Towards Implementation of Industry 4.0 in Cement Plants

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***Abstract*- In recent years, there have been specific focus on improvement of productivity in cement industry due to decreased profitability as well as high rate of energy consumption and consequently increased production of carbon monoxide. Implementation of Industry 4.0 allows improved productivity and optimum use of energy and resources which directly lead to lower consumption of energy and better optimization of the production processes. Towards smart production, this paper reports on application of real-time x-ray fluorescence (XRF) analyzers that perform real-time elemental and mineral analysis on raw and processed materials (solid and slurry) during different stages of production. Online and real-time quality control in cement production lines enables managers to make right-time and fact-based decisions. Moreover, the obtained real-time vital data of the production line can later be used in digital twin model of the plant.**

Keywords – Industry 4.0, x-ray analyzer, digital twin model, smart quality control

1. Introduction

Today, industrial production is experiencing the fourth industrial revolution or the so-called Industry 4.0 which is based on the use of digital technologies such as IoT (internet of things), robotics, virtual reality, artificial intelligence, and 3D printing, and has significantly changed the lifestyle and workstyle in societies. Applying this digital transformation in industries makes them more profitable, efficient and sustainable and that clearly explains why industrial managers are the leaders in alignment with Industry 4.0.

Mining industry consists of a group of different operations including drilling and explosion, milling and processing which are intrinsically connected to each other. As each operation can influence on the quality of the other operations, improvement of each individual operation cannot necessarily lead to the optimization of the production. In other words, all the operations have to be observed in an integrated framework in which any action is taken in accordance to the whole chain. This is achievable, if and only if, information regarding all the events is accurately and instantly collected on a cloud server to be accessible by all the managers in real-time. Smart control of vital data such as temperature, moisture, pressure, vibration, percentages of materials and components, etc. is essential for optimization of cement production. According to the Gartner Analyst, by 2020 it is expected that 526 million machines be connected to each other via internet network, among which nearly 90 million machines are designed to be installed in the mining industry [1]. Moreover, based on the report by Energy International Agency (EIA), consumption of cement will reach up to 600-800 million ton per year in the Middle East and Africa by 2050 and this will directly lead to more energy consumption and carbon monoxide production [2]. Thus, implementation of Industry 4.0 as a smart solution to improve production process is a necessity.

2. SMART QUALITY CONTROL IN CEMENT PRODUCTION PROCESSES

Extraction of the mineral is a vital stage in production of cement and has a significant effect on the production costs and quality of the final product. Thus, despite of all the human and environmental conditions, the most challenging pre-requisite in planning and operation of a cement plant is to provide stable and sufficient raw materials. Obviously, t is necessary to control the quality of the feed, as it is the basis for design of the plant and optimum functionality of the plant is directly dependent on that. However, due to large area of extraction, quality of the minerals may vary at times which affects the production processes and increased the costs according to the following reasons:

- Consumption of electric energy to homogenize the raw material
- High consumption of expensive additional materials such as bauxite, limestone, etc.

- More abrasion of the mill (if amount of quartz is ignored)
- High cost of fuels due to fluctuations in thermal processes

Provide of raw materials is not limited to limestone and even high-grade limestone are useless without additional materials such as marl. Therefore, continuous provide of the correct combination of the both raw minerals and additional materials is a necessity. Due to the extensive extractions in last half century, most of the high-grade materials are already extracted or are not easily accessible, thus the remaining materials are usually low-grade and this makes it challenging to constantly provide sufficient raw materials. Therefore, often additional materials such as high-grade limestone, bauxite, iron ore, sand and etc. are used which results in significant increase of costs. One should notice that most of these additional materials already exists in the mine and are extractable, however, usually limestone and the second materials are searched for during exploration and other worthy minerals are considered as waste [3]. On the other hand, some elements and oxides such as Chlorine, Magnesium, Sulfur and organic carbon can have destructive effects on the process or the quality of the product and the most effective solution for their elimination from the process is early detection at their source at the mine and continuous monitoring of the quality (by elemental analysis) during all the processes [3]. Other parameters such as moisture, hardness, etc. can also affect the process and require specific sensors to be monitored and controlled.

