Comminution '10, Cape Town, South Africa, April 13-16, 2010
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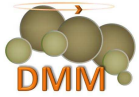


Tuesday April 13th

08.30 Opening Remarks
J. Wills (MEI, UK) and M.S. Powell (JKMRC, Australia)

08.50 *Technical Session 1*
Chairmen: R.Y. Yang (University of New South Wales, Australia) and P.W. Cleary (CSIRO Mathematical and Information Sciences, Australia)

08.50 **Modeling breakage rates in mills with impact energy spectra and ultra fast load cell data**
E.T. Tuzcu and R.K. Rajamani (University of Utah, USA)

The objective is to model breakage rates in large mills from fundamental studies. The two primary modes of breakage are impact and attrition which can be readily studied in the laboratory. The impact breakage mode was studied in a drop-weight apparatus and in a specialized device known as the ultra fast load cell. The abrasion mode of breakage was studied in a laboratory scale ball mill. Next, the particle breakage versus energy data was converted into breakage rates with the impact energy spectra of the grinding mill.

The proof of the modeling concepts is shown for a 90 cm laboratory scale ball mill. The material used in the study was limestone. In the batch mill, approximately a 10 kg mass of limestone in the 32x25 mm size was ground with 100 kg of 50 mm steel ball charge. The fundamental material breakage information was converted into energy based breakage distribution function and breakage rate function. These functions constitute the parameters of the batch population balance model. It is shown that accurate particle size distribution predictions are possible with this modeling approach.

09.10 **Breakage of particles in unconfined particle beds**
G.K.P. Barrios, R.M. de Carvalho and L.M. Tavares (Universidade Federal do Rio de Janeiro – COPPE/UFRJ, Brazil)

Mathematical models of grinding mills and crushers are undergoing significant advances in recent years, demanding ever more detailed information characterizing ore response to the mechanical environment. In a mechanistic model of a comminution machine, the type of characterization data used should cover, as much as possible, the conditions found in the comminution machines. This applies to the particle size, the stressing energy and rates that particles are subject to, the breakage mechanism and the level of interaction of the particles during stressing, which all must be described appropriately. Whereas a very large number of experimental techniques and published data exist that allows understanding and quantitatively describing the response of single particles to stressing, comparatively little information exists on the breakage of particles when interacting with each other in a bed. The present work investigates breakage of particles beds impacted by a falling steel ball in unconstrained conditions, such as those found in tumbling mills. The influences of particle size, impact energy, ball size and bed configuration are investigated for selected materials and a mathematical model is proposed that describes the influences of all these variables. The key element of this model is that it allows predicting breakage in unconfined particle beds with a combination of single-particle breakage data and functions that describe energy partition and volume captured in a particle bed. This model has been calibrated and validated with data from quartz, an iron ore and a copper ore with very good agreement.

09.30 **Comparison of different breakage mechanisms in terms of product particle size distribution and mineral liberation**

Ö. Özcan and H. Benzer (Hacettepe University, Turkey)

The comminution process is still governed by a large number of factors that influence the liberation of the valuable components in the ore. A better understanding of these basic factors will provide more certanity about the design of equipment in order to achieve the best liberation and energy efficiency.

The aim is to improve our understanding of the influence that breakage and the intensity of breakage has on the particle size distribution and the liberation of the valuable minerals. Liberation enhancement is sought for two main reasons. Firstly, if liberation is achieved without needing to grind particles to fine sizes, less is spent on energy. Secondly, over-grinding is not only costly, but produces fines that tend to interfere with subsequent separation processes thus making the downstream processes both inefficient and more expensive.

Two distinctly different modes of breakage used in the breakage tests. Impact and bed breakage were investigated as two distinctly different modes of breakage. Standard drop weight tests and hydraulic piston tests were conducted with different energy intensities on samples.

This paper describes the work carried out for the comparison of mineral liberation and particle size distribution in the particle bed breakage with impact breakage of three different copper ores. Ground products from these two different modes of breakage were screened into size fractions which were analyzed for the particle size distributions by sieve analysis and the degree of liberation by an image analysis system. The results of these analyses were statistically compared to make inferences in relation to the stated objective of the work. Test results indicated that compressive bed breakage mechanism gives finer product particle size distribution and provide better mineral liberation compared to impact breakage mechanism.

