ASEAN Journal of Chemical Engineering 2024, Vol. 24, No. 3, 321 – 327

Utilization of Plastic Waste as an Alternative Fuel in Cement Industry for Improved Energy Sustainability

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Submitted 6 June 2024 *Revised* 30 November 2024 *Accepted* 6 December 2024

Abstract. The cement industry primarily relies on fossil fuels, particularly coal, which carries a significant environmental impact and constitutes about 30 – 40% of the total production costs per ton of cement. Thus, prioritizing the reduction of both economic expenditure and environmental impact through diverse alternative energy sources becomes a crucial objective in the cement industry. With a target of incorporating 11% alternative fuels by 2025, PT Indocement Tunggal Prakarsa (ITP) Tbk unit Palimanan Cirebon has adopted plastic waste as an alternative fuel in its production process. This study aims to assess the energy contribution of plastic waste and its economic benefits. Based on 2022 data, the PT. ITP Palimanan unit utilized 796 tons/year of plastic waste as an alternative fuel, reflecting an annual increase of around 241%. The heating value of plastic waste was evaluated at 7234 kcal/kg to ensure the alternative fuel's quality. Compared to low-grade coal like lignite coal, this plastic waste holds a higher heating value, resulting in additional advantages for the cement factory. Consequently, this program could substitute nearly 24,113 GJ/year of fossil energy. This utilization not only replaces fossil fuels but also combats marine pollution as the waste originates from the north coast of Java. Considering a coal price of approximately 82,767 IDR/GJ, this program can yield savings of almost 1.99 billion/year. Prioritizing process reliability and cement product quality can consistently encourage the development of more environmentally friendly cement products. Additionally, this program addresses society's waste problem by transforming it into a renewable energy source.

Keywords: Alternative Fuel, Cement Industry, Plastic Waste

INTRODUCTION

The cement industry, renowned for its pivotal role in global infrastructure development, stands at a crossroads where the pursuit of sustainability intersects with the urgent need for innovative solutions to address environmental challenges. As is known, cement materials produced from limestone and other additives are essential materials for building construction. Besides requiring a lengthy process, cement production also demands high temperatures to ensure good product quality. Cement production processes require significant energy and result in significant CO_2

DOI: 10.22146/ajche.13829

emissions. For instance, cement plants use approximately 15% of the total industrial energy in a country (Mokhtar & Nasooti, 2020; Madlool *et al.*, 2011), with total CO_2 emissions of 5–7% (Wei & Cen, 2019). Generally, the energy cost accounts for around 40-60% of the total cost of cement production (Hasanbeig *et al.*, 2012; Lim *et al.*, 2020; Bramantiyo *et al.*, 2022). Therefore, every cement plant strives to enhance energy efficiency in its operations. On the other hand, Indonesia is highly committed to reducing CO_2 emissions nationally through the Nationally Determined Contribution (NDC) target of 29% from the Business as Usual (BAU) scenario by 2030 without international assistance (Abi Suroso et al., 2022). To achieve this target, the government encourages industries, especially cement, to reduce fossil energy consumption and increase the use of renewable energy to minimize existing CO_2 emissions.

Apart from energy issues, Indonesia struggles to address the mounting waste problem, especially in urban areas. According to data from the Ministry of Environment and Forestry (KLHK), it is found that urban waste transported and dumped in Final Processing Sites (TPA) in cities/districts in Indonesia averages 41–42% of the waste generated, reaching 61 million tons per year (Wikurendra *et al.*, 2024). The problem becomes more complex as about 66.81% of TPAs are operated openly (open dumping), leading to environmental damage and human health impacts (Ramadan & Sembiring, 2023). Investments in environmentally friendly sanitary landfill TPA construction are considered too expensive and unattractive for regions. Innovations are needed to convert this waste into valuable products for society.

