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Overview of ArcelorMittal Mining Operations and Research & Development Function

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1. Introduction

ArcelorMittal is among the largest world's producers of iron ore. With a geographically-diversified portfolio of iron ore and coal assets, it is strategically positioned to serve the network of steel plants, as well as supply the external global market. While ArcelorMittal steel operations are important customers, the supply to the external market is constantly increasing. ArcelorMittal Mining has a global portfolio of 14 operating units with mines in operation and development. In 2015, the mines and strategic contracts produced 73.7 million tons of iron ore and met 62% of the company's iron ore requirements. The company also produced 6.29 million tons of coking coal and PCI (Pulverized Coal injection), meeting 15% of the company's PCI and coal requirements.

Innovative thinking is encouraged across ArcelorMittal thanks to the influence of ArcelorMittal's research and development team. Research and development (R&D) helps the company to realize its ambitions in technological innovation, to support its sustainability goals as well as ensuring future growth. With 1,300 full-time researchers in 11 research centers across the globe, ArcelorMittal R&D is highly business oriented, ensuring a shorter time to market and improved competitiveness in a variety of sectors, including Mining.

2. Iron ore mines

ArcelorMittal Mining currently has iron ore mining activities in Brazil, Bosnia, Canada, Kazakhstan, Liberia, Mexico, Ukraine and the United States. Iron ore products include concentrate for sintering and pelletising, pellets, and direct shipped fines and lump ore.. As of December 31st 2015, ArcelorMittal's iron ore reserves are estimated at 4.3 billion tons run of mine. The figure 1 is presenting the world's map including the location of each iron ore mine.

a. ArcelorMittal Mining Canada (AMMC)

Located in Mont Wright, Quebec, AMMC is the largest iron ore producer among ArcelorMittal's mines. In 2015, the company produced 25.8 million tons of sinter feed concentrate and pellets. The deposit is a banded iron formation with hematite as the only iron-bearing mineral. The mine is an open-pit operation producing Run of Mine ore at approximately 30% Fe. Beneficiation of the ore is achieved through crushing, screening, grinding, classification and gravity separation. The resultant product is a coarse concentrate sold as sinter feed to the market. Prior to pelletizing,

the ore is further classified and concentrated by spirals at Port-Cartier. Sinter feed concentrate accounts for approximately 60% of total sales from AMMC.

Figure 1: World map showing the location of ArcelorMittal iron ore mines

b. Baffinland Iron Mines (BIM)

BIM is a 50:50 joint venture between ArcelorMittal Mining and Nunavut Iron Ores Holdings LP, with ArcelorMittal Mining as operator. The main asset is the Mary River mine, an open cut operation, which commenced mining in late 2014.The mine is located in the north central plateau of Baffin Island, approximately 160 km directly south of the settlement of Mittimatalik (Pond Inlet) in the north of Canada, in the province of Nunavut – well inside the Arctic Circle. It is a high-grade hematite body in majority, with portions of magnetite and few goethite encompassing also iron silicates and quartz as the gangue material. The process was design to maximize the production of Lump Ore, with a crushing system followed by screening. Today the production is divided in 70% of lump production and 30% of fines, with an estimated total production of 6.5 Mtpa in the final stage of the project. One particularity of Baffinland is that due the hard weather conditions in the polar circle, shipping is restricted to the summer season, when all the production has to be shipped inside a 70 to 80 day window.

c. Minorca and Hibbing Mines

Minorca mine produces about 2.7 million tons of fluxed iron-bearing pellets and **Hibbing** Taconite Mines produces about 5.1 million tons of pellets (data from 2015). Taconite, banded iron formation composed mainly by magnetite and quartz, is mined in both mines and processed by crushing, grinding, classification and magnetic concentration. In Minorca, reverse flotation of

quartz is also applied to further concentrate the ore. The final concentrate from both mines are agglomerated in the pellet plants and sold in the US market.

d. ArcelorMittal Mexican Mines

Peña Colorada mine is located in the north of the Sierra Madre del Sur, in the north-west part of the state of Colima, Mexico. This operation is a 50/50 joint-venture between ArcelorMittal and Ternium S.A. The ore is composed mainly by magnetite, approximately 89% of its composition, and of different phases of gangue particles, including silicates. The ore is processed by crushing, grinding, classification and magnetic concentration to produce, in 2015, 1.7 million tons of pellet-feed as ArcelorMittal production share. All pellet feed is transformed into pellets.

