM E 790-87 (2004) guidelines, known as the "Standard Test Method for Residual Moisture in a Refuse-Derived Fuel Analysis Sample." This process involved heating the samples in an oven, ensuring accurate moisture level assessments.

Similarly, ash content measurement in the waste sample adhered to the standard ASTM E 830-87 (2004), titled "Standard Test Method for Ash in the Analysis Sample of Refuse-Derived Fuel." This part of the analysis required an electric furnace capable of reaching the high temperature necessary to incinerate the waste samples completely, leaving behind ash residue. This residue was then measured to determine the ash content.

The third parameter that was analyzed in this research is calorific value. The calorific value was determined using a bomb calorimeter, following the standard measurements outlined in ASTM D5865, "Standard Test Method for Gross Calorific Value of Coal and Coke."

These three parameters were compared with standards set by the Ministry of Energy and Mineral Resources of Indonesia (Ministerial Regulations No. 47 of 2006 concerning Guidelines for the Production and Utilization of Coal Briquettes and Solid Fuel Based on Coal) and Italy. RDF with a low heating value (LHV) of 15.58 MJ/kg can be an alternative to conventional fossil fuels in various industrial sectors, including the cement industry (Hemidat et al., 2019). The utilization standards for RDF as a fuel are outlined in the Ministry of Energy and Mineral Resources Regulation No. 47 of 2006, specifying a maximum water content of 15% and a minimum calorific value of 4,400 kcal/kg (18.42 MJ/kg). This research also used Italian RDF standards because they align closely with the waste characteristics at the Rajamangala University of Technology Isan Surin Campus in Thailand, where they were similarly applied (Weerasak & Sanongraj, 2015). The similarity in waste characteristics between Universitas Pertamina and Rajamangala University highlights the potential applicability of these standards in the context of higher education.

2.3. Estimation of the Potential Calorific Value

Based on the calorific value analysis and waste generation data and composition, the potential energy generated from Universitas Pertamina's temporary shelter through waste utilization as RDF raw materials can be estimated. The estimation of the potential calorific value per day can be seen in Eq.(1). Each type of waste has its calorific value. As discussed in the previous section, each type of waste is generated in different amounts. Therefore, the total potential calorific value for each type of waste can be determined by multiplying the calorific value of each waste type by its respective waste generation.

$$Estimation\ of\ the\ Potential\ Total\ Calorific\ Value\ \left(\frac{MJ}{day}\right) = Waste\ Generation\ \left(\frac{kg}{day}\right) X\ Calorific\ Value\ \left(\frac{MJ}{kg}\right) \quad (1)$$

This calculation is deemed crucial as it facilitates understanding how transforming waste into RDF can serve as an effective method for both waste management and simultaneous energy production. This strategy encompasses more than merely disposing of waste; it involves the intelligent utilization of resources to fulfill the university's energy requirements.

3. Results and Discussion

3.1. Waste Generation and Composition

Figure 1 shows the average waste generation over eight consecutive days. The total average waste generation produced in the area of Universitas Pertamina is recorded at 605.2 kg/day. The highest waste generation is food waste, with a value of 190.7 kg/day, while the lowest is rubber waste, at 0.5 kg/day.

