Computational Modelling '11

Sponsored by: DEMSolutions

Tuesday 21st June

08.00 Registration desk opens

09.00 Opening Remarks
B.A. Wills (MEI, UK) and S.J. Neethling (Imperial College, UK)

09.30 *Technical Session 1*
Chairmen**:** P. Jonsén (Luleå University of Technology, Sweden) and P. Dupuy (CSIRO Mathematics, Informatics and Statistics, Australia)

09.30 **A review of process flowsheeting in the mineral processing industries**
Z. Harber and C. Aldrich (University of Stellenbosch, South Africa)

The construction of process simulations is an activity often left to a select group of experts. Reasons for this include the lack of fundamental process insight, the absence of modelling structure in existing simulations and a general non-existence of process modelling methodology. In this paper, which forms part of the literature survey for a PhD thesis, a study of current trends in process modelling is followed by an in-depth discussion about the manner in which a simulation is constructed from fundamental principles, based on constitutive, conservation and constraint equations. Flowsheeting software like METSIM and JKSimMet are critiqued, based on their thermodynamic models, process synthesis capability and range of applications in the mineral processing industry. Potential research areas in this field are highlighted.

09.50 **Modelling multi-phase through packed beds and heaps using Smooth Particle Hydrodynamics (SPH)**
S.J. Neethling (Imperial College, UK)

Multi-phase flow is a characteristic of many minerals processing systems, with interfacial effects being important to the behaviour of many processes ranging from flotation to heap leaching. Simulating multi-phase systems can be difficult and computationally expensive. This is especially true when interfacial forces and contact angles need to be considered as the interfaces between the phases need to be tracked. Smooth Particle Hydrodynamics (SPH) provides a convenient method for simulating such systems as the Lagrangian nature of the method means that interfaces are naturally tracked. In this paper I will describe how SPH can be used to model multi-phase flow through packed beds. Results will be presented showing both 2D and 3D simulations at a range of different particle sizes, flow-rates and contact angles that are representative of typical heap leaching conditions.

10.10 **DEM investigation of optimum sizes of grinding media in tumbling ball mills**
M.H. Wang, R.Y. Yang, A.B. Yu (University of New South Wales, Australia)

The grinding medium size and size distribution are two important variables in grinding process. While some models have been developed to predict the optimum grinding medium size for improved grinding performance, these methods often require parameters determined from experiments, which is time and capital consuming and also limits their applicability for general use. This work performs a discrete element method (DEM) based study of grinding process in a tumbling ball mill. The effects of grinding media/ore particle size ratio and grinding medium size distributions will be investigated. The micro-dynamic properties of particle flow, such as collision energy and impact force among particles are analysed. By linking the DEM information with population balance model (PBM) and particle breakage characteristics obtained from physical experiments, the product size distribution at different times can be predicted. It is expected that the selection of proper grinding media can improve grinding performance.

10.30 Coffee

11.20 **Discrete modelling of gas-solid flow and heat transfer in a three-dimensional sector model of blast furnace**
W.J. Yang, Z.Y. Zhou, A.B. Yu (University of New South Wales, Australia), D. Pinson and P. Zulli (BlueScope Steel Research, Australia)

An ironmaking blast furnace (BF) is a complex multiphase flow system. It is of paramount importance to understand its flow and thermal behaviour for the optimization and control of the process. In this paper, the approach of combined discrete element method (DEM) and computational fluid dynamics (CFD) is used to establish a model framework for the first time for the modelling of BF flow and thermal behaviour in a three-dimensional sector model. The main chemical reactions occurring in a BF are assumed and considered in terms of heat balance at different flow regions. The simulation results are consistent with the physical experiment in terms of solid flow patterns. Gas and solid temperature distributions are consistent with the general understanding of BF thermal behaviour. The effects of variables such as solid flow rate, gas flow rate and burden distribution on the flow pattern and heat transfer are then investigated on this basis. It is shown that the model framework provides a solid base for further development in discrete modelling of this complicated process.

11.40 **Development of particle flow simulator in charging process of blast furnace by discrete element method**
H. Mio, M.K. S. Matsuzaki and K. Kunitomo **(**Nippon Steel Corp., Japan)

Discrete Element Method (DEM) is one of the most popular simulation methods for the analysis of solid particle behavior, and it has a high potential to be a simulator for analyzing the particle flow in a charging process of blast furnace. The objective of this paper is to develop such a simulator using Discrete Element Method. The charging processes from the surge hopper to the top of blast furnace via several storages were modeled. The particle behaviors in these processes were simulated, and the particle segregation and its traveling behavior during charging the storages or discharging were analyzed.

