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Optimizing Alternative Fuel Mix Quality as a Sustainable Fuel in the Cement Industry Through Screening Processes

Randa M. Sayed [1,*], Hisham Sherif [1,2], Shaimaa Saeed [3]
[1] *Chemical Engineering Dep., Faculty of Engineering, Minia University, Minia, Egypt*
[2] *Egyptian Company for Solid Waste Recycling (ECARU), Qalyubia, Egypt*
[3] *Chemical Engineering Dep., Tanta Higher Institute of Engineering and Technology, Tanta, Egypt*
[*] *Corresponding Author: Email: randa@entag.net*

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A B S T R A C T

This study examines the effect of the screening process on the quality of Biomass-Derived Fuel (BDF) and Refuse-Derived Fuel (RDF) used as alternative fuels in the cement industry. Key parameters analyzed include calorific value, ash content, and moisture content of the alternative fuel mixtures. The screening process, which involves removing unwanted contaminants and reducing particle size, significantly enhances fuel properties. Improved screening increases the calorific value of the fuel mixture, lowers ash content, and reduces moisture content, thereby enhancing fuel efficiency and overall quality. Results revealed that the initial moisture content of the RDF sample was 24.6%, well above the desired range (below 15%). Screening reduced the moisture content to 14.2% in the fuel mix. Similarly, initial ash content in RDF and biomass samples was 21% and 22%, respectively, but effective screening reduced the ash content in fuel mixtures to 15.5%, improving suitability for cement production. The calorific value improved with better screening, reaching up to 3851 kcal/kg in the fuel mix. This is notably higher than the 3620 kcal/kg for RDF and 3359 kcal/kg for biomass before final screening. This highlights the critical role of effective screening in enhancing the energy potential of alternative fuels. Inconsistencies in the screening process can adversely affect fuel quality, leading to fluctuations in calorific value, ash content, and moisture levels. These findings underscore the importance of strict control measures during screening to ensure the production of high-quality alternative fuels for the cement industry.

1. Introduction

The cement industry is one of the largest industrial sources of CO2 emissions, responsible for approximately 7% of global emissions (International Energy Agency, 2020). This significant contribution is primarily due to its reliance on energy-intensive processes, particularly the calcination of limestone and the burning of fossil fuels such as coal, natural gas, and petroleum coke, which are the main energy sources used in cement kilns (Andrew, 2018). These fossil fuels release large quantities of greenhouse gases (GHG) during combustion, exacerbating climate change and contributing to air pollution (Gartner & Hirao, 2015). In response to growing environmental concerns and increasing regulatory pressures, the cement industry is actively seeking alternative fuels that can replace fossil fuels and reduce its carbon footprint (World Business Council for Sustainable Development, 2018).

Among the most promising alternatives are Biomass-Derived Fuel (BDF) and Refuse-Derived Fuel (RDF), which are gaining popularity due to their environmental benefits. BDF is produced from organic materials such as agricultural waste, forestry residues, and other biodegradable feedstocks, while RDF is derived from non-recyclable waste materials, including plastics, paper, and textiles, after recyclable components are removed (Mokrzycki & Uliasz-Bochenczyk, 2003). These alternative fuels help reduce GHG emissions because they contain biogenic carbon, which is considered carbon-neutral when released during combustion, and they divert waste from landfills, promoting a circular economy (Gaunt & Lehmann, 2008).

The use of RDF and BDF in cement kilns not only reduces CO2 emissions but also supports waste management strategies by transforming waste that would otherwise end up in landfills into valuable energy sources. RDF, in particular, is effective in mitigating landfill pressure, as it utilizes materials that are difficult to recycle through traditional methods (Velis et al., 2009). Moreover, RDF has a higher calorific value than many forms of waste, making it an efficient energy source for cement kilns (Chang, Shoji, & Shibata, 2016). The utilization of these alternative fuels has the potential to lower operational costs for cement producers by reducing dependency on costly fossil fuels (Karagiannidis & Angelakoglou, 2021).

This paper specifically examines the screening process involved in the production of RDF and BDF, and how this process affects the quality of the final fuel mixture used in cement kilns. The screening process plays a critical role in fuel preparation, as it involves the removal of contaminants such as metals, glass, and other non-combustible materials from the feedstock (Brunner & Rechberger, 2015). This step is essential to prevent damage to kiln equipment and to ensure that the fuel mix burns efficiently without producing excessive ash or emissions. Additionally, screening reduces the particle size of the RDF and BDF, which is important for achieving optimal combustion conditions in cement kilns (Chang, Shoji, & Shibata, 2016).

