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Optical sorting technology for magnesite triage waste recycling: A two-stage process for reducing impurities

Manyezit triyaj atığı geri dönüşümü için optik ayıklama teknolojisi: Kirlilikleri azaltmak için iki aşamalı bir işlem

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Abstract

This study evaluated the effectiveness of sensor-based optical sorting technology for recovering magnesite from triage waste. Approximately one ton of magnesite waste samples, containing 45.9% MgO, 4.7% Fe_2O_3, and 10.6% SiO_2, were sampled from different regions of a waste site at a magnesite plant in the Eskişehir region. Two size fractions (-35+15 mm and -15+8 mm) were subjected to magnetic separation, washing, and two-stage optical sorting. For the -35+15 mm fraction, impurity levels were reduced from 9.94% to 1.91% SiO_2, 1.22% to 0.15% Fe_2O_3, and 2.41% to 0.81% CaO, achieving 65.12% concentrate yield. The -15+8 mm fraction showed similar improvements with a 72% concentrate yield. Results demonstrate that optical sorting technology can effectively upgrade magnesite waste to acceptable quality levels, supporting sustainable mining practices and circular economy principles while providing economic benefits through waste evaluation.

Keywords: Magnesite, Optical sorting, Magnesite recovery, Triage waste, Impurity reduction

Öz

Bu çalışmada, triyaj atıklarından manyezitin geri kazanılmasında sensör tabanlı optik ayıklama teknolojisinin etkinliği değerlendirilmiştir. Eskişehir bölgesindeki bir manyezit tesisinin atık sahasının farklı bölgelerinden, %45,9 MgO, %4,7 Fe_2O_3 ve %10,6 SiO_2 içeren yaklaşık bir ton manyezit atık örneği alınmıştır. İki boyut fraksiyonu (-35+15 mm ve -15+8 mm) manyetik ayırma, yıkama ve iki aşamalı optik ayıklamaya tabi tutulmuştur. -35+15 mm fraksiyonu için safsızlık seviyeleri %9,94'ten %1,91 SiO_2'ye, %1,22'den %0,15 Fe_2O_3'e ve %2,41'den %0,81 CaO'a düşürülerek %65,12 konsantre verimi elde edilmiştir. -15+8 mm fraksiyonu da %72 konsantre verimi ile benzer iyileştirmeler göstermiştir. Sonuçlar, optik ayıklama teknolojisinin, atık değerlendirmesi yoluyla ekonomik faydalar sağlamanın yanı sıra sürdürülebilir madencilik uygulamalarını ve döngüsel ekonomi prensiplerini destekleyerek, manyezit atıklarını kabul edilebilir kalite seviyelerine etkili bir şekilde yükseltebileceğini göstermektedir.

Anahtar kelimeler: Manyezit, Optik ayıklama, Manyezit geri kazanımı, Triyaj atığı, Kirlilik azaltımı

1 Introduction

Magnesite ($MgCO_3$), utilized in the production of magnesia (MgO), represents the industry's primary source of magnesium (Mg). It is also one of the most strategically important industrial minerals on a global scale. The formation of magnesite occurs through the contact metamorphism of dolomites or the alteration of serpentine [1-2] and similar ultramafic rocks, which results in significant variations in chemical composition across different geographical regions. This geological diversity directly affects the quality, processing requirements, and economic viability of magnesite deposits worldwide, making regional characterization essential for optimal processing strategies.

The mineralogical composition of magnesite ore typically contains various impurities (e.g., CaO, SiO_2, Fe_2O_3, and Al_2O_3), including quartz, apatite, and trace quantities of iron compounds, which significantly influence processing requirements and final product quality. Depending on its geological formation and source location, magnesite exhibits 40-47% MgO (or 84.0-99.0% $MgCO_3$), 0-3.5% CaO, 0-7% SiO_2, 0-3% Al_2O_3, and Fe_2O_3 [3]. The industry classification system categorizes magnesite as high quality when the MgO content exceeds 46%, medium quality when it is between 43% and 46%, and low quality when it is below 43% [4]. This classification system directly influences the economic viability and industrial applications of different magnesite deposits, making accurate grade assessment crucial for processing optimization.

