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Scoping the life cycle assessment of Fine Future flotation technology-towards more sustainable mining

Hazem Eltohamy[a], Giuseppe Cecere[a], Lucia Rigamonti[a]*

[a]*Department of Civil and Environmental Engineering, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy*

* Corresponding author. Tel.: +39-02-23996415. *E-mail address:* lucia.rigamonti@polimi.it

Abstract

Separation by flotation is one of the common technologies used during beneficiation stage in mining industry, aiming at concentrating valuable minerals for downstream refining stages. Currently a new froth flotation technology is being developed under FineFuture (FF) project, funded by the European Union Horizon 2020 research and innovation programme (grant agreement No 821265). If implemented, this technology can valorise fine mineral particles instead of discarding them as residues, nevertheless this does not necessarily ensure the sustainability of the technology. In this paper, the environmental sustainability of the new technology is addressed by showing goal and scope phase set-up of two life cycle assessments applied to two industrial partners of the project. Each company works on a different mineral and has a different beneficiation scheme. The goal of assessment is to compare the current production chains with the new one where FF technology is to be implemented to eventually evaluate which option is more sustainable for each company. Both case studies do not contain flotation unit in their current beneficiation system. The first is Grecian Magnesite whose main products are magnesite concentrates ($MgCO_3$) and magnesia (MgO). The foreseen plan is to apply the new flotation technology either on residual fines (< 4 mm) from washing units in beneficiation which are currently discarded, or on low quality $MgCO_3$ concentrates (<90% $MgCO_3$) after beneficiation stage to acquire higher concentrations of $MgCO_3$. The second case study is Eramet for manganese (Mn) concentrate production. The objective is to apply the FF technology to tailings which are the discarded residues of manganese beneficiation process, yet they contain a considerable amount of Mn. The tailings are currently sent to storage ponds, but the future aim is to process them with FF technology to recover enriched slimes that contain high concentration of Mn before sending the rest to the ponds.

Keywords: Life Cycle Assessment; FineFuture; Flotation; Mining; Environment

1. Introduction

Sustainable economic growth in Europe depends strongly on access to a broad range of raw materials at reasonable costs. Securing access to a stable supply of raw materials for industrial use is a major challenge for Europe, the awareness of such challenge has led, in the 2020, to the launch of an industrial alliance dedicated to securing a sustainable supply of raw materials in Europe, called European Raw Materials Alliance [1]. Europe's industry has a leading role in the manufacturing of mining equipment and technologies for metallurgical processing and for the recovery of critical raw materials, of which Europe possesses reasonable quantities that can be exploited for the benefit of the European society [1]. Some of the largest mineral reserves in Europe and worldwide are indeed owned by European companies like Eramet and KGHM [2], [3], however for the most efficient exploitation of these resources, the valorisation of by-products from base metals is a much needed and urgent response to the shortage that the European industry is facing. This can reflect very positively on economy, environment, and society whether in Europe or in other non-European countries where some European mining corporations

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are operating. One of the biggest challenges that industry needs to address is the valorisation of metal contained in fine-grained materials. Therefore, novel, eco-friendly and ground-breaking separation/beneficiation technologies are needed to shift the current mining paradigm towards the exploitation of natural mineral deposits that are very fine-grained (below 20 µm particle size), and of "residues" that now are considered mining waste or what is so-called tailings in some mining industries. The FineFuture project, funded by the European Union Horizon 2020 research and innovation programme (grant agreement No 821265), will advance the fundamental understanding of fine particle flotation phenomena and it will lead to the development of innovative technological solution to recover and valorise fine-grained particles. This paper focuses on the environmental pillar of sustainability of an innovative froth flotation technology which is being developed currently within the FineFuture project. Two case studies of the four mine-operating industrial partners of the European project will be discussed showing the ongoing activities of the research. This analysis is aiming at comparing the environmental performance of current beneficiation schemes of the two companies with future beneficiation schemes where the FineFuture (FF) technology is to be implemented.