The effectiveness of the screening process has a direct impact on the calorific value, ash content, and moisture content of the alternative fuel. Properly screened RDF and BDF can significantly improve the calorific value by eliminating materials that do not contribute to energy production, thus enhancing the overall energy efficiency of the kiln (Karagiannidis & Angelakoglou, 2021). Moreover, reducing the ash content is crucial, as high ash levels can lead to operational issues, such as clinker quality deterioration and increased kiln maintenance requirements (Mokrzycki & Uliasz-Bochenczyk, 2003). Lowering the moisture content is equally important, as excessive moisture reduces the energy output of the fuel, requiring more energy for drying before combustion can occur effectively (Reijnders, 2007).

In contrast, inconsistencies in the screening process can negatively affect the quality of the final fuel mixture. If contaminants are not adequately removed, non-combustible materials can enter the kiln, resulting in increased emissions and potential damage to kiln components (Brunner & Rechberger, 2015). Variations in particle size can also lead to uneven combustion, reducing fuel efficiency and increasing CO2 emissions. These challenges highlight the need for stringent control measures and consistent screening protocols during the preparation of RDF and BDF to ensure a high-quality alternative fuel suitable for use in cement kilns (Velis et al., 2009). This paper underscores the importance of refining the screening process to enhance the overall performance of alternative fuels in cement manufacturing.

2. Materials and Methods

2.1. Materials

The materials used in this study include two primary types of alternative fuels: Biomass from agricultural residues (Fruit Crops, orange, Mango . Gap , etc ..) and Refuse-Derived Fuel (RDF) produced from municipal solid waste (MSW). Each material underwent specific processing to ensure it met the required quality and specifications for use in heavy consuming industry (cement industry)

Biomass agricultural residues (Fruit Crops - BDF):

Biomass was sourced from agricultural operations, specifically Fruit Crops collected after the harvesting season. The biomass was gathered using mechanized collection systems, such as balers and rakes, to streamline the collection process and minimize manual handling. Once collected, the biomass was transported to a centralized processing site for further treatment.

Refuse-derived Fuel (RDF):

Refuse-Derived Fuel (RDF) was produced from municipal solid waste (MSW) containing non-recyclable materials, including plastics, paper, and textiles. These materials were processed in a specialized RDF production facility, where they went through several stages to ensure uniformity and optimize energy content. The waste first underwent manual sorting to remove large recyclable items such as PET plastics, glass, and metals. After this initial sorting, the remaining waste materials were subjected to further processing steps, including shredding, drying, and screening. Each of these steps played a critical role in preparing the waste for efficient use as green sustainable fuel.

3. Production Process

3.1. Biomass agricultural residues (Fruit Crops)

The production of Biomass from tree trimmings involved a multi-step process:

- Collection, Transportation, and Storage Process: Biomass, agricultural residues were collected from farms using mechanical collection equipment such as rakes and balers. This equipment gathered the biomass into windows, facilitating easier transport to processing facilities. The biomass was loaded onto trucks and transported to a centralized storage facility where it awaited further processing.
- Shredding Process: Once delivered to the processing site, the biomass was fed into a Shredding Machine, which is designed to reduce the particle size of the biomass to between 35-20 cm. This primary shredding step aimed to make biomass manageable for further treatment.
- Biomass National Drying: as illustrated in Figure 3 After shredding, the biomass was stored in open-air piles or windrows to undergo natural drying. Moisture content was reduced by exposing the biomass to sunlight and air circulation. The goal was to achieve a moisture content of less than 10%, which is critical for improving combustion efficiency and reducing the risk of excessive emissions.
- Biomass Gridding (Secondary Shredding) and Screening: The dried biomass was further processed by a secondary shredding machine to reduce the particle size to 2.5–5 cm. This size range was selected based on the pneumatic feeding system used in cement kilns, ensuring the fuel would flow smoothly through the kiln system. After the final shredding, the biomass was screened to remove contaminants, such as stones or metals, and ensure uniform particle size distribution. Screening is crucial for removing impurities and contaminants that could negatively affect the combustion process or damage kiln components.
- Shipping to clients: As illustrated in Figure 4, biomass and RDF is transported to clients using specialized trucks equipped with walking floors. This innovative design enables the easy discharge of bales at the client’s facility, facilitating efficient delivery and handling of the biomass-

derived fuel. This approach ensures that transportation logistics are streamlined, contributing to effective supply chain management and maintaining the integrity of the biomass fuel throughout the delivery process.