09.50 **Influence of grinding media contact points' number in a ball mill on disintegration rate of grains of small size**

A. Heim and T.P. Olejnik (Lodz Technical University, Poland)

Investigations were carried out in a semi-industrial ball mill tampworking rock materials utilized as broken stone for road building. Milling was conducted under dry conditions. The process of milling was carried out periodically. Samples of milled material were collected every 30 minutes. Disintegration rate of particular size classes was defined for particular samples. We analyzed granulometric composition of milled material changing in time and, particularly, the influence of ball's magnitude, mill packing with bed and the number of grinding media on the rate of the process. The rate is constant for particular grain size classes. The process of milling in ball mills is determined by the complex influence of grinding media on milled raw material.

The main aim of the study was to determine the impact of the number of grinding media contact points on the disintegration rate of grains of various size. Additionally, we determined the influence of mill packing with bed on the changing milling rate of particular size fractions.

Based on the granulometric analysis, we determined the percentage of each size fraction for time intervals defined in the procedure of investigations. Granulometric composition changing in time allowed to calculate disintegration rate of particular size fractions. To perform calculations we applied Gardner and Austin equation in its differential form for discrete fraction values, assuming the ideal mixing of milled material.

$$\frac{dw_i(t)}{dt} = -S_i w_i(t) + \sum_{j=1,i>1}^{i-1} S_j b_{i,j} \cdot w_j(t)$$

Analysis of results allowed us to draw conclusions concerning the choice of grinding media ensuring the most beneficial course of the process when the required product is of small grain size.

10.10 **Studies of the effect of tracer activity on positron emission particle tracking measurements on tumbling mills at PEPT Cape Town**
T.S. Volkwyn, I. Govender, A. Buffler, J.P. Franzidis (University of Cape Town, South Africa), N. van der Meulen and E. Vermeulen (iThemba LABS, South Africa)

Prescribed 3D motion within tumbling mill environments has been investigated using the high resolution PET scanner recently installed at iThemba LABS near Cape Town, South Africa. A range of PET isotopes, fixed to predefined trajectory paths in typical mill environments, were run over several half-lives. The functional range of operation of the new system in the context of tumbling mill environments is presented using quantitative measures of accuracy, smoothness and tracking frequency as a function of tracer activity.

10.30 Coffee

11.10 **A new method for determination of fine particle breakage**
D. Ekşi, H. Benzer and A. Sargın (Hacettepe University, Turkey)

Material characterization plays a crucial role by means of equipments efficiency and overall circuit performance. These parameters are required for modelling and simulation works.

Breakage behaviour of material is important for size reduction equipments and it is defined by breakage distribution function. Commonly; single particle breakage method is used to determine breakage behaviour of materials which assumes that breakage is not size dependent. As new surfaces formed material behaviour changes so particle size effect should also be introduced into the grinding model structure. Determination of fine particle breakage becomes important. This will make models more reliable. With this aim a bed breakage method was developed for determination of fine particle breakage. In this study new breakage model is presented and effects of different breakage distribution functions on breakage rate and discharge function is investigated. The bed breakage test results are compared with single size drop weight test results in the aspect of modelling. It was observed that, the breakage rate and discharge function variation by size indicates a characteristic change at fine size ranges compared to regular curve.

11.30 **Power draw estimations in tumbling mills using PEPT**
L.S. Bbosa, I. Govender, A.N. Mainza (University of Cape Town, South Africa) and M.S. Powell (JKMRC, Australia)

Positron emission particle tracking (PEPT) is employed to reconstruct the motion of real charge particles in a scaled industrial tumbling mill. The experimental mill was fitted with lifter bars, pulp lifters and a discharge grate and run with particles and re-circulating slurry. The detailed trajectory fields of the charge and slurry are used to investigate the power drawn at steady state operation. The traditional approaches for determining the power drawn by the steady state charge body (centre of mass power draw, power per voxel summed over the charge body and mechanical energy of the moving charge per mill revolution) are computed using time average kinematic quantities derived from the PEPT trajectory fields and the results compared across a range of operating conditions and particle sizes to measured power.

11.50 **Circulation rate modelling of mill charge using position emission particle tracking**
D.V.V. Kallon, I. Govender and A.N. Mainza (University of Cape Town, South Africa)

A model linking the circulation rate of charge particles with physical mill parameters (load fraction, shoulder angle and friction) has been developed and tested using experimental data derived from positron emission particle tracking (PEPT). A ϕ300mm by 270mm long mill, fitted with 20 lifter bars was used. A range of experiments spanning 5 loads and speeds between 50 and 100 percent of critical were performed. The mill parameters employed in the model are obtained directly from the in-situ flow field mapped out by the PEPT tracer particles and show clear trends with particle size and mill speed.

