Current Applied Science and Technology e-ISSN: 2586-9396

Curr. Appl. Sci. Technol. 2025, Vol. 25 (No. 6), e0265123

Research article

Sustainable Waste Management Improves the Quality of Industrial RDF Production and Benefits the Environments

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Received: 25 October 2024, Revised: 3 February 2025, Accepted: 24 February 2025, Published: 22 April 2025

Abstract

Waste management significantly influences environmental conditions and living standards. This research examined raw material wastes derived from different waste managements: pre-treatment of municipal solid waste (MSW) and landfill solid waste (LSW) recovery, along with their potential effects on the quality of refuse-derived fuel (RDF), to determine an appropriate management system. Waste samples from the Eastern region of Thailand were gathered and categorized according to their source and quality. The two sample groups exhibited similarities in waste classification but differed in quantity of waste components. MSW displayed a slightly elevated average moisture and contaminant level relative to LSW. MSW had a larger fraction of soft plastics (58.78% w/w) compared to recycled landfill waste (36.55% w/w). Hard plastics represented a minor segment in both categories, yet their quantity in recycled landfill waste exceeded that in household waste by over onefold. Notably, LSW generally demonstrated superior quality compared to MSW. Both sources of solid waste were processed for RDF production in industrial operations. The RDF3 produced from the process represented 45-55% of the input raw material. The average heating value (HHV/GCV) of the RDF3 was ascertained to be 4786.90±144.10 kcal/kg. These RDF3 exhibited an average moisture content of 26.20±1.65%. The average chlorine content recorded throughout the experiment was 0.79±0.23%. Raw materials from both origins are essential for maintaining industrial production processes. RDF facility performance, when optimized, can contribute to landfill space minimization and environmental pollution mitigation. Effective management of raw materials and waste segregation provides a viable alternative fuel source for domestic industries.

Keywords: alternative energy; landfill; municipal solid waste; RDF; MSW; waste management

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https://doi.org/10.55003/cast.2025.265123
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1. Introduction

Municipal solid waste (MSW), commonly known as garbage, is made up of everyday items that are discarded by the general public. Wastes from households, businesses and commerce, and industrial sectors are also included in MSW. MSW management represents a national concern that possesses global ramifications. The production of waste on a global scale has experienced a notable escalation in recent times, with no signs indicating a potential deceleration. It is anticipated that the mass of municipal solid waste globally will rise by over 75% by the year 2050, culminating in an estimated total of nearly 3.8 billion metric tons. In the absence of immediate intervention, it is projected that more than 2 billion metric tons of municipal solid waste were produced globally (Alves, 2024).

The ASEAN region represents one of the most rapidly developing areas globally, characterized by significant population growth, swift urbanization, and the expansion of industrial sectors. Furthermore, the significance of tourism as a pertinent economic component is on the rise. The rapid pace of economic advancement has elevated the living standards of urban inhabitants, thereby facilitating a transformation in their consumption patterns, and causing increased waste generation on a per capita basis. Waste volumes in Southeast Asia are expected to increase by 150% by 2025 compared to 1995 unless comprehensive solutions are implemented (Zurita, 2024).

Over the preceding decade prior to the onset of the COVID-19 pandemic, the volume of waste generated in Thailand has experienced a continuous increase. Subsequent to the COVID-19 pandemic, the volume of waste has once again escalated, with the average waste generation within the nation over the past decade recorded at 26.7 million metric tons (Statista Research Department, 2023). The substantial quantity of waste produced necessitates effective systems for accumulation, transportation, and disposal. However, municipal authorities do not retain the requisite technical and managerial capabilities to effectively address the continuously growing waste volume. This situation is compounded by insufficient private sector participation in waste management and resource-efficient strategies. This scenario thus underscores the shortcomings inherent in the current municipal solid waste management frameworks, leading to illegal dumping, open burning and waste leakage into the environment (Wichai-utcha & Chavalparit, 2019).

The substantial increase in waste volume will precipitate escalated costs associated with waste management, alongside additional expenses stemming from pollution, adverse health effects, and climate change resulting from improper waste disposal. These financial implications are forecasted to rise by US$ 361 billion; without prompt action to address waste management, this global annual expenditure could nearly double to US$ 640.3 billion by the year 2050 (UNEP, 2024). The implementation of waste prevention and management strategies aimed at averting the most detrimental scenarios and constraining the net annual cost are needed (Abubakar et al., 2022).