Volcan/Sonora mine is located in the north of Mexico, near the cities of Obregon and Guaymas in the state of Sonora. The ore is composed by iron oxides, as magnetite, iron sulfides, as pyrite and the presence of apatites, as fluorapatite and chlorapatite. Other gangue minerals are also encountered as quartz, calcite and grunerite. The crushing facilities at the mine include crushing, a dry cobbing magnetic separator and four tertiary crushers. The ore is then transported by truck to the concentration plant, which is located 120 kilometers from the El Volcan mine facility, and it includes two ball mills on line, a magnetic separation circuit, flotation systems (sulfide and phosphate removal), a belt conveyor filter and a disposal area for tails. The annual production in 2015 was 1.7 million tons of concentrate and pellets.

Las Truchas mine is located near the steel plant at the port of Lázaro Cárdenas, south-east of Mexico. Las Truchas mine is an integrated iron ore operation that includes mine exploitation, crushing, dry cobbing pre-concentrate and final concentration performed by magnetic separation. Mineralogical analysis of the ore show a presence of some sulfides (pyrite/pyrrhotite) and the main iron-bearing phases are magnetite and hematite with some participation of goethite. The annual production of Las Truchas mine in 2015 was 1.8 million tons of iron ore concentrate, lump and fines. All the three mines in Mexico supply iron ore to the steelmaking facility located at Lázaro Cárdenas, also in Mexico.

e. ArcelorMittal Brazilian Mines

Serra Azul mine lies within the iron quadrangle, in Itatiaiauçu, which is located 70 km south-west ward from Belo Horizonte, Minas Gerais State. The current operation consists of mining and processing the friable itabirite (Banded Iron Formation), which produce lump and sinter feed being sold on both domestic and international markets. Serra Azul ore is mainly hematitic and main gangue phase is quartz. The beneficiation plant consists of crushing, classification, gravity (jigging and spiral concentration) and magnetic separation (wet rare earth drums and WHIMS). The annual production of Serra Azul mine in 2015 was 1.5 million tons of lumps and fines.

Andrade is an open pit mine situated in the south-east of Brazil, in the state of Minas Gerais. The deposit is located in the Iron Ore Quadrangle and it is classified by Banded Iron Formation.

Principal minerals are hematite and quartz. The processing plant is composed only by crushing and screening, no concentration is applied since only hematite body is exploited. The sinter-feed produced is transported by railway to João Monlevade steelmaking plant, which is around 8 km away. The annual production in 2015 was 1.5 million tons of fines.

f. ArcelorMittal Prijedor

Buvaç open-pit mine is situated near the town of Prijedor in the north-west of Bosnia and Herzegovina. It's a Bilbao type deposit in Upper-Carboniferous to Lower Triassic limestone. Principal minerals are goethite and siderite. The ore contains around 43% Fe and reserves are estimated at 180 Mt of ore. The goethite ore is processed in the GMS beneficiation plant to remove mainly silica where crushing, scrubbing, classification and magnetic separation by WHIMS and SLon are applied. The product is filtered by vacuum and press filtration before being transported by railway to Zenica steelmaking plant. The annual production in 2015 was 2.1 million tons of lumps and fines.

g. ArcelorMittal Ukrainian Mines

ArcelorMittal Kryvyi Rih is the largest full-cycle metallurgical enterprise of the Mining and Metallurgical Complex of Ukraine.

The **open-pit mine** in Kryvyi Rih is producing magnetite iron ore concentrate with Fe ~65% from the mined crude ore at Fe ~34%. The processing plant has a capacity of approximate 25 million tons of crude ore per year and 10.1 million tons of concentrate per year (data from 2015). The beneficiation process includes crushing, grinding, classification and a series of magnetic separator units to upgrade the ore and ultimately achieve a high iron grade (>65%) magnetic concentrate.