12.10 **Time-averaged kinematics in tumbling mills using positron emission particle tracking**
A.J. Morrison, I. Govender and A.N. Mainza (University of Cape Town, South Africa)

Positron emission particle tracking (PEPT) is employed to reconstruct the motion of charge particles in an experimental tumbling mill. The mill (120mm in diameter) was fitted with 12 lifter bars and run over 5 loads and speeds between 50 and 100 percent of critical. The velocity and acceleration are derived from the 3D trajectory maps using 2^{nd} order Lagrange interpolation polynomials and the resultant flow field is binned to yield time averaged maps. Charge features (toe, should, centre of circulation, centre of mass) are then computed from the resultant time-averaged quantities.

12.30 **Simulation of a locked-cycle test using a mechanistic ball mill model**
R.M. de Carvalho and L.M. Tavares (Universidade Federal do Rio de Janeiro – COPPE/UFRJ, Brazil)

A great deal of effort has been put on recent years on the mechanistic modeling of ball mills as an alternative to both empirical and phenomenological approaches. With the potential advantage of allowing parameter-free simulation of continuous full-scale operation from fundamental information regarding the collision energy spectrum in the mill and detailed material breakage models, this approach has only been validated in batch operation. Recognizing the complexities associated with the description of material transport and internal classification in continuous mill operation, an attempt is here mad to further validate it in prediction of locked-cycle grinding tests. The popular Bond ball mill grindability test emulates continuous operation by using a sequence of batch grinding and classification steps in a standardized locked-cycle test. From this it is possible to determine the ore grindability, which, in turn, is used to estimate the Bond ball mill work index. The paper simulates this locked-cycle test with the aid of a combination of batch grinding test predictions using the mechanistic model and predictions of classification by the laboratory sieves. First, the collision energy spectrum for the standard Bond ball mill as well as detailed data on material breakage characterization are presented. Predictions of batch grinding tests are then compared to experiments and a simple model is proposed to classification by dry screening that follows each grinding cycle. Results demonstrate that the model is capable of predicting the dynamics of the test, with reasonable agreement to the measured grindability values. Simulations were also able to predict the effect of closing sieve size on the grindability also observed in the experimental tests, which yielded variable values of work index for finer grinds.

12.50 Lunch

14.00 *Technical Session 2*
Chairmen: L.M. Tavares (Universidade Federal do Rio de Janeiro – COPPE/UFRJ, Brazil) and M. Evertsson (Chalmers University of Technology, Sweden)

14.00 **Prediction of the Bond Work Index for variability analysis**
V.K. Alves (Vale, Brazil) and C.L. Schneider (CETEM, Brazil)

Variability analysis for new mining projects has become a standard procedure for Vale. The Bond work index is attractive for the assessment of the energy requirements of comminution because a single parameter contains all the information that is required for scale-up of the ball milling circuit in the context of ore body variability.

The Bond procedure requires at least 15 kg of crushed sample and it is time consuming. This becomes expensive when hundreds of samples from drill cores need to be characterized. With this motivation, alternative procedures that require less sample and time are currently being investigated at the Technological Development Department. In this work a simplified Bond work index prediction procedure is presented. The procedure is based on population balance model characterization of a 700 cc sample in the Bond standard mill for two grinding times, 100 and 1000 rotations. Feed and product size distributions for the tests produce PBM parameters that may be used to simulate the entire Bond procedure at any test sieve size. It has been found that the screening efficiency at the test sieve plays an important role in the determination of the Bond work index. Also, screening efficiency changes with ore type besides the opening of the sieve.

Results of a testing campaign with predicted work indexes has been shown to be consistent with the distribution of measured work indexes using the Bond standard procedure. Repeatability was also

evaluated and found to be accurate. The procedure is simple, requires very little sample and may be used to predict Bond work index at any test sieve size.

14.20 **The effect of mixtures of grinding media shapes on milling kinetics**
P. Simba and M.H. Moys (University of the Witwatersrand, South Africa)

The effect of grinding media on milling kinetics has been studied using one media shape and, sometimes investigators compared performances of two or more different media shapes. However, very little work has been done on mixtures of media shapes.

Combining different grinding mechanisms, namely point contact, line contact and flat surface contact, the volume of grinding zones can be increased when there is an optimal mixture of two grinding media with different shapes and, therefore the milling kinetics will be improved.

Batch tests based on the Mass-Size Balance using two shapes of grinding media of the same mass were conducted at the same conditions.

It was found that a mixture of grinding media of different shapes, compared to a single grinding media shape, can improve the rate of breakage of particle in a particular milling environment, produce a finer size distribution and reduce grinding media costs.

