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ADVANCEMENTS IN MINERAL PROCESSING: COLLABORATIVE EFFORTS AND TECHNOLOGICAL INNOVATIONS AT ARCELORMITTAL

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ABSTRACT – This article presents a comprehensive overview of recent advancements in mineral processing achieved by ArcelorMittal's Global R&D team. Through a multidisciplinary and innovative approach, the team has optimized beneficiation processes, reduced impurities, and improved product quality, contributing to operational efficiency and sustainability of the company. The studies highlighted in this article were developed in collaboration with universities and equipment suppliers, focusing on key areas such as mineral characterization, decarbonization, new beneficiation routes, comminution optimization, and chemical reaction modelling. ArcelorMittal aims to strengthen networking in Europe by seeking strategic partnerships with third-party companies, research centers, and universities. The exchange of knowledge and collaboration with new partners can further drive the development of advanced technologies and innovative solutions for the sector's challenges.

Keywords: Mineral Processing, Iron Ore, Collaboration, Research And Development.

INTRODUCTION

In 2024, ArcelorMittal demonstrated its significant global presence and operational strength with an EBITDA of $7.1 billion [1]. The company's mining sector also presented impressive performance, producing 42.4 million metric tonnes of iron ore [2]. The main seaborne iron ore mines are in Quebec, Canada, and Liberia, producing iron ore lump, concentrate, sinter feed, and pellets. The Mont-Wright mine in Canada, operational since 1974, is the largest open-pit iron ore mine in the country, with reserves for more than 30 years and a production capacity of around 26 million tonnes of iron ore concentrate annually [3]. In Liberia, operations are undergoing an expansion to increase production capacity to 15 million tonnes of iron ore concentrate, with commissioning expected in Q4 2024 [4]. The company also operates several other mines in Europe, Mexico, Brazil,

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South Africa and India, often through joint ventures, primarily producing iron ore for internal consumption.

The Global Research and Development Group of ArcelorMittal counts with a mineral processing team located in Mazières-lès-Metz, France. The team consists of a few permanent engineers and technicians. Frequently, the team hosts people with temporary contracts, such as PhD's students, apprentices and interns. Among the permanent staff, there are a few PhDs and MSc in mineral processing. Despite having an average engineer age of close to 36 years, the team collectively holds decades of experience in mineral processing across various plants. The team is highly diverse, comprising members from three nationalities across three continents – the Americas, Europe, and Asia – with women representing 48% of the team. The area is equipped with laboratory infrastructure capable of simulating mineral processing plant operations on bench scale, batch scale, and continuous pilot scale. The team's activities are focused on five key pillars: safety, decarbonization, digitalization, knowledge, and operational support to plants. Additionally, the team collaborates with an external and internal network of partners to develop projects in areas outside its core expertise, such as, for example, mine planning, ironmaking, data science, etc. Some examples of past studies conducted by the company and published in the literature are summarized in the next paragraph.

The work by Barbosa et al [5] provided an overview of ArcelorMittal's mining operations, addressing the various types of iron ore present in its global operations. Correa de Araujo and Reisinger [6] investigated the flotation of pyrrhotite from magnetite ores in a deposit in Kazakhstan. Barbosa et al [7] conducted a study on the development of alternative surfactants for flotation of phosphorus-bearing minerals, with a focus on the pelletizing plant at ArcelorMittal Lazaro Cardenas in Mexico. Xuan et al [8] developed an innovative solution for phosphorus removal from oolitic goethitic iron ores. Guimarães et al [9] explored the use of polyacrylate in the treatment of iron ores with high moisture content.

The objective of this paper is to present recent advancements in mineral processing, focusing on ArcelorMittal's efforts to improve beneficiation methods and the technological innovations implemented across its mining operations.

DEVELOPMENT

In this chapter, several examples of recent studies produced and published by the Mineral Processing area of ArcelorMittal's Global R&D are presented. These articles exemplify the team's focus on various critical aspects of mineral processing, including mineral characterization, decarbonization of the steel production chain (production of high-grade iron concentrate), development of new treatment routes, optimization of comminution (for energy saving) and concentration (for iron recovery increase) processes, and modelling of chemical reactions in mineral processing. These works were developed in close collaboration with universities and equipment suppliers, highlighting the essential role of partnerships in driving innovation and achieving significant advancements in the field.

Material characterization is a crucial first step in mineral processing studies, providing essential data for subsequent beneficiation strategies. A key example of its importance in optimizing downstream processes is demonstrated in a study by Omaga et al. [10], who analyzed samples from two pits at Thabazimbi mine to support processing route development. The samples were crushed to -5mm and homogenized, and several techniques were used for characterization: optical microscopy for mineral identification, SEM-EDS for grain shape and chemistry analysis, AMICS for liberation studies, X-ray diffraction (XRD) for mineral composition, and DRIFTS for qualitative identification. Chemical composition was determined using ICP-AES. The analysis revealed that itabirite samples (BIF) had higher impurity content compared to waste dump samples (VDB), which was mainly hematite and quartz. The BIF samples contained iron-bearing silicates and carbonates, while the VDB sample had simpler mineralogy with minimal supergene alterations. Liberation analysis showed hematite and goethite were liberated in finer size fractions (50-80 µm for BIF and 160-250 µm for VDB), and gangue minerals like quartz and aegirine were liberated in coarser fractions. The findings suggest that gravity and magnetic separation could be effective for pre-concentration to reduce gangue material early on, with further investigation underway by a PhD candidate. XRD and FT-IR analyses confirmed the presence of quartz, kaolinite, and carbonates, with notable mineralogical differences between the sample types. SEM-EDS analysis indicated that gangue minerals, including aegirine, were concentrated in finer fractions, while modal analysis showed hematite and goethite were more abundant in these fractions. The study indicates that flotation could be an effective technique for recovering iron oxides from these ores.