12.00 **CFD modelling of pulverized coal injection in ironmaking blast furnace: effect of key operating conditions**
Y. Shen, A. Yu (University of New South Wales, Australia), and P. Zulli (BlueScope Steel Research, Australia)

Pulverized coal injection technology is widely used in ironmaking blast furnace for various benefits. In order to understand the complicated phenomena, a three-dimensional CFD model has been developed to simulate the in-furnace phenomena in not only raceway cavity but also the surrounding coke packed bed. The model considers two fuels, pulverized coal and coke. The model is validated against the measurements in terms of coal burnout and gas composition, respectively. An array of parametric study is carried out to evaluate the effects of key operating conditions under practical conditions. The results confirm that notable improvements in burnout over raceway surface and particle temperature can be achieved for high blast temperature, high oxygen enrichment and the use of oxygen as cooling gas. The present model is able to provide a more reliable way to describe coal burnout, *i.e.* burnout over raceway surface, rather than burnout only along the centreline. The model is useful for understanding the flow-thermo-chemical behaviours and then optimising the PCI operation in full-scale blast furnaces.

12.20 **CFD-DEM study of the multiphase flow in a dense medium cyclone: the effect of fluctuation of solid flow**
K.W. Chu, A.B. Yu (University of New South Wales, Australia) and A. Vince (Elsa Consulting Company Pty Ltd, Australia)

Dense medium cyclone (DMC) is widely used to upgrade run-of-mine coal in the coal industry. The flow dynamics/fluctuation in a DMC has not been studied previously. In this work, the dynamics is studied by numerically investigating the effect of the mass fluctuation of solid particles. The simulation is carried out by use of a combined approach of Computational Fluid Dynamics (CFD) and Discrete Element Method (DEM) (CFD-DEM). It is predicted that under high fluctuation frequency, the performance of DMC is not sensitive to both the fluctuation magnitude and period of coal flow at the DMC inlet. However, under low fluctuation frequency, it is found that separation efficiency decreases and the operational pressure increases as fluctuation magnitude increases, with the fluctuation magnitude of 30% as a critical point. The work shows that the CFD-DEM model is able to study the dynamics of the flow in a DMC.

12.40 Lunch

14.00 *Technical Session 2*
Chairman: A.B. Yu (University of New South Wales, Australia)

14.00 **A comparison between deformable and rigid particle behaviour in FEMDEM simulations of angular fragment processing**
J.-P. Latham and J. Xiang (Imperial College, UK)

DEM methods are employed widely in optimisation and design of processing as computational speeds now allow the handling of larger numbers of particles. The combined FEMDEM method (Munjiza, 2004, Xiang et al. 2009) can achieve greater grain scale accuracy and for certain granular applications is likely, at some point in the future, to be worth its greater computational expense when compared with DEM. One way to speed up the efficiency of FEMDEM is to make the simplifying assumption that the material is rigid. By adopting a rigid grain interior and the generality of the penalty function and potential contact force FEMDEM algorithm it is possible to utilize realistic Young's Modulus and Poisson's Ratio thereby giving excellent handling of the corner-edge-planar contacts in complex-shaped rock blocks and fragments including frictional behaviour. This paper aims to illustrate results to help identify applications best suited to these various different modelling approaches.

14.20 **An immersed body method for modelling arbitrary shaped particles settling in a fluid: two-way coupling of FEMDEM solids with a multiphase adaptive mesh CFD code, Fluidity**
J. Xiang, D. Pavlidis, J.-P. Latham, C. Pain, F. Milthaler, M. Piggott and A. Vire (Imperial College, UK)

Mineral processing often involves both dense and dilute mixtures of particles and fluids. A powerful modeling framework for such mixtures developed by AMCG is reported in this paper. Modeling the two-way coupled interaction of the solids and fluids at the grain scale is important for the coarse grains. However, drag parameterization cannot capture complex shapes settling through a water column. Our approach introduced in this paper uses an immersed body method with the combined finite-discrete element method coupled to the adaptive multi-phase CFD code, Fluidity. Sub-grid multi-phase continuum models are compatible with this approach enabling the volume fraction of finer particles in suspension to be tracked while the motion of coarse irregular shaped particles and interactions modeled with FEMDEM are resolved explicitly.

14.40 **The advantages of using mesh adaptivity to model the drainage of liquid in froths**
P.R. Brito-Parada, S.J. Neethling and J.J. Cilliers (Imperial College, UK)

A key factor in most CFD techniques is the computational grid that contains the representation and connectivity of the elements into which the domain has been subdivided. Unstructured meshes present benefits over structured meshes in that they are more easily adapted, which is an important feature to obtain higher resolution only where it is required, allowing the mesh to be optimised to adequately resolve local features occurring during the solution of the physical problem.

This paper will examine how transient simulations of the drainage of liquid in flotation froths can be benefited from using adaptive meshing. The capabilities of Fluidity (a finite element method code that uses anisotropic mesh adaptivity) to accurately resolve the boundary layers present in the liquid-foam interface, as well as other strong gradients that can develop during the process, are highlighted. The use of mesh adaptivity resulted in higher accuracy of the solutions at lower computational cost.