14.40 **Using DEM and SPH to model wet industrial banana screens**
J. Fernandez, P.W. Cleary (CSIRO Mathematical and Information Sciences, Australia) and R.D. Morrison (JKMRC, Australia)

Very large banana screens with multiple decks now dominate classification of commodities such as iron ore and coal. However, their optimisation provides many challenges because the lower decks are difficult to access for measurement or sampling. DEM modelling using non-spherical particles has provided significant insight into the operation of dry industrial screens. Here we introduce the use of Smoothed Particle Hydrodynamics (SPH) to model the flow of slurry (water and fine material) through a double deck banana screen. The method is ideally suited for the high speeds and the high fragmented and filamentary nature of the fluid flow through the screen deck openings. The non-mass diffusive nature of SPH allows slurry to be realistically tracked through the system. A fully coupled DEM-SPH model will then be presented allowing both the coarse particle classes (modelled by DEM) and the fine particles in the slurry (modelled using SPH) to both be included in the model. The effect of the fully coupled slurry on the separation rates for different coarse particles sizes will be assessed.

15.00 **Study of RTD (residence time distribution) and mill hold up for a continuous centrifugal mill with various G/D ratios**
Hee Chan Cho, Kwan Ho Kim and Hoon Lee (Seoul National University, South Korea)

A knowledge of the residence time distribution (RTD) of a mill is critical to predict performance of the mill. In this study, the residence time distribution measurement of a continuous centrifugal mill was performed by experimentally using an aluminum powder as a tracer. An aluminum powder was put into the continuous centrifugal mill chamber as a pulse at steady state condition, and then the discharge time and proportional concentration of tracer was measured using metal detector at various G/D ratios and feed rates. During measurement procedure, mill product was collected and analyzed for size distribution to investigate the relationship between mill product and characteristics of RTD. In addition, the mill hold-up data was also analyzed after measurement.

This tests result can be used to predict the mill powder size distribution with a combination of a kinetic grinding model.

15.20 Coffee

16.00 **Classifying best access points for return of external flows into flowsheets**
P. Oghazi and B.I. Pålsson (Luleå University of Technology, Sweden)

External flows are process streams that come from auxiliary processes or events. They are re-routed into the ordinary flowsheet, since they are thought to be too valuable to be sent to any tailings pond.

External flows come from multiple sources, e.g., drainage sumps, spillage thickeners, depleted products etc. Therefore, external flows may fit or not fit into an existing flowsheet depending on several factors like, flow rate frequency, dilution ratio variation, chemical and mineralogical composition, particle size or particle morphology.

By using Particle Texture Analysis (PTA) to investigate external flows and compare them with existing ordinary flows, it is possible to pin-point from a process mineralogy point of view to what extent the external flow in question fits into the ordinary processing flowsheet. Results from this category of information helps to reach a higher quality of process knowledge and control for every step in the concentrator.

Result from analyses show that some re-routed flows that are reconnected to the main flow are misplaced. The benefit from this type of analysis is to prevent overloading of the primary mill in the grinding section. Thus, increasing the retention time in the primary mill.

16.20 **Using the same type of hydrocyclones for different duties in the circuit and their contribution to overall plant performance**

A.N. Mainza (University of Cape Town, South Africa), M. Lombard, J. Obiri-Yeboah and S. Arthur (Tarkwa Gold Mine, Ghana)

Hydrocyclones are commonly used to classify the product from the grinding circuit or to provide a thickened feed the secondary of tertiary milling devices such as ball mills. It is common practice to use different cyclone designs with notable variations in operating conditions for the two duties. At Tarkwa Gold Mine hydrocyclones that were used to classify the product from a single stage SAG mill have been retained to provide a thickened feed to the secondary ball mill after expanding the circuit. A cluster of similar hydrocyclones has been installed in closed circuit with the ball mill to provide the final product for leaching. Experiments were performed to evaluate the performance of the same design hydrocyclones when employed in the circuit to perform pulp thickening and classification duties, respectively. The experimental work performed involved sampling the feed to each cluster and then individual hydrocyclone overflow and underflow streams. New spigots and vortex finders were installed prior to this work to ensure that all the hydrocyclones in the cluster had similar design components. The paper reports the performance of the individual cyclones and their contribution to the overall plant performance.