A limited quantity of waste is subjected to recycling on an annual basis; however, substantial volumes continue to be disposed of in landfills, which serve as the primary method of waste management in developing nations. This practice is largely attributed to its fundamental nature and cost-effectiveness as a disposal method (Agamuthu, 2013; Alves, 2023). Despite the fact that landfills are addressing the escalating need for immediate waste disposal, the expansion of landfill capacity is prohibited due to considerations pertaining to environmentally sustainable development and public health implications (Sharholy et al., 2008). The majority of landfills exacerbate various environmental challenges, including the contamination of groundwater resulting from leachate production and the emission of greenhouse gases stemming from landfill gas generation (Iravanian & Ravari, 2020; Ozbay et al., 2021; Siddiqua et al., 2022). Consequently, the selection of landfill sites constitutes a crucial endeavor that necessitates a meticulous approach. The identification of an appropriate location for landfills is a complex undertaking influenced by an array of criteria and regulations, including elevation, slope, geology, lineament, land valuation, proximity to rivers, roads, and residential areas, as well as land use and land cover, which must be evaluated to establish a landfill site (Rezaeisabzevar et al., 2020; Asefa et al., 2021).

Many countries, including Thailand, are concerned that the increasing volumes of waste may lead to a significant deficiency of land that is suitable for disposal purposes because the unsustainable landfills will not be able to meet the normal 20-year limit (Chinda et al., 2012). At present, waste management strategies across various countries are concentrating on minimizing waste, reusing, and recycling materials to maximize their utility. The transformation of waste into renewable energy is recognized as one of the most appealing technologies in solid waste management, attributable to its substantial volume and accessibility (Weerasak & Sanongraj, 2015; Homdoung et al., 2019).

Waste-to-energy technologies are presently employed in both developed and developing countries, including France, Norway, New Zealand, Japan, Brazil, and Indonesia (Dadario et al., 2023; Rezania et al., 2023). This adoption arises from the capability of this technology to mitigate carbon dioxide and other greenhouse gas emissions while delivering beneficial environmental impacts, fostering a sustainable environment within the system, and enhancing the effectiveness of municipal waste management (Vilaysouk & Babel, 2017; Shan et al., 2021). The generation of refuse-derived fuel (RDF) from waste stands out as one of the most appealing alternative fuels for energy recovery. It has been used since the early 1970s and is presently adopted as an RDF substitute fuel across several countries (Sarc et al., 2019).

RDF quality can be classified according to the waste that has been processed as defined by the American Society for Testing and Materials (ASTM). RDF1 refers to the unprocessed original MSW that is collected and utilized as fuel. RDF2 involves the separation of non-combustible components like metals and glass, followed by size reduction through coarse grinding or cutting. RDF3 is similar to RDF2, but it has been reduced in size until 95% of the separated waste is smaller than 2 inches (Clover Power, 2023; Tahir et al., 2024). The solid materials are then shredded and treated before being processed into high-quality RDF, then rendering it to be suitable for electricity or heat generation.

RDF can be burned together with coal to reduce the amount of coal used in the cement industry. In Algeria, a study of the incorporation of RDF derived from MSW as a substitute fuel within the cement industry demonstrated that a 15% utilization of RDF would result in savings on natural gas and a reduction in carbon dioxide emissions, alongside a net reduction in gas costs (Sakri et al., 2021). Conversely, the production of RDF in another nation has encountered challenges in some case attributable to the variability in RDF composition and fuel qualities (Santos et al., 2023). The calorific value, which is quantified by the energy obtainable from RDF, holds significant importance in evaluating the commercial viability of the fuel and serves as a foundation for contractual agreements between producers and consumers.

Although municipal solid waste has a calorific value when burned, the careful separation of waste is very important in the production of high-quality RDF. Upgrading RDF to have high energy value and suitable quality is essential for use in various industries (International Finance Corporation, 2017). The raw material wastes composed in the production of RDF constitute the primary source of calorific energy. This waste commonly comprises a multitude of unseparated waste types at its source, including food scraps, organic waste, mixed plastics, glass, textiles, paper, and other assorted waste.