2. Materials and methods

The sustainability analysis started with the selection of the case studies and the subsequential decision making process to properly assess the systems boundaries. Given the different possibilities for future implementation of the FF technology within the different production lines, it was not possible to identify a typical scenario. To tackle this issue of uncertainty, it was decided that all possible future scenarios proposed by the industrial partners will be analysed separately.

As the scope of this paper is the environmental sustainability, Life Cycle Assessment (LCA) methodology was adopted to evaluate the potential environmental impacts of current systems compared to future systems with FF technology.

The second phase of LCA is being developed now which implies primary data collection from companies within the project and the elaboration of this data to eventually obtain a mature inventory of current beneficiation systems and foreseen future systems.

3. Case studies

Two case studies are chosen to be discussed here given that they are the most actively ongoing cases for what concerns the environmental sustainability study. The two case studies are:

- Grecian Magnesite for magnesite concentrate ($MgCO_3$) and magnesia (MgO) production.
- Eramet for manganese concentrate (Mn) production out of tailings.

Both case studies do not incorporate any flotation units in their current production lines, hence upgrading their production lines with FF flotation technology can represent a significant enhancement to recover valuable minerals from very fine particles or upgrading the quality of their usual products.

3.1. Grecian Magnesite

The current system of Grecian Magnesite (Figure 1) starts with Magnesite ore acquisition from an open pit mine using explosives then it is transported to the pre-beneficiation steps. During pre-beneficiation, the ore is crushed, screened at various size fractions and washed. The fraction below 18 mm is separated to go through further sieving, while the > 18 mm fraction passes through laser sorting and magnetic separation to remove the largest portion of colored or magnetic impurities (e.g. serpentine, sepiolite and other silicates), and then enters the main beneficiation stage. Here it either passes through camera sorting or a combination of dense media and magnetic separation stages depending on the desired chemistry of the kiln-feed magnesite at calcination stage. The intensive washing before optical sorting generates fines (<4mm) that contain pre-beneficiated magnesite ore.

The output of beneficiation is then sold as high magnesite concentrate without calcination or it continues to calcination process where it is burned in kilns to produce magnesia (MgO). Kiln feed magnesite is fired to produce either caustic calcined magnesia (at about 900°C) or dead burned magnesia (at about 1800°C). During calcination, magnesite ($MgCO_3$) is decomposed to Magnesia (MgO) and Carbon dioxide.

The plant has also another line, with the purpose to exploit the 0-18 mm fraction which, until recently, was being stockpiled for future use. The 0-18 mm fraction from the old stockpiles are passed through specially designed sieves to remove the currently unprocessable 0-4 mm fraction and then is separated to 4-10 mm and 10-18 mm.

The 4-10 mm fraction passes through special magnets able to process fine-grained materials and a cyclone unit. The 10-18 mm fraction goes through new generation optical sorters and then is sent for calcination. The intensive washing before optical sorting generates fines (< 4 mm) that contain significant amounts of magnesite ore.

According to the aforementioned information and as shown in Figure 1, the fraction <4 mm of the very fine particles is not utilized and is discarded and stockpiled despite the mineral concentration this fraction contains. Therefore, Grecian Magnesite suggested that one of the future scenarios should be the processing of fines <4mm from washing units with FF flotation technology. This can allow obtaining high quality magnesite concentrate for calcination in the future.

However, the other plan of Grecian Magnesite is to apply the technology to relatively low-quality magnesite concentrate ($MgCO_3$ < 90%) that they are actually producing from their current beneficiation system. This can enhance the product to provide higher quality feed to the kilns in the calcination stage.

Figure 2 shows the LCA system boundaries of the two cases which were proposed by Grecian Magnesite. As the LCA here