The favorable physicochemical properties of magnesite enable its use in various industrial settings, including ceramics manufacturing, metallurgical processes, cement production, fertilizer production, animal feed supplements, and particularly in the creation of refractory materials [3, 5-8]. Magnesia is a key refractory raw material essential for producing a wide range of refractory products, particularly the widely used magnesia-carbon brick, which is vital to steelmaking worldwide. Over 90% of mined magnesite ore is converted into sinter and caustic-calcined magnesite to make basic refractory bricks, which are critical components

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in high-temperature industrial processes [9]. The remaining roughly 10% is used to produce magnesium salts for pharmaceutical purposes and in various processes within the cement, paper, and sugar industries.

The extraction of raw materials, removal of waste rock, quality grading, and thorough beneficiation processes are essential steps in modern magnesite mining operations. Beneficiation methods include hand sorting, size reduction, magnetic separation, electrostatic separation, heavy media separation, optical sorting, flotation, and calcination. Triage, a manual sorting process that relies on visual identification and the manual separation of different mineral components based on their color, texture, and other observable characteristics, is typically used in the pre-beneficiation stage to remove coarse serpentine and siliceous impurities from magnesite.

Hand sorting, based on the distinctive color properties and visual characteristics of different minerals, represents one of the oldest and most fundamental mining techniques known to humanity. Historical records suggest that early metalworkers employed manual sorting several millennia ago to remove coarse gangue particles, and this traditional method continues to be observed in contemporary mining operations worldwide [10-11]. The increasing demands for cost reduction, productivity enhancement, and consistent quality control in modern mining operations have led the industry to pursue technological advancements that can replicate and significantly improve upon human capabilities while lowering operational expenses and safety risks.

The shift from hand to automated sorting marks a major change in mineral processing technology. Advanced camera systems, pneumatic valves, and computer processing have replaced human senses like eyes, hands, and memory, resulting in extremely effective optical sorting techniques. The advanced line scan cameras used in modern optical sorters are capable of simultaneously analyzing multiple spectral bands and controlling large volumes of data with integrated hardware and software. This approach, in contrast to manual methods, enables faster processing, more accuracy, and greater consistency.

Optical sorting technology has a variety of uses in mineral processing flowsheets, including pre-concentration of raw materials, production of final concentrate, and reprocessing of waste [11-12]. Studies by various researchers have demonstrated the effective use of optical sorters in the pre-concentration of gold [10, 13], chromite, diamond [14], and sulfide ores [15], as well as in the recovery of final products from materials such as coal [16], marble, and feldspar [17].

Although optical sorting technology shows promise, its application in waste utilization studies remains relatively limited, resulting in a scarcity of published research articles addressing this topic. Every research conducted in this area will improve resource utilization and environmental sustainability in the mining sector, creating significant opportunities for scientific research and technological advancements. The increasing focus on sustainable mining practices has sparked interest in recovering valuable materials from old waste.

The quality assessment of magnesite products requires careful evaluation of both magnesium oxide content and impurity levels, as these factors are critical for determining the product's suitability for specific applications. Impurities such as CaO, SiO_2, Fe_2O_3, and Al_2O_3 in magnesite often negatively affect processing efficiency and the refractory properties of the final products. Therefore, keeping impurity levels within acceptable limits is crucial for ensuring quality and meeting increasingly stringent industry standards. By using optical sorting technology in waste processing, it is possible to increase resource recovery in mining, minimize environmental impact, and support circular economy initiatives. Mining companies worldwide are increasingly adopting this method as it aligns with global sustainability goals and legal requirements for responsible mining practices [18].

Integrating artificial intelligence and machine learning algorithms with optical sorting systems [19-20] represents the next advancement in mineral processing. These advanced systems can learn from processing data, optimize sorting parameters in real-time, and adapt to variations in ore characteristics, further enhancing recovery rates and product quality while reducing operational expenses [21-28].