16.40 **Comparison of different chemicals used in grinding operation on the quality of the cement and the performance of the grinding circuit**

N.A, Toprak, O. Altun, N. Aydogan and H. Benzer (Hacettepe University, Turkey)

Grinding aids and strength enhancers have been used in dry grinding technology for many years. Each improvement has brought major value in energy efficiency and quality improvement. Aim of the present research work was the investigation of the effects of different grinding aids and strength improvers used in the industry on cement grinding circuit. For this purpose, tests were carried out for three different additive rates when plant was producing CEM II A-M (L-W) 42.5 R type cement. The rate of gypsum added to system was constant at 5% and limestone and ash rates were different. Reference samples were collected without grinding aid when 10% limestone and 6% ash was using as additives. Then for the same condition grinding aid was added to system and after reaching the steady-state conditions samples were collected around the circuit. All the samples were analyzed down to 2 microns and mass balancing study was conducted. Similar tests were carried out with grinding aid and strength improver when 10% limestone and %10 ash and 11 % limestone and 9 % ash was using as additives. With using grinding aids and strength enhancers, the capacity of the circuit was improved at the same product fineness and by pass of separator was decreased. According to the type of the strength enhancer and clinker content of the cement product quality results varied. . The effect of the rheology on the breakage and the discharge mechanism of the mill were observed.

17.00 **Can cyclones improve grinding?**

I. du Plessis (Multotec Process Equipment, South Africa)

The advantages of closed circuit grinding have been known for a long time and this technique is generally employed in industry. Extensive testwork has been carried out by various researchers to

determine the effect of circulating load, but very little attention was given to the effect of classification efficiency.

A cyclone improves the overall milling circuit by removing the right sized particles and then creating space for new particles to enter the system, thus improving the overall circuit performance.

In a closed milling circuit, the cyclone performance largely determines the water and mass balance of the circuit, the water and mass balance in turn influence the input parameters to the cyclone which once again influence its performance. These results in a complex interaction that can be best understood by setting up a simulation model to study these complex interactions.

Wednesday April 14th

08.30 *Technical Session 3*
Chairmen: B.I. Pålsson (Luleå University of Technology, Sweden) and R.K. Rajamani (University of Utah, USA)

08.30 **Real-time statistical process control in crushing plants**
M. Evertsson and E. Hulthén (Chalmers University of Technology, Sweden)

Statistical Process Control (SPC) is an effective method for monitoring a process through the use of control charts. However, although the method has been accepted by numerous industries, it has only recently found its application in aggregates production and in mining crushing plants.

Control charts enable the use of statistically-based objective criteria for distinguishing background variations from events of significance. Much of its power lies in the ability to monitor both the process center and its variation. By collecting data from samples at various locations within the process, variations in the process that may affect the quality of the end product or the service can be detected and corrected, thus reducing waste as well as the likelihood of problems being passed on to the customer. With its emphasis on early detection and prevention of problems, SPC has a distinct advantage over traditionally used quality methods in aggregates production, such as inspection and manual sampling that apply resources for detecting and correcting problems in the end product or the service.

In this paper, SPC system has been implemented in a full-scale industrial crushing plant with a production of high quality aggregates. In order to apply SPC to a production process in real-time, the traditional manual SPC method has been modified. The objective of this SPC-implementation is to improve product yield and quality. Information about the process flows is retrieved from a real-time supervisory control and data acquisition (SCADA).

The developed system is able to determine exactly when to correct the process by using the existing process control parameters. Furthermore, the presented real-time SPC system can also determine the appropriate time for changing screen cloths. In addition, SPC data can be used to identify bottlenecks, wait times, and other sources of delays within the process.

08.50 **A comparative study between cone crushers and theoretically optimal crushing sequences**
E. Lee and C.M. Evertsson (Chalmers University of Technology, Sweden)

The supply of minerals, ores and aggregates are crucial for the continuous development of today's society. With a rising world population, growing urbanization, and increasing standards of living, the escalating demand on these products will only be met if the performance and efficiency of existing crushers are improved. The current paper thus presents a comparative study between existing cone crushers and theoretically optimal crushing sequences.

The performance and efficiency of existing cone crushers are evaluated against what is considered as theoretically optimal. Simulations, laboratory tests and full scale experiments are conducted in order to examine the effects of stroke and eccentric speed on the crusher output. The ensuing results show that existing cone crushers are, in fact, not operating optimally under the studied conditions. The study indicates that gains can be made in terms of product yield and overall capacity by e.g. lowering the stroke or decreasing the eccentric speed.

09.10 **DEM simulation of performance and rock breakage in cone crushers**
J. Quist and M. Evertsson (Chalmers University of Technology, Sweden)

Cone crushers are the most frequently used crusher type for secondary and tertiary crushing stages in the aggregate and mining industry. Hence knowledge about the crushing process in these machines is of great interest in order to develop and optimise the overall process. In this paper the *Discrete Element Method* (DEM) together with a *Bonded Particle Model* (BPM) are used for simulating rock crushing. The particle flow is visualised and machine parameters are evaluated regarding their impact on process performance parameters such as capacity, flow behaviour and breakage rate. The advantages and

disadvantages of using DEM with a BPM model is also investigated and compared to other strategies stated in the literature.