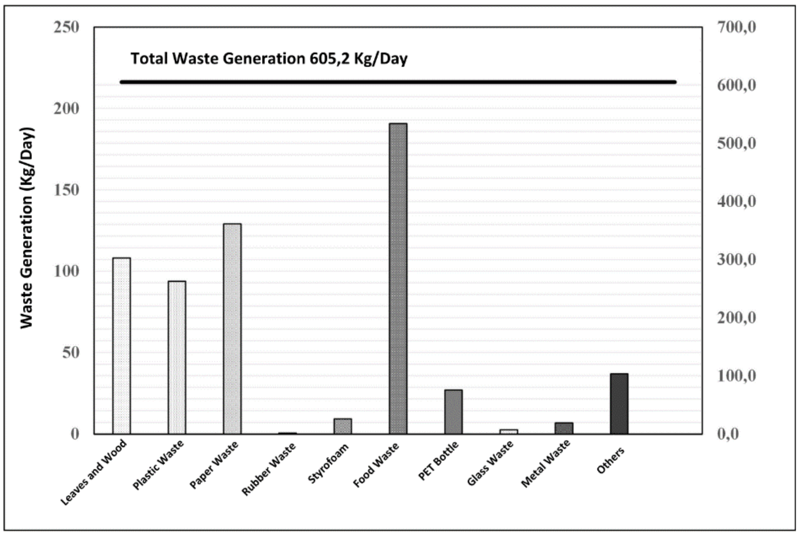

Figure 1. Average waste generation in the area of Universitas Pertamina

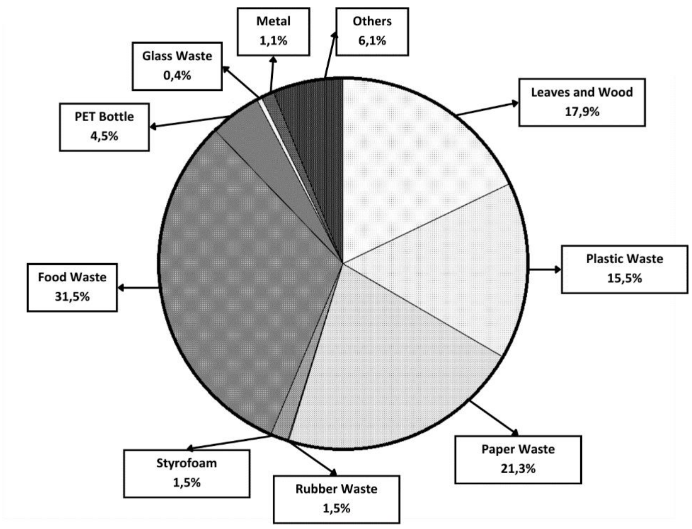

Figure 2. Waste composition in the area of Universitas Pertamina

Understanding the composition of the generated waste is essential for evaluating its suitability for RDF production. Therefore, the waste composition was analyzed to identify materials with the highest potential for energy recovery.

The waste composition in the area of Universitas Pertamina significantly affects RDF processing. Figure 2 shows that food waste has the highest composition (31.5%), followed by paper waste (21.3%), leaves and wood (17.9%), and plastic waste (15.5%). These results align with the National Waste Management Information System, where food waste is also the highest at 40.6% (GOI, Indonesia Waste Composition, 2022). Studies at other universities (Yuliandri et al., 2019; Dewilda, 2015) similarly found that university waste is mainly organic (food leftovers), paper, and yard waste (leaves and woods). Inert materials waste such as glass, metal, and other waste are included in the low composition of waste. These inert wastes typically become residues and can be landfilled or recycled. On the other hand, based on Aziz et al. (2023), iron materials, glass, and metals are non-combustible solid waste materials. Therefore, metals, glass, and other solid waste (called "Others" in Figure 2) should be excluded from RDF raw materials.

3.2. Water and Ash Content Analysis

After determining the waste composition, it is crucial to assess the water and ash content of these wastes, as these parameters significantly affect their potential as RDF materials. The water content of waste impacts its calorific value and the treatment for RDF. High water content produces low calorific value because water (H2O) has no heating value. Therefore, the water content in solid waste should be minimized to accelerate the combustion process (Intang et al., 2021).

The water content analysis (Figure 3) shows that food waste has the highest water content (48.0%), primarily due to the high water content of rice, a common food waste component in Indonesia. In contrast, plastic waste has the lowest content (0,1%), making it highly sutiable for RDF production. These findings are consistent with previous studies that highlight the moisture variability among different waste types (Intang et al., 2021).

Figure 3 shows that all types of waste, except food waste, meet the standards set by the Ministry of Energy and Mineral Resources of Indonesia, which is maximum 15% (GOI, Regulation of The Minister of Energy and Mineral Resources of The Republic of Indonesia 047/2006 Regarding Guidelines for the Production and Utilization of Coal Briquettes and Solid Fuels Based on Coal, 2006) and the Italian national standard for RDF in terms of water content, which is maximum 25% (A. Gendebien, 2003). It indicates that food waste is less suitable for direct use as an RDF raw material. High water content in waste reduces energy recovery effectiveness (Tom et al., 2016). Food waste typically needs prior processing using methods that require time and energy, such as bio-drying (Fadlilah & Yudihanto, 2013), rotary dryers (Naryono & Soemarno, 2013), carbonization (Ristianingsih et al., 2013), and others. For instance, a study at Institut Teknologi Bandung found that cafeteria waste needs to undergo a 17-22-day bio-drying process (Chaerul & Fakhrunnisa, 2020). Another study in a cafeteria at Universitas Airlangga concluded that food waste is not potential RDF raw materials (Adelia et al., 2014). Therefore, in this study, food waste is not recommended as a raw material for RDF production in the area of Universitas Pertamina.