In this investigation, the management of solid wastes in the Eastern region of Thailand was examined, focusing on the conversion of waste to RDF energy through authentic industrial processes. The quality of the raw material wastes arrived at the facility, derived from MSW and LSW management processes, were categorized and characterized. These comprehensive waste materials were amalgamated and processed in RDF3 utilizing industrial operation. Samples of the generated RDF3 underwent examination regarding their industrial attributes including heating value, proximate moisture, and chlorine concentrations. These results will be relevant to the management of the process of converting large amounts of solid waste to RDF energy.

2. Materials and Methods

2.1 Solid waste collection and analysis

Examples of solid wastes obtained from two distinct management processes were used as the raw materials for industrial RDF processing. Solid wastes originating from municipalities (MSW) and landfills (LSW) in Eastern region of Thailand were separately transported and stored on the grounds of the RDF factory located in Chonburi Province, Thailand. LSW was typically stored at landfill locations for a period of 3 to 5 years, while MSW, which was collected at the source and underwent an air drying process. This preliminary process took up to 10 days before the waste was sent to the RDF plant. Solid wastes entering the RDF production processes and analytical processes are shown in Figure 1.

Prior to the RDF production process, the raw material waste from each truck entering the RDF factory was sampled and inspected for moisture and contaminants including heavy fractions and soil. This samples were subjected to a heating process at 110°C for a duration of 3 h. Then, the separated dry soil was weighed and recorded. The percentage of moisture content within the solid waste was computed utilizing the equation: moisture content (%) = (weight of moisture / total weight) x 100. The respective weights of contaminants were recorded.

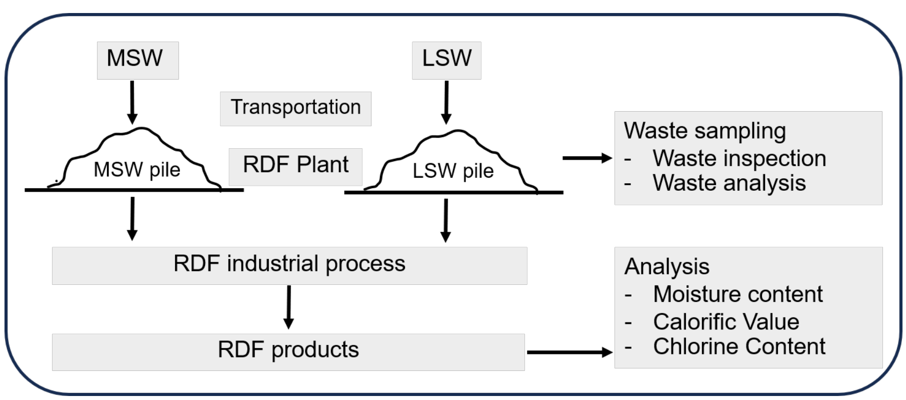

Figure 1. Municipal waste management into industrial-scale processes of RDF production

For waste analysis, solid waste from each type of management was accumulated separately as piles and subsequently mixed within each pile. Five kg of solid waste were randomly selected from each waste pile at a depth of approximately 30 cm. Waste samples were collected from ten distinct locations. The solid waste underwent the quartering method as presented by Terashima et al. (1984). The classification of solid waste was conducted based on the compositional characteristics of the waste. The sampled wastes were categorized into several waste types, including hard plastic, soft plastic, foam, paper-based materials, plant-based materials, electronic devices, metals, fabric-based materials, and glass. The percentage of sample weight relative to total weight (Ws/Wt) was classified within a defined range for each waste type. Furthermore, the average percentage for each sample was calculated. Different waste types were characterized in accordance with the primary chemical composition of the materials, and their heating values were presented.

A statistical analysis to ascertain significant differences among groups within each experimental trial was conducted utilizing one-way analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was employed to evaluate the means of the data with a significance threshold set at a probability of ≤ 0.05.