A Sandvik CH430 cone crusher is chosen for the study and parameters such as close side setting, eccentric speed and chamber design is investigated. Results are compared to simulations and empirical data from previous work by Evertsson (2000) and show a good correlation regarding capacity, flow behaviour hypothesis and size reduction.

09.30 **Real-time algorithm for cone crusher control with two on-line variables**
E. Hulthén and C.M. Evertsson (Chalmers University of Technology, Sweden)

Cone crushers are used in the mineral, mining, and aggregate industry for fragmentation of rock materials. Control systems for cone crusher settings (CSS) are widely used to compensate for wear and to protect the machines. With a frequency converter also the eccentric speed in a cone crusher can be adjusted in real-time in addition to CSS. The eccentric speed affects the number of compressions the material is exposed to and thus the particle size distribution of the product. Eccentric speed also affects crusher capacity. By applying mass-flow sensors to the process, a feedback from the sellable products is given every moment. With two parameters adjustable in real-time a non-trivial optimization problem with a large solution space arise.

A monitoring and control system is therefore developed, including a two-variable online algorithm for selection of setpoints for both eccentric speed and CSS. The different product flows from the crushing plant is monitored by mass flow meters and evaluated by a fitness function continuously. The fitness function is set by the plant management. Since the process is varying continuously, due to wear and feed material variations, the performance landscape is also varying.

The developed algorithm is tested and evolved at a crushing plant for aggregates that produces around 400 kton a year. The algorithm was implemented in a computer that could communicate with the frequency controller, retrieve data from ten mass-flow meters in the process, and also interact with the operator.

09.50 **The advantage of half scale to full scale HPGR modelling**
F. Heinicke (Polysius AG, Germany)

HPGRs are said to be one of the key technologies in future comminution circuits. Benefits are liked to be shown using simulation programs before investments are funded. Therefore every simulation needs mathematic models. The publication will show how sensitive the selection of the start point for the calculations is to predict the right product size distribution for industrial scale machines. The behaviour is shown with detailed laboratory, half scale and industry measurements. The tests include the performance of several minerals. An upgrade on the normal population balance method is used to handle the breakage characteristics. This is due to the fact that there are both typical and special breakage phenomena inside a HPGR.

10.10 **A preliminary investigation into the feasibility of a novel HPGR-based circuit for hard, weathered ores containing clayish material**
P. Rosario, R. Hall, B. Klein (University of British Columbia, Canada) and M. Grundy (AMEC Americas Ltd, Canada)

The paper reports the progress of a research project using rock samples from a large copper-gold mining project in North America. This orebody contains a mixture of hard rock, softer material, and clays (sericite), in proportions that are expected to vary throughout the mine-life. The feasibility of a novel comminution circuit, using an autogenous (AG) mill/scrubber and parallel trains of cone crushers and high-pressure grinding rolls (HPGR) is being investigated. The process enables the application of energy efficient HPGRs to ores containing clay which are usually processed using SAG mill circuits.

The work presented in this paper involved custom-designed laboratory testwork including pilot HPGR testing, and modelling and simulation of both the HPGR-based circuit and an equivalent SAG-based circuit. The preliminary analysis reported herein includes a comparison of the energy and steel consumption of both circuits; complete operating and capital cost comparisons will be reported in due course.

10.30 Coffee

11.10 **Comparison of open and closed circuit HPGR application on dry grinding circuit performance**
O. Altun, N.A. Aydogan, N.A. Toprak, H. Dundar and H. Benzer (Hacettepe University, Turkey)

A conventional cement grinding circuit is composed of a two compartment tube mill, a mill filter which collects the fine material inside the mill and a dynamic air separator where final product with required fineness is collected. In general the material fed to the circuit has a top size of 50 mm which is very coarse for the ball mill. For this purpose later in 1990s high pressure grinding rolls (HPGR) has found applications as a pregrinder which increased throughput of the grinding circuit at the same fineness.

In the beginning HPGR was operated in open circuit. But later as the operating principle of the equipment based on the compression, some portion of the HPGR discharge recycled back to improve efficiency of the mill. This application provided HPGR to have a finer size distribution which improved the overall circuit performance. Within this study effect of the HPGR operated at different recycling loads between 0% and 80%, on the air separator and ball mill performance were examined. Air separator performance was evaluated based on the Whiten's efficiency curve approach. In this approach the parameters such as sharpness of the separation, cut size, fish-hook behaviour were examined. Ball mill performance evaluation studies were based on perfect mixing model.

It was understood from the studies that, as the amount of recycling load was increased equipment's efficiency showed some improvement.