Figure 4 shows that the ash content of each waste type at Universitas Pertamina's Temporary Shelter meets the Italian RDF standard, based on A. Gendebien (2003), the maximum value is 20%. Leaves and wood have the highest ash content (14.1%), followed by PET bottles (9.6%) and food waste at 5.5%. The lowest ash content is found in styrofoam waste, at 0.1%. Ash content represents the amount of inorganic residue that does not disappear during high-temperature combustion (Rania et al., 2019). A higher ash content can affect the quality of RDF, which in turn influences the characteristics of the combustion residue.

In general, the water content is inversely proportional to the calorific value (Lokahita & Damanhuri, 2013), so the solid waste that has a low water content has the potential to have a high calorific value, notwithstanding the solid waste that has a high-water content have the potential to inhibit the combustion process.

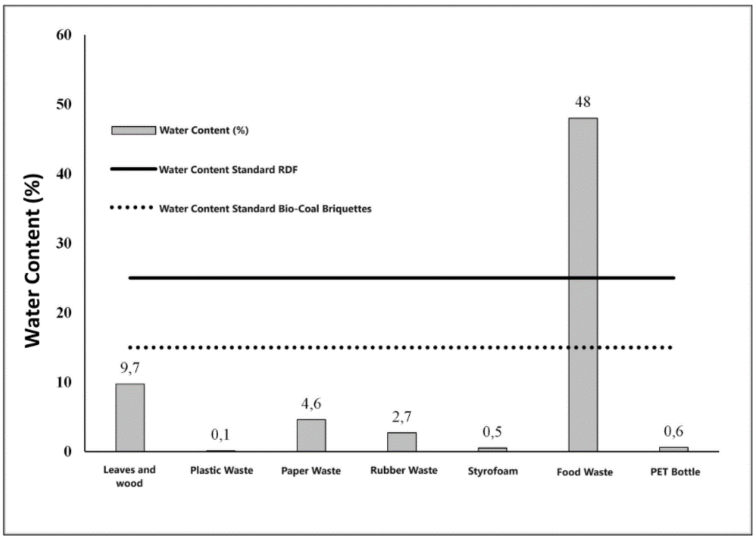

Figure 3. The measurement results of water content for each waste type at Universitas Pertamina's temporary shelter

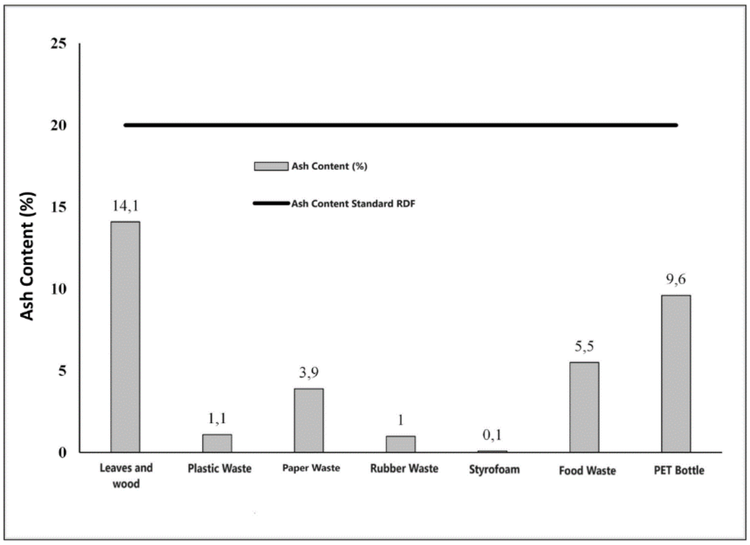

Figure 4. The measurement of ash content for each waste type at Universitas Pertamina's temporary shelter

3.3. The Measurement of Calorific Value

With food waste excluded, the remaining waste types were analyzed for calorific value. Figure 5 displays the results of the calorific value (lower heating value) for each type of waste, compared to the standards set by the Indonesian Ministry of Energy and Mineral Resources for bio-coal briquettes and the Italian national RDF standard. All types of waste (plastic, paper, rubber, styrofoam, and PET bottles) meet the calorific value standards set by the Indonesian Ministry of Energy and Mineral Resources (a minimum of 4,400 kcal/kg) and the calorific value standard of Italy, which is based on A. Gendebien (2003) greater than 15 MJ/kg. Plastic waste has the highest calorific value (45.6 MJ/kg), followed by rubber (40.1 MJ/kg), styrofoam (35.0 MJ/kg), PET bottles (24.7 MJ/kg), leaves and wood (20.1 MJ/kg), and paper (18.8 MJ/kg).