This study aims to evaluate the effectiveness of an industrial-scale optical sorting process in reducing contaminant levels, such as CaO, SiO_2, Fe_2O_3, and Al_2O_3, to acceptable standards using approximately one ton of samples collected from different areas of the triage waste location. The study highlights the technical and economic feasibility of utilizing optical sorting for waste recovery while also expanding knowledge of sustainable mineral processing technologies. Focusing on environmental sustainability, this study examines the potential for improvements in separation efficiency, product quality, and the integration of optical sorting into existing magnesite processing flowsheets.

The study differs from earlier magnesite optical sorting research in several important ways. Unlike previous studies [10, 13-17] that primarily concentrated on processing raw ores or pre-beneficiation of raw materials, the present research focuses on waste materials produced during triage processes. This topic has been rarely explored in the literature. Furthermore, by applying a two-stage optical sorting method and examining two size fractions (-35+15 mm and -15+8 mm), this study highlights how multiple processing stages can significantly enhance product quality and offers practical insights into how particle size affects sorting efficiency.

The study methodology supports advancements in the field by bridging research findings with commercial applications using industrial-scale equipment rather than laboratory-scale instruments. Furthermore, by demonstrating that optical sorting can be effectively integrated with traditional magnetic separation and washing processes, it highlights how advanced technology can complement, rather than replace, existing beneficiation methods. This innovative approach offers more realistic and directly applicable results for the mining industry.

2 Material and method

2.1 Material

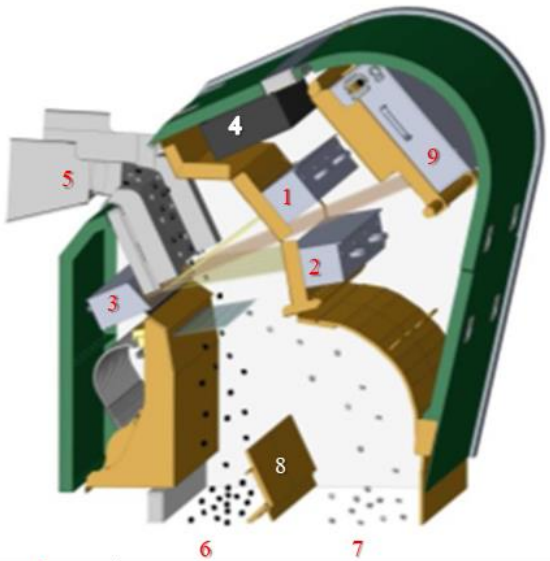
The region, which includes Eskişehir, is home to a significant share of Turkey's magnesite reserves. The majority of enterprises operating in this region have been producing magnesite since the early 1960s. Triage wastes produced by existing magnesite plants are gradually increasing in stock areas. Evaluation of these wastes will provide some economic and environmental benefits to the enterprises, as well as important financial support for the improvement of production areas.

The sample used for optical sorting tests has consisted of approximately one ton of material taken from different sections of the waste dump of a local company, Magnesite Co. The composition of the sample includes 45.9% MgO, 4.7% Fe_2O_3, and 10.6% SiO_2.

2.2 Experimental equipment

The experiments were conducted using an industrial-sized optical sorter supplied by Binder+Co (Figure 1.b).

The essential components of sensor-based sorters include the vibrating feeder, the identification system, and the blowing system. Sorting is a way of separating individual particles. To ensure successful separation, each particle must be fed to the sensor individually and at an optimal distance from other particles. The feeder's primary task is to deliver a single-layer and evenly distributed supply. The material properties have an important impact on determining the feeder's vibration frequency and amplitude.



1 Detection
2 Illumination systems
3 Blowing system
4 Recognition cameras
5 Vibrating feeder
6 Accepted
7 Rejected
8 Separation plate
9 Sensor unit

(a)



(b)

Figure 1. MINEXX mineral sorter (b) and its schematic illustration (a)

For effective separation, the particle size distribution of the feed material should be between 5 and 130 mm. Another important factor is the incline of the feeder, which must correspond to the size distribution of the material. Additionally, optical sorters are equipped with special illumination systems and high-resolution sensors to help identify material-specific characteristics of the feed material, such as color, whiteness, shape, and texture (Figure 2).