11.30 **Investigation of the breakage of hard and soft components under high compression: HPGR application**
H. Benzer, N.A. Aydoğan and H. Dündar (Hacettepe University, Turkey)

In the cement industry, high pressure grinding rolls (HPGR) has been used since 1985. At the first applications, this equipment has been installed in the existing cement grinding circuits as an open circuit pre crusher in order to crush clinker especially. The cement factories produce different type of cement by using basically clinker, gypsum and additives like limestone and trass (natural pozzollan). The additives generally are not pre-crushed prior to ball milling.

In this study, three different mixed feeds were prepared with clinker (hard component), gypsum, limestone (soft component) and trass (weak component) to evaluate the performance of an industrial scale open circuit HPGR. The results of the tests show that due to the stress concentrates on soft and fractured material, the performance of HPGR becomes worse when the relatively hard material (clinker) is fed together with soft and weak materials (i.e. gypsum, limestone, trass). In addition to the industrial tests, the piston die tests have been also performed with closed size particle fractions of the mixed materials. The industrial tests' results were also supported by the laboratory tests.

11.50 **Breakage of waste concrete for liberation using an autogenous mill**
Kwan Ho Kim, Hee Chan Cho and Ji Whan Ahn (Seoul National University, South Korea)

It is known that autogenous milling promotes preferential breakage along the grain boundaries. Therefore, in this study, autogenous milling of waste concrete was conducted for better liberation of aggregate and cement mortar. The two scale autogenous mills 1) a 710mm diameter by 530mm length lab scale autogenous mill, 2) a 2000mm diameter by 800mm length pilot scale autogenous mill were used for breakage process. Tests involved grinding of lumps of waste concrete for various times and examining the quality of produced aggregates. The resistance to breakage was reduced considerably when a sample was preheated with heat before breakage process. The degree of liberation increased as grinding time increased and the quality of recycled aggregate satisfied the 1st grade quality standard after 30 minute grinding for lab scale autogenous mill, 10 minute grinding for pilot scale autogenous mill. Currently, locked-cycle grinding tests are being conducted to simulate closed-circuit grinding circuit for developing a commerce-scale process.

12.10 **TPL Technology and its effect on grinding efficiency of ABC/SABC circuits**
S. Latchireddi (Outotec Inc., USA)

Turbo Pulp Lifter (TPL) technology is an Outotec patented design developed to improve material transport in autogenous (AG) and semi-autogenous (SAG) grinding mills. Significant savings in energy while increase in capacity have been demonstrated by using TPL technology. This paper will discuss how TPL has helped to eliminate material transport issues in AG/SAG mills and increased the grinding efficiency in ag/sag mills. The influence of the TPL technology is not only limited to primary AG/SAG grinding stage. The benefits are also seen as improved grinding efficiency in the secondary grinding stage in the ball mill - hydroyclone circuit. The overall effects on the ABC/SABC grinding circuit using TPL technolgy will also be discussed in this paper using the actual plant operating data.

12.30 **SAG kWh/t measured using a standard test – 53 mill design projects in 6 years**
J. Starkey (Starkey & Associates Inc., Canada)

At SAG 2006, the SAGDesign^{TM} Test was introduced. After 6 years and 53 successful mill design projects, this technology has emerged as a proven mill design method based on the direct measurement of SAG pinion energy in kWh/t using commercial grinding conditions.

In the database, SAG pinion energies (to grind to T80 1.7 mm) vary from 1.5 to 34 kWh/t and Bond ball mill work index values vary from 6 to 25 kW/t for the same suite of ores. Project design tonnages varied from 1,000 to 150,000 t/d, SAG mill sizes varied from 18 ft diameter to 40 ft diameter in multiple mills, and ball mill sizes varied from 10 ft in diameter to 28 ft in diameter.

SAG pinion energy measurements are within 3% of actual plant power consumption using SAGDesign testing on proper samples. This technology can therefore be considered for every new project prior to mill purchase.

12.50 Lunch

14.00 *Technical Session 4*
Chairmen: H. Benzer (Hacettepe University, Turkey) and S. Latchireddi (Outotec Inc., USA)

14.00 **Optimization of the SAG mill circuit at Kinross RPM Brazil**
M.P. Gomes, L. Tavarez Jr. (Kinross' Rio Paracatu Mineração (RPM), Brazil), E.S. Nunes Filho, J. Colacioppo and W. Valery (Metso Process Technology and Innovation, Australia)

Kinross' Rio Paracatu Mineração (RPM) and Metso Process Technology and Innovation (PTI) have reviewed and optimized the operating strategies for the SAG mill circuit at RPM operation in Brazil. The focus of this project was to reach design throughput and final grinding circuit product, conditions which have not been achieved since commissioning in December 2008.