15.00 **Effect of microwave treatment on mineral liberation through bonded particle modelling of simulation of single particle compression**
A.Y.Ali and S.M. Bradshaw (University of Stellenbosch, South Africa)

The effect of microwave treatment on mineral liberation was investigated through simulation of single particle compression of bonded-particle models of untreated and microwave treated ores. Image analysis of the model outputs was used to determine fragment size distribution and degree of liberation. Microwave treatment altered the fracture pattern and degree of liberation; the fracture pattern of microwave treated ore was preferentially localized around the grain boundary compared with that of the untreated ore. A greater degree of liberation was obtained for the ore treated at high power density under all crushing conditions. An increase in strain rate increased the amount of fines for both treated and untreated ores. A low crushing velocity is needed if it is desired to achieve liberated mineral at coarse size from the treated ores. It was also shown that an optimum crusher gap is required for maximizing the benefit of microwave treatment of ores.

15.20 Coffee

16.20 Optional Guided Coast Path Walk, ending with a beer at the Chain Locker Pub, Old Falmouth

Wednesday 22nd June

09.00 *Technical Session 3*
Chairmen: L.A. Cisternas (Universidad de Antofagasta, Chile) and G. Morris (Imperial College, UK)

09.00 **Discrete element modelling for the simulation of particle distribution to a sensor-based sorter**
R. Fitzpatrick, R.D. Pascoe and H.J. Glass (University of Exeter, UK)

The efficiency of a sensor-based sorter depends on both correct identification and separation of individual particles. The sorter first has to generate sensor data which is representative of physical properties of the particle, correctly classify particles based on the sensor data and then accurately separate the particles typically using compressed air jets.

It is known that a number of factor including particle size, throughput and distribution at the point of separation will affect separation efficiency. When particles are touching, or in close proximity, at the separation point there is an increased probability of co-deflection of unwanted particles. The aim of this work was to predict the distribution of particles at the identification and separation point using discrete element modelling (DEM) for a sensor-based sorter fed by a feed conveyor. The results of the modelling were compared with information on particle size and position captured from a CommoDas optical ore sorter operating at varying throughputs with different size and shape fractions.

The geometry of the CommoDas feed mechanism was first modelled in AutoCAD and imported into EDEM 2.3, a DEM software package. Particles were then created to simulate the three sizes and two shape fractions used during physical testing. The model behaviour of particles at varying throughputs was then investigated and their velocity and positioning tracked. It was found that the relationship between throughput and particle proximity as determined by the DEM simulations were in reasonable agreement with that found through physical testing. The research demonstrated that it was possible to use the DEM simulation results to predict the sorter's particle separation efficiency.

09.20 **CFD simulation of a gravitational air classifier**
R. Johansson and M. Evertsson (Chalmers University of Technology, Sweden)

Air classification of manufactured sand (i.e. fine aggregates from crushed rock, particle size smaller than 4 mm) is utilized to separate the crushed rock material into a fine particle fraction (filler, <100 micron) and a coarse particle fraction (>100 micron). Reducing the filler content of the manufactured sand is of special interest for the concrete industry in order to assure the rheology of the cement paste.

There is an ongoing search for productions method that can be applied to produce a full worthy manufactured sand that fulfills the requirements set by ready-mix concrete producers.

A Gravitational Air Classifier has been investigated using computer fluid dynamics (CFD) to increase the understanding of the parameters controlling the flow field and how these affect the behavior and efficiency of the classification process. Influence of the design and geometrical parameters of the classifier on the flow field and air classification performance were also simulated and evaluated by using the CFD technique.

09.40 **The effect of liner wear on gyratory crushing – a DEM case study**
J. Quist, M. Evertsson (Chalmers University of Technology, Sweden) and J. Franke (Scanalyse Pty Ltd, Australia)

Gyratory crushers are frequently used for first stage sizing in the minerals processing industry and are typically critical path fixed plant equipment. Hence any associated downtime or inefficient operation can have serious consequences for downstream processing and therefore the overall plant productivity. Despite the pressing requirement to tightly control gyratory crusher operation, no accurate, reliable, cost efficient, or practical condition monitoring tools or holistic performance assessment methods have been utilized by practitioners to date.

This paper introduces a new method combining laser scanning based CrusherMapper™ software 3D liner shape information and Discrete Element Method (DEM) modelling to assess the effect of measured concave and mantle liner wear on gyratory crusher production. In order to illustrate this effect, two DEM models of an iron ore case study site are presented, one based on the 3D shape of newly installed liners, and the second on that of very worn liner geometry as at the time of replacement. The Bonded Particle Model (BPM) approach is used for modelling the rock material during the crushing sequence inside the crusher and other relevant DEM crushing parameters closely resemble actual production settings. A comparison between resulting modelling output parameters for the two liner geometries provides the basis for aligning actual with desired operational crusher performance.