The Ukrainian Underground mine is called **Artyom** and it is basically a hematitic ore, with approximately 48-52% Fe content and 14-18% SiO_2 content. The process flowsheet of Artyom mine comprises only crushing and screening facilities to produce 0.9 million tons of lumps and sinter feed (data from 2015).

h. ArcelorMittal Kazakhstan Mines

ORKEN is the name of ArcelorMittal Iron ore department in Kazakhstan which manages the four local ArcelorMittal mines. The total production of the mines is transported to ArcelorMittal Temirtau steelmaking facility, also in Kazakhstan.

The **Lisakovsky** mine is a sediment marine iron ore with goethite free or almost free oolithes. The annual production is around 0.9 million tons of concentrate (data from 2015). The ore is beneficiated by jigs, classifiers, and wet high intensity magnetic separators to yield a gravity-magnetic concentrate, upgrading the ore from 39.8%Fe to 49%Fe. The phosphorus content is quite high, varying from 0.6% to 0.8%P.

The **Atasu** mine is located near the town of Karajan in the Atasu district. The mine deposit is a skarn. The ore is composed by 25% Hematite and 75% Magnetite. At the beginning of its operation in 1954, the mine was an open pit but until the 70's it was changed to underground mine with a production of 0.9 million tons of lumps and fines per year in 2015. The beneficiation of the ore is done by crushing, screening and gravity separation by jigging.

The **Kentobe** mine is an open pit mine with a capacity of 1.5 to 2Mt/y but the production was only 0.9 million tons in 2015. The mine deposit is a skarn with massive magnetite ore. This iron ore contains an important amount of sulfides. The process flowsheet comprises three stages of crushing, classification and magnetic separators is applied to remove gangue minerals but the concentrate remains with high level of sulfur content (>2-3 %).

Atansor open-pit mine is located in north-central Kazakhstan, about 45 km north-west of Stepnogorsk. The deposit is a moderately dipping skarn magnetite of magmatic origin, but the ore has been oxidized and enriched due to weathering in some zones. The main result of weathering is martite, with hematite and goethite also present. The mine produces hematitic (martite) lump and fines and the beneficiation plant comprises crushing, screening and magnetic separation. The annual production in 2015 was 0.4 million tons.

i. ArcelorMittal Liberia

ArcelorMittal Liberian deposits all belong to the Nimba mountain range, in the north-east of Liberia. All ArcelorMittal Liberian deposits have approximately the same geological configuration: first itabirites, a metamorphosed Banded Iron Formation (BIF) then a weathering profile composed of a transitional zone and finally a laterite horizon, or canga. Deposits are composed of three iron oxides: magnetite, hematite and goethite and quartz as the main (and sometimes the only one) gangue mineral. ArcelorMittal actually possesses 3 concessions in the Nimba region: the Tokadeh, Gangra and Yuelliton deposits. The Tokadeh is nowadays producing a Direct Shipping Ore (DSO) product and exploitation of the transition zone should begin in a near future. The DSO is processed only by dry crushing and screening to produce 4.3 million tons of sinter-feed (data from 2015).

3. Research and Development activities

a. Mining and Mineral Processing

The ArcelorMittal group is actively developing its raw material base to raise self-sufficiency levels, and for this reason, the research Centre of Mining and Mineral Processing (MMP) was created in 2008 within ArcelorMittal's Global Research & Development in Maizières-lès-Metz, France. Since its establishment, MMP has been developing processing solutions for both existing operations and new projects, with iron ores from Europe, Asia, America and Africa. The main missions of MMP are to contribute to ArcelorMittal's overall strategy to increase iron ore self-sufficiency, to provide technical assistance to existing mineral processing plants improving efficiency, increasing safety, decreasing environmental impacts and operation costs, to develop

conceptual level studies for the beneficiation of new potential sources of iron ores, to characterize raw material sources for iron making and to identify and assess emerging trends in the field of iron ore characterization and processing. In addition, MMP supports sales and raw material purchasing activities. In terms of expertise, MMP performs:

- Mineralogical characterization and interpretation
- Design, supervision and conduction of mineral processing test-work programs
- Process flowsheet design and simulation
- Equipment sizing and selection (pre-scoping/scoping level)
- Plant audits and identification of potentials for optimization
- Benchmarking of mineral processing unit operations