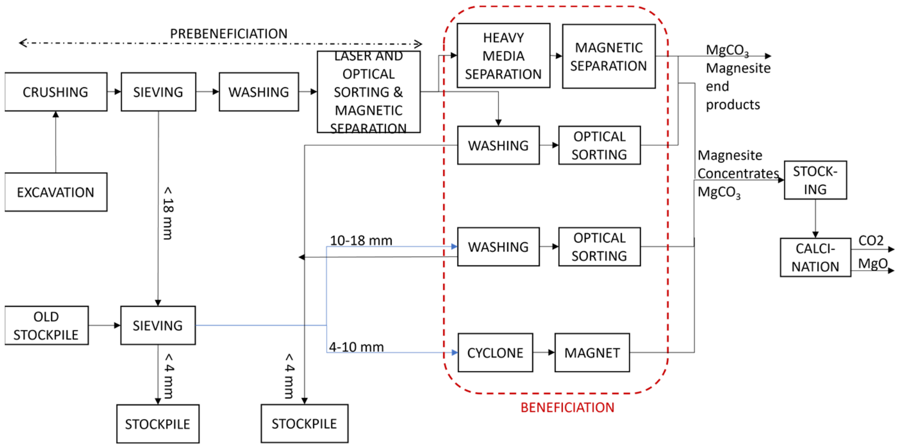

Fig. 1. Traditional current system of Grecian Magnesite.

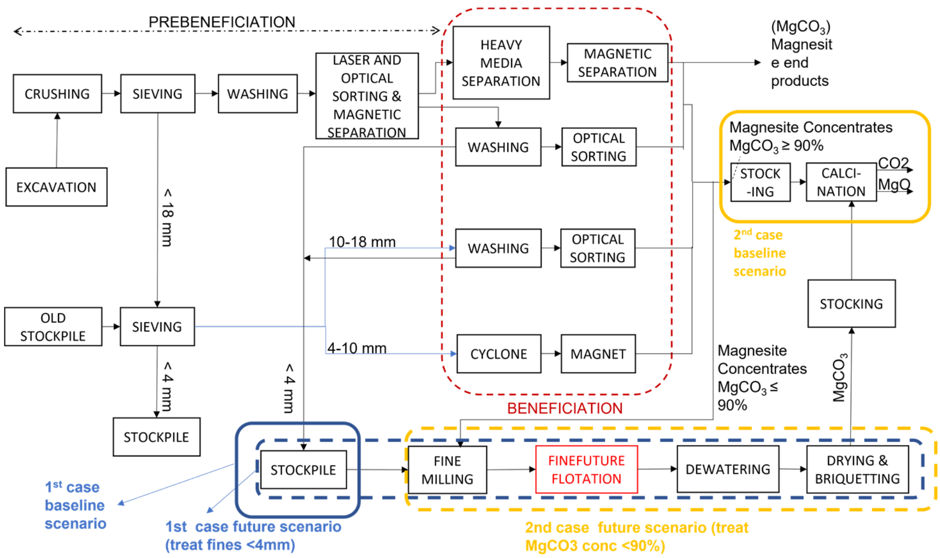

Fig. 2. System boundaries of baseline scenario and future scenario of the two Grecian Magnesite cases under study.

is a comparative LCA, the units which are common between baseline (current) scenario and future scenario were omitted [4]. The first case requires comparing current stockpiling of <4mm fines (baseline scenario) with future processing of this fraction with FF technology.

It has to be noted that applying the flotation technology will imply some additional steps like:

- Fine milling of the feed (stockpiled <4mm)
- Dewatering
- Drying and Briquetting of the $MgCO_3$ concentrate from the flotation before calcination.

Nevertheless, for the second case, the targeted input flow to the FF line is the output magnesite of the beneficiation stage with magnesite concentrate <90%. Therefore, in this case, current stocking and calcination processes will be compared to the other units to be added including the FF flotation unit.

At the moment, Grecian Magnesite case inventory is being developed after a successful first round of primary data collection like fuel and electric energy consumption, the nature of stockpiling, emissions measured in different phases. This is being done considering different functional units (F.U.) for each case as shown in Table 1. Eventually, the most convenient F.U. will be chosen depending on the level of detail of future data to be received from the company.

For case 1, the system will be considered a waste management system as it deals with currently unused flow of material. But in addition to the waste management function, a useful product will be available for market (i.e. Magnesia) at the end of the upgrade process of the fines using FF flotation technology. To tackle this problem of multifunctionality, substitution by system expansion will be implemented. The environmental credit will be calculated as the avoided impact of Magnesia production from a conventional beneficiation process. The substituted technology will be modelled using secondary data as obtaining primary data about the main beneficiation plant of GM is very complex and out of scope of the project.