Generally, the composition of waste generated in Indonesia consists of 55% organic and 45% inorganic waste (Miliati *et al.*, 2019; Andriani & Atmaja, 2019; Maleiva *et al.*, 2023). Some inorganic waste components, such as paper and metal, have been reused, while the rest is still disposed of in TPAs. With a heating value ranging from 3500 to 4500 kcal/kg, this residual waste can be utilized as an energy source in suitable industries (Khalil *et al.*, 2019). The abundant and continuously generated waste makes it attractive as an industrial energy source because its availability is guaranteed. This residual waste mixture can be turned into a solid fuel product called RDF (Refuse Derived Fuel). However, due to its specific characteristics, using waste as an energy source in industries faces difficulties such as air pollution, combustion process optimization, and others (Madlool *et al.*, 2005; Demirbas, 2020; Beyene *et al.*, 2018). As mentioned, the cement industry requires high temperatures around 1300°C to produce high-quality products. Fossil fuel coal is the mainstay fuel for cement plants to reach this temperature. Substituting coal with RDF fuel is highly feasible as it has similar characteristics in terms of being a solid and its heating value. Research development on the production and benefits of using RDF has been extensively conducted, but evaluations of its direct application in the industry have not yet been conducted. Therefore, this paper discusses the evaluation of the direct use of RDF in the cement industry process.

PT Indocement Tunggal Prakarsa (ITP) Tbk, Palimanan unit, is a cement plant located in Cirebon, West Java, producing three different products: Portland Composite Cement (PCC), Portland Pozzolan Cement (PPC), and Ordinary Portland Cement (OPC). With increased production capacity, PT. ITP Palimanan Unit continues to seek alternative energy sources for its production processes. The achievement of using alternative energy sources, which currently stands at around 20%, could be more satisfactory for the company, prompting it to continue searching for feasible alternative energy sources.

Therefore, PT Indocement Tunggal Prakarsa (ITP) Tbk, Palimanan unit in Cirebon, as one of the leading cement industries, continues to innovate in converting fossil energy sources into renewable energy, one of which is utilizing RDF waste in its processes. Large-scale substitution presents stability, mixing, compaction, and energy conversion challenges. Information on the implementation of RDF waste utilization in production processes in this industry is limited. Thus, only a few industries dare to implement it. This article aims to evaluate the utilization of RDF waste as an energy source in one of PT. ITP's plants, along with its environmental and energy impacts. Economic benefits will also be evaluated to assess the gains obtained.

MATERIALS AND METHODS

Materials

The data used for this research came from the production process at PT. ITP Unit Palimanan, West Java, Indonesia. The RDF waste used as fuel substitution originated from Cirebon and its surrounding areas.

Only RDF that meets the minimum standards, especially heating value and moisture content, was accepted by PT. ITP. Quality testing was performed when RDF vendors submitted their samples to the company. RDF waste was performed before the production process, with the results in Table 1.

The small content of fixed carbon was compensated by the high content of volatile matter, resulting in a high heating value that meets the technical specifications required for fuel. The moisture content was maintained at a maximum of 15% to ensure the obtained heating value results in an efficient process.

Method and Data Analysis

In addition to RDF raw materials with specific specifications, the equipment and operating parameters used in this study represent the normal operating conditions of the PT. ITP Unit Palimanan factory. The existing factory produced PCC (Portland Composite Cement) and OPC (Ordinary Portland Cement) using a dry process with raw materials such as limestone, clay, silica sand, and iron sand obtained from the areas around the factory.

Table 1. Standard specification of RDF fuel based on municipal solid waste

Solid fuel	Proximate analysis (%wt)			Water content (%wt)	Sulphur content (%wt)	GHV (kcal/kg)
	FC	VM	Ash			
SNI RDF	Min. 15	65	Max. 15	Max. 15	-	Min. 4776
Coal	66.9	24.4	8.7	-	0.5	5000
RDF	4.9	82.6	9.9	6.8	0.07	7582

Note: FC: Fixed Carbon, VM: Volatile Matter, GHV: Gross Heating Value
SNI RDF is the reference standard for RDF products as defined by the government and industry.