As example of the latest achievements of MMP team, it is possible to mention the development of new sinter-feed fines products from Liberia and the development and subsequent marketing and sale of Baffinland lump at a premium price in the pellet market. In addition to that, the design for reconfiguration of the crushing circuits at Baffinland enabling a 50% improvement in throughput. Other examples are the improvements achieved on the low grade ore concentration flowsheets for Bosnia and Peña Colorada (Mexico), these achievements being very important to supporting sustainable ongoing operations at these mines. At last, but not least, the work performed for tailings thickening in the Ukrainian operation which has the potential to reduce energy costs in the Ukraine by several million dollars per year.

b. Research activities for AM Prijedor and AM Zenica

Since 2009, MMP has been contributing to technological improvements in the GMS beneficiation plant of ArcelorMittal Prijedor. Since the exploitation in Jezero Pit in Omarska Mine was over some years ago, ArcelorMittal Prijedor started to exploit the Buvaç Mine. The two deposits are near to each other but they have different mineralogical characteristics and it affects a lot the mineral processing of the ore. Fe content in Buvac Pit is lower by approximately 4% against Jezero Pit. Therefore, the studies were focusing on plant optimization in order to improve the beneficiation of this new ore trying to keep as much as possible the design of the plant. Laboratory and pilot scale tests were performed throughout the years, the feasibility of the project was evaluated and finally in 2014, two magnetic separators (SLon) to treat the -1+0.5mm ore fraction and one filter-press, to recover the -0.025mm fraction, were installed at GMS plant adding value to the process. Research and development activities are still going on especially for the quality improvement of the -0.025mm fraction and possible recovery of “Fe rich” tailings pond material.

c. Sinter pot tests with Prijedor ores for Zenica sinter plant

ArcelorMittal Maizières Process Research Center, located in the same site as MMP, is equipped with a sinter pot pilot to simulate the sintering process and access results as productivity, sinter

quality and energy consumption. This tool allows to characterize various ores mixes and fluxed and to define optimal sintering operational conditions.

In 2009, first study is done in a context where the sinter strand at Zenica was bottleneck in terms of hot metal production so the increase of sinter productivity was considered as first priority. Different possibilities were studied to attain this objective and sinter pot test was performed to optimize the sinter mix with a maximum of local iron ore. Significant increase of productivity was obtained replacing the initial ore mix with 80% of Bosnian sinter-feed ore and 20% of Kryvyi Rih concentrate, with very fine size distribution, by 100% of Bosnian sinter-feed ore with addition of 1% burnt lime in mix and optimization of the moisture leading to improvement of granulation process. However, the solid fuel consumptions were increased with the increase of Bosnian BPR goethite ore.

Recently, another series of trials were performed in the sinter-pot aiming to characterize the sintering performances of Buvaç (BPR and BPR+) and carbonate ores. The objective of the trials is to assess the possibility of using binary mixes: BPR or BPR+ with carbonate ore without negative impact on sintering conditions and sinter quality. The usual Buvaç ore used in Zenica sintering plant is called BPR and it contains around 10% of -0.025mm. With the new configuration of the GMS plant, filtration residue of very fine ore in form of dense cake, from press filter, is available and can be used in the sinter plant. 7 to 10% of this very fine compound is added to BPR to constitute BPR+. The sinter pot tests show a light but acceptable decrease of productivity (-1t/m2/d) with BPR+ compared to BPR.

Other ore named Carbonate ore (~26%Fe, ~14% CaO, ~2.4% SiO2, ~4.8% MgO) is also available in Ljubija deposit close to the current mine. This ore very poor in Fe but with high amount of CaO and MgO could replace a part of fluxes such dolomite and a part of limestone in the sinter blend while allowing increasing the level of iron in sinter. Results were encouraging and showed that carbonate ore can be used in the sinter plant replacing fluxes in the order of maximum 30% in the sinter mix without decrease of productivity, with increase of Fe content in sinter (+1.8%) but also increase of MgO content in sinter to 2.2%. This level is high but not detrimental in Zenica conditions. Sinter quality is slightly worse compared to when only BPR and fluxes are used.

These encouraging results have to be confirmed during industrial trials in Zenica sinter plant at end of 2016.