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WASTE MANAGEMENT IN MAGNESITE MINES IN TURKEY

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Abstract

Brick is a building material obtained by mixing clay, earth, or similar materials with water, shaping them, drying them, and usually firing them in a kiln. Today, it is used in reinforced concrete structures for many purposes, such as infill, walls, and cladding, in addition to the load-bearing system. The first bricks were unfired adobe (sun-dried clay blocks), but later they began to fire bricks in kilns to make them more durable. This made the material more resistant to water and time. Industrial bricks fired at high temperatures are widely used in interior and exterior walls, chimneys and furnaces, and aesthetic cladding.

Fire bricks, a special type of brick (resistant to high temperatures), are a refractory material and are widely used, especially in the steel, glass, and cement industries. Magnesite fire bricks, which are basic fire bricks based on their content, are the basic material of basic refractories.

The recovery of magnesite-based firebricks is more difficult than that of alumina or silica-based bricks. The main reasons for this are that MgO is a highly basic material and therefore reacts strongly with slag during use. Consequently, end-of-life bricks are heavily contaminated with foreign oxides (FeO, SiO₂, CaO). It becomes difficult to separate pure MgO.

Sommario

Il mattone è un materiale da costruzione ottenuto mescolando argilla, terra o materiali simili con acqua, modellandoli, essiccandoli e solitamente cuocendoli in un forno. Oggi è utilizzato nelle strutture in cemento armato per molteplici scopi, come tamponamenti, pareti e rivestimenti, oltre che come parte del sistema portante. I primi mattoni erano adobe non cotti (blocchi di argilla essiccati al sole), ma successivamente si iniziò a cuocere i mattoni nei forni per renderli più durevoli. Questo rese il materiale più resistente all'acqua e al tempo. I mattoni industriali cotti ad alte temperature sono ampiamente utilizzati in pareti interne ed esterne, camini, forni e per rivestimenti estetici.

I mattoni refrattari, una tipologia speciale di mattone (resistente alle alte temperature), sono materiali refrattari e sono ampiamente impiegati, in particolare nelle industrie siderurgica, del vetro e del cemento. I mattoni refrattari a base di magnesite, che costituiscono i refrattari basici in base alla loro composizione, rappresentano il materiale fondamentale dei refrattari basici.

Il recupero dei mattoni refrattari a base di magnesite è più complesso rispetto a quello dei mattoni a base di allumina o silice. La ragione principale risiede nel fatto che l'MgO è un materiale altamente basico e quindi reagisce fortemente con la scoria durante l'utilizzo. Di conseguenza, i mattoni a fine vita risultano fortemente contaminati da ossidi estranei (FeO, SiO₂, CaO), rendendo difficile la separazione dell'MgO puro.

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Chapter1

1 Introduction

Global raw material demand has increased significantly over the past century due to economic growth and industrialization. According to UNEP's *Global Resources Outlook 2024* report, if current trends continue, resource extraction could rise by 60% by 2060 compared to 2020 levels (United Nations Environment Programme [UNEP], 2024). Historically, material use has also increased approximately eightfold during the 20th century (Krausmann et al., 2009).

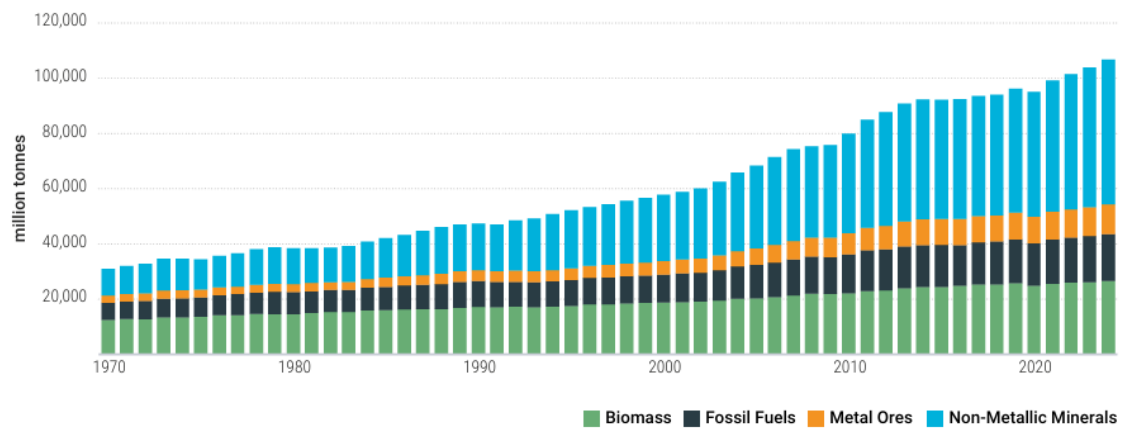


Figure 1-1 Global material extraction, four main categories, 1970-2020, million tonnes. Global Material Flows Database (UNEP 2023a)

Growing demand for raw materials can be addressed not only through the discovery of new sources but also by using existing resources more efficiently. In this context, the concept of waste management and the circular economy come to the forefront. The circular economy approach aims to transform products at the end of their life cycle from waste into resources (Geissdoerfer et al., 2017). Particularly in resource-intensive sectors such as mining and the refractory industry, the recovery of defective products or end-of-life materials can provide both environmental and economic benefits (Willsten et al., 2021).

The mining and refractory industries are highly resource-dependent and energy-intensive, which places them at the center of sustainability discussions. Magnesia-based refractories, in particular, are indispensable in steel, cement, and glass production due to their high resistance to extreme temperatures (Önal & Topkaya, 2015).

1.1 Background and Motivation

This project aims to reclaim the valuable minerals contained in products that have reached the end of their useful life or cannot be reused due to manufacturing defects, and reintroduce them into production processes. Thus, instead of simply disposing of waste materials, they are recycled into the economy in line with the circular economy approach (Ellen MacArthur Foundation, 2019; Geissdoerfer et al., 2017), contributing to a reduction in raw material needs. This approach, directly aligned with the sustainability and resource efficiency principles prioritized within the European Green Deal (European Commission, 2019), serves to reduce environmental impacts and minimize carbon footprints.

One of the most significant elements that distinguishes the project is that the material in question is fire brick. To date, no systematic recycling efforts have been conducted on fire brick, and bricks that have reached the end of their useful life or have manufacturing defects are generally left in landfills or disposed off (Horckmans et al., 2019; RHI Magnesita, 2023). In this context, the reprocessing of fire brick waste to recover its valuable minerals is a first in the literature and industrial applications. The fact that these materials have been overlooked until now due to their inability to be utilized through traditional methods makes this project an innovative initiative from both scientific and industrial perspectives.

