APPLICATION OF FLEXSIM IN THE DISIRE PROJECT

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Summary

The need to trace the ore composition in KGHM has been discussed so as to give a processing plant at least one shift advance to adjust beneficiation parameters and optimize efficiency of this process. The discussed DISIRE project proposes dropping to an ore stream on conveyors special tags carrying source data about the origin of loaded ore which can be connected with deposit quality based either on channel samples stored in MOPRONA database or data from a block model containing processed data (e.g. interpolated geometallurgy domains). Tags readings done enough earlier should give possibility to prepare required forecasts. The FlexSim program has been selected for the preparation of the tag experiment in the ZG Lubin copper ore mine and analysis of its results. FlexSim combines the possibility of continuous and discreet event simulations of material flow. In the future it can be used to make such forecasts even with a bigger time advance based on production plans (e.g. prepared in the specialized geological and mining Datamine software).

Keywords: ore tracking, blending, mixing, DISIRE, geometallurgy, conveying, haulage, simulation

Introduction to current challenges facing KGHM and mining industry

A modern mining industry faces new challenges which were not common several decades ago. Decreased ore grades [6], increased variability within an ore body [16, 19] and highly fluctuating commodity prices [35] have higher impact on the projects profitability and thus, require more accurate short and long term planning. One of the possible solutions for this is an implementation of geometallurgy. Geometallurgy is an instrument which allows connecting geological and mineral processing information for a predictive model to be used in the short and medium term planning [27].

The Polish resources of the copper ore exploited by the KGHM S.A. underground mines are considered as one of the most complex in the world and – consequently - the most difficult to be processed. The ore consists of three lithology forms: dolomites, shales and sandstones [30] but in different proportions which has a significant impact on the effectiveness of the grinding and flotation processes.

The lithological composition of the ore is generally recognized in-situ by channel samples but after being mined it is blended during blasting and by mixing it with ore from other mining faces and joining ore streams on its long way from various mining fields to the processing plant in the complex transportation system. It consists of dozens of kilometers of belt conveyors with numerous switching points, ore bunkers and shafts. Identification of the lithological composition of the ore being supplied to the processing plant should improve the adjustments of the ore processing machinery equipment aiming to decrease the specific processing (mainly grinding) energy consumption as well as increase the metal recovery due taking into account geometallurgy parameters such as - for example - different lithology compositions [15].
Methodology for the accurate interpolation of geological parameters of the copper ore deposit for production purposes and identification of different geology domains using geostatistical methods with implementation procedures for creating domains in copper geology block model created in Datamine Studio (Fig.2) was developed during two research projects sponsored by KGHM and worked out by members of Industrial and Geoeconomics Division at the Faculty of Geoengineering, Mining and Geology in the Wroclaw University of Science and Technology [13, 14]. Unfortunately identification of geometallurgical domains is still not resolved and need further investigations and research. One of new ideas is the application of the game theory to solve practical mine production decisions taking into account quality of the deposit and its real value [25].

A part of the geometallurgy solution connected with ore composition tracking on its way from mining faces to processing plant is developed within the DISIRE project.
1. The DISIRE Project

SPIRE (Sustainable Process Industry through Resource and Energy Efficiency) is a proposal for Public Private Partnership that aims to regain competitiveness of the ailing European process industry. It consists of several groups of projects including the DISIRE (Distributed In-Situ Sensors Integrated into Raw Material and Energy Feedstock) research project. It was launched in 2015 within the HORIZON 2020 framework with 15 partners from several European countries coming from the field of mining, mineral processing, steel and chemical: ABB AB, Dow Chemicals Ibérica, D’Ap- polonia, Electrotech AB, Fraunhofer IMW, Gstat SA, IMT Lucca, KGHM CUPRUM, KGHM Polska Miedz SA, Luleå University of Technology, Luossavaara-Kiirunavaara Aktiebolag AB, MEFOS, ODYS S.r.l., Research Center for Energy Resources and Consumption, Wroclaw University of Science and Technology [20]. The project is focused on the idea of use of the Integrated Process Control (IPC) for the improvement of process industry by the implementation of Process Analytical Technology (PAT) tags (sensors hidden in durable pellets) embedded into the processed (or transported) raw material for storing and reading relevant information [20].

The DISIRE project aims at developing and introducing novel inline measurement techniques that will enable a significant transition of the current state of the art existing control and monitoring systems, from a static sensing and control in multiple parallel loops perspective, into a product based, online, and in-situ process, reconfiguration of the IPC strategies based on extended online and near to real time PAT analysis of a vast stream of data from the internal process dynamics [8].

![Figure 3. The structure of the overall DISIRE work plan divided into 10 Work Packages](source)

PAT has been defined as “a system for designing, analyzing, and controlling manufacturing through timely measurements (i.e., during processing) of critical quality and performance attributes of raw and in-process materials and processes, with the goal of ensuring final product quality”.

Source: [8].
The idea has been adopted for the needs of ore tracking to improve mining and processing of metal ore and aggregates [20].