Table 1. Possible functional unit for GM case study.

	Option 1	Option 2
Case 1	The management of *1 ton* of rejected fines <4 mm from washing step	-
Case 2	The management of *1 ton* of magnesite concentrate ($MgCO_3$ <90%)	The production of a certain amount of Magnesia (this option is possible only if the product «Magnesia» has the same characteristics and same market) in both present and future situations

The same approach will be applied for case 2 if the low-quality magnesite input is considered as waste. While if in case 2 the system is considered a conventional production system, direct comparison with current system will be possible.

3.2. Eramet

Eramet is a French company, however it operates in many mines worldwide to acquire manganese (Mn) concentrates. The geographical context of this case study is the manganese mines in Gabon which are managed by Eramet.

The current beneficiation process produces different types of mineral ores as can be seen from the qualitative representation in Figure 3. Depending on their grain size, products are divided into lumpy, Fines and sands. While lumpy ore (>8mm) is sold directly without further processing, part of fines (2-8mm) and sands (1-2mm) are furtherly refined.

Very fine particles (i.e., slimes) with granular size of <0.15mm are considered as waste or discarded materials which are currently disposed in huge ponds as tailings from water treatment unit that follows the wet sieving. The target of Eramet is to recover these slimes which can contain a considerable manganese content (around 20% on dry mass of slimes as estimated by Eramet) by applying FF flotation technology.

The Functional Unit is chosen to be the management of *1 ton* of slurry. Slurry is practically the same thing as tailing, but Eramet uses these two terms to distinguish between the flow before reaching the ponds (i.e. slurry) and once it is in the pond (i.e. tailings).

Same as Grecian Magnesite case, this LCA is meant to be comparative, hence the current system which deals with tailings is to be compared with future scenarios if these tailings are treated with FF technology.

The baseline system boundary can be seen in Figure 4 (i.e. current system). The input is the slimes in form of slurry, then the slurry is pumped and transported through pressurized piping system to the ponds. For the ponds, the construction and operation impacts will be taken into consideration.

In this phase of the project, more data and details are being communicated with Eramet to develop the inventory of the baseline scenario. This data contains information about the energy used for pumping, materials consumption of piping system, material and energy used in ponds construction and lastly any possible direct emissions from the system.

On the other hand, for future application of FF technology in Eramet mining line in Gabon, there is no certain decision about how the flotation will be embedded into the current system of tailing management. Thus, after discussions with Eramet, future scenarios of application will range from what is called "lower scenario" with the least new equipment to be added along with FF unit, and "upper scenario" with maximum equipment that the new system might imply. These two scenarios are illustrated in Figure 5 and Figure 6 in more detail. The required additional equipment for the enriched slimes recovery ranges from thickening units and pelletizers to wastewater treatment unit. Depending on the configuration, the final environmental impacts will certainly vary.

The system here is explicitly a waste management system that yields a useful product after FF application (i.e. Manganese). Thus, the multifunctionality will be dealt with using substitution by system expansion to include the avoided impact of primary manganese production from a conventional way. Similarly to GM case study, the substituted technology will be modeled based on secondary data.

4. Future steps and associated challenges

As both case studies are almost at the same phase of completing the data collection of baseline scenarios and building the inventories, the next steps to complete the study includes the following:

- Modelling of baseline scenario in SimaPro software.
- Data collection to model the possible future scenarios for both case studies.
- Modelling future scenarios and comparing the environmental impacts of them compared to the baseline scenario.
- Interpretation and support the decision making of the industrial partners.