However, the economic dimension of the project is also noteworthy. These materials, normally considered direct losses, become reusable when processed with appropriate technologies. Especially in today's world, where raw material prices are rising and access to natural resources is becoming increasingly difficult, recovering valuable minerals from waste makes a strong contribution to economic sustainability (World Bank, 2024; European Commission, 2023). This not only provides an environmental benefit but also enhances businesses' competitiveness and resource efficiency.

In conclusion, this project aims a dual benefit in terms of both environmental sustainability and economic added value creation (European Comission, 2020; Ellen MacArthur Foundation, 2019). The fact that fire bricks have never been recycled before makes the project innovative; the recovery of valuable minerals opens up a new application area in both literature and industry (Horckmans et al., 2019). Thus, the project stands out not only as a waste management approach but also as a pioneering initiative in sustainable mining and material technologies (OECD, 2019; European Comission, 2023).

1.2 Overview and Thesis Structure

The present thesis aims to establish a coherent framework for examinng problems and formulating solutions.

The opening chapter encompasses a brief introduction to waste management of magnesite mine, the importance of considered research topic.

Chapter 2 described the general properties of magnesite mine in Turkey and then explains processing techniques.

Chapter 3 covers the project details include processing of obsolete brick materials with X-Ray (tomra) separator with chosen parameters.

Chapter 4 present both evaluation of the case study and economic and technical feasibility researches.

In chapter 5, the main results obtained from the analyses and recovery experiments are presented.

1.3 Scope and Limitations

This thesis focuses on a research and development study aimed at recovering valuable minerals from fire bricks that are unusable due to production defects and from those that have reached the end of their service life. The study examines the determination of the physical, chemical, and mineralogical properties of waste bricks, the application of methods such as crushing, screening, and X-Ray separator, the assessment of the environmental and economic contributions of recycling, and the importance of this process within the framework of the European Green Deal (European Comission, 2019).

Limitations are listed;

- The study was conducted at a plant-scale and it is intended for industrial application.
- Only specific recycling methods (crushing, screening, and X-ray separator) were examined; chemical or thermal methods were not evaluated.
- Economic analyses was conducted in general terms due to avoid disclosing company proprietary data, and a detailed cost-benefit analysis was excluded.
- Findings are specific to the samples examined and may not be representative of all refractory waste types.
- In facilities like Mutaş, integrating this recovery process into the existing production line may necessitate additional investments.
- In this study, carbon footprint and Life Cycle Assessment (LCA) have not been comprehensively evaluated.
- Due to the absence of systematic recycling studies on fire bricks in the existing literature, the availability of comparative data is limited.

Chapter 2

2 Literature Review (Magnesite Mines in Turkey)

2.1 General Properties of Magnesite Mine

Magnesite (MgCO_3) is a significant carbonate mineral that holds strategic importance due to both its geological formation characteristics and industrial applications (Zedef & Tüysüz, 2009; USGS, 2022). It typically forms as a result of hydrothermal alteration of ultramafic rocks, particularly serpentine, dunite, and peridotite. In addition, some deposits may originate in sedimentary environments through carbonate depositional processes. Magnesite is usually white, gray, or yellowish in appearance and occurs as massive or vein formations. Its physical properties include a hardness of 3.5-5 on the Mohs scale and a density of approximately 3.0 g/cm^3 (MTA, 2023).

From an industrial perspective, high-grade magnesite with low iron content is especially valued in the refractory industry, while silica-rich material is more commonly used in chemical and agricultural applications (USGS, 2022). Turkey plays a significant role in the global magnesite market. According to the General Directorate of Mineral Research and Exploration (MTA, 2023), Turkey possesses some of the largest magnesite deposits in Europe, positioning the country as a key supplier for international refractory markets.

2.2 Global Distribution of Magnesite Mines

The global distribution of magnesite reserves, however, is highly uneven, with only a few countries holding the majority of economically viable deposits. Understanding the worldwide reserve base is essential to place Turkey's position in the global context.

Table 1 illustrates the distribution of magnesite resources across the world.

Table 2-1 World magnesite mine production and reserves (USGS, 2025)

	Mine production ^e		Reserves
	2023	2024	
United States	W	W	35,000
Australia	500	490	⁸ 280,000
Austria	771	760	49,000
Brazil	1,800	1,800	200,000
Canada	150	150	NA
China	13,000	13,000	680,000
Greece	393	390	280,000
India	123	160	66,000
Iran	216	210	10,000
Russia	2,500	2,500	2,300,000
Slovakia	391	380	1,200,000
Spain	680	670	35,000
Turkey	1,330	1,300	110,000
Other countries	373	370	<u>2,500,000</u>
World total (rounded)	¹⁰ 22,200	¹⁰ 22,000	7,700,000

1

World magnesite mine production and reserves are reported by USGS as gross weight of magnesite, but standardized in terms of magnesium oxide (MgO) equivalent.

While global production remains stable around 22 Mt annually, it is highly concentrated in a few countries. According to USGS (2025), China dominates both mine production and reserves of magnesite, accounting for more than half of global supply. Turkey ranks among the leading producers with 1.3 Mt of production and 110 Mt of reserves, highlighting its strategic role as a supplier for the European refractory industry.

2.3 Major Magnesite Mines in Turkey

Turkey holds approximately 15% of the world's total magnesite reserves and is Europe's largest producer (USGS, 2022; MTA, 2023). Reserves are concentrated primarily in the Eskişehir-Kütahya-Bilecik-Konya-Burdur regions (MTA, 2023). The vast majority of these companies produce high-quality cryptocrystalline magnesite, which provides raw materials for the refractory industry.

In Turkey, Kümaş Manyezit A.Ş. (based in Kütahya) is recognized as the country's largest magnesite producer and one of the leading companies worldwide in the production of sintered and fused magnesia. Alongside Kümaş, Mutaş A.Ş., located in Eskişehir, plays an important role in magnesite mining and beneficiation.

⁸ For Australia, Joint Ore Reserves Committee-compliant or equivalent reserves were 37 million tons.

¹⁰ Excludes U.S. production.

^W Withheld to avoid disclosing company proprietary data.

^{NA} Not available.

^e Estimated.