During production of cement, elemental analysis from mine to the process lines can be performed as follows:

- At the mine to make block model and define quality of the limestone and the exact boundary of mineral and waste in order to smartly manage the drilling operations,
- On the conveyor belts from mine to the processing plant after the first and secondary crushers, in order to smartly control the grade and manage combinations of the materials for homogenization
- At the processing lines in order to control and manage proper amount of additional materials and vital parameters.

In the following sections, towards the goal of implementation of Industry 4.0 in cement, smart XRF analyzers are introduced to collect chemical data (including grade, amount, etc.) associated with the critical materials and parameters for production of cement. The key advantage of XRF analyzers is elimination of use of radioactive source which makes it an environment-friendly equipment. The x-ray overcomes all challenges and obstacles associated with radioactive sources and thus puts no limit on the installation location.

3. SMART BLOCK MODELING OF THE MINE

As shown in Fig 1, in order to manage the loading operation and define the boundary between minerals and waste in the planned exploration area, it is necessary to analyze the samples taken from drill rigs and add the collected data on the block model of the mine. This is usually done by sending selected samples to the laboratory for mineral analysis. In the addition to the human errors during sampling and transfer to the laboratory, limited number of the analyzed samples can cause considerable errors in the block model and the whole procedure takes long and requires sample preparation as well. Therefore, in order to create the block model in an accurate way, a smart solution is to perform fast and precise real-time automatic analysis during drilling without any need for sample preparation and any role of human user and simultaneously transfer the collected data to the cloud server of the plant.

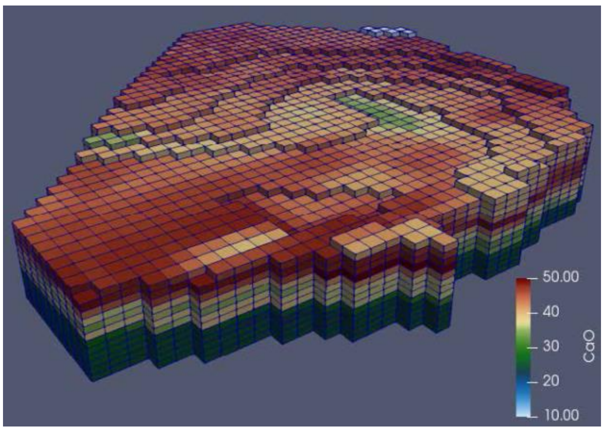

Fig. 1. A typical block model of a cement mine [3].

By fast and accurate block modeling of the mine, enables smart management of the loading operation to obtain homogenous input feed. In Fig. 2 a schematic illustration of the planned loading operation based on the average grade in the block model is depicted which prevents loading from the waste regions.

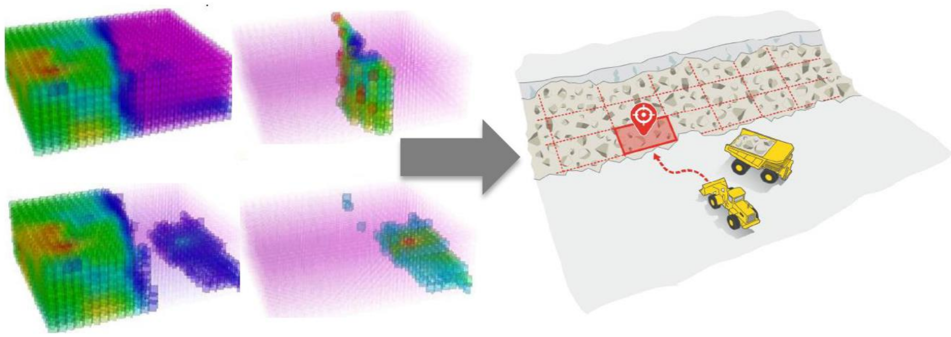

Fig. 2. Schematic illustration of smart loading based on the exact location of the mineral and waste according to the block model [Courtesy of IMA Engineering].

In Fig. 3 a smart XRF analyzer (manufactured by IMA Engineering) installed on the drilling machine model SmartROC D65 of Atlas Copco company is shown. This analyzer is capable of performing fast, accurate and real-time analysis of samples during drilling and sends instant reports of the containing minerals in each centimeter of the drilled rigs to the cloud server via a wifi system.