Biomass Technical Specification: As shown in Table 1, the biomass has a moisture content of 16.9%, which indicates a moderate level of moisture that may affect combustion. The calorific value of 3,359 kcal/kg reflects a reasonable energy potential for fuel use. However, the ash content is relatively high at 22%, posing potential challenges in terms of combustion efficiency and increased post-combustion waste management. Proper management of these factors is essential to enhance the biomass's performance as a fuel source.

Table 1: Technical Specifications of Biomass

Parameter	Biomass
Moisture Content %	16.9
Ash Content %	22
Calorific Value, kcal/kg	3359

3.2. Refuse-Derived Fuel (RDF) Production

The production of RDF involved a more complex series of steps, as the waste materials were heterogeneous and required multiple stages of sorting, shredding, and drying to achieve a fuel product suitable for cement kilns:

– MSW Manual Sorting Process: After collecting, the municipal solid waste (MSW) was transported to an RDF production facility, where the first step involved manually sorting the waste. During this process, workers removed large recyclable materials such as PET, metals, glass, and other non-combustible items from the waste stream. This minimized contamination ensured that the remaining waste would be suitable for RDF production.

– Trommel Screening process: After manual sorting, the remaining waste was fed into a trommel screen—a cylindrical drum with perforations that rotate to separate materials by size. This process separated the organic fraction (approximately 60% of the total waste) from the combustible materials like paper, plastics, and textiles, which are essential for producing RDF. The organic material was sent for composting, while the combustible fraction continued through the RDF production process.

– Wind Shifting process: The next step involved wind shifting, a process that uses air to separate light materials from heavier contaminants. This step effectively removed stones, glass, and other non-combustible materials from the RDF feedstock, leaving behind lighter, high-energy materials like plastic films and paper.

– Shredding process: The screened waste was then sent through a secondary shredding machine, which reduced the particle size to 5–7 cm. This step is essential to ensure that the RDF particles are small enough for combustion in cement kilns. A uniform particle size helps with consistent feeding and burning of the fuel, maximizing energy output.

– RDF Drying Process: The shredded RDF material was dried to reduce the moisture content from an initial level of around 35% to below 25%. Drying was conducted using natural air drying, often assisted by turning machines that aerate the material to accelerate the drying process. A lower moisture content improves the calorific value of the fuel and ensures efficient combustion in cement kilns.

– Final secondary Screening process: After drying, the RDF underwent a final screening process to remove any remaining contaminants and ensure uniform particle size. The processed RDF was then stored in wind rows until it was ready for transport to the cement kilns. The fuel was stored in a manner that minimized re-absorption of moisture and prevented contamination.

– RDF Technical Specification: As shown in Table 2, the RDF has a good calorific value of 3,620 kcal/kg, indicating strong energy potential. However, its relatively high moisture content (24.6%) and ash content (21%) may reduce combustion efficiency and increase the need for post-combustion waste management. Proper handling of these factors is essential for optimizing RDF's performance as an alternative fuel.

Table 2: Technical Specifications of RDF

Parameter	RDF
Moisture Content %	24.6
Ash Content %	21
Calorific Value, kcal/kg	3620

4. RDF and Biomass Fuel Mix process

The fuels were initially weighed separately using high-precision scales to guarantee accurate measurement of each component—RDF and BDF—based on the desired mixing ratio. This step was crucial to ensure that the proportions of RDF and BDF in the fuel mix were consistent with the experimental requirements and allowed for precise control over the fuel’s properties, such as calorific value, ash content, and moisture content.

Once the fuels were weighed, the mixing process began. A mechanical loader bucket was employed to facilitate the thorough blending of RDF and BDF. This mixing method was selected to ensure that both fuels were uniformly combined, minimizing any risk of segregation during subsequent handling or combustion. The loader bucket repeatedly lifted and overturned the fuel mixture, ensuring an even distribution of RDF and BDF throughout the blend. This mechanical action ensured that no "hot spots" (areas with higher concentrations of one fuel) formed, which could otherwise lead to inconsistent combustion performance in the kiln.