Kümaş and Mutaş work in collaboration. While Mutaş carries out the open pit operations and pre-concentration processes, Kümaş is responsible for the final concentration and the production of the end product, bricks. (MTA, 2023; Field knowledge, 2024).

2.4 Production and Processing Techniques

Main reserves of magnesite are concentrated in Kütahya, Eskişehir and surrounding areas. Open pit mining method is employed as a production method. The extracted magnesite undergoes manual sorting, crushing and screening and, in some cases, beneficiation processes, depending on the quality, it is transferred to the central plant.

2.5 Waste Generation Types in Magnesite Operations

The European Commission's Waste Framework Directive 2008/98/EC establishes a hierarchy of waste management options, prioritizing prevention, preparation for reuse, recycling, recovery (such as energy recovery), and finally disposal. A limitation of this hierarchy is that it does not distinguish between various recycling approaches in terms of maximizing the value of waste. In closed-loop recycling, the recycled product retains properties that are largely similar to the original material, allowing it to substitute for virgin inputs in identical applications. In contrast, open-loop recycling results in materials with altered characteristics, making them suitable primarily for different product uses, often replacing other raw materials. Closed-loop systems are therefore associated with greater economic benefits and improved resource efficiency (European Commission, 2008; Horckmans et al., 2019).

Open-loop recycling of spent refractories has mainly been restricted to low-value applications. Common uses include aggregates in road construction and additives for steelmaking slags (Dominguez et al., 2010; Conejo et al., 2006; Lule et al., 2005; Nakamura et al., 1999). The financial return from such practices is limited, as the market value of recycled materials rarely exceeds 20 USD per ton road aggregates or 60 USD per ton for fluxes (Lule et al., 2005). In contrast, the price of high-quality dead-burnt magnesia can be several times higher, which highlights the gap between conventional recycling pathways and the potential of recovering raw materials for the refractory industry.

Chapter 3

3 Case Study: Mutaş Fire Brick Reprocessing Project

3.1 Company Profile

Mutaş Mining was established in 2012 in Tavşanlı (Kütahya, Turkey) with the primary purpose of providing open-pit magnesite mining services, focusing on stripping (overburden removal), ore extraction, and beneficiation operations. The company operates across three separate sites and employs nearly 300 workers.

As a subcontractor of Kümaş Magnesite, Turkey's largest integrated refractories producer, Mutaş plays a critical role in the supply of sintered magnesite used in refractory brick and material production. Through this cooperation, Mutaş contributes to both the domestic and export-oriented refractories market.

Mutaş has been acting as a long term subcontractor for Kümaş, responsible for overburden removal and raw magnesite extraction in Kütahya-based deposits. This collaboration ensures a stable raw material flow for Kümaş's sintered magnesite and refractory production lines (Field knowledge, 2024).



Figure 3-1 Kümaş Beşçam Open Pits

3.2 Magnesite Production of the Company

Raw magnesite ore extraction from the open pit is reduced in size using jaw crusher and a cone crusher. Through various screens, materials of different size ranges are obtained. These materials are then transferred to different units of the plant for beneficiation purposes.

At the separation and purification stage the goal is to separate the magnesite fraction within a high MgO content. Methods are manual sorting, magnetic separation and optical separation.

Magnetic Separation

Magnetic separation is one of the most critical purification methods in the magnesite reprocessing process. In this method, magnetic impurities such as iron oxide are removed using high-intensity magnetic field. Magnesite (MgCO_3), a non-magnetic mineral, passes freely through the separator. This increases MgO purity while reducing the Fe_2O_3 ratio, improving the quality of the raw material used in refractory brick production (Habashi, 1997; Field knowledge, 2024).



Figure 3-2 Magnetic separator

Optical Sorting

Other method used in the reprocessing of magnesite waste is optical sorting. This method automatically separates impurity-containing particles based on differences in the mineral's colour and surface properties. It is particularly effective in separating white or light-coloured magnesite from dark-coloured serpentine, clay, or ferrous phases.

In optical sorting systems, particles moving on the conveyor belt are scanned using sensors, and impurity particles are removed from the material flow with an air jet. This method operates faster and more continuously than manual sorting, thus contributing to increased MgO purity in magnesite during reprocessing stage (Will & Finch, 2016; Field knowledge, 2024).



Figure 3-3 Optic Separator

Manual Sorting

Manual sorting is one of the most important methods used in the recycling of refractory waste. In this method, operators visually classify the particles moving along the conveyor belt based on colour, purity, texture, and grain structure. This method, particularly implemented at Kümaş facilities, allows the separation of magnesite particles with high MgO content from fractions containing low quality or foreign phases. This improves the quality of the raw material entering the reprocessing process before magnesite separation or screening.

The most significant advantage of manual sorting is that it increases purity and does not require simple equipment. However, its labor-intensive nature and the fact that efficiency depends largely on operator experience are considered significant disadvantages (Field knowledge, 2024).



Figure 3-4 Manual sorting application regarding to colour

3.3 X-Ray Separator (Tomra) Case Study: Processing of Obsolete and Defective Fire Brick Material with X-Ray Separator

Description of the Reprocessing Project

This project is designed as a case study for the reprocessing of defective fire bricks, which are difficult to recycle using conventional recycling methods due to their heterogeneous composition. Rather than developing an industrial-scale process, the project aims to examine combined applicability of material characterization and modern separation techniques. This will contribute to the circular economy goals envisioned by identifying the technical barriers, potential opportunities, and sustainability dimensions of recycling these wastes.

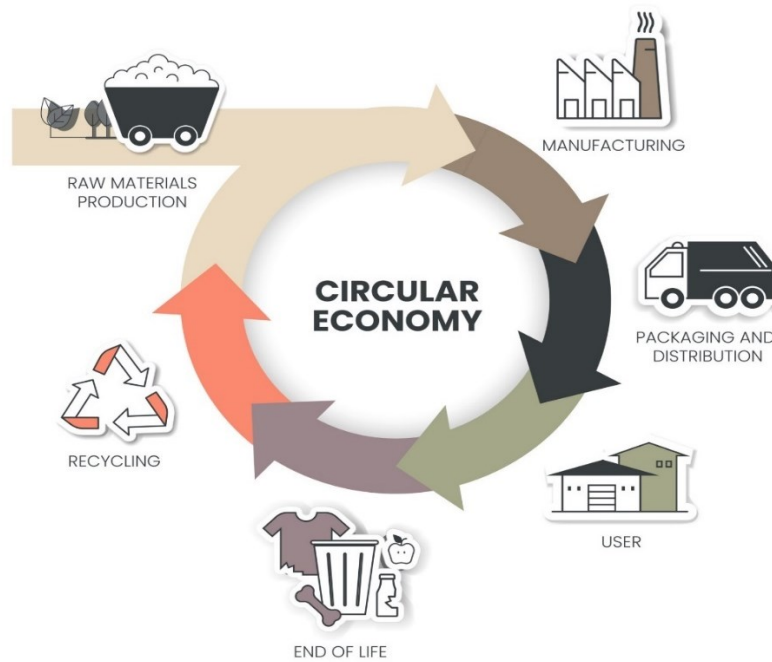


Figure 3-5 General framework of the circular economy emphasizing waste reduction ,resource efficiency, and material recovery

3.4 Collection and Preparation

Defective bricks from the plant and end-of-life bricks from customers were collected for use in this study and transported to the plant for size reduction.