The overall DISIRE work plan (Fig. 3) is divided into 10 Work Packages (WPs): 1 is dedicated to the project management related necessities (WP10), 4 to direct research and development activities (WP1-WP4) in the area of industrial process control, electronics and sensor development and data mining, 3 to research and demonstration activities with respect to real industrial applications and process (WP5-WP8) that cover the ferrous and non-ferrous mineral processing, the steel and the combustion industries, while 1 is dedicated to dissemination and innovation purposes (WP9). The overall management and oversight functions of DISIRE are contained within WP10, with a single leader assigned to it and its respective tasks. The setup of governance bodies and the functions of internal project communication, quality assurance, and economic management are responsibilities which are also located in the context of this WP [7].

![Figure 4. DISIRE concept for the pelletizing process of raw material transporting](source: [7]).

In the specific case of KGHM (WP5), the DISIRE technological platform will enable the sensor based tracing of the ore in the belt conveyor system and continuous fault detection in the transportation system which will result in decrease of energy consumption of floatation processes and increase the copper recovery due to the better adjustment of process parameters which is enabled by the identification of incoming ore by pellets (Fig. 4) [7]. Active participation of KGHM in the DISIRE project can lead to energy savings what not only save money but also proves its engagement in sustainable and environmentally conscious development [31].

The DISIRE PAT will help to identify and mark the chosen parameters of exploited and transported copper ore and – due to use of the PAT-based information for control of flow of the ore of a given quality – to reduce the idle work of belt conveyor. This will facilitate improvement of transport efficiency, energy consumption reduction, development of new sensors, algorithms and strategies for a large, spatial transportation system. Furthermore the outcomes of the DISIRE project can be applied in any industry where large belt conveyor systems are used for transporting bulk material whose variable parameters should be identified and recorded for the needs of further processing. Some examples are: large lignite surface mines and mine-mouth power plants [2, 9, 21, 23, 28, 32, 33], coal mines [3, 29], bauxite mines [5], rock mines [4], bulk material depots in harbors [1], food industry [36], waste management [12] or airport terminals [24]. In all cases both PAT
technology for quality tracking as well as simulation of material flow can be applied. Simulation can also be used as a useful tool at the design stage of belt conveyor systems [26].

2. Mining operations in KGHM

KGHM is a vertically integrated enterprise which produces electrolytic copper based on its own copper ore deposit located in south-western Poland, approx. 80 km to the west of Wroclaw. The copper ore extracted by the three underground mines: Lubin, Rudna and Polkowice-Sieroszewice is processed using flotation in three processing plants located nearby each of the mines and belonging to the Ore Enrichment Plants Division of KGHM. The company is a world leader in the extraction and processing of valuable natural resources such as copper and silver. With over 50 years of experience in the mining industry KGHM has built a reputation of a reliable producer, a trusted business partner and a company with a sustainable development policy.

The role of KGHM in DISIRE Project is to identify the key factors that need to be considered from automatic control perspective about the process of transporting the copper ore from the mining face to the processing plant in the underground mines.

The copper ore mining technology in all 3 mines is based on the room-and-pillar system with the use of blasting for ore extraction. This involves the excavation of a drift network on all four sides of the site to be mined, cutting of the unmined rock mass with rooms and drifts separating a number of operating pillars, as well as extracting of the ore followed by hauling the ore to underground dumping stations. Depending on the distance from the face to the loading bridge over a specific section’s belt conveyor, ore will be transported directly by LHD or, over greater distances, LHDs load trucks, which haul the ore to the loading bridge. Here the large ore lumps are crushed using hydraulic hammers and sifted through a grate (approx. 42 cm x 42 cm), and then the crushed ore is transported by conveyor belts and in the Lubin mine also by rail to the storage areas near the shafts. There ore is crushed and loaded to shaft bunkers.

Intensity of loaders and trucks operation was investigated on site [34] and results of conducted research create input data to the simulation model.

3. Selection of the FlexSim program to tag and ore flow modelling

The modelling of ore flow in transportation system is complicated due to conveyors operate continuously when loaders, trucks and hoist skips operate cyclically. In order to use both modelling techniques the FlexSim simulation program was selected [1, 10].

In the DISIRE project FlexSim software is used to model flow of tags and ore in the Lubin underground copper ore mine (Fig.5). The program allows on modelling transportation of bulk material and discrete objects such as tags on different types of conveyors.

In the first stage only a tag simulation model is to be developed in order to plan a special experiment in the mine and analyze its results. It is now under preparation in the Lubin mine. A great number of tags (sensors hidden in special ruggedized pellets) will be dropped underground into the ore stream in different locations with the frequency corresponding to discharge of ore from loaders or LHD cars (what means one tag for each discharge). As tags will be uniquely numbered and their dropping points and moments will be registered using handheld recorders it will be possible to associate them with the geological data from channel samples stored in MOPRONA database system [22] or with the data derived from the digital, geological block model. Part of tags will be dropped on conveyor belts before bunkers in order to check their flowing time through bunkers. Pellets will be registered by 2 recording
gates placed on 2 parallel conveyors receiving unloaded ore from cyclically working hoist with 2 skips. Planned experiment will give answer about tags reliability in harsh environment. All tags have to go through the system of bunkers and crushers localized before hoist. There will be also tests to estimate effectiveness of reading gates by dropping tags after crushers to find out how many of them will be recorded by the system.