The best particle lighting is accomplished using controllable, robust LED lines outfitted with cutting-edge diffusion technology. The resolution of the color recognition cameras is less than 0.5 x 0.5 millimeters per pixel. This feature contributes significantly not only to increased product quality but also to increased production. Its modular and robust design allows it to operate even in extremely dusty and humid conditions.



Figure 2. MINEXX's long-life LED light

The distance between two nozzles that can act independently is determined by the mean particle size (Figure 3). The software adjusts the blowing pressure for the heaviest particle in the feed. The computer determines the optimal valve control parameters in addition to sorting the feed material.



Figure 3. MINEXX's air valve system

Based on the system's specifications, impurities are blown into the corresponding sorting paths by compressed air when the sensitive valves are activated at just the right moment. The sorter is equipped with the appropriate number of valves based on the particle size distribution of the feed material.

2.3 Sample preparation and sorter adjustment

It is crucial to prepare the feed material before it is fed into the optical sorter due to the significance of material size and surface characteristics. It should be ensured that the ratio of the coarsest particle size to the smallest particle size in the feed material is between 3:1 and 2:1 as much as possible for efficient sorting. The particles must be presented to the sensor after they have been appropriately prepared for classification. Each particle must be supplied to the sensor individually and at an appropriate distance from the others, as optical separation is designed for single-particle separation. In this context, the feed rate and material handling methods, such as chutes and conveyor belts, are critical parameters for effective optical sorting [10, 29-30].

For the classification of triage waste, sieves with sizes of 100, 35, 15, and 8 mm were chosen based on the particle size ratios. The weight distributions of the resulting classified products are presented in Table 1.

Table 1. Triage waste's sieve analysis result [31]

Size range (mm)	Weight (%)
+100	13.18
-100+35	23.29
-35+15	12.50
-15+8	7.64
-8	43.39
Total	100.00

Based on the preliminary evaluations, it was decided to use two product groups for optical separation. As shown in Table 1, about 20% of the feed material falls within the size ranges of -35+15 mm and -15+8 mm.

Samples were run through a magnetic separator first to ensure efficient optical separation. Subsequently, the non-magnetic product groups underwent washing. The results are presented in Table 2.

Table 2. Product distributions after magnetic separation and washing [31]

Size range (mm)	Magnetic Separation		Washed	
	Product	Weight, %	Product	Weight, %
-35+15	Magnetic	71.75		
	Non-Magnetic	28.25	Concentrate	91.20
			Tailing	8.80
-15+8	Magnetic	75.82		
	Non-Magnetic	24.18	Concentrate	90.30
			Tailing	9.70

Table 2 highlights the effectiveness of magnetic separation and washing processes. In both size groups, the magnetic product ratio exceeds 70%, while the concentrate yield after washing surpasses 90%.

Setting up the system's parameters is a crucial step before conducting the tests. The digital value of the images captured by the camera serves as the primary control parameter. Another important control parameter is the ratio of lighter and darker components relative to the values introduced into the system. Adjusting the ratios can further improve the separation if necessary.

Four groups were created from the materials selected from the test sample based on color differences (Figure 4). The white colored samples in Figure 4 were coded as concentrate (C), the mixed colored samples as middling (M1 and M2), and the dark colored samples as rejected product (R) and photographs of each group were added to the system individually.

Belt speed, band surface, and compressed air valves are adjusted before testing. The blowing system is critical to the separator's efficiency, so the valves must be checked for functionality. These checks are crucial because while the optical separator's fault detectors can identify other problems during operation, they are unable to detect this specific issue.