After the mixing process, the fuel blend was subjected to a screening phase to eliminate contaminants and maintain uniformity in particle size. The screening equipment, designed specifically for this purpose, removed unwanted materials such as stones, metals, and oversized particles that could interfere with the combustion process. This step was critical in ensuring that only clean, appropriately sized fuel particles entered the kiln, thus optimizing the combustion efficiency and reducing the risk of operational disruptions, such as clinker formation or incomplete burning by increasing the heating value from 3620 kcal/kg RDF, 3359 kcal/kg to 3851 kcal/kg, in fuel mix as well reducing the Ash Content % & Moisture content % from 21% . 22 RDF and Biomass to 15.5 % in Fuel Mix,

Finally, the screened fuel mix was carefully fed into the cement kiln for combustion testing. The consistent particle size and homogeneity of the fuel blend, achieved through meticulous weighing, mixing, and screening, were essential for ensuring stable combustion, optimal energy output, and minimal emissions during the kiln operation.

4.1. Specification of the fuel mix

Table 3 highlights the technical improvements in the fuel mix after screening, focusing on moisture content, ash content, and calorific value. The moisture content was reduced to 14.2%, which enhances combustion efficiency by minimizing the energy lost in drying the fuel. The ash content decreased to 15.5%, indicating a lower level of non-combustible residue, which is crucial for reducing maintenance and improving the performance of the fuel in cement kilns. The calorific value increased to 3851 kcal/kg, reflecting a higher energy potential, which directly enhances the thermal efficiency of the fuel. These improvements make the screened fuel mix more suitable for use as an alternative fuel in cement production.

Table 3: Technical Specifications of fuel mix screened

Parameter	Fuel mix/ Screened
Moisture Content %	14.2
Ash Content %	15.5
Calorific Value, kcal/kg	3851

5. Results and Discussion

The analysis involved testing various RDF and biomass. Key parameters analyzed were moisture content, ash content, and calorific value, which directly affect combustion efficiency and environmental impact