3.5 Crushing and Screening

After separation and purification, the resulting product is classified into two different particle sizes. Larger fractions (8-20 mm) are crushed and used in granular form, while finer fractions (5-20 mm) are repressed with a powder binder and used in new brick production. Waste bricks are first crushed to coarser sizes using a jaw crusher. They are then converted to finer sizes using a cone crusher. They are classified by grain size using sieves.

3.6 X-Ray Based Separation Technology

Kümaş conducted a trial study using X-ray separator for the processing of the obsolete and defective refractory fire brick materials. The main objective of this study was to evaluate the efficiency of x-ray separation in recovering high-grade magnesite fractions from waste refractory bricks.

The trial demonstrated that x-ray technology can be integrated into the reprocessing workflow, enhancing the purity of recycled magnesite and supporting both economic recovery and environmental sustainability.



Figure 3-6 Turan tomra facility

In the trial study conducted at the Turan tomra facility, bricks are broken into 5-20 mm and 8-20 mm sizes were used as material.

Bunker is a large funnel-shaped silo where material is temporarily stored and regularly transferred to the next processing stage. In this stage, material fed into from the bunker is fed into the line at a constant and controlled flow rate before being passed through a washing screw. During this stage, dust, clay, and fine binder phases adhered to the surface of the particles are dissolved by water and mechanical friction and transferred to the fluid phase. The mixture at the screw outlet is transferred to the washing screen; here, thanks to spray lines, fine fractions are removed from the screen openings as bottom product, while the cleaned, coarse fraction is obtained as top product. This effectively removes dust and clay from the material, reducing the likelihood of misclassification in optical or magnetic separation stages, and also reducing wear and dust emissions in crushing and screening equipment. Wet fines arriving via the underside of the screen and screw overflow are directed to the sludge line/sedimentation unit; process water is recycled and recirculated as much as possible.



Figure 3-7 Screw washer

Screw washer units are frequently used mineral processing facilities for both washing and classifying particle sizes. The larger particles accumulate at the base, while the lighter fractions are transported with the overflow (Wills & Finch, 2016).



Figure 3-8 Screw Washing screen

Washing screens are essential equipment used in ore processing and aggregate production facilities. Water spray nozzle placed on vibrating or rotary drum screens classify material based on grain size and remove fine dust, clay, and dirt particles from the surface. This method is widely used, particularly in sand, gravel, and aggregate production, to clean material and achieve high-quality products. Washing screens, unlike dry screening systems, effectively clean the material surface, making them preferred in aggregate, coal and metallic mineral processing facilities (Wills & Finch, 2016).



Figure 3-9 X-ray separator

X-ray separator is an optical sorter technology developed by the Norway-based company Tomra. It is used primarily in the mining, recycling, and food industries. Working mechanism of the machine is as the materials move along the belt conveyor, they are scanned with high-resolution cameras, lasers, x-rays, or near-infrared sensors.

Sensors identify differences in colour, density, mineral composition, or shape. Targeted material type is separated from others using an air jet. This allows for the selection of valuable minerals (e.g. magnesite, chromite). Tomra usage in mining provides economical enrichment of low-grade ores. In magnesite mines, low-quality rock fragments are discarded and high-quality magnesite is separated. Tomra reduces waste, improves concentrate quality, and reduces operating costs. It also provides environmentally friendly enrichment without the use of chemicals. It operates quickly and automatically therefore reduces human error. It can also make low-grade fields economical.

3.7 Modification of the X-Ray Separator (Tomra) for the Experiment

Operating principle of this machine primarily starts with the definition of the target material. Personnel from the manufacturer defines the desired quality of material as the main product in the machine, and all the materials outside this quality are classified as waste. Materials similar to the reference sample are identified as the main product, while those deviating from it are classified as waste. In the opposite scenario, the waste product can be defined instead; in this case, materials close to the waste sample are obtained as waste, while those distant from it are considered the main product.

As the original configuration of the machine was designed for raw magnesite separation, an experimental-specific setup of the x-ray separation machine was requested from the company representative. For the brick experiment, the machine needed to be specifically programmed.

Since the reference sample was composed of brick mortar, its separation was more difficult than that of raw magnesite. When defining the reference material, the manufacturer programmed the separation process according to its MgO content. In these conditions, it was deemed appropriate by the officials to define three different programs along with two separate size ranges.

Two materials at 5-20 mm and 8-20 mm were processed separately in the 4P, 5P and 6P programs. In the program 6P refers to the highest MgO content and 4P refers to the lowest MgO content. The operation of the machine below a particle size of 5 mm was not recommended by the manufacturer on the grounds of inefficiency. The manufacturer suggested the range of 5 mm to 20 mm as the efficient operating interval. In order to achieve maximum efficiency, it was intended to test every fraction size within the operating range of the machine. Selection of the 8-20 mm particle size fraction, on the other hand, was made to observe the efficiency at different size ranges.



3.8 Field Tests and Observations



Figure 3-11 Samples

Samples were utilized in the P4, P5, and P6 programs for feeding into x-ray separator, and the corresponding analysis results are provided in the table below.