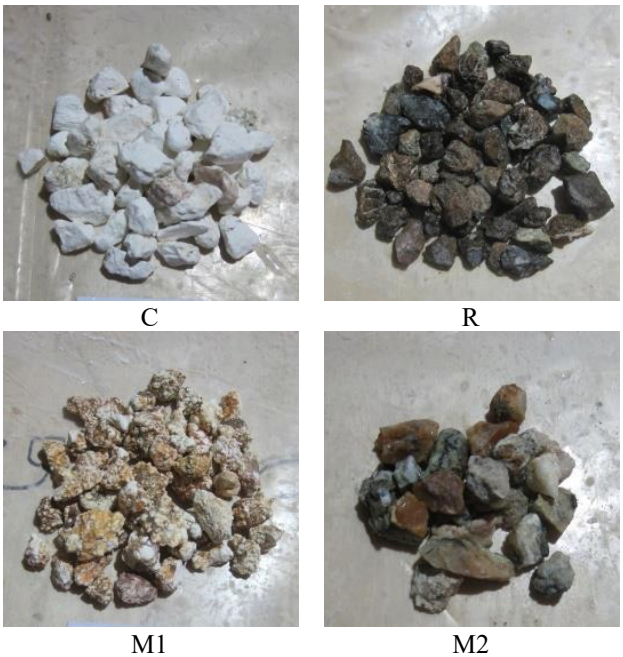


Figure 4. Photos and codes to be set in the system

3 Experimental results and discussion

The -35+15 mm size group was fed to the optical sorter after the necessary inspections and adjustments were completed. Test results are illustrated in Table 3.

Table 3. Analyses of products in the size group of -35 +15 mm after the initial pass

Product	Weight (%)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)
Concentrate-1	72.61	3.38	0.25	0.03	1.28
Tail-1	27.39	27.33	3.79	0.32	5.41
Feed	100.00	9.94	1.22	0.11	2.41

The product quality was found to be below average following the test because the concentrate contained dark-colored contaminants. The concentrate-1 obtained at the end of the first test was fed to the optical sorter a second time after the necessary adjustments were made. Table 4 shows the results of this experiment.

Table 4. Analyses of products in the size group of -35 +15 mm after the second pass

Product	Weight (%)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)
Concentrate	89.69	1.91	0.15	0.01	0.81
Tail-2	10.31	16.17	1.12	0.20	5.37
Concentrate-1	100.00	3.38	0.25	0.03	1.28

Table 5 shows the distribution and chemical analyses of products in the size range of -35+15 mm. The product obtained by combining “Tail-1” and “Tail-2” is designated as "Tail" in the table, while the concentrate from the second pass is represented as "Concentrate."

Table 5. Distribution and chemical analysis of products in the -35 +15 mm size range

Products	Weight	Impurities, %			
	(%)	SiO_2	Fe_2O_3	Al_2O_3	CaO
Concentrate	65.12	1.91	0.15	0.01	0.81
Tail	34.88	24.94	3.22	0.29	5.40
Feed	100.00	9.94	1.22	0.11	2.41
Product	Weight	Distribution, %			
	(%)	SiO_2	Fe_2O_3	Al_2O_3	CaO
Concentrate	65.12	12.5	8.0	6.0	21.9
Tail	34.88	87.5	92.0	94.0	78.1
Feed	100.00	100.0	100.0	100.0	100.0

The optical sorting process in the -35+15 mm size fraction demonstrated remarkable success in reducing impurities (Table 5). The SiO_2 content was decreased from 9.94% to 1.91%, resulting in an 80.8% reduction in silica contamination. This significant improvement brings the material very close to meeting acceptable quality standards for refractory applications. The Fe_2O_3 content was decreased from 1.22% to 0.15%, resulting in an 87.7% reduction. Iron contamination is highly critical, as it significantly affects the refractory properties of magnesite products. The Al_2O_3 content was reduced from 0.11% to 0.01%, resulting in a 90.9% reduction, demonstrating that the system can effectively remove even trace impurities. The CaO content was reduced from 2.41% to 0.81%, a 66.4% decrease, while maintaining acceptable levels for most applications.

In the -35+15 mm fraction, 65.12% of the feed material was recovered as high-quality concentrate. During the process, 87.5% of the silica, 92% of the iron oxide, 94% of the aluminum oxide, and 78.1% of the calcium oxide were successfully diverted to the waste stream. The results suggest that the triage waste in this size group was enriched in two stages using an optical sorter.

After the experiments with the first group, the optical sorter was thoroughly cleaned, and all necessary preparations and checks were completed. The -15+8 mm size group was then fed into the sorter. The results are illustrated in Table 6.