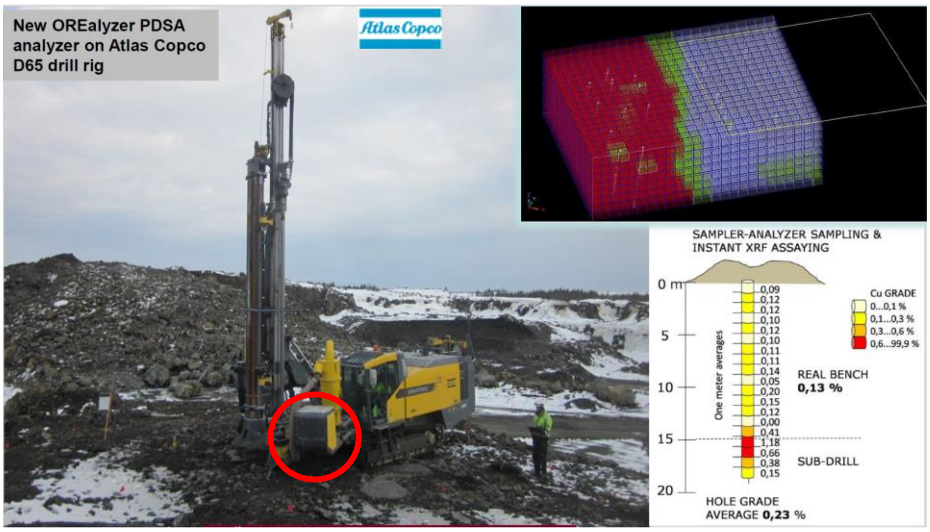

Fig. 3. The smart XRF analyzer manufactured by IMA Engineering (shown in red circle) performs real-time mineral analysis during drilling of the rigs and instantly sends the associated data to the cloud server [4].

Block model of the mine and real-time transfer of the extracted data help managers of the plant to make daily plannings of the loading operations and control the process lines according to the grade of the input feed. Moreover, drivers of the loaders can also receive the real-time information of the block model enabling them to load only the minerals and avoid any waste in the feed. Fig. 4 shows a case of in which a driver of a loader uses data of the block model during loading.

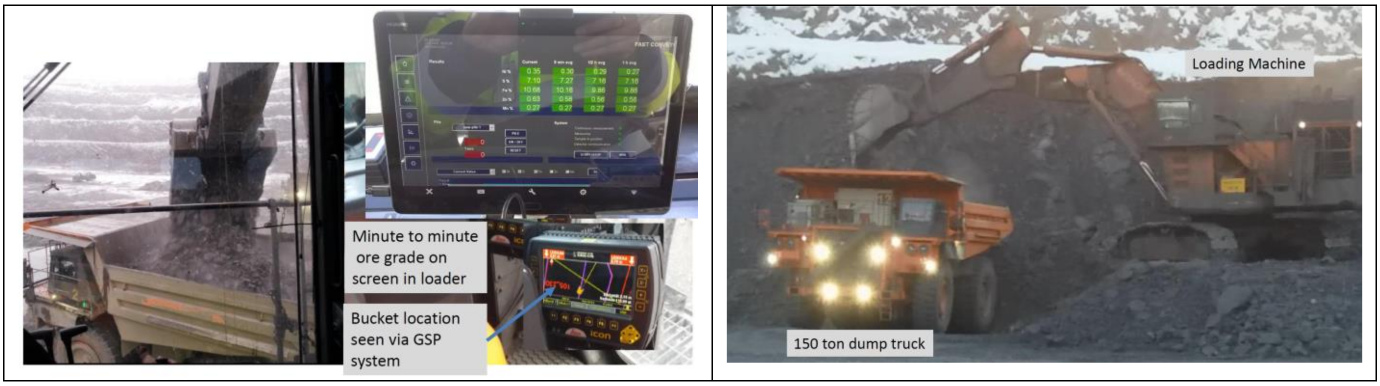

Fig. 4. An example of using data of the block model by driver of a loader. In the case of loading from unplanned area, the implemented alarm system allows correction of the loading operation [Courtesy of IMA Engineering].