10.00 **A novel method for full-body modelling of grinding charges in tumbling mills**
P. Jonsén, B.I. Pålsson and H.-Å. Häggblad (Luleå University of Technology, Sweden)

The smoothed particle hydrodynamic (SPH) method is used to model a ball charge and its interaction with the mill structure, while the flexible rubber lifter and the lining are modelled with the finite element method (FEM). This approach opens up the possibility to have a full-body simulation of a rotating mill with grinding charge and pulp liquid. The deflection profile of the lifters obtained from SPH-FEM simulation shows a reasonably good correspondence to pilot mill measurements as measured by an embedded strain gauge sensor. To study the charge impact on the mill structure two different charges are used in the simulations. This computational model also makes it possible to predict charge pressure and shear stresses within the charge, the contact forces for varying mill dimensions, liner combinations and pulp densities.

10.20 Coffee

11.10 **Commminution efficiency improvement, based on SAG mill mechanics, evaluated by discrete element method (DEM) w/ particle breakage**
L. Nordell and A. Potapov (Conveyor Dynamics, Inc., USA)

Research into comminution techniques, based on the mechanics of SAG mills, has led to a novel concept that significantly improves performance over conventional comminution circuits of primary crusher, secondary crusher or High Pressure Grinding Roller (HPGR), and first stage of Ag or SAG milling down to a top size of 40 mm. Single pass rock size reduction ratio of 25:1 may be achievable with a work index efficiency of 0.50 kW-hr/ton for a medium strength ore. Harder ores can also be processed at higher work indices. A 3-D particle breakage technique, utilizes an advanced Discrete Element Method (DEM) model, first published at SAG 2001. Computational Simulation of comminution efficiency is shown for the new technique compared to a circuit with gyratory and cone crusher followed by a SAG mill. Patent is filed for.

11.30 **Empirical-based design of minerals handling and processing equipment: end of era?**
J. Favier (DEM Solutions Ltd., U.K)

Mining and mineral processing operations typically require a high level of capital investment and are often costly to operate. Mine operators are seeking better return on investment in the form of increased availability and in-service life of equipment. The reliability and durability of handling and processing equipment is critical along the whole value chain in mining and mineral processing from extraction, transport, ore concentration to export terminals. Substantial losses can be incurred if equipment is not available when needed or malfunctions during operation.

Designers and operators of bulk minerals handling and processing equipment such as transport and feed conveyors, conveyor transfer points, crushers, screens and mills have traditionally had to rely on empirical methods and field experience for design and troubleshooting. Empirical methods limit the options for engineers to improve the performance of equipment relative to the properties of the bulk material, and variation in operating conditions. Process optimisation is very often difficult and laborious using such methods while over-dependence on use of "design rules" constrains design innovation.

There are now alternatives based on computational modelling that offer a more powerful, and flexible toolkit for engineers to increase the performance and reliability of their equipment. Computational models, provided they are properly calibrated using measured material and process properties, offer many benefits to equipment designers and plant operators. Simulation enables "virtual testing" of the relative effect of changes in equipment design, process configuration and operating conditions on performance. It is well established that use of simulation accelerates convergence on the optimum design solution and reduces cost of physical testing. Computational models also very often provide information that is difficult or impossible to measure – this is particularly the case for bulk particle systems.

This paper examines some of the computational modelling technologies that are beginning to replace empirical methods as the default tools used by engineers designing and troubleshooting minerals handling and processing equipment. In particular, the paper will look at the requirements for deploying DEM simulation tools in the design and optimisation of bulk materials handling and comminution equipment and the benefits being realised by practitioners in the industry.

11.50 **Predicting bulk material flow and behaviour for design and operation of bulk material handling and processing plants**
P. Wypych, A. Grima (University of Wollongong, Australia), R. LaRoche (DEM Solutions, USA) and D. Curry (DEM Solutions, UK)

The reliable design and operation of bulk materials handling and processing plants can be difficult when dealing with complex geometries and difficult-to-handle materials. Often a lack of detailed analysis of bulk material flowand process boundary interactions can lead to costly mistakes which can typically be identified easily once in operation. These problems can occur due to inaccurate characterisation during design, miscalculation of particle trajectories and velocities, and a lack of engineering tools to thoroughly visualise and analyse material flow through complex designs. This paper investigates the application of DEM (Discrete Element Method) simulation to bulk material plant design by identifying current issues and presenting new methods of calibration and length-scale/dynamic validation. Examples and case studies are presented to demonstrate the key issues of this paper.