Table 6. Analyses of products in the size group of -15 +8 mm after the first pass

Product	Weight (%)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)
Concentrate-3	78.54	3.95	0.36	0.04	1.10
Tail-3	21.46	34.79	5.07	0.55	7.62
Feed	100.00	10.57	1.37	0.15	2.50

After the first pass of the -15+8 mm size group, it was observed that the concentrate was not of the desired quality due to the presence of dark-colored particles in it. Therefore, the “Concentrate-3” of the first pass was fed to the optical sorter a second time. Table 7 shows the results of this experiment.

Table 7. Analyses of products in the size group of -15 +8 mm after the second pass

Product	Weight (%)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)
Concentrate	91.68	2.58	0.19	0.02	1.05
Tail-4	8.32	19.05	2.23	0.26	1.65
Concentrate-3	100.00	3.95	0.36	0.04	1.10

Table 8 shows the distribution and chemical analyses of products in the size range of -15+8 mm. The product obtained by combining “Tail-3” and “Tail-4” is designated as "Tail" in the table, while the concentrate from the second pass is represented as "Concentrate."

Table 8. Distribution and chemical analysis of products in the 15+8 mm size range

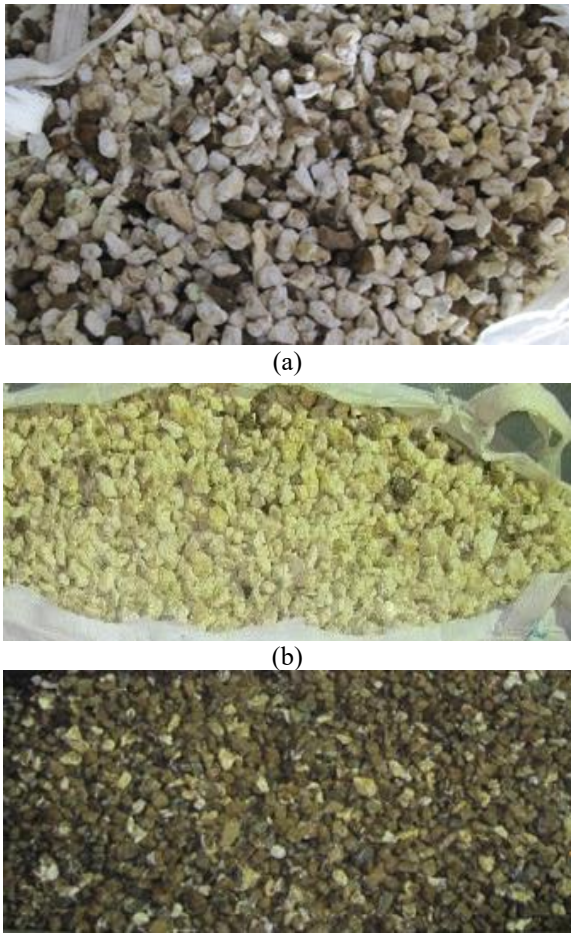
Product	Weight	Impurities, %			
	(%)	SiO_2	Fe_2O_3	Al_2O_3	CaO
Concentrate	72.00	2.58	0.19	0.02	1.05
Tail	28.00	31.12	4.41	0.48	6.23
Feed	100.00	10.57	1.37	0.15	2.50
Product	Weight	Distribution, %			
	(%)	SiO_2	Fe_2O_3	Al_2O_3	CaO
Concentrate	72.00	17.6	10.0	9.6	30.2
Tail	28.00	82.4	90.0	90.4	69.8
Feed	100.00	100.0	100.0	100.0	100.0

Similar results were seen in the -15+8 mm size fraction (Table 8). Reducing SiO_2 from 10.57% to 2.58% led to a 75.6% improvement, slightly less than in the coarser fraction. Reducing Fe_2O_3 from 1.37% to 0.19% resulted in an 86.1% decrease, confirming that the high efficiency of the coarse fraction was maintained. Reducing Al_2O_3 from 0.15%

to 0.02% improves results by 86.7%, while lowering CaO from 2.50% to 1.05% leads to a 58.0% decrease.