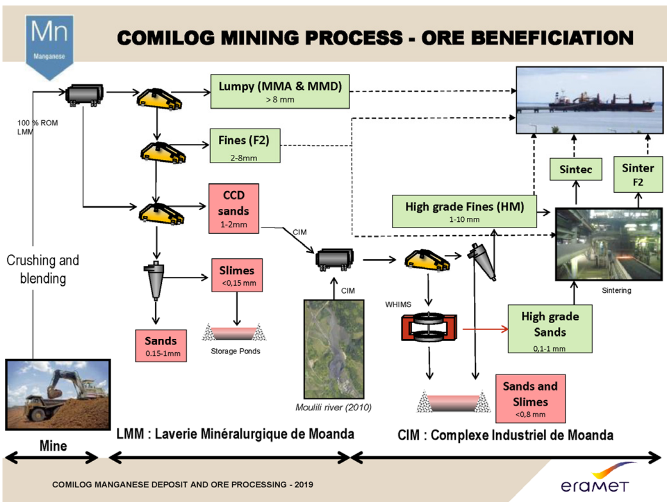

Fig. 3. Production line of Eramet in Gabon (source: Eramet).

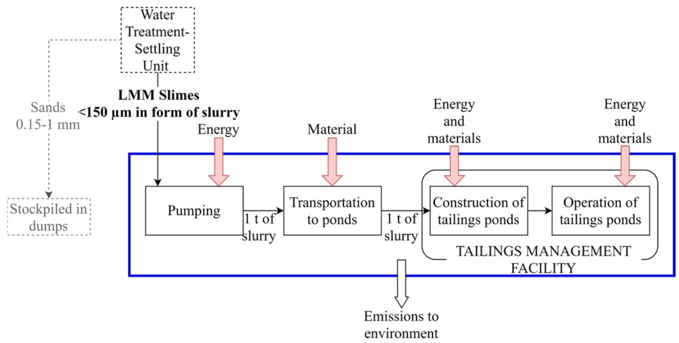

Fig 4. System boundary of baseline scenario of Eramet.