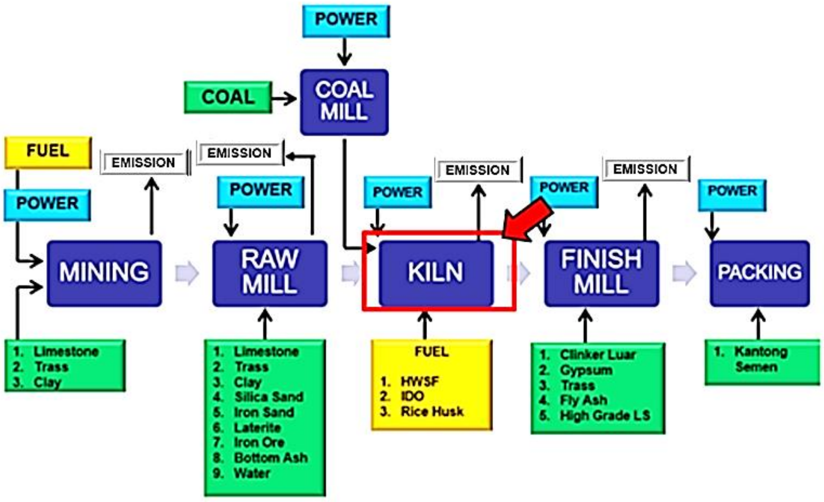

Fig. 1: Schematic Diagram of Cement Production and the Location of RDF Utilization

Figure 1 shows a schematic diagram of the cement production process starting from mining, raw material preparation (raw mill), clinker production (Kiln), finishing product (finish mill), and bagging, along with the types of energy sources used at each stage.

The largest fuel consumption occurred in the kiln for the calcination reaction and clinker production. The substitution was done by replacing the existing coal in the rotary kiln unit with RDF waste fuel at a certain ratio. Several technical adjustments were made to ensure the existing equipment could handle the change in fuel composition. The use of RDF waste was monitored and collected for several evaluations, namely absolute energy and economic savings, using various instruments.

- Absolute energy

  Using the heating value data and the mass amount of RDF, absolute energy can be estimated using Eq. (1).

$$E_{RH} = F_{RH}\ x\ HHV_{RH} \qquad (1)$$

- Direct economic benefit

  Based on coal as the primary energy source at the cement plant, energy savings can be estimated using the standard price of coal energy. Therefore, the direct economic benefit obtained can be estimated using Eq. (2).

$$IDR_{benefit} = Coal\ price\ xE_{RH} \qquad (2)$$

RESULTS AND DISCUSSION

Figure 2 shows the raw materials of municipal waste to be used for RDF production stored in the warehouse. The waste types, including plastic residues, paper, hard organic materials, and others, are obtained from the areas surrounding the factory. After characterizing the waste, it is dried and shredded to the required size. If any waste does not meet the specifications, it is removed by personnel or separation equipment. The mixing process is carried out to achieve the specified requirements, as shown in Table 1. To ensure the specifications are met, the RDF mixture is sampled and subjected to laboratory tests, including proximate analysis and heating value. Using municipal waste as the raw material for RDF ensures the continuous production of this alternative energy source, providing both an energy source and a solution to community waste issues.

Fig. 2: Typical RDF storage at PT. ITP Palimanan Plant

RDF fuel that meets the technical specifications is fed into the rotary kiln along with coal. Figure 3 shows the amount of RDF waste used in cement production over the past three years. The amount of alternative RDF fuel has increased to approximately 820 tons/year in 2023. Efforts to increase the amount of RDF sometimes help with the availability of raw materials that meet the specifications. This is reflected in the heating value data of the RDF product, which has decreased compared to 2021. The heating value of approximately 7500 kcal/kg still meets the required standards. This fluctuation in heating value is closely related to the waste of raw materials generated by the community or vendor. Waste sorting efforts must continue to be promoted and implemented to produce high-quality RDF raw materials.