4. SMART MONITORING OF GRADE AND COMPONENTS ON THE CONVEYOR BELT AT DIFFERENT PROCESSING STAGES

The necessity to control percentage of the minerals and components and is not only limited to the mine and this quality control is also further required during homogenizing process in order to stabilize quality of the feed of the kiln. Using smart online XRF analyzers on the conveyor belt allows fast, continuous and real-time analysis of the conveying materials in large volume and without any need for sample preparation. The obtained results can help operation managers to optimize all the processes by control of the vital parameters such as LSF, SR and AR. Consequently, this leads to smart energy management resulting in less fuel consumption and environmental pollutions. Fig. 5 shows a smart XRF analyzer (manufactured by IMA Engineering) installed on the conveyor belt to control the grade and additional materials in a processing line of a mining complex.

Fig. 5. Example of a smart XRF analyzer on conveyor belt. For smart grade control of the feed, the analyzer can be installed on the belts after the first and secondary crusher or during the processing stages [5].

Data obtained from on-conveyor belt analysis and the data extracted from drilling can be shared together which allows tracking of the loaded materials during the process. Using the real-time analysis on conveyor belts provides the following advantages:

- Elimination or decrease of processing on waste
- Increased grade and enhances efficiency of the mill
- Reduced energy consumption
- Detection of hidden waste and dangerous elements in the mineral
- Improved functionality of the processing stages
- Improved ratio of mine to mill
- Improved functionality of the homogenizing units based on the grade and percentage of the components
- Optimized use of minerals with proper combination of different grades

By performing real-time analysis on conveyor belt after the first crusher, the average grade of the mineral during loading is obtained and thus the data related to the variations of grade at the entrance point of each processing stage can be recorded. The resulting report can be simultaneously sent to managers of the process lines and managers of the mine to control and correct their plans. Based on these analyzes, grade of the mineral in each carrying truck is accessible in one to two minutes and therefore it is possible to stop those trucks that are carry loading from low-grade areas. Moreover, in the boundary area of the waste and minerals, this instant analysis allows correction of the loading operation, in the case of any mistake. More importantly, very low-grade materials are usually considered as waste and thus removed from the production chain. However, by using results of the real-time analysis, it is possible to detect and separate waste from the very low-grade materials. Therefore, managers of the processing plants and mine in total alignment with each other, can make more accurate and integrated planning based on hourly averages, level of waste or cut-off or the shut-down point and etc. Therefore, the following can be achieved:

- Prevent loading of waste
- Definition and setting of the grade in a desired range
- Avoid milling of the waste and save energy
- Improved functionality

Fig. 6, schematically illustrates the real-time transfer of data obtained from smart XRF analyzer installed on the conveyor belt to both manager of the mine (to correct drilling operation) and managers of the processing plant (to control grade of the feed).

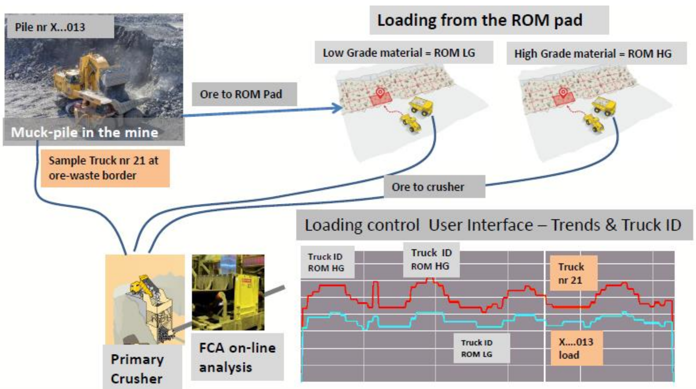

Fig. 6. Schematic illustration of the functionality of the smart XRF analyzer on conveyor belt. Managers of the mine receive report of the drilling operation. Simultaneously, managers of the processing plant receive a report on grade and percentage of components in feed [Courtesy of IMA Engineering].