A significant focus in the activities of the area is the optimization of concentration processes, as enhancing separation efficiency directly impacts overall plant performance. The following few examples focus on this objective.

Turrer et al. [11] conducted a study aimed at improving iron content in magnetite ore concentrates to support green steel production. The study evaluated magnetic separation performance in bench-scale and explored the potential use of HPGR for pre-concentration. Two samples were collected from an industrial plant: one before and one after the dry magnetic separation stage. The samples were crushed to 8 mm, and X-ray diffraction (XRD) analysis revealed that iron was primarily associated with magnetite and pyrrhotite, while gangue minerals included garnets, amphiboles, and pyroxenes. Magnetite liberation occurred below 425 µm, indicating benefits from finer grinding. Magnetic separation tests using an Outotec wet drum low-intensity magnetic separator (LIMS) at 30% solids and 1.5 l/min feed rate showed that lower drum speeds improved concentrate quality, achieving up to 66% Fe and 82% Fe recovery at a P_{80} of 105 µm. Magnet position had minimal impact on results. HPGR tests performed at the Weir lab in Venlo, Netherlands, produced two batches with P_{80} sizes of 1.5 mm and 3.5 mm. Dry magnetic separation of HPGR products showed similar performance between batches, with higher recovery at lower drum speeds.

A flotation process was investigated to upgrade magnetite concentrate from the Mont Reed deposit for DR pellet feed quality [12]. This research, part of a PhD project, aimed at developing a production route for the greenfield deposit, mainly containing magnetite, hematite, and minor iron silicates. Flotation tests on magnetic separation concentrate achieved an optimized Fe grade of 66.28% using ether amine as a collector and starch as a depressant. The optimized conditions (150 g/t collector, 400 g/t depressant, pH 10, 30 wt.% solids) produced a concentrate with 70.04% Fe, 1.68% SiO_2, 23.9% yield, and 52.0% Fe recovery. The results confirmed flotation as a suitable option for achieving DR quality, despite some Fe recovery loss.

Mesquita et al. [13] evaluated the Crago flotation process (largely used in phosphate industry) to recover iron from Mont-Wright fine tailings, achieving 65.63% Fe and 2.14% SiO_2 with 70.4% Fe recovery and 22.5% yield. The Crago process demonstrated superior selectivity and concentrate quality compared to conventional reverse cationic flotation.

Pilot-scale tests were conducted using a Reflux Classifier RC 100 model from FLSmidth [14], testing two different size fractions: coarse (-1000 +400 µm) and medium (-400 +100 µm). Three tests were performed for each fraction, with a feed rate of 120 kg/h and pulp density of 1,500 kg/m³. The study aimed to assess the impact of bed density and fluidization water flow on the concentration process for a project in Western Africa. Results showed that both variables significantly influenced mass recovery and concentrate quality. For the coarse fraction, reducing bed density and fluidization water flow increased mass recovery but slightly raised SiO_2 content. However, excessive reductions led to process failure. For the fine fraction, fluidization water was more dominant in affecting mass recovery and concentrate quality. Lowering water flow and adjusting bed density improved mass recovery but also raised SiO_2 content, with the best results at lower water flow and reduced bed density. These findings emphasize the importance of optimizing both variables for better performance.

Comminution is a critical area of research due to its impact on liberation and downstream recovery. A study focused on optimizing grinding operations at Mont-Wright involved grinding tests on three ore blends using the Donda method to estimate energy consumption [15]. The tests were performed at three target particle sizes: 600 µm, 106 µm, and 75 µm. The ore blends had varying mineral compositions, including hematite, magnetite, quartz, and others. The estimated grinding energy to reach 600 µm was about 3.7 kWh/t, aligning with the average energy consumption at the Mont-Wright plant. Results suggested that this methodology could estimate ore grinding variability. Blend B3, a sample coming from a important region of the deposit, showed the highest energy consumption, particularly at the finest particle size (75 µm), with 30.5 kWh/t. This study contributed to the geometallurgical program development at Mont-Wright.

Recent research has incorporated chemical modeling to enhance process understanding, focusing on reagent-mineral interactions and beneficiation efficiency, supported by the University of Lorraine. Machine learning (ML) simulations were used to study water adsorption on kaolinite surfaces, overcoming the limitations of classical molecular dynamics (CMD) and ab initio molecular dynamics (AIMD). By combining traditional methods with ML models, more accurate simulations were achieved. Results showed stronger adsorption of water molecules on octahedral surfaces, with well-structured hydration layers potentially impeding flotation efficiency by blocking reagent adsorption and bubble adhesion (16). Similarly, the Machine Learning Force Field model (MLFF) was used to study water dynamics on iron oxide surfaces, revealing shorter residence times on ferrosilite, which improved reagent interaction and separation efficiency. The density profiles of water on hematite and magnetite indicated structured hydration layers that influence reagent adsorption and flotation efficiency, aiding in the design of effective reagents for optimizing flotation (17).

CONCLUSION

The studies highlight and summarize significant advancements made by ArcelorMittal's Mineral Processing team in collaboration with universities and equipment suppliers. Through innovation, the team optimized beneficiation processes, reduced impurities, and improved product quality, enhancing operational efficiency and sustainability. The team aims to strengthen networking in Europe by seeking partnerships with companies, research centers, and universities to foster knowledge exchange and develop advanced technologies to address sector challenges.

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