Table 3-1 Summary of main oxides relevant for refractory quality

SIZE	TYPE	PROGRAM	SiO ₂ (%)	CaO (%)	Fe ₂ O ₃ (%)	Al ₂ O ₃ (%)	MgO (%)
5-20 mm	Feed	*	1,04	1,78	0,6	10,95	85,63
	Product	P-4	1,08	1,81	0,57	6,77	89,77
		P-5	1,08	1,98	0,63	0,87	95,44
		P-6	1,13	2,04	0,61	2,04	94,18
	Waste	P-4	0,81	1,02	0,47	49,36	48,05
		P-5	0,71	0,98	0,49	51,91	45,62
		P-6	1	1,63	0,61	20,35	76,3
8-20 mm	Feed	*	1,06	1,92	0,62	1	95,4
	Product	P-4	1,16	1,97	0,63	0,76	95,48
		P-5	1,13	1,96	0,61	1,74	94,56
		P-6	1,09	2	0,64	0,74	95,53
	Waste	P-4	1,74	1,57	0,7	24,36	71,5
		P-5	1,14	1,35	0,5	39,37	57,43
		P-6	1,15	1,98	0,67	1,21	94,99

In natural magnesite ore, 85% MgO is considered medium-to-high grade. Most companies consider MgO contents above 80% economical. However, for refractory quality (firebrick, dolomite brick, etc.), the target is generally 90-95% MgO. This is because high-temperature durability depends on MgO purity.

In this case, 85.63% is considered low grade. In the table specific feed, while the feed is 85.63 %, tomra increases the products to 94-95% MgO. In other words, the system enriches the feed, which might be considered low for refractory materials, into high-quality refractory grades.

Among the impurity oxides, SiO₂ and Fe₂O₃ are particularly important since they negatively affect the refractory properties, and therefore their reduction in the product is desirable. On the other hand, CaO and Al₂O₃ are present in smaller amounts and have less impact on the overall quality.

Table 3-2 Complete chemical analysis of feed, product and waste samples

Size	Type	Program	Silicon Dioxide SiO ₂ (%)	Calcium Oxide CaO (%)	Iron Oxide Fe ₂ O ₃ (%)	Aluminium Oxide Al ₂ O ₃ (%)	Magnesium Oxide (MgO) (%)	Loss on Ignition (LOI) (%)	TO ₂
5-20 mm	Feed	*	1,04	1,78	0,60	10,95	85,63	12,21	0
	Product	P-4	1,08	1,81	0,57	6,77	89,77	13,55	0
		P-5	1,08	1,98	0,63	0,87	95,44	13,18	0
		P-6	1,13	2,04	0,61	2,04	94,18	13,23	0
	Waste	P-4	0,81	1,02	0,47	49,36	48,05	11,44	0,29
		P-5	0,71	0,98	0,49	51,91	45,62	10,15	0,29
		P-6	1,00	1,63	0,61	20,35	76,30	11,56	0,11
8-20 mm	Feed	*	1,06	1,92	0,62	1,00	95,40	12,34	0
	Product	P-4	1,16	1,97	0,63	0,76	95,48	13,60	0
		P-5	1,13	1,96	0,61	1,74	94,56	13,80	0
		P-6	1,09	2,00	0,64	0,74	95,53	12,65	0
	Waste	P-4	1,74	1,57	0,70	24,36	71,50	11,45	0,13
		P-5	1,14	1,35	0,50	39,37	57,43	10,32	0,21
		P-6	1,15	1,98	0,67	1,21	94,99	11,52	0,00

When appra sample is placed in a furnace at high temperature (generally between 900-1000 °C), volatile components in the sample (such as water, carbon dioxide, organic matter, hydrates) burn off or evaporate. The reduction in the weight of the sample is exposed as loss of ignition (LOI).

The CO₂ loss during this reaction is reflected in the LOI value. Thus, a high LOI indicates a carbonate-rich structure. If LOI is low, the sample may already be partially calcined (or closer to pure MgO composition).

- Unit : % (percentage of weight loss)

Importance for Magnesite

When magnesite ore ($MgCO_3$) is heated, CO_2 gas is released.



In the analysed feed material, an LOI value of approximately 12% was determined, which confirms the carbonate-rich structure of magnesite minerals. It is observed that LOI values tend to decrease as the MgO content increases. This indicates that higher MgO content is associated with lower carbonate loss.



Figure 3-12 Product fed into the x-ray separator

3.8.1 Analysis of 5-20 mm Material with P-4 Program

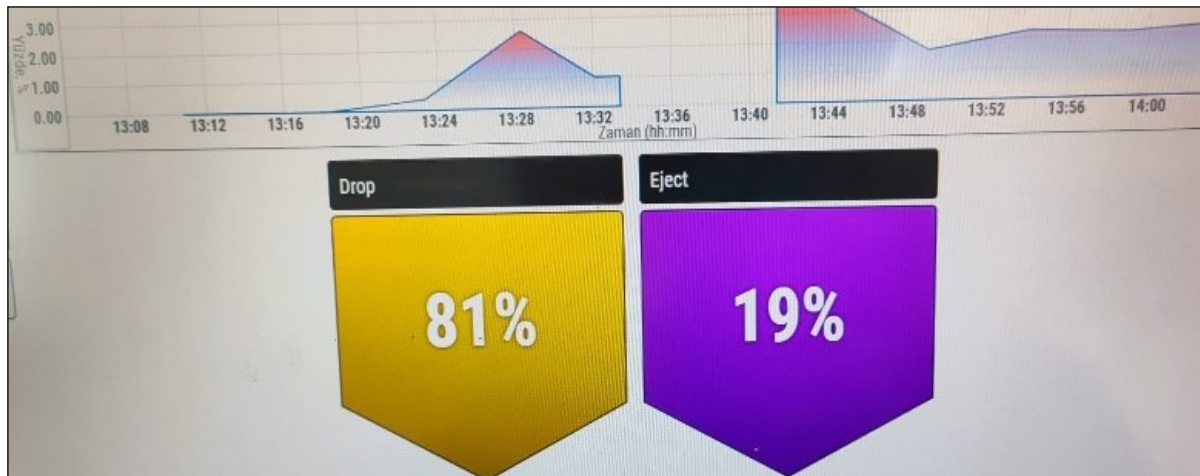


Figure 3-13 Data analysis of P-4

In program 4, drop refers to the 81% material that falls directly off the conveyor. In other words, the portion left as product (the accepted, good fraction). In this example, 81% of the 5-20 mm feed is accepted as product.

Eject refers to the material detected by the sensor as unwanted (dirty/low-grade) and ejected by air jets. This is usually the waste portion. Here, 19% is discarded.

Feed : MgO = 85,63%

Product : MgO = 89,77%

Reject : MgO = 48,05%

$$\text{Recovery (\%)} = \frac{\text{RN Amount} \times \text{RN Grade}}{\text{Feed Amount} \times \text{Feed Grade}} * 100$$

RN Amount = Running Amount (running quantity, processed material quantity)

It gives the total grain passing through the machine gives the tonnage amount.