With the adoption of a systematic calibration process relevant to the end application, DEM modelling provides a powerful optimisation tool to predict and improve bulk material flow and prevent operational problems, such as build-up, blockage, spillage, dust emissions, conveyor belt mistracking and excessive belt/component wear.

12.10 **Computer simulation of the direct reduction iron fabrication in Midrex ovens**
A.C Silva (Federal University of Goiás, Brazil) and A.T. Bernardes (Federal University of Ouro Preto, Brazil)

Using the cellular automata computational technique it was possible to simulate the generation and discharge of an iron ore pellet pile inside a direct reduction iron oven, as well as calculate the reduction degree of the pellets as they leave the oven. It allows us to simulate the variation of operational parameters and verify the results of those variations in the pellet reduction degree. The simulated data was validated in two instances: for the dynamics of the pellet flow inside the oven it was used an acrylic bi-dimensional silo; and data from direct reduction iron literature was used for validation of the pellet reduction. The simulated results were considered acceptable to describe the movement of the iron pellet inside the direct reduction iron oven (this result is also applicable to grain flow in silos, which in essence is the same problem) and to describe the iron pellet reduction in the oven.

12.30 Lunch

14.00 *Technical Session 4*
Chairman: S.J. Neethling (Imperial College, UK)

14.00 **On the modelling of caliche minerals: phenomenological and analytical models–some comparisons**
E.D. Gálvez (Universidad Católica del Norte, Chile), L. Moreno (Royal Institute of Technology, Sweden), M.E. Mellado (CICITEM, Chile) and L.A. Cisternas (Universidad de Antofagasta, Chile)

The Antofagasta region of Chile has one of the most important deposit of saltpetre in the world which it is called caliche. This is composed mainly nitrate ($NaNO3$), halite, sodium anorthite and quartz. Minor species include anhydrite, glauberite, loeweite, calcite, polyhalite, probertite, and gypsum. In the last years several industrial operations began to use heap leaching for the extraction of saltpetre from caliche. Modelling the heap leaching of caliche mineral is not trivial due to factors such as the caliche is formed by a mixture of many minerals, which may present different dissolution rate or the fraction of soluble minerals is very high, leaching values of about 40%; this cause that the heap height decreases appreciably when the soluble minerals are dissolved. In this work, we present a model that is an extension of the one published in Mellado et al. 2009 with particle radius as entity varying in time. The model show different kinetic behaviour as compared with others models for instance, copper heap leaching. The second model, phenomenological, is an extension of the model published by Valencia et al., 2007, where it has been taken into account variation of the height of the heap with time in a simple way the system is modelled as a column comprises of N small columns, In each of these small columns the height of the solid is varying with time when the soluble minerals are dissolved. The liquid in each small column has the same composition (well stirred reactor). The objective of this work is to compare both approaches and comment their industrial applications.

14.20 **Heap leach multi-scale modelling**
P. Dupuy, K. Akama, P. Schwarz (CSIRO Mathematics, Informatics and Statistics, Australia) and M. Leahy (CSIRO Earth Science and Resource Engineering, Australia)

Heap leaching of low grade copper ores has become very common in some parts of the world. As a front end for solvent extraction / electrowinning processing, the heap leach represents a relatively low cost extraction route. Copper can be extracted from very low grade ores at the same mine by using dump leaching for very low marginal cost. If greater recovery could be achieved in some way by different ore preparation or heap design, substantial additional earning would result. Similarly, if the extraction time could be reduced, even by relatively modest amounts, substantial cost savings could be made.

Two common problems with heap leach macroscopic models are that these models are in some cases too coarse to correctly capture all the relevant physical phenomena and that the number of validation options versus the number of model parameters might be low. Particularly macroscopic models are penalized when the involved phenomena are scale dependent, e.g. heterogeneous reactions depend directly on the surface-area-to-volume ratio and the capillary pressure on the pore diameter.

In this work we will discuss using a multi-scale model as an alternative to the macroscopic approaches. It has been shown that other models used in the literature are a particular case of the present approach.

Heap leach simulations are given to investigate the influence of ore preparation and heap design. As the model increases in resolution and the number of model variables grows, the application-specific parameters are reduced making both validation and extrapolations to large heaps more feasible.

14.40 **Stochastic analysis of heap leaching process via analytical methods**
M.E. Mellado, E.D. Gálvez (Universidad Católica del Norte, Chile) and L.A. Cisternas (Universidad de Antofagasta, Chile)

Heap leaching is an hydrometallurgical process which has been used since a long time and which it was originally designed for oxide minerals but nowadays, it can include sulphide and caliche minerals. Heap leaching is an engineering field which has carried out a wide research in the development of mathematical models that allows to simulate, design and optimizate the underlying process. Recently, the authors have presented analytical models of heap leaching which describe scales of time for the particle and the heap in a rather simple model, but enough accurate to be applied in planning, optimization, control and design of heap leaching. The simplicity of these models allows to overcome mathematical complexities of the partial differential differential equations based models and the error of empirical models. In this work we first present the analytical models and then we show how the uncertainty in the input variables and parameters affects the response of the process by comparing the response curves with fixed parameters against with then ones with uncertainty. Here we present simulation experiments of heap leaching processes under uncertainties, based upon analytical models, by using Monte Carlo techniques. We conclude that, in some cases, there exists a rather important influence of the uncertainty of the input variables in the response of the heap leaching process.