Figure 5. KGHM Lubin East mine transportation system selected for industrial trials
Source: [18].

Attempting to ensure high reliability of the conveying system (including duplication of some transport routes) and continuous production with full capacity has led to the loss of control of ore quality supplied to processing plants. One way to restore such control is tracking of dropped tags in the DISIRE project. FlexSim program, combining cyclic and continuous simulations in a single environment [110], is intended to assist in preparing and analyzing the results of the experiment. It will help in selection of number, places and frequencies of sensors/tags insertions depending on their survival rate and gate efficiency in tags detection. Electronic readers/gates will be mounted on belt conveyors on the surface. The experiment will identify the actual survival rate of prepared pellets and reading gate efficiency in the working condition of KGHM’s mines. This should allow on an estimation of feed composition accuracy at the entrance to processing plants. Even full restoration of transportation condition will not give precise ore quality forecasts due to the final ore stream is a mixture of several ore portions loaded in different locations with different ore lithology compositions. Even each portion taken from one localization has not precise quality and ore composition due to portion loaded on conveyors is taken from not fully mixed material blasted at the mining face. Each load is therefore a random variable drawn from blasted ore characterized by individual histogram (Fig.1). Results of mixing process therefore have a stochastic character and only simulation
can help in preparation of such forecasts. The developed, dedicated FlexSim model is presented below (Fig.6).

![Figure 6. 3D view of objects representing belt conveyor system in Lubin mine](source)

Source: [18].

5. Conclusions

Without the knowledge of ore lithological composition and useful mineral content (geometallurgy parameters) of ore supplied to processing plant it is not possible to adjust and optimize beneficiation processes in ore enrichment plants.

Ore tracking with special sensors carrying data about place of ore origin proposed in the DISIRE project can help in preparation of better forecasts. However the available time advance can be too short for the practical use of obtained information. The final ore stream is created on conveyors receiving ore from skips and the shaft is placed too close to the processing plant. Placing reading gates underground will increase required number of gates and lower accuracy of forecasts because important decision regarding content of ore stream composition is done later by the hoist operator selecting loading bunkers and rate of their discharge. Such decisions can influence the final ore mixture so final reading gates should be placed above ground.

This obstacle can be resolved by forecasting composition and lithology content of the final ore stream based not on on-line sensors readings but on results of sensors flow simulations done in the FlexSim program for the next shift based on production plans (e.g. prepared in the Datamine system) and connecting them with data about deposit quality taken from MOPRONA (database of channel samples) or a block model containing processed information (e.g. interpolated geometallurgy domains).

Such forecasts can be verified by comparison of simulated ore stream with the information about real ore stream composition provided by CBJ (The Center of Quality Research) based on detail samplings analyzed outside the mine. Significant autocorrelations of ore quality parameters in this stream [17] suggest that forecasting should be possible. CBJ does not use on-line analyzers due to...
their high costs and need of many installations. The electronic gates used in the DISIRE project are less expensive so it is worth to test the proposed solution.

Possibility to ore tracking using sensors dropped to the ore stream will help in tracking and understanding mixing process of ore coming from hundreds of mining faces. In the whole KGHM there are up to 500 blasts per one shift so manual calculation of mixture content is impossible. Application of computers is necessary and the use of FlexSim seems to be an adequate solution.

Without good tools for modeling and simulation of transportation processes in such complex systems as exist in KGHM's mines and capability to trace quantity and quality of the loaded and transported ore, forecasting of ore quality will not be possible.

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ZASTOSOWANIE PROGRAMU FLEXSIM W PROJEKCIE DISIRE

Streszczenie

Omówiono potrzebę śledzenia składu rudy w KGHM by dać zakładom przerób- 
czym co najmniej 1 zmianę wyprzedzenia na dopasowanie parametry procesów 
wzbogacania i zoptymalizować ich efektywność. Omówiony projekt DESIRE propo-
nuje wzmacnac do strumienia urobku na przenośnikach specjalnych sensorów 
nioskych źródłowe informacje o miejscu pochodzenia rudy. Może być ona powiązana 
z jakością złoża poprzez dane z prób bruzdowych przechowywanych w bazie MO-
PRONA lub model blokowy zawierające przetworzone informacje (np. interpolowane 
domy geometalurgiczne). Odczyty danych z sensorów dokonane odpowiednio wcze-
śnie powinny umożliwić opracowanie odpowiednich prognoz. Do przygotowania 
ksymentu z sensorami w ZG Lubin i analizy jego wyników wybrano program 
Flexsim łączący możliwość symulacji ciągłej i cyklicznej. W przyszłości może być on 
wykorzystany do przygotowywania prognoz z większym wyprzedzeniem na bazie pla-
nów produkcyjnych (np. opracowanych w systemie Datamine).

Słowa kluczowe: śledzenie rudy, uśrednianie, mieszanie, DISIRE, geometalurgia, transport 
przenośnikowy, transport kołowy, symulacja

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