RN Grade refers to the average grade of the processed material.

If we assume that feed is 100 kg for all calculations, then;

Product : 81 kg MgO content = $0,8977 * 81 = 72,72$ kg MgO

Waste : 19 kg MgO content = $0,4805 * 19 = 9,13$ kg MgO

Total Feed : MgO = $85,63\% * 100 = 85,63$ kg MgO

$$\text{Recovery (\%)} = \frac{72,72}{85,63} * 100 = 85,0\%$$

X-ray separator machine recovered 85% of the magnesium oxide (MgO) in the feed, and the remaining 15% escaped to the rust side.

3.8.2 Analysis of 5-20 mm Material with P-5 Program

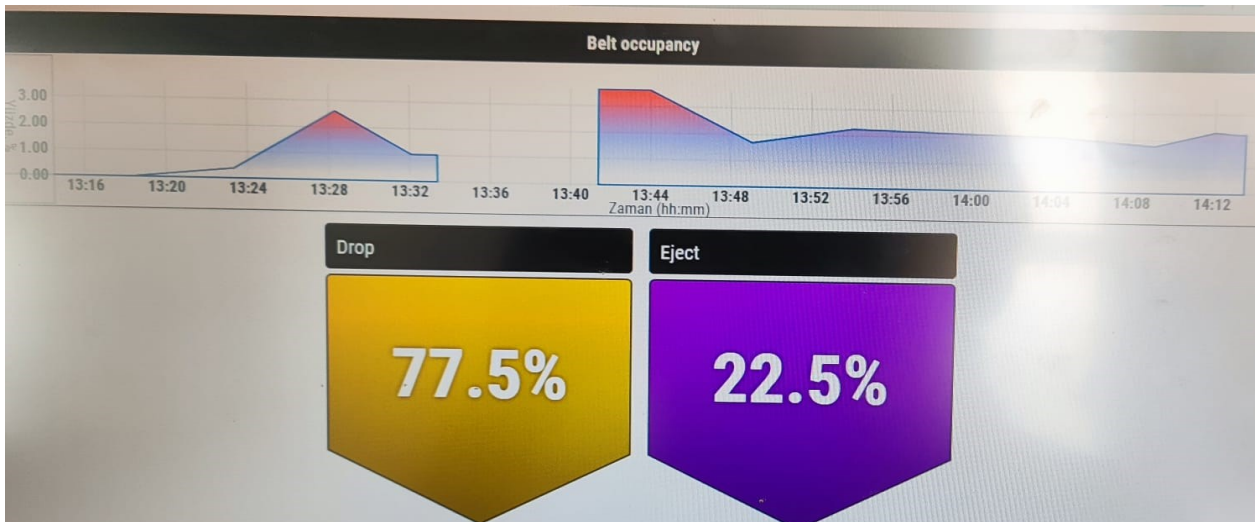


Figure 3-14 Data analysis of P5

MgO grade : 85,63%

Total MgO : 85,63 kg

P-5 results would be;

Drop (product) : 77,5% = 77,5 kg

MgO grade : 95,44%

MgO content : $77,5 * 0,9544 = 73,966$ kg MgO

Eject (waste) : $22,5 * 0,4562 = 10,2645$ kg MgO

$$\text{Recovery (\%)} = \frac{73,966}{85,63} * 100 = 85,38\%$$

$$\text{Upgrade ratio} = \frac{95,44}{85,63} = 1.115 (+11.5\%)$$

For the 5-20 mm fraction under program P-5, the belt split was 77,5% product and 22,5 reject. Using assay data (feed 85,63% MgO; product 95,44% MgO; reject 45,62% MgO), the MgO recovery to product was 86,38%, while the upgrade ratio reached 1.115(+11.5%). The product-reject MgO gap of 49,82 percentage points indicates strong selectivity.

3.8.3 Analysis of 5-20 mm Material with P-6 Program

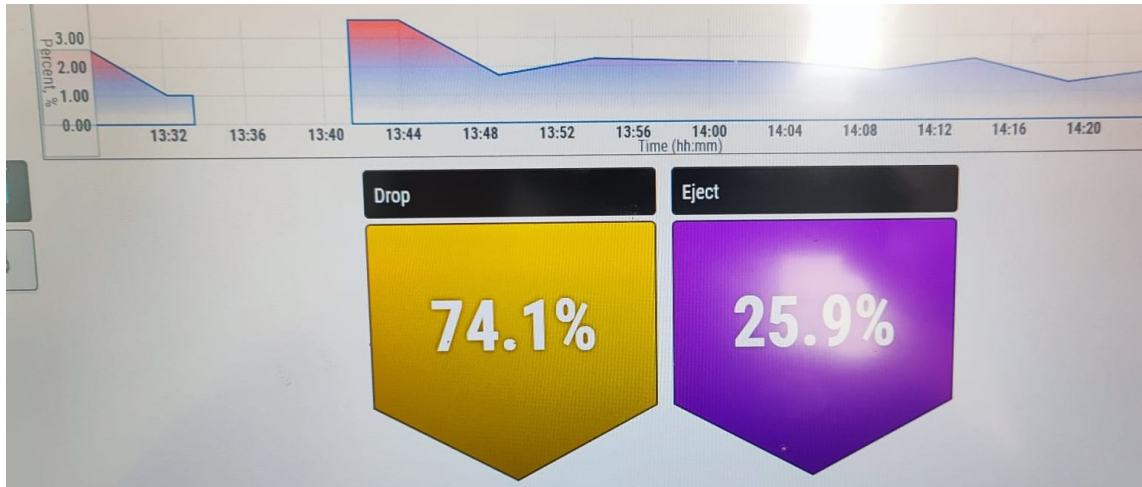


Figure 3-15 Data analysis of P-6

Drop (product) : 74.1% = 74.1 kg

MgO grade : 94,18%

MgO content : $74,1 * 0,9418 = 69,78$ kg MgO

MgO grade : 76,30%

MgO content : $25,9 * 0,7630 = 19,762$ kg MgO

$$\text{Recovery (\%)} = \frac{69,787}{85,63} * 100 = 81,5\%$$

$$\text{Upgrade ratio : } \frac{94,18}{85,63} = 1.100 (+10\%)$$

In the 5-20 mm size fraction, the band distribution under program P-6 was 74,1% product and 25,9% waste. Analysis results showed that the feed contained 85,63% MgO, while the product contained 94,18% MgO and the waste contained 76,3% MgO. Based on these data, MgO recovery on the product side was calculated as 81,5%, with a grade increase of 1.100 (approximately a 10% increase). However, since the MgO difference between the product and waste was only 17,88 points, selectivity was limited, and a significant amount of valuable minerals migrated to the waste side. This suggests that, despite achieving high grades, program P-6 did not offer optimal performance in terms of recovery and selectivity.