In the -15+8 mm fraction, 72% of the feed material was recovered as concentrate. The process removed 82.4% of the silica, 90% of the iron oxide, 90.4% of the aluminum oxide, and 69.8% of the calcium oxide.

Figures 5-a, 5-b, and 5-c, respectively, display the photos of the -35+15 mm material fed to the optical sorter, the concentrate obtained after combining the concentrated products passed through the optical sorter twice, and the tail obtained after combining the tail products fed to the optical sorter twice.



(a) (b) (c)

Figure 5. Images of feed (a), concentrate (b), and waste (c) products

By feeding the concentrate obtained from the first pass into the sorter a second time, Concentrate-2 in the -35+15 mm fraction demonstrated better results in all impurity parameters. The second pass yielded 89.69% recovery, resulting in minimal losses during reprocessing. This two-stage process eliminates any remaining dark contaminants, ensuring consistent product quality.

Comparisons between size fractions show that the -35+15 mm fraction offered higher impurity reduction rates, particularly for silica and calcium oxide. Both size fractions achieved similar iron and aluminum oxide reduction rates, demonstrating strong performance. The finer fraction (-15+8 mm) achieved a slightly higher mass recovery (72% vs. 65.12%), indicating better liberation.

The resulting concentrates meet or exceed standard industry requirements for medium- and high-quality magnesite. Maintaining the MgO content and significantly reducing impurities make these concentrates ideal for the following areas: refractory brick production, steel industry applications, and cement production support.

Among economic feasibility indicators, high mass recovery rates (65-72%) support economic viability, while reducing impurities eliminates the need for additional processing, and converting waste into resources generates additional revenue.

In terms of environmental benefits, material recovery reduces waste dump volume, reduces the need for raw ore extraction, and reduces the environmental footprint through circular economy practices.

The results demonstrate that optical sorting technology can effectively convert magnesite separation waste into valuable concentrate, achieving impurity reductions of 75-91% while maintaining mass recovery of 65-72%. The two-pass processing method demonstrates that iterative optical sorting can achieve higher product quality compared to single-pass processes.

4 Conclusion

This research successfully demonstrated the viability of optical sorting technology for upgrading magnesite triage waste to commercial quality standards. The two-stage optical sorting process proved highly effective in removing impurities from both size fractions tested. For the -35+15 mm size group, the process achieved remarkable impurity reduction: SiO_2 content decreased by 80.8% (from 9.94% to 1.91%), Fe_2O_3 by 87.7% (from 1.22% to 0.15%), Al_2O_3 by 90.9% (from 0.11% to 0.01%), and CaO by 66.4% (from 2.41% to 0.81%). Similarly, impressive results were obtained for the -15+8 mm fraction, with SiO_2 reduced by 75.6%, Fe_2O_3 by 86.1%, Al_2O_3 by 86.7%, and CaO by 58%.

The concentrate yields of 65.12% and 72% for the respective size fractions indicate substantial material recovery from triage waste. These results will significantly contribute to the magnesite industry, particularly in the Eskişehir region of Turkey, where a major amount of triage waste has accumulated. The successful application of optical sorting technology addresses multiple industry challenges simultaneously: it reduces environmental impact by converting waste to valuable products, enhances resource utilization efficiency, and provides additional revenue streams for mining operations.

The integration of advanced camera systems, LED illumination, and pneumatic separation mechanisms proved superior to traditional hand sorting methods, offering consistent quality control, higher processing rates, and reduced operational risks. The technology's ability to process materials in the 5-130 mm size range makes it particularly suitable for treating coarse waste materials that are typically difficult to upgrade using conventional beneficiation methods.

Future research should focus on optimizing processing parameters for different magnesite waste compositions and investigating the economic feasibility of large-scale implementation. The successful results obtained in this study support the broader adoption of optical sorting technology in mineral processing flowsheets, contributing to the industry's transition toward more sustainable and economically viable waste management practices.

Conflict of interest

The author declares that there is no conflict of interest.

Similarity (iThenticate): 3%

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