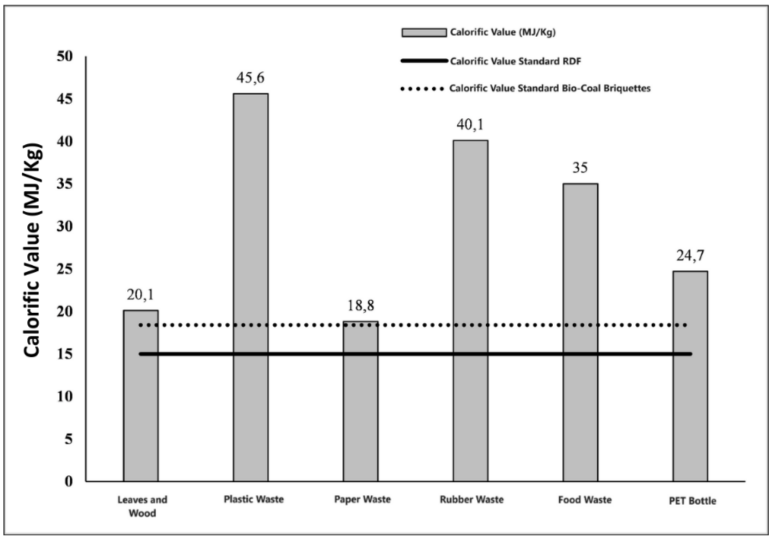

Figure 5. The measurement results of calorific value for each waste type at Universitas Pertamina's temporary shelter

The calorific value represents the heat energy a material generates during combustion (Rania et al., 2019). As discussed earlier, water content is inversely related to calorific value. Izaty et al. (2018) also state that high ash content tends to lower calorific values and vice versa. This relationship can be observed in Figures 3, 4, and 5. If waste has lower waste and ash content (such as plastic, rubber, and styrofoam), the test results show higher calorific values than other waste types.

Solid waste (leaves and wood, paper, and PET bottles) exhibits different characteristics. For leaves and wood waste, it is evident that their water and ash content are higher than other waste types, resulting in relatively lower calorific values. On the other hand, paper and PET bottle waste have relatively low water content, but their ash content is high compared to other types. It is a factor contributing to their relatively lower calorific values compared to the others.

3.4. Calorific Value Estimation

Following Eq.(1), the calorific value from waste at Universitas Pertamina's Temporary Shelter as RDF raw material is estimated. This calculation determines how much energy Universitas Pertamina can get from its waste. By examining the potential daily waste production and understanding the energy value of the waste, the total energy that could be converted into RDF can be estimated.

As detailed in Table 1, plastic waste has the highest estimated calorific value (4,278.1 MJ/day), followed by paper waste (2,426.9 MJ/day), and leaves and wood waste (2,175.0 MJ/day). High-quality alternative fuel is derived from materials with high calorific values (Paszkowski et al., 2020), making plastic waste a promising candidate for RDF production. This finding aligns with research conducted by Kan et al (2017), which also identified plastic waste as having a high calorific value and consistent quality.

Although paper waste has the lowest calorific value, its high generation rate significantly contribute to the total energy potential. According to Sangkham & Sangsrichan (2020), the composition of paper waste is crucial in the sustainable waste management of higher education institutions, given the significant use of paper in office and academic activities. Therefore, enhancing paper waste calorific value through combinations with high-calorific materials (such as plastic, rubber, or styrofoam) could be beneficial.

Considering the daily waste generation and the potential calorific value of all waste types in Table 1, the total estimated calorific value can reach 9,895.1 MJ. This value is undoubtedly an opportunity for Universitas Pertamina to implement a waste-to-energy-based waste management system.

Table 1. The estimation of the total calorific value that can be generated from the utilization of waste as RDF raw material in the area of Universitas Pertamina

The types of waste	Generation of waste (kg/day)	Calorific value (MJ/kg)	Estimation of the total calorific value (MJ/day)
Leaves and wood	108.2	20.1	2,175.0
Plastic waste	93.9	45.6	4,278.1
Paper waste	129.1	18.8	2,426.9
Rubber waste	0.5	40.1	21.7
Styrofoam	9.3	35.0	324.0
PET bottle	27.1	24.7	669.4
Total			9,895.1

3.5. The Assessment of Universitas Pertamina's Waste Management based on Technology, Economics, and Environmental Aspect

According to Rao et al. (2017), the waste intended for treatment as RDF raw materials must undergo several processing stages, including collection, segregation, size reduction, drying, and pelletizing. The initial step involves removing non-combustible waste. Subsequently, combustible waste is shredded into a smaller and uniform particle size, preparing it for drying. Following this, the waste is compressed into pellets through a process known as pelletization.