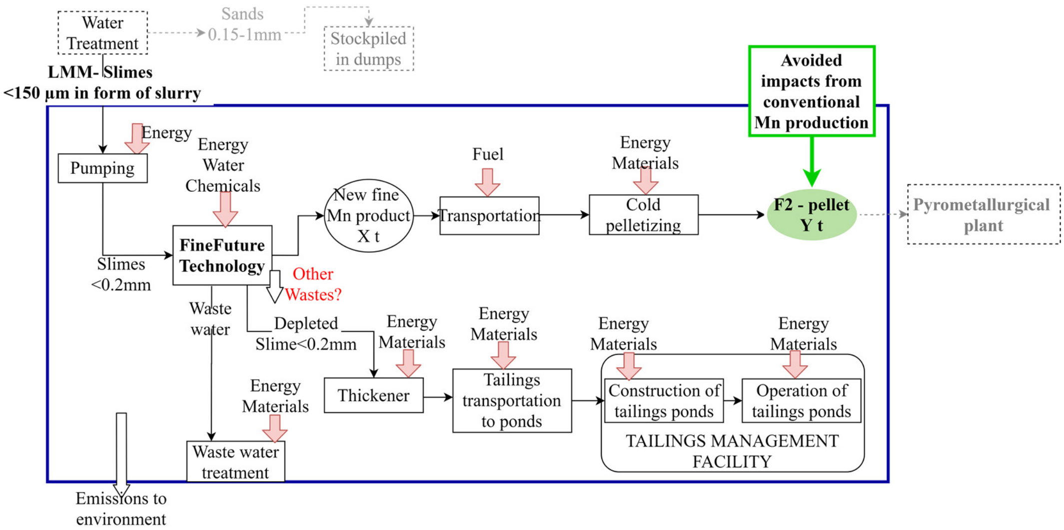

Fig. 5. Minimum equipment future scenario of Eramet

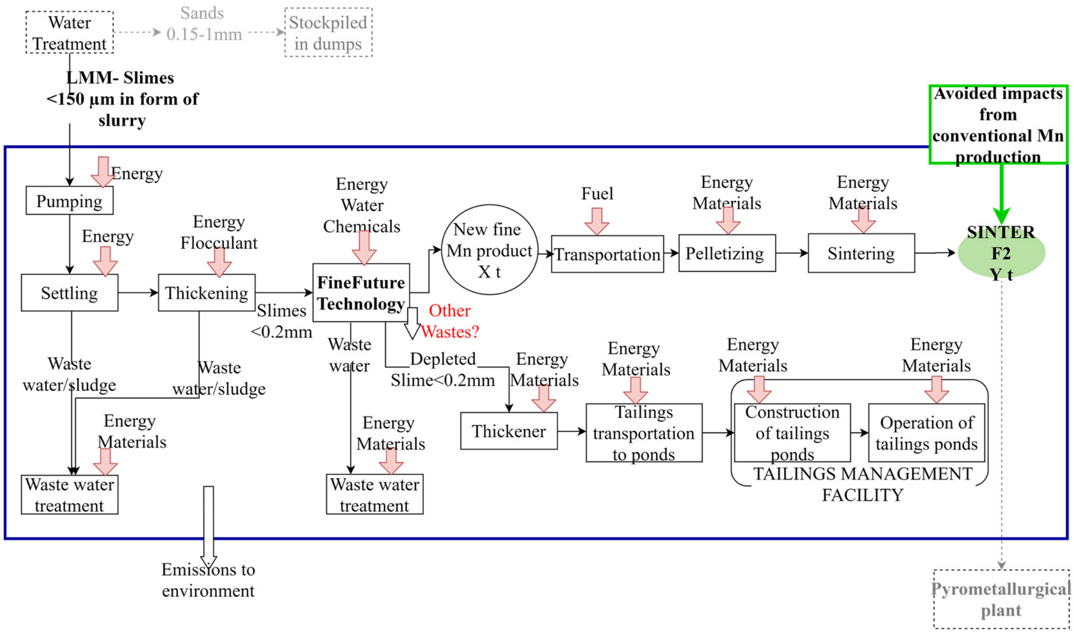

Fig. 6. Maximum equipment future scenario of Eramet

It should be noted that the ongoing data collection of complex processes in beneficiation of minerals is not quite straightforward. Some of the data needed to carry out an LCA are not always available right away from the companies.

Furthermore, part of the collected primary data is not given in a usable form which means some data requires further elaboration to be suitable for usage in compiling the inventories and building the models in the software.

Carrying out an LCA of an emerging technology (i.e. technology under development) is another challenge when it comes to future scenarios modelling. In addition to the possible lack of data, and the uncertainty of how the flotation unit will be incorporated into the existing beneficiation plants, a lot of uncertainties are expected to emerge during the scaling up of the FF technology lab tests that are being done now by the other partners in the project. Moving from lab-scale tests or pilot tests to industrial scale in later stages can be accompanied with some nonlinearity in the inventory which might affect the impact results of the potential application of the technology on industrial scale [5].

Besides the mentioned technical challenges, some modelling choices can also be tricky such as choosing the most convenient functional unit for each case study. [6] provides an extensive discussion about the functional unit choice in their literature review about flotation in mining industry which shows that it is debatable and not straight forward as it might seem.

In fact, despite the increasing use of LCA at these early stages of similar projects, there is a lack of a systematic guidance for LCA analysts to tackle the particular challenges of emerging technologies [7].

5. Conclusions

The research is ongoing to evaluate the environmental impacts of current beneficiation systems of minerals of two European companies in mining business. The final objective is to compare it with an enhanced beneficiation system which will incorporate a new froth flotation technology developed under FineFuture project by European Union’s Horizon.

This technology will allow the recovery of minerals lost in very fine particles that are not exploited at present. From the companies’ point of view, the FF technology can be utilized in different ways within the beneficiation process. So, to address this uncertainty of future application, each possible configuration is being studied separately to be compared with the current on.

The study is in the second phase of LCA for both case studies. The data collection is at its final phase for the baseline scenario and next step is to model the baseline scenario in SimaPro and obtain the impact assessment results. Another round of data collection will start after that for possible future scenarios to model them as well so that finally the comparison of environmental impacts of current and future systems can be achieved.

This environmental study is a part of a holistic sustainability assessment being developed that targets the three pillars of sustainability (i.e. environment, society, economy). A similar approach to the one described in this article is adopted in the ongoing economic and social sustainability assessments.

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