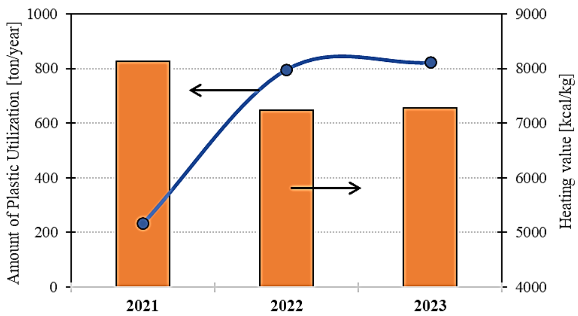

Fig. 3: Total amount of plastic RDF utilization and their heating value in the last several years

To examine the impact of alternative fuel usage in more detail, Figure 4 presents the amount of RDF waste used each month over the past three years. The monthly RDF usage fluctuates depending on the availability of waste materials meeting the specifications, averaging 50-70 tons per month. During the RDF waste substitution, line 9 and line 10 of the factory remained stable and produced cement according to the set targets. As shown in Table 1, the exhaust gas composition of RDF still meets the established environmental quality standards, particularly the SOx content, which is lower than coal. No reports of equipment damage or process disruptions have been found, ensuring that the RDF alternative fuel substitution does not hinder the factory's performance in terms of process or environmental aspects.

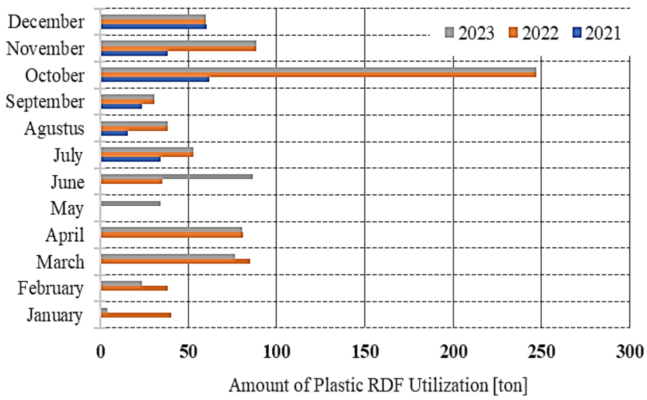

Fig. 4: The amount of plastic RDF utilization in each month

The energy contribution and economic benefits are calculated, as shown in Figure 5, to evaluate the contribution of RDF waste usage in more detail.

Based on the average data in Figure 3, the energy contribution from RDF waste reaches 25,000 GJ per year, and it has been increasing over the past three years. Using a reference coal price of approximately 82 million IDR per GJ, this energy value results in approximately 2000 million IDR economic savings. Besides the direct benefits, RDF waste usage improves environmental quality by reducing municipal waste pollution and generating more environmentally friendly gas emissions. Additionally, the organic fraction in RDF composition creates an eco-friendlier closed carbon cycle.

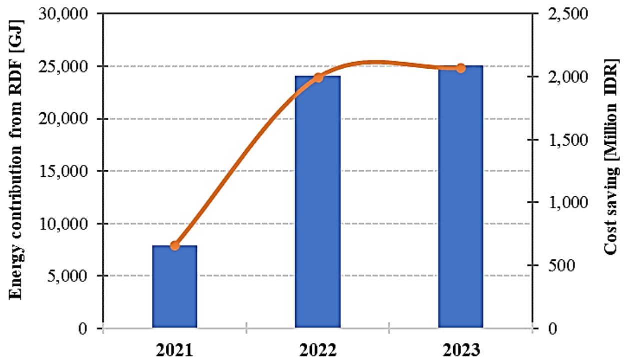

Fig. 5: The amount of plastic RDF utilization in each month

CONCLUSIONS

The cement industry faces significant pressure due to high fossil fuel consumption in its production process. On the other hand, society faces acute waste problems due to the lack of reliable waste management systems. PT. ITP Unit Palimanan has utilized RDF waste as an alternative fuel in its rotary kiln since 2021. The RDF alternative fuel is made from municipal waste from the surrounding area, and its amount has increased to 820 tons/year in 2023. The heating value of plastic waste was evaluated at 7234 kcal/kg to ensure the quality of the alternative fuel. Compared to low-grade coal like lignite, this plastic waste holds a higher heating value, providing additional advantages for the cement factory. The energy contribution from RDF waste reaches 24,113 GJ/year and has been increasing over the past three years. Considering a coal price of approximately 82,767 IDR/GJ, this program can yield savings of almost 1.99 billion/year. No reports of equipment damage or process disruptions have been found, ensuring that the RDF alternative fuel substitution does not hinder the factory's performance in terms of process or environmental aspects.

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