Figure 3-16 5-20 mm recovery waste



Figure 3-17 Product of 5-20 mm feed

3.8.4 Analysis of 8-20 mm Material with P-4 Program

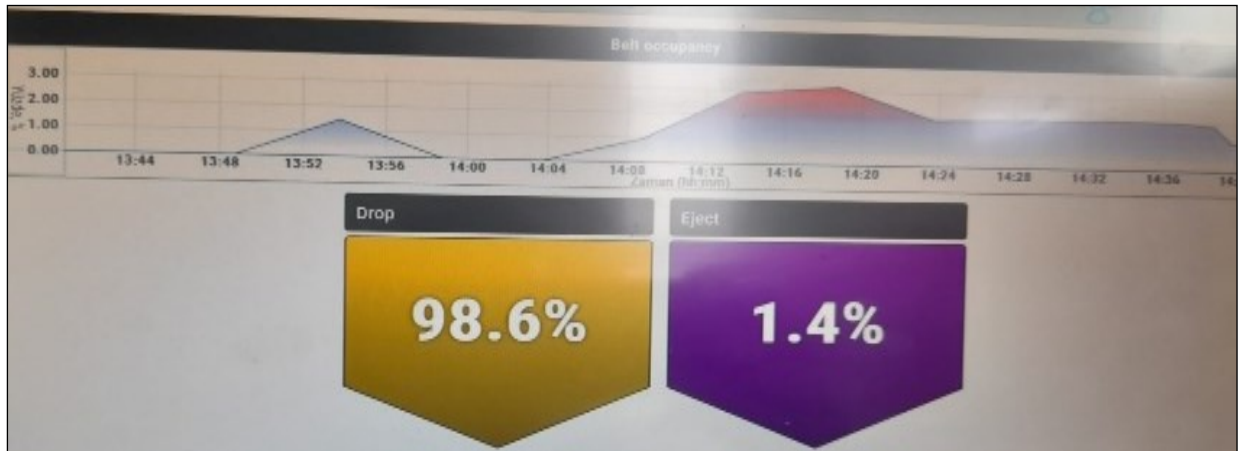


Figure 3-18 Data analysis of P-4 (2)

Feed : 95,4% MgO

Product grade : 95,48% MgO

Product mass fraction : 98,6% MgO

$$\text{Recovery (\%)} = \frac{\text{Product mass fraction} \times \text{Product grade}}{\text{Feed}} * 100$$

$$\text{Recovery (\%)} = \frac{0,986 \times 95,48}{95,4} * 100 = 98,7\%$$

This value shows that almost all of the MgO has passed to the product side.

3.8.5 Analysis of 8-20 mm Material with P-5 Program



Figure 3-19 Data analysis of P-5(2)

Feed : 95,4% MgO

Product grade : 94,56% MgO

Product mass fraction : 98,3%

$$\text{Recovery (\%)} = \frac{\text{Product mass fraction} \times \text{Product grade}}{\text{Feed}} * 100$$

$$\text{Recovery (\%)} = \frac{0,983 \times 94,56}{95,4} * 100 = 97,4\%$$

In this case, the product amount is very high (98,3% yield), but because the product grade is slightly lower than the feed ($94,56 < 95,4$), the recovery value is 97,4 instead of 98%. So, there is a slight loss in quality (grade), but almost all of the MgO has transferred to the product side.

3.8.6 Analysis of 8-20 mm Material with P-6 Program

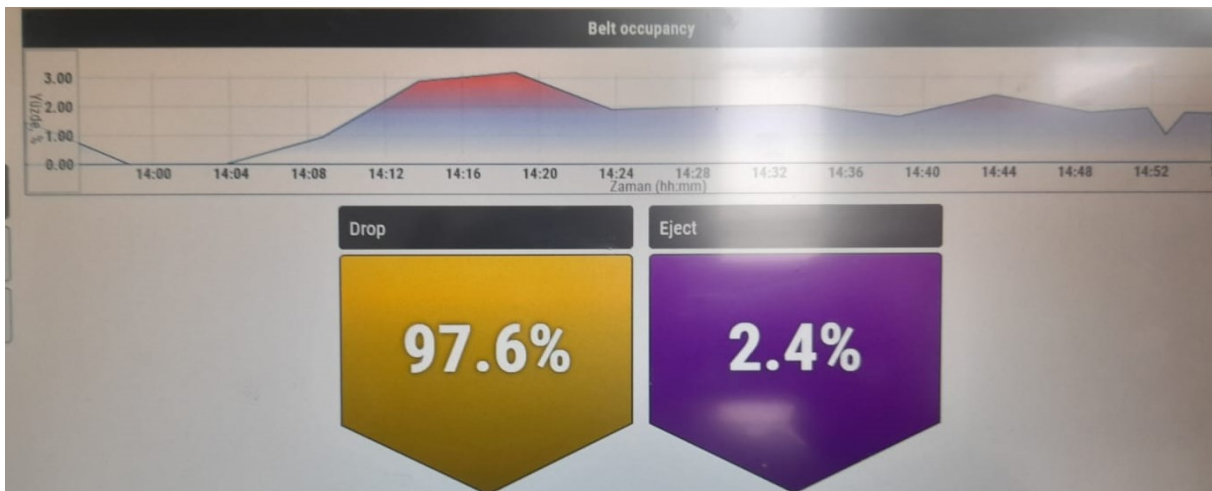


Figure 3-20 Data analysis of P-6(2)

Feed grade : 95,4% MgO

Product grade : 95,53% MgO

Product mass fraction : 97,6% MgO

$$\text{Recovery (\%)} = \frac{\text{Product mass fraction} \times \text{Product grade}}{\text{Feed}} * 100$$

$$\text{Recovery (\%)} = \frac{0,976 \times 95,53}{95,4} * 100 = 97,7\%$$

An examination of the results of three different programs performed on the 8-20 mm fraction reveals that the system generally operates with high efficiency.