The development of RDF technology from waste at Universitas Pertamina needs to consider several technical challenges. If plastic waste, paper waste, leaves and wood are chosen as raw RDF materials, the existing waste management system at Universitas Pertamina will need modifications to align with the stage of RDF processing. Appropriate pre-processing facilities must be provided to ensure the consistency of RDF raw materials. The facilities will be used as an area for sorting incompatible waste and helping to reduce its water content. Developing the facilities will be challenging due to the limited space available at Universitas Pertamina. Additionally, RDF can burn efficiently with an adequate fuel supply and air pollution control facilities (Purwanta, 2021). Therefore, the facilities should be effectively designed to support the combustion process.

The implementation of campus-scale waste-to-energy can be achieved using a relatively simple thermal processing method or up to the production of RDF. One such approach is installing a waste processing system with a simple pyrolysis process. This process typically requires a relatively low investment cost (Wahyudi et al., 2018). The construction of a simple pyrolysis reactor can also involve the use of repurposed tanks (Wahyudi et al., 2018) or used drums (Armadi, 2016), which can be adjusted to accommodate the waste processing capacity and generation in the area of Universitas Pertamina.

From an economic perspective, conducting a cost-benefit analysis is crucial to determine the feasibility of implementing RDF at Universitas Pertamina. According to Khan et al. (2022), a cost-benefit analysis is calculated by subtracting total costs from revenue. The total costs include initial investment and operational expenses. The initial investments required for implementing RDF production at Universitas Pertamina include technology design and installation costs, purchasing supporting vehicles and equipment, and developing infrastructure and auxiliary facilities. The depreciation costs of vehicles and other equipment also need to be analyzed. On the operational side, expenses include the salaries of the employees, the cost of general operations and maintenance, the cost of support services, and the cost of energy consumption. The revenue side includes interest income and revenue generated from RDF production.

Identifying the potential industries that could use RDF made from Universitas Pertamina's waste is essential for estimating possible revenue. However, if the implementation seems too complex, the economic benefits of the RDF system can be evaluated from different angles. Producing RDF can reduce the waste generated at Universitas Pertamina's temporary shelter, leading to cost savings by decreasing the frequency of waste transport from the university to the landfill.

From an environmental perspective, converting combustible solid waste into RDF is more environmentally friendly (Anasstasia et al., 2020). It minimizes the ecological footprint of waste disposal and recovers energy from materials that would otherwise contribute to environmental degradation. Nevertheless, there are potential risks to the sustained operation of the RDF system. These include maintaining consistent waste quality, managing the technical aspect of RDF production, and ensuring continual uptake by companies seeking alternative energy sources. This ongoing market can validate the economic viability of RDF production at Universitas Pertamina and strengthen financial stability over the long term.

Sangkham and Sangsrichan (2020) emphasized that the implementation process for waste management at the campus level necessitates cooperation from all departments, personnel, and students, including anyone involved in campus activities. The Department of Environmental Infrastructure plays a crucial role in waste management, including budgeting, campaigns, and promoting awareness among the academic community. Applying waste management at the university level is one of the steps toward achieving a 'zero waste university' (Mason et al., 2003).

4. Conclusions

This study has successfully identified the potential of waste in the area of Universitas Pertamina as RDF raw materials. The water content analysis indicates that all types of waste, except food waste, meet the RDF water content standard, with plastic waste having the lowest water content at 0.1%. Regarding the ash content parameter, all types of waste have met the RDF ash content standards, and styrofoam waste has the lowest ash content at 0.1% compared to other waste types. Based on the water and ash content analysis, food waste is not recommended as a direct raw material for RDF due to the need for preliminary processing to reduce the moisture content. All waste types analyzed for calorific value meet the standard criteria for RDF calorific value. Plastic waste has the highest calorific value at 45.9 MJ/kg, followed by rubber at 40.1 MJ/kg and styrofoam at 35.0 MJ/kg. Based on the waste generation data and calorific values, plastic waste is estimated to have a total calorific energy of 4,278.1 MJ/kg, followed by paper waste at 2,426.9 MJ/kg and leaves and wood waste at 2,175.0 MJ/kg. When calculating the overall total of waste generation and calorific values for all types of waste with the potential to be used as RDF raw materials, an estimated total calorific value of 9,895.1 MJ/day is obtained. With this significant potential, it is an opportunity for Universitas Pertamina to develop a waste-to-energy-based waste management system.

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