In Fig. 7, the report obtained by continues XRF analysis on conveyor belt (manufactured by IMA Engineering) is shown and compared with the results of the laboratory analysis as well as the results of the analyzer model Courier (manufactured by Outotec) and excellent agreement is observed. Obviously, the results from laboratory are limited and not real-time.

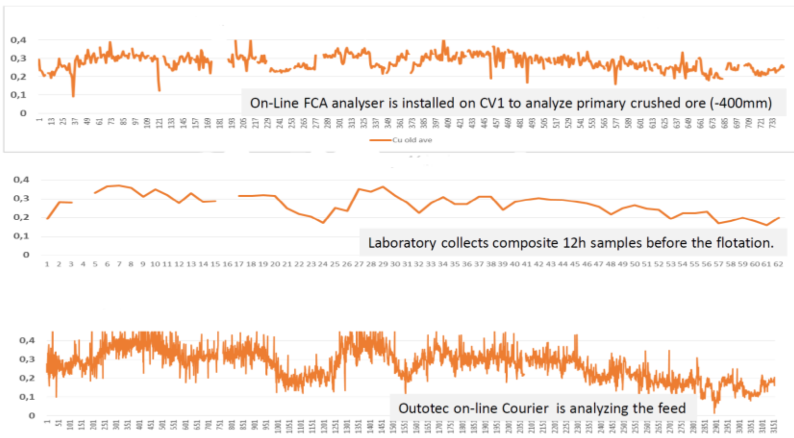

Fig. 7. Comparison of the obtained results from smart XRF analyzer on conveyor belt (top) and laboratory (middle) and Courier analyzer (bottom) [5].

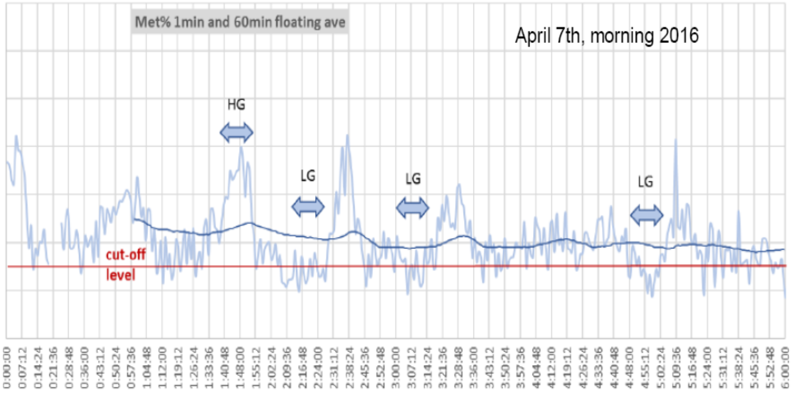

Fig. 8. A sample report indicating the low-grade and high-grade as well as cut-off level obtained from the smart XRF analyzer on conveyor belt [5].

In Fig. 8, results of the smart XRF analyzer on conveyor belt are shown which report on the low-grade and high-grade materials as well as the cut-off level. In Table. 1, range of measurements, repeatability and accuracy of the analysis performed by the XRF analyzer on conveyor belt is presented.

Table 1. Repeatability and accuracy of the analysis by FCA. (Confirmed by IMA Engineering)

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Range (%)	5 – 15 %	1 – 3 %	0.5 – 1.5 %	44 – 50 %	2 – 4 %
Repeatability	< 0.25 %	< 0.2 %	< 0.1 %	< 0.25 %	< 0.25 %
Accuracy	< 0.7 %	< 0.3 %	< 0.2 %	< 0.7 %	< 0.3 %

5. Smart Analysis of Processed Stream

During different stages of the processing, in order to make corrections on the continuous stream of the materials, it is required to detect and obtain information regarding the percentage of the critical components. This can be achieved by real-time analysis of the slurry and powder materials. Thus by using smart XRF analyzers, it is possible to keep the level of critical oxides as well as LSF in the desired range allowing stable quality of the feed. As shown in Fig. 9(a), in the absence of real-time analysis, there are fluctuations in the grade of the feed. At times, the grade is lower than the standard level which yields in lower quality and there are times when the grade is much higher than the standard causing waste of energy and resources. However, performing real-time analysis on the material stream keeps variations of the grade in a safety margin and thus saves energy and high-grade materials, as illustrated in Fig. 9(b).