In the P-4 program, the product grade was determined to be 95,48% MgO, and the product mass fraction was determined to be 98,6%. Under these conditions, the MgO recovery value demonstrates that almost all of the MgO in the feed was transferred to the product side, demonstrating that P-4 provides particularly high purity and efficiency.

In the P-5 program, the product grade was 94,56% MgO, and the product mass fraction remained at 98,3%. In this case, the recovery achieved was 97,4%. Although a slight decrease in product grade was observed compared to P-4, a significant portion of the feed was still transferred to the product side. Therefore, the P-5 program also provides high recovery, but slightly behind P-4 in terms of quality.

In the program 6, product grade was calculated as 95,53% MgO and product mass fraction as 97,6%. Based on these data, MgO recovery was found to be 97,7%. This value offers slightly higher product quality than P-5, but remains below the level achieved by P-4.

Generally speaking, all three programs yielded very successful results for MgO in the 8-20 mm fraction. Recovery values exceeding 97% indicate that the system transferred almost all of the MgO in the feed to the product side and demonstrated high enrichment performance. However, there were minor differences between the programs; P-4 stood out with its highest recovery and product grade, while P-5 offered slightly lower quality and efficiency, while P-6 exhibited a balanced performance between the two programs.



Figure 3-21 8-20 mm recovery waste

Images also highlight the material stream rejected during the sorting processes. The waste fraction is characterized by a darker appearance and irregular fragments, typically containing a lower MgO content.



Figure 3-22 Product of 8-20 mm feed

In contrast, the product fraction obtained after sorting demonstrates a comparatively cleaner and more homogeneous appearance. The lighter-coloured fragments correspond to material enriched in MgO.



Figure 3-23 Products



Figure 3-24 Wastes

Chapter 4

4 Evaluation and Discussion

4.1 Assessment of Reprocessing Efficiency

The assessment of reprocessing efficiency demonstrates that the applied methods, including crushing, classification, and optical sorting, provide a recovered material with sufficiently high MgO content and physical quality to be reused in refractory production. The reprocessed fraction shows reduced levels of impurities such as FeO, SiO₂, and CaO, which indicates that the process does not compromise product standards (Horckmans et al., 2019). Moreover, the procedures can be integrated into existing production lines with only minor adjustments, confirming the technical feasibility of the approach (RHI Magnesita, 2023).

4.2 Technical and Economic Feasibility

Evaluations have shown that the process is technically feasible. Recovered material obtained from experimental applications exhibited MgO content and physical strength sufficient to meet production standards. This indicates that no obstacle exist in terms of quality.

From an economic perspective, however, the outcome is different. The initial investment costs required for the reprocessing line, particularly for optical sorting equipment and additional infrastructure, were found to be quite high. Moreover, the energy consumption and maintenance expenses associated with the operation further increased the overall costs, making the process more expensive compared to the use of conventional raw materials.

From a strategic standpoint, while the initiative is consistent with the objectives of environmental sustainability and the circular economy, it has not been deemed economically viable due to the short-term cost pressures and extended payback periods. Combination of high capital and operating expenditures, along with efficiency losses, has constrained its applicability under current market conditions. This underscores the necessity of a holistic evaluation in sustainability-oriented projects, where not only

Technical feasibility but also economic and operational dimensions must be rigorously considered.

4.3 Sustainability Perspective

From a sustainability perspective, the reprocessing of defective and end-of-life bricks hold a strategic importance not only for waste management but also for its environmental, economic, and social implications. Process contributes to resource conservation by reducing waste volumes and minimizing disposal requirements, while simultaneously lowering the dependency on primary raw materials.

However, experimental results indicated that the procedure was associated with higher energy consumption compared to conventional raw material use, which limits its environmental advantages under current conditions.

Economically, it shows potential for reducing raw material procurement and disposal costs, while socially, the reduction of environmental impacts has the potential to strengthen stakeholder confidence and corporate reputation. In this study, both defective products and end-of-life materials examined.

Although the samples were analyzed at the laboratory scale, direct collection of end-of-life fire bricks customers enabled the research to partially reflect real field conditions.

Thus, findings provide a preliminary yet meaningful basis for evaluating the industrial applicability of such reprocessing strategies.

4.4 Challenges and Recommendations

Although the laboratory-scale trials demonstrated the technical feasibility of reprocessing defective and end-of-life refractory bricks, several barriers remain before the approach can be considered suitable for industrial adoption. These barriers go beyond simple cost considerations and highlight broader issues related to process efficiency, market acceptance, and policy support. Identifying these challenges and formulating clear recommendations is crucial to guide future developments in this field.

Thus, findings provide a preliminary yet meaningful basis for evaluating the industrial applicability of such reprocessing strategies.

4.4.1 Challenges

- From a technical point of view, heterogeneity of fire bricks (MgO content, binders, size).
- From the economic & operational point of view, need for workforce training & adaptation.
- For the feasibility aspect, it depends on the market fluctuations.
- From sustainability & policy point of view, lack of standards for recycled materials.
- Limited regulatory incentives and weak circular economy framework.
- Industry reluctance due to short-term cost focus.

4.4.2 Recommendations

- Investing R&D (sorting technologies).
- Developing QC systems (real-time monitoring).
- Applying multi-stage processing.
- Pilot-scale studies to validate cost-benefit.
- Establishing national/international standards.
- Align with EU Green Deal targets.
- Promoting academia-industry-government collaboration.

Chapter 5

5 Conclusion

5.1 Summary of Findings

Within the MgO-rich defective bricks, the presence of mortar components, particularly resin, was found to significantly reduce process efficiency. From an industrial standpoint, the process was therefore deemed economically unfeasible.

This conclusion was reached by taking into account the machine's hourly production rate and the volume of waste generated. Moreover, as the hourly feed rate increased, a marked decline in product quality was observed.

Under these conditions, the recovery process was determined to be economically non-viable.

5.2 Contribution to the Field

Firebricks that are discarded or do not meet quality standards often have substantial amounts of MgO.

Previously, there has been no organized system to recycle these discarded materials.

By grinding, breaking down, and sorting brick waste, valuable materials can be separated and recovered. This technique allows for the recovery of usable raw materials that can be used to create high-quality bricks.

This method backs the idea of a circular economy and helps to ease pressure on the environment.

Using recycled brick components means that fewer new raw materials are needed.

Information and real-world examples of effectively recycling firebricks are scarce in Turkey and around the world. This research helps the industry by being one of the first studies explore this area.

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Notes

1. *Author's field knowledge (2024) refers to personal observations and professional insights gained during academic and sectoral work; not a publicly available sources.*