15.00 **Employing CFD technology in the modeling of heap leach processes**
D. McBride, M. Cross (Swansea University, UK, and J.E. Gebhardt (Process Engineering Resources, Inc., USA

Industrial mining through the process of heap leaching of low grade ores can be employed in the extraction of a range of base and precious metals, such as copper, gold, silver, nickel, zinc and uranium. It involves the percolation of a leaching solution, typically cyanide, sulfuric acid or acidic ferric sulfate, through crushed ore involving a range of interacting oxide and sulfide minerals. These systems involve a complex suite of interacting fluid, gas, thermal and chemical reactions. A comprehensive computational model needs to account for variably saturated liquid and gas flow in porous media together with the transport of many species through a continually growing geometry, plus multi-phase heat and mass transfer arising from a range of phase change and gas-liquid-solid chemical reaction processes. A number of computational modeling tools employing CFD technology have been developed for the analysis of metals recovery through stockpile leaching. This contribution describes some of the technologies developed and addresses some of the key challenges of model parameterization, validation and embedding within the data acquisition systems of operating plants.

15.20 Closing Remarks
S.J. Neethling (Imperial College, UK) and A.J. Wills (MEI, UK)

15.30 Coffee

POSTERS

Cold climate application of bioheap leaching knowledge
R. Wakelin, N.P. Dang and A. Verhoef (Northern Research Institute Narvik, Norway)

As attention increases on development of mineral resources in Northern Norway, there are also demands for increasing the yield and handling of the tailings. Bioheap leaching can be a useful alternative to traditional processing, and has been proven with industrial scale implementations and thorough studies including computational modelling. The bioheap leaching is a slow and complex process with many intercoupled and at times conflicting processes. Computational modelling can shorten the process development phase and facilitate better operative control.

The application of bioheap leaching with air temperatures below freezing presents advantages and disadvantages. It has been successfully implemented at Talvivaara, and growth of psychrotolerant, acidophilic iron-oxidising bacteria has been reported at 5 °C. In addition, studies of acid mine drainage in arctic regions contain additional relevant information.

With reference to findings reported from field trials and computational modelling this article will identify the potential for application of bioheap leaching under the prevailing cold climatic conditions typical for Northern Norway. For industry potentially interested in the practical application of bioheap leaching the article aims to provide a practically oriented guide to the complex information contained in the literature.

Parameter estimation and modelling of heap leaching by using analytical models

M.E. Mellado, E.D. Gálvez (Universidad Católica del Norte, Chile) and L.A. Cisternas (Universidad de Antofagasta, Chile)

In this work, we present the application of the analytical models previously presented for the authors in the literature for the ore parameters estimation on the modelling of heap leaching process of solid reactants from porous pellets. We first present the scalable analytical models and then we demonstrate mathematically that one can obtain ore parameters just by solving nonlinear algebraic systems of equations with the some input from actual operations. The presented analytical models are valid in what concerning numerical experiments and then we carried out a mathematical proof of existence and uniqueness to obtain good ore parameters. Our proof is based in the Banach fixed point theory to then conclude that we can use, with some little assumptions, this approach can be used to compute valuable parameters. Also, we show that with a very few sample of observations, we can obtain an accurate model to predict the heap response. As a remarkable is that, with a little sample of observations, we can obtain a model and obtain valuable ore parameters without requiring expensive plant experiments. Due to the simplicity of the analysis, one can design and have an insight in the control and optimization of heap leaching processes without mathematical complexities and large number of experimental work. The model and the technique include the effect of heap height, particle sizes, flow rates, and several operation-design variables. Finally, some numerical experiments are presented and corroborate our mathematical analysis.

Design of flotation circuits under uncertainty

N.E. Jamett, L.A. Cisternas (Universidad de Antofagasta, Chile) and J.P. Vielma (University of Pittsburgh, USA)

Flotation is a physico-chemical process which allows the separation of minerals, such as copper sulfide minerals and molybdenum, from the remaining minerals which form most of the parent rock substrate. The behavior of the entire process depends on the configuration of the circuit and the chemical and physical nature of the pulp treated. It is for this reason that the preliminary design of the flotation circuit is very important, as it must take into account all the variables, parameters, and operational conditions needed to be considered. None of the preceding methods for designing flotation circuits has considered that the design may contain parameters which cannot be completely defined, or values which may be subject to degrees of uncertainty. These usually involve external factors such as product demand, economic factors, environmental factors, or internal plant conditions including kinetic constants (among others) which may lead to an inefficient process design.