2.2 RDF industrial process

After the inspection process, waste from two sources (MSW and LSW) were mixed together, and subsequently transferred to the manufacturing process for producing RDF3. The procedure for the production of RDF3 commenced with the introduction of waste materials into the reduction process. This equipment system had the capability to process waste at a rate of 15-20 tons per hour. The RDF plant was able to operate 21 h a day, 6 days a week. The shredding operation necessitated the utilization of a pre-shredder apparatus (M&J PreShred 4000S), which comprised both a cutting table component and a conveyor mechanism. The pre-shredder with power pack of 264 kW electrical motor was equipped with a cutting table. Inside the cutting table consisted of rotating knives that featured two cutting edges directed forward and directed backward. The presence of a free opening between each pair of counter knives in the cutting table facilitated the smooth passage of sand, soil, gravel, and small metallic fragments, thereby mitigating wear in the cutting region. The resultant grain size was contingent upon both the quantity of knives employed and the nature of the waste material. The raw materials underwent size reduction. Metals and other heavy fractions were removed, utilizing a metal detector in conjunction with a magnetic conveyor belt. Subsequently, the sample was directed to an air separation process to eliminate any remain inorganic materials. Concurrently, lighter fraction materials were passed through an air classifier and subjected to size screening for enhanced separation. The size screenings utilized a coarse sieve with a size of 50 mm. The concluding step yielded fine and RDF-releasing samples.

2.3 Industrial quality analysis of RDF production

2.3.1 Sample preparation and moisture content analysis

RDF samples, comprising ten replicates, were subjected to a visual examination for potential contamination. RDF were sampled from different positions and subsequently mixed together. The collected samples were reduced in size utilizing a cutting mill (Retsch model SM 300). The particle size was reduced to 0.6 mm. A quantity of 100 g of the sample was employed to ascertain the moisture content (%) through oven-drying as per standard industrial testing protocols (Reeb & Milota, 1999).

2.3.2 Analysis of calorific value and chlorine content of RDF

The mixed RDF sample underwent further size reduction to 0.4 mm utilizing a ball mill (Retsch model PM 100). These solid forms of RDF were subsequently utilized for calorific value assessment via the bomb calorimeter method. The LECO AC-500 isoperibolic calorimeter was employed to evaluate the energy content present in the RDF sample. The RDF sample was placed within the combustion vessel and then introduced into the calorimeter. The analytical methodology followed the ASTM E711-87 standard procedure. Calibration of the calorimeter was achieved through the combustion of a reactive standard, specifically benzoic acid. The chlorine content (%) within the RDF was quantified employing titrimetric methods using an auto titrator (Metrohm Eco Titrator).

3. Results and Discussion

3.1 Solid waste analysis

The solid wastes gathered from municipalities and landfill in the Eastern region of Thailand exhibit high levels of organic waste and moisture content, which varies depending on the environment and season. However, before entering this RDF plant, both MSW and LSW raw materials must go through a preliminary process to remove the main part of the organic material and control the quality of the raw materials. MSW was subjected to natural air drying under sunlight prior to their transfer to the RDF plant in order to mitigate moisture content and organic matter and thus reduce undesirable odors. LSW arriving at the plant tended to be smaller in size and had less odor than MSW. The microbial fermentation process that occurs in landfills causes the decomposition of organic and inorganic materials present in the waste, resulting in a reduction in the size and mass of the organic and inorganic materials. In particular, organic materials that are stored in landfills for longer periods of time will decompose completely, resulting in reduced odors of LSW. However, when organic waste is disposed into landfills, it readily releases methane gas into the atmosphere. Various strategies have been implemented over time to mitigate the environmental impact of the organic fraction. The primary approach of waste management involved the decomposition of organic material prior to its reuse or final disposal (Ripa et al., 2017). Recyclable materials within waste collection systems may also be contaminated with microbial organisms that proliferate from organic wastes (Browne & Murphy 2014; Salambanga et al., 2022).