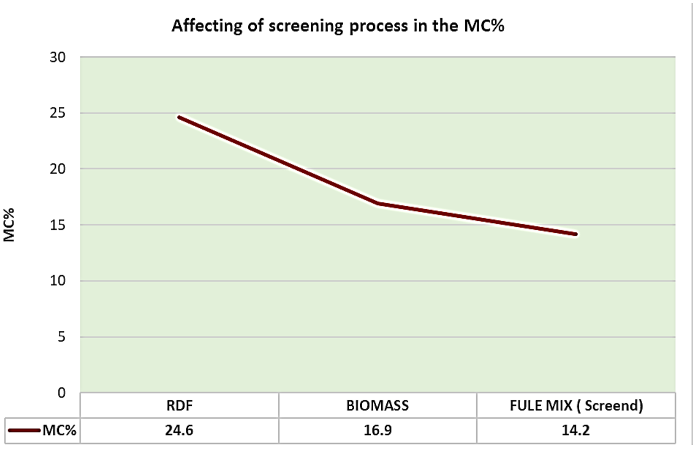

Figure 1: Affecting screening process on fuel mix MC%

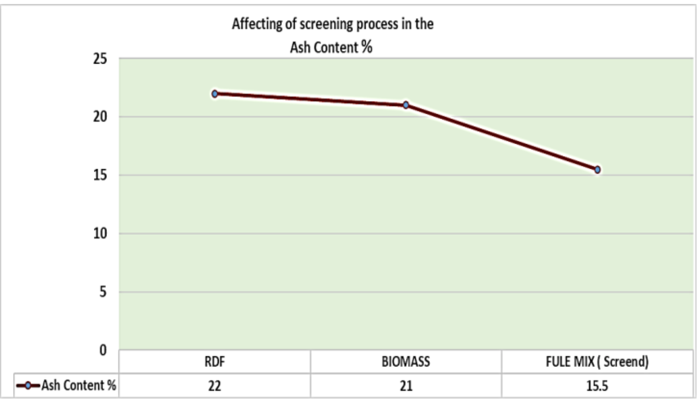

Figure 2: Affecting screening process on fuel mix Ash Content %

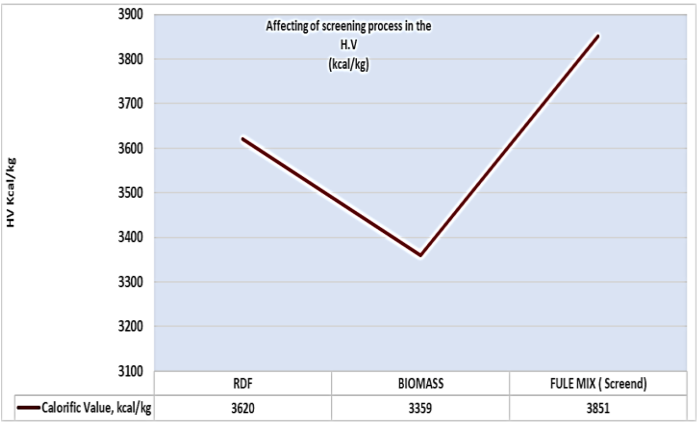

Figure 3: Affecting screening process on fuel mix net heating value

5.1. Moisture Content

As illustrated in table NO.2 The RDF sample had moisture content ranging from 24.6%, which was significantly higher than the desired range (below 15%) for optimal fuel quality. Screening during RDF production helped reduce moisture content to 14.2 %b in the fuel mix screened sample as illustrated in Table 3.

5.2. Ash Content %:

High ash content can negatively affect the cement production process. The study found that fuel mix samples with improper screening showed ash content below 15 % which is 15.5 % in fuel mixes, compared to higher levels both RDF 21 %, and Biomasses 22 % before mixing and final screening

5.3. Heating Value:

As illustrated in Table 3 Calorific values improved with better screening, reaching as high as 3851 kcal/kg in fuel mix. This result highlights the importance of effective screening in enhancing the energy potential of alternative fuel. If that compare by the RDF 3620 kcal/kg and Biomass 3359 before the final secondary screening process,

6. Conclusion:

This study emphasizes the critical role of screening in improving the quality of alternative fuels like Refuse-Derived Fuel (RDF) and Biomass-Derived Fuel (BDF) by removing contaminants such as metals, glass, and stones, and ensuring uniform particle size, which enhances combustion efficiency in cement kilns. Improved screening increased the calorific value to 3,851 kcal/kg, compared to 3,620 kcal/kg for RDF and 3,359 kcal/kg for biomass, while reducing ash content to 15.5% and moisture content from 24.6% to 14.2%. These improvements boost energy efficiency and reduce disposal costs. Conversely, poor screening leads to inconsistent fuel quality, operational inefficiencies, and higher emissions, compromising both energy output and environmental compliance. To address these challenges, the study recommends investing in advanced screening technologies, conducting regular quality tests, refining contaminant removal procedures, providing operator training, establishing clear quality standards, and continuously optimizing screening processes. These actions will help waste management companies produce higher-quality alternative fuels, supporting efficient and sustainable waste-to-energy solutions while ensuring compliance with environmental regulations.

This study underscores the pivotal role of the screening process in determining the quality and performance of alternative fuels like Refuse-Derived Fuel (RDF) and Biomass-Derived Fuel (BDF). Screening serves as a critical step in removing non-combustible contaminants such as metals, glass, and stones, which can negatively affect combustion efficiency and cause operational issues in cement kilns. Additionally, by ensuring a uniform particle size, the screening process enhances the homogeneity of the fuel, leading to more stable combustion and improved heat distribution.

A key outcome of effective screening is the optimization of the fuel's calorific value. Higher calorific value translates into more energy per unit of fuel, which is essential for maximizing the thermal efficiency of cement kilns. Moreover, proper screening helps to reduce the fuel's ash content, minimizing the residue left after combustion, and lowering disposal costs. Reduced moisture content is another advantage, as it decreases the energy required for fuel drying and improves combustion efficiency.

On the other hand, poor or inconsistent screening can result in fuel with a higher proportion of contaminants and a lack of particle uniformity, leading to operational inefficiencies such as incomplete combustion, lower thermal output, and increased emissions of pollutants. These issues not only compromise the energy performance of the kiln but also heighten environmental concerns, particularly in relation to air quality and regulatory compliance.

Therefore, to meet both energy efficiency and environmental regulations, it is essential to implement stringent quality control measures during the screening process. These controls ensure the production of high-quality alternative fuel mixes that are suitable for use in cement kilns, providing a more sustainable solution for waste-to-energy applications while adhering to environmental and performance standards Top of Form.

Conflict of Interest

The authors declare no conflict of interest.

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