In the specific case of the design of flotation circuits, large numbers of variables are handled, of which some may involve uncertainty, such as the feed grade, the metal or product price, distribution of mineral particle size, and others.

The objective of the present study is to develop a procedure for flotation circuit design under uncertainty uncertainty. In preliminary works, we applied stochastic programming to the designs of copper mineral flotation circuits and compared them with results obtained by using deterministic programming (mean values of design parameters). In a first stage, three optimization problems are develop; for each it's desired to find the optimal configuration of the operation for a superstructure that has three stages, rougher, scavenger and cleaner. One of these problems includes uncertainty in the determination of the feed grade, the second uncertainty in the copper price, and the third uncertainty in both parameters. Each parameter uncertainty is characterized probabilistically, this means everyone has scenarios with different occurrence probability. On this stage we used stochastic programming with recourse. The optimization of profit was used as objective function obtaining better profits in the stochastic models than deterministic models.

In the present stage of this work, we are developing an improved flotation model, including additional design and operation variables, such as, design cell volume, residence time of each stage and cell number for each stage bank. Due the complexity of this model, we must use another strategy to analyze uncertainty on the superstructure design. Some of these new strategies considered are "expected value", "the works case", "risk measurement", among other methodologies.

Numerical study of blast furnace process under different burden patterns

S.B. Kuang, X.F. Dong and A.B. Yu (University of New South Wales, Australia)

The structure of burden consisting of alternative coke and ore layers controls the gas aerodynamics inside the blast furnace and therefore decides the shape and location of cohesive zone. Directly or indirectly, it influences process, performance and products. In this study, the blast furnace mathematic model recently developed in our research group is used to study multiphase flow, heat transfer, and chemical reaction in the blast furnace charged with different burden patterns constructed by different thicknesses of coke and ore layers. In this model, the steady state composition, velocity, temperature of multi phases (gas, solid and liquid) are calculated, with the layered cohesive zone being predicted explicitly. The effect of burden structures constructed are examined in terms of the distribution of temperature, velocity of gas, solid streamline, reduction degree of iron oxide, volume fraction of gas species and pressure, and size of deadman. In particular, the predicted cohesive zones are discussed with reference to the performance of blast furnace.

Grinding mill simulation using Austin model

A.C Silva (Federal University of Goiás, Brazil) and J.A.M. Luz (Federal University of Ouro Preto, Brazil)

The comminution stage is almost always required in mineral processing. The mill calculation and dimensioning has been target of researches and studies of scientists since middle of the XIX century. There are many comminution models in the literature, with emphasis, however, in the Austin's model for mineral impact breakage (2002). The present work has the objective of implement the Austin's model and finds out if this model can be applied in the milling in revolving tubular mills, knowing about the differences in the breakage mechanism in the both cases. Once the initial approaching of the model is for batching process, it was created an artifice for the model is able to be used in continuous process. Interesting results was obtained, errors less than 0,005, for mills in which the average residence time has a sharp distribution.

Dynamic modelling and simulation of gradual performance deterioration of a crushing circuit including time dependence and wear

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The use of steady-state models in process simulation is a well established method in many process industries. Designing a large crushing plant by relying on steady-state simulation alone can have severe consequences. The dynamics and variation between equipment and stochastic events can significantly reduce the predicted plant performance. In order to dynamically simulate the crushing circuit, models for process equipments need to be further developed.

The purpose of this paper is to take an existing Particle Size Distribution (PSD) function (Swebrec-function), which is defined by three parameters (X_{max}, X_{50}, b) and fit it to data of a real crusher operated at different Closed Side Settings (CSS). This is done to create an accurate updated model of the crusher where also the consequences of wear is captured in the short time perspective. The Swebrec-function and correlation model were implemented into a simulation software with simulated events, where it was validated with actual process readings.

A fractal approach for mineral breakage

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Hukki's law is an empirical law, that does not take into account several events of energy loss during the fragmentation processes. Since experimental results are very difficult to obtain, for a large range of fragments' sizes, the verification of the law is very difficult. The relation between fractures and fragmentation processes with fractal geometry has been proposed some decades ago. Empirical laws known in this context show basic features of fractal geometry, mainly self affinity and power law behavior. Thus, in this work we developed a model to simulate the fragmentation process and to check the relation between energy consumption and fragments sizes. Our model is represented on a regular lattice. Links can represent pathways for fracture processes. The events of fragmentation have energy given by a probability distribution function. In our model, there is no mass loss. Propagation of fractures occurs as self avoiding random walks on the regular lattice.