Wastes originating from diverse sources that are directed to the RDF facility undergo inspection to assess raw material quality in accordance with established industrial standards. Waste with strong odor and high moisture content is rejected before entering the plant. The moisture content of the wastes was evaluated and subsequently accepted, as illustrated in Table 1. The MSW raw materials demonstrated an average moisture content (35.68±6.51%) that exceeded that of the LSW raw materials (29.82±7.81%), while LSW exhibited a marginally elevated average heavy fraction percentage compared to MSW; however, the differences in these two parameters were not statistically distinguishable. The proportion of soil contaminants present in MSW was statistically greater than that found in LSW. The total contaminants in MSW were slightly higher than

Table 1. Inspection and testing results of raw material derived from municipal solid waste (MSW) and landfill solid waste (LSW)

Raw Materials	Moisture Content (%)	Heavy Fractions (%)	Soil (%)	Dry Soil (%)	Contaminants (kg)
MSW	35.68±6.51[a]	2.76±1.09[a]	2.03±0.39[b]	0.39±0.06[a]	5.17±1.36[a]
LSW	29.82±7.81[a]	2.97±1.28[a]	1.65±0.27[a]	0.29±0.11[a]	4.92±1.57[a]

The average values (mean ± SD) shown with different superscript letters (a-b) in the same column are significantly different ($p \leq 0.05$).

those in LSW, yet this difference was not statistically significant. A quantity of 5 kg from each source of solid waste was classified into distinct material types based on their physical structure and chemical composition, as shown in Table 2.

The composition expressed in terms of weight percentage for eight distinct categories of waste encompasses hard plastic, soft plastic, foam, plant-based materials, paper-based materials, fabric-based materials, electronic devices including metal, and glass (%w/w). The predominant waste composition observed in both MSW and LSW was soft plastic, which constituted approximately 58.78% and 36.55%, respectively. Plant-based materials (15.46%) and fabric-based materials (12.16%) were identified as the second and third most prevalent waste components within MSW. Conversely, hard plastic and paper-based waste represented merely about 3-5% of the total solid waste, while electronic devices including metal, and glass comprised negligible amounts or were entirely absent. Within LSW, the average composition included 20.38% fabric-based materials, 12.43% plant-based materials, 8.15% paper-based materials, 10.05% hard plastic, 4.67% electronic devices and metal, 4.28% glass, and 3.49% foam.

Table 2. Compositions of municipal solid waste (MSW) and landfill solid waste (LSW)

Waste Composition	MSW		LSW	
	Range (%w/w)	Mean (%w/w)	Range (%w/w)	Mean (%w/w)
Hard Plastic	2.14 - 7.09	4.38	8.35 - 13.89	10.05
Soft Plastic	45.69 - 69.87	58.78	18.46 - 52.69	36.55
Foam	1.17 - 8.92	5.12	0.50 - 5.52	3.49
Plant based	2.16 - 34.56	15.46	0.59 - 32.17	12.43
Paper based	0.52 - 6.25	3.35	1.60 - 10.79	8.15
Fabric based	8.41 - 19.23	12.16	5.20 - 36.46	20.38
Electronic device & metal	0.28 - 3.11	0.75	0.00 - 13.68	4.67
glass	ND	ND	1.02 - 11.10	4.28
Total		100.00		100.00

ND = Non detectable

Waste collected from both sampling piles exhibited similar compositions. The proportion of soft plastic materials present in MSW significantly exceeded that found in LSW. Conversely, LSW contained a greater quantity of hard plastic compared to MSW. This phenomenon may be attributed to the fact that certain soft plastics within the landfill waste may decompose and fragment into smaller materials more readily than their hard plastics.

The combustible solid wastes include plastics, paper, textiles, and plant-based materials, with the predominant component being a mixture of both soft and hard plastics, can be utilized to generate RDF product (Dong & Lee, 2009; Tihin et al., 2023). Given that combustible solid waste, particularly plastic, possesses a substantial heating value of approximately 10,000 kcal/kg (refer to Table 3). Variations in the composition of waste entering the RDF production process have an impact on the overall calorific value of the resultant RDF product. Hence, from waste management process, this calorific value can be estimated with a reasonable degree of accuracy.