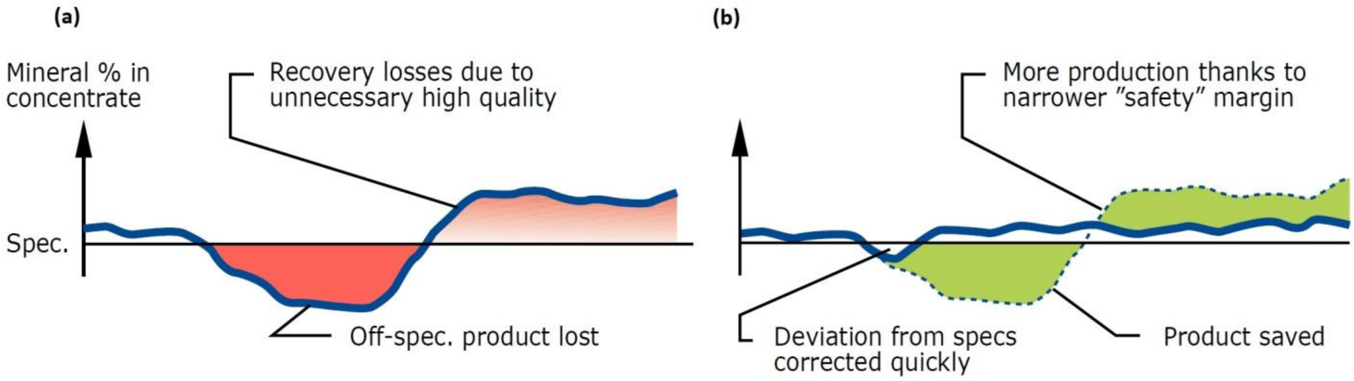

Fig. 9. (a) High fluctuations in the grade in the absence of real-time analysis (b) Safe variations in the grade of the product by performing real-time analysis. [Courtesy of IMA Engineering Ltd.]

6. CONCLUSION

Applications of smart analyzers are discussed for online and real-time control of the grade of minerals and percentage of components during all stages of cement production including (i) drilling at mine to prepare the block model, (ii) transfer lines on conveyor belts and (iii) processing lines. Using these analyzers allows real-time collection of all the vital mineralogy data on a cloud server during all stages of the process. According to the type and volume of the collected data, it is possible to generate a digital twin model of the cement plant which enables managers of the mine and process lines make right-time and fact-based decision in alignment with all units of the production chain. A digital twin model of the plant can depict trend of the production processes in an integrated framework in which all units are monitored in real-time. This definitely leads to enhanced productivity and decreased costs resulting in improved profitability which is the ultimate outcome of Industry 4.0. Moreover, it is worth mentioning other data associated with parameters such as temperature, pressure, moisture and etc. can also be included in a digital twin model for which specialized smart sensors are required. However, this paper reported on implementation of Industry 4.0 based on mineralogy data that are assumed as the most critical and vital data required by mine and processing lines in the cement industry.

REFERENCES

[1] Patnala, B. D. (2016). Role of IoT in digitization of Data. *International Journal of Innovative Research in Advanced Engineering (IJIRAE)*, vol. 13, no. 2, p. 1-3.

[2] (2009). Cement roadmap milestone, International Energy Agency OECD/IEA and World Business Council for Sustainable Development, 2009, retrieved on 9. 9 .2019, from www.iea.org/roadmaps.

[3] Kawalec, P. and Bockemühl, C. (2018), Block Model Based Cement Quarry Optimization. *Cement and Building Materials Review*, vol. 37, p.70-77.

[4] Raatikainen, J. (2011). Latest technology in grade control, health and safety, towards greener mining. *Proceeding of the 5th World Conference on Sampling and Blending*, Santiago, Chile, October 25-28. 2011.

[5] Perala, A., Alli, J., Raatikainen, J., and Auranen, I. (2015). On-line Analyser optimizing mill feed at FQM Kevitsa Nickel-Copper-PGE mine. *Proceeding of the Workshop on Mining, Mineral and Metal*, Oulu, Finland, August 25-27. 2015.