Computer simulation of the granular material flow in silos

E.M.S. Silva, A.C. Silva and S.O. Freitas (Federal University of Goiás, Brazil)

Silos are structures used in various areas with the purpose of storing grain. Several authors have dedicated themselves to carry out studies to simulate the behavior of granular material discharging silos. To this end, many simulation techniques computing have been tested. One can, however, highlight some works of recognized importance such as Langston et al. (1995) who used a computer model based on discrete element (DE) to simulate the flow of granular material stored in a silo with a hopper. This work was still running, the aims development of software using a technique called cellular automata for simulate both the generation of a dense granular pack, but still porous in a silo two-dimensional as his subsequent discharge, producing a flow of granular material by the discharge orifice of the silo.

Digital analysis of the granular media porosity

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Porosity is the term used when referring to the percentage of empty spaces in certain matters, which are called pores. Their study is of paramount importance how, for example, in the determination and evaluation of petroleum deposits. Based on these existing problems in relation to the generation of granular packages, many authors have been devoted to test several techniques for computer simulation. One can, however, highlight some works of major importance such as Allen and Tildesley (1987) and Rapaport (2004) who used models based on molecular dynamics (MD) of elastic particles. Already Lubachevsky (1991) and Herrmann and Luding (1998) used the simulation conducted by events (SDS) for rigid particles. This study, still running, aims to develop a simulator capable of generating dense granular packets, but still porous. This article presents the results of porosity obtained from treatment of two-dimensional images of a loaded silo, which will be the basis for the simulation of porosity.

Simulating particles in thin films and at interfaces

G. Morris, S.J. Neethling and J.J. Cilliers (Imperial College, UK)

Particle stabilised thin films are key to the froth behaviour in flotation systems, thus affecting the performance of the whole process. However, the interaction between the particles in the film is difficult to observe experimentally due to the highly dynamic nature of the system. Particle shape, hydrophobicity and packing arrangements all distort shape of the liquid vapour interface of the film. This in turn affects the forces acting on the particles. It is possible to simulate this film shape using the *Surface Evolver* program, which can be used to calculate the forces acting on the particles and model their behaviour in the film. This approach has been used to investigate the behaviour of orthorhombic particles in a film and their propensity to adopt different stable orientations depending on their contact angle and shape. It has also been used to model the behaviour of spherical particles in a film.

Effect of grinding media size distribution on wet grinding
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Grinding media size distribution is one of the significant factors which affect the mill performance. Wet stirred mill grinding with grinding media having a size distribution have been tested under laboratory conditions. In parallel to the lab experiments, simulations have been carried out using combined discrete element method (DEM) and computational fluid dynamics (CFD) approach. The correlation between impact energy and the grinding rate constant has been examined for wet grinding. Under different operating conditions, mill performance has been discussed in terms of grinding rate to the input power ratio. It is shown that the numerical modeling can be used to examine the performance of operation of stirred mills under wet grinding conditions. The numerical model can also be used to determine the optimum grinding media size distribution of wet grinding.

CFD modelling and analysis of the combustion of ternary coal blends
Y. Shen, T. Shiozawa, A. Yu (University of New South Wales, Australia) and P. Austin (BlueScope Steel Research, Australia)

The practice of blending coals for pulverized coal combustion is widely used in power plant and ironmaking blast furnace. It is desirable to understand the combustion behaviours of binary or ternary coal blends and their component coals. A three-dimensional CFD model is described to simulate the flow and combustion of ternary coal blends under simplified blast furnace conditions. The model is validated against the experimental results from a pilot-scale combustion test rig for a range of conditions, which features an inclined co-axial lance. The overall performance of coal blend and the individual behaviours of their component coals are analysed, with special reference to the influences of coal type and blending ratio. The synergistic effect of coal blending on overall burnout is examined. The results show that the synergistic effect of ternary coal blends is higher than binary coal blends. The interactions between component coals, in terms of particle temperature and volatile content, are responsible for the synergistic effect. The model provides an effective tool for the design of coal blends.

Structural analysis of a rotating mill with the finite element method
F. Berglund (Luleå University of Technology, Sweden)

In this paper, a structural analysis, using the finite element method, of a rotating mill and the results from wireless strain measurements on a mill in service, are presented. Stresses, strains and displacements in the mill structure have been calculated with a numerical global quasi static simulation model of a running mill. In order to verify the computed results, circumferential and longitudinal strains have been measured on the outer mandrel surface. The registered strain range for one complete rotation of the mill has been compared with the corresponding calculated strain range. As the difference is less than 10%, it is assumed that the computational model is accurate enough for engineering purposes. In particular, it is believed that the global displacement field of the entire mill structure is accurate enough to provide realistic sub-model boundary conditions in detailed calculations of static and fatigue strength, residual fatigue life calculations, etc.