3.2 RDF process

After the inspection process, the mixed solid waste from two sources was transferred to the RDF3 manufacturing process. Since industrial RDF plants are designed with high production capacity, they require a continuous supply of raw materials to achieve optimum performance and obtain the associated benefits from industrial operations. The inflow of waste is directed towards the reduction process at an approximate capacity of 400 tons per day and 2,400 tons per week. The achievable production capacity depends on the weight and moisture content of the input materials. This machinery process has the capability to transport a maximum of 20 tons of waste per hour, and following pre-shredder processing, the modified waste exhibits an output size of less than 50 mm. Approximately 97% of the waste successfully traversed the metal separation process, while 75% of the residual waste originated from the air separator. Contaminants, including soil, gravel, metallic fragments, organic materials, and other heavy fractions, were eradicated after the metal separation and air separation processes. These materials underwent further reduction in size through a two-step size screening procedure. RDF3 (45-55%) products were generated from this plant process. Figure 2 shows the approximate amounts of unwanted wastes and products obtained from the steps of the RDF process. The moisture contents of initial raw materials varied depending on their source and environmental factors, while the foreign wastes were extracted from the main product, followed by the implementation of air-drying. The resulting RDF products are presented in Figure 3.

Table 3. Classification of waste type based on their material composition, showing their heating values

Waste type	Waste Products	Heating Values (kcal/kg)	Ref.
Hard plastic	Polypropylene-package	10904	Sutha et al., 2020 & The Engineering Tool Box, 2014
	Pet bottle	5681	
Soft plastics	Polyethylene - film	10505	
	Glass tape - resin covered	4345	
Foam	Foam - scrap	6765	
Plant base	Wood	4736	
Paper base	Paper	4164	
Fabric base	Fabric - nylon	7260	
	Fabric - rubber coated	6050	
	Fabric - vinyl coated	4895	
	Rags	4208	

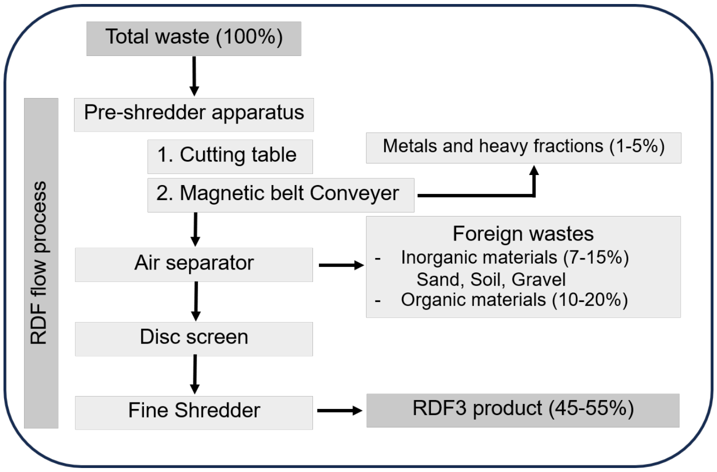

Figure 2. RDF flow process and product intensity

3.3 RDF quality analysis

The RDF3 derived from industrial process were analysis for the standard quality. Table 4 presents the outcomes of ten trials involving RDF-releasing samples, specifically regarding moisture content, chlorine content, and calorific value. The moisture content observed during this study varied between 24.16% and 29.08% (26.20±1.65% average). The comparatively low moisture content results in diminishing microbial growth in the solid materials at the source, rendering it compliant with the RDF industry standards of Thailand's local cement industry, similar to RDF produced via the bio-drying method (Bhatsada et al., 2023). Volatile components, mainly chlorine, which is a critical element, can impair the efficiency of waste-to-energy processes due to its corrosive characteristics at elevated temperatures. The average chlorine content recorded during the experiments was 0.79±0.23% and fluctuated between 0.39% and 1.05%. Chlorine can come from various sources including rigid plastics such as polystyrene and PVC (Ma et al., 2020).

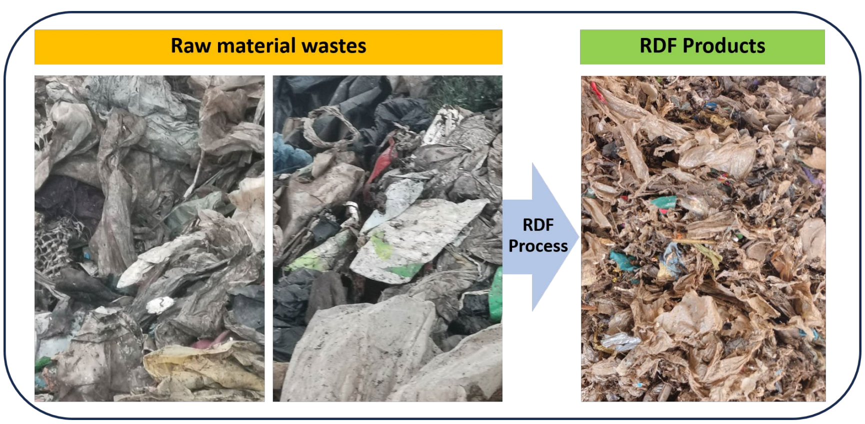

Figure 3. Material wastes before and after industrial RDF process, left: mixtures of raw material, right: finished RDF products

Table 4. Characteristics of RDF3-releasing samples from industrial process

Trial	Moisture Content (%)	Chlorine Content (%)	HHV/GCV (kcal/kg)
1	24.16	0.63	4,763
2	28.23	0.45	4,528
3	25.40	0.39	4,917
4	25.25	0.96	4,742
5	29.08	0.92	4,675
6	27.56	0.76	4,941
7	24.26	1.05	4,678
8	25.78	0.85	4,746
9	25.53	0.96	4,984
10	26.72	0.89	4,895
Average	26.20±1.65	0.79±0.23	4786.90±144.10

During the combustion process, elevated concentrations of chlorine in RDF react with other volatile components and promote the formation of low melting point compounds in fly ash, which precipitate on superheaters and instigate corrosion, thereby affecting the operational processes of the equipment (Ma et al., 2010, Mut et al., 2015). Previously, the elevated chlorine content in RDF posed challenges to the combustion efficiency of cement kilns and subsequently impacted the quality of the cement produced. The acceptable threshold for the cement industry is stipulated to be less than 1.5% (Garg et al., 2007). Currently, in factories that mainly use energy from RDF combustion, the installation of gas bypass system is considered the most effective method to prevent the operation problems caused by the accumulation of dust with high chloride value (Madlool, 2016; Wojtacha-Rychter et al., 2022).

The calorific value, commonly identified as the higher heating value (HHV) or the gross calorific value (GCV), varies with the composition of the sample mixture. By quantifying the thermal energy liberated subsequent to the combustion of the sample, the average calorific value (HHV/GCV) of the RDF-releasing samples was determined to be 4786.90±144.10 kcal/kg, with observed values spanning from 4,528 to 4,984 kcal/kg. RDF3 obtained from this industrial process had a suitable calorific value and could be used as an alternative fuel in cement kilns and power plants. The calorific value quality of RDF-releasing samples generated from various management processes exhibits minimal variation. However, the calorific value of the RDF-released sample can be estimated from the composition of the incoming waste into the plant.

Average calorific values of RDF derived from LSW stored over the intervals of 0-3 years and 3-10 years in the western region of Thailand were recorded as 6,305.96 and 4,268.84 kcal/kg, respectively (Sawasdee et al., 2023). However, the mean calorific values of RDF generated from the industrial process in this study were situated between the aforementioned values; this difference in our result may be attributed to the utilization of a raw material composition that encompassed both MSW and LSW.

Our investigation revealed that the total plastic content in raw materials from MSW and LSW was comparable to that of MSW sourced from Bangkok and LSM from the Nonthaburi Province (Teerawattana et al., 2011; Rahotharn et al., 2023). Conversely, the RDF generated from MSW originating in Bangkok exhibited an average higher heating value (HHV) as high as 6,888.1 kcal/kg for air-dried specimens (Teerawattana et al., 2011). The HHV of RDF derived from LSW in Nonthaburi Province fluctuated upon the year of waste accumulation in landfills (Rahotharn et al., 2023). Our findings indicated that the RDF produced from a composite of MSW and LSM raw materials had a superior average HHV in comparison to the RDF derived from 50:50 mixture of MSW and LSM (3776.29 kcal/kg) with a similar industrial RDF process (Infiesta et al., 2019).

The calorific value exhibited a correlation with the moisture content; as the moisture content diminished, the calorific value correspondingly increased. Additional research indicated that the calorific value of RDF was based on the composition of waste materials and was significantly influenced by the augmented heating values, particularly the proportion of plastic content (Aliaghaei et al., 2020; Cheela et al., 2021). Although the large amount of plastic packaging in waste causes environmental problems, this high polymer plastics, which are components of MSW and LSW, have a positive effect on the calorific value of RDF. In accordance with the findings of Sutha et al. (2020), the potential energy inherent in plastic waste was situated within a comparable range to that of pet coke (approximately 8500 kCal/kg) and coal (roughly 4500 kCal/kg). In addition, RDF is sold for only half the price of coal in Thailand. The amalgamation of MSW with alternative materials (specifically woody biomass) in a composite fuel blend serves to enhance its combustion efficiency (Edo et al., 2016). Waste separation at the source and moisture content reduction are essential to increase the heat value and improve the quality of the produced waste-to-energy (RDF) (Āriņa et al., 2020; Suknark et al., 2023).

LSW contains less organic waste contamination but higher levels of polymer-based wastes, which are beneficial for calorific value. Consequently, LSW is normally preferable for the RDF process and RDF production. The calorific value of LSW stored over the period of 0-10 years was considered suitable for RDF production (Dong et al., 2022; Pudcha et al., 2023). However, in this study, both waste sources were converted to RDF production under the industrial process. This type of process management supports the circular economy by converting waste into energy resources, which helps conserve natural resources and promotes environmental care. The conversion of waste to RDF energy has great potential to alleviate the constraints caused by landfill space, thereby prolonging the operational lifespan of existing landfill sites and diminishing the volume of waste necessitating disposal in landfills. Furthermore, the increased volume of waste diverted to the RDF process is beneficial to both environmental sustainability and public health, as it contributes to the reduction of long-term pollutants associated with landfills (Heyer et al., 2013; Siddiqui et al., 2013). In particular, plastic waste, which exhibits significant resistance to natural decomposition and poses considerable environmental challenges, when utilized for energy generation, yields a substantial calorific value. As a result, this strategy for management serves as an essential purpose in the field of sustainable waste management. However, the initial establishment of an RDF plant requires large-scale production planning and site preparation, including consideration of environmental impact, which require significant investment. However, the investment in setting up a large-scale plant allows waste to be managed over a large area and reduces the problem of landfill overflow.

Industries can benefit from RDF as a cost-effective energy solution, allowing them to meet energy demands while aligning with sustainability goals (Grabowski & Smoliński, 2021). The cement industry is known for its high energy consumption and carbon emissions, making RDF a suitable alternative to traditional fossil fuels (Ghenai et al., 2019). Therefore, cement manufacturers can reduce their reliance on non-renewable energy sources while also decreasing waste going to landfills. The high calorific value of RDF, derived from various waste materials, allows it to effectively be a substitute for coal and other fossil fuels in cement kilns (Mistri et al., 2021). By integrating RDF into their processes, industries cannot only reduce greenhouse gas emissions but also lower fuel costs and enhance energy security (Shehata et al., 2022). Moreover, RDF combustion emits less carbon dioxide than coal combustion, thus reducing the amount of carbon dioxide released into the atmosphere (Kristanto & Rachmansyah, 2020).

4. Conclusions

Based on these findings, the composition of solid waste from both sources (MSW and LSW) exhibited slight variations. The waste originating from the landfill site comprised a higher proportion of refuse-derived fuel (RDF) raw material and a reduced amount of organic waste in comparison to the municipal solid waste. This is a direct benefit of the management processes applied in the RDF plant. Nonetheless, the quantity of raw material from both sources is imperative for sustaining continuous feeding into the industrial plant process to achieve optimal plant capacity and for the RDF3 products to provide suitable heating value for industrial uses. The mixed plastics, particularly the soft plastics, constitute the primary component and contain a minimal proportion of non-combustible materials in the overall waste, which significantly influences the volume of RDF produced for use as an alternative fuel in the cement industry. The raw material represents the most critical aspect of the RDF production process. Thus, the waste-separation process has the potential to enhance the quantity of refuse-derived fuel. The conversion of waste to RDF significantly aids in the mitigation of landfill space utilization, facilitates the diminishment of environmental contaminants, reduces fuel cost, and concurrently fortifies energy security.

5. Conflicts of Interest

No potential conflict of interest was reported by the authors.

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