For the first time a full circuit survey was conducted followed by a complete mass balance and model fit, and these have been utilized to investigate possible circuit changes and alternative operating strategies. This project looked at the process variables, from ore characterization, through SAG mill practices and finally ball mills and cyclones strategies and resulted in significant improvement in overall comminution performance of the RPM operation.

Several options were investigated using the currently available equipment. Further simulations were performed to evaluate a circuit expansion, with the inclusion of a third ball mill.

14.20 **Monitoring of the operational states of a semi-autogeneous mill**
J.J. Burchell, C. Aldrich, J.P. Barnard (University of Stellenbosch, South Africa) and J.W. de V. Groenewald (Anglo Platinum Management Services, South Africa)

In many comminution systems, control strategies are aimed at the maintenance of maximal mill power draw by manipulation of the mill feed rate. This is challenging, since the power load curve is affected by other process variables and it may therefore be difficult to track the maximum point. Being able to visualize the operational states of the mill would therefore be a major advantage and this paper presents an investigation into the dynamics of a semi-autogenous mill on a platinum concentrator plant. The primary mill variables were analyzed using a phase space reconstruction and included the mill power,

mill load, the fine ore feed rate, coarse ore feed rate and combined ore feed rate. The mill states, as they are defined by the mill controller, were derived and projected onto the mill phase space for visualization purposes and the use of this information in advanced control strategies will be discussed.

14.40 **Wear and design improvements in discharge cones for large SAG/AG mills**
C. Faulkner **(**Bradken, Australia)

Discharge cones for large SAG/AG mills are subjected to high wear as significant volumes of ground ore and slurry exit the mill. With the larger diameter mills of 32ft to 40ft in size becoming the norm, very high, concentrated wear is highlighting the limitations of conventional discharge cones and frequent changes are subsequently required.

This paper outlines the advances made in the design of the Bullnose discharge cone. Superior wear materials to increase wear life over conventional rubber or chrome-moly steel discharge cones and the introduction of key design features to reduce reline times and improve fit and safety during installation offer significant opportunities for the mill operator.

Collated from multiple case studies, the wear data and reline history from 2004 to present clearly illustrate the way in which superior component longevity has reduced the frequency of relines over the life of the product to increase mill availability and effectively increase the tonnes milled in a period.

15.00 **Energy efficient grinding circuits from operators' view point**
Mingwei Gao (JKTech Pty Ltd, Australia) and R. Harvey (Mount Isa Mines, Australia)

Grinding circuits in a mineral processing plant account for more than 60% of the production cost. Its primary function is to produce a grinding product with a required particle size distribution at a set throughput. There are many projects in recent years developing new energy efficient technologies for crushing and grinding. However, the biggest area for energy saving is still with exiting mineral processing plants and their day to day operations.

Plant operators often demand one of the following outcomes from a grinding optimisation study,

- Increased production with existing equipment at the same grinding product size
- Maintenance of unit cost when the plant feed is reduced due to mine production change, or
- Maintenance of feed rate and grind size with reduced power cost

On the other hand, plant operators in general have no immediate budget for new equipment, have little tolerance to production interruptions, and have no keen desire for new technologies. Implementing an energy efficient grinding circuit in an existing plant often implies that the project team has to deliver major improvement with simple changes.

This paper draws together three case studies on SAG and ball mill circuits carried out in the Mount Isa Copper and Zinc/Lead Concentrators. These studies were aimed at reducing grinding power cost while maintaining plant performance, increasing circuit throughput without adding new equipment or maintaining the production unit cost at reduced feed rates. A common feature of all three studies is that they have achieved significant efficiency improvement with simple circuit changes.

15.20 **The development of a dry energy efficient grinding circuit for Anglo American**
W. van Drunick, N. Palm (Anglo Research, South Africa) and C. Gerold (Loesche, Germany)

The work conducted in this paper followed a series of previous pilot trials at Anglo Research. The common objectives to all the work were to develop comminution circuits / flowsheets that can produce liberated grind sizes at improved efficiency of energy use. The "Energy Efficient Comminution" circuit would also need to be economical from a holistic point of view, and would therefore have to be favourable when all factors are taken into account – i.e. capital expenditure, operational expenditure, operability, sensitivity to feed variability, safety, relining time, etc.

The progression of the work done at AR resulted in the piloting of a "Cone Crusher-VRM" and "HPGR-VRM" circuit at Loesche, using Gamsberg ore. The VRM has previously been identified as an energy-efficient comminution device, with the added benefit of producing a dry final product. A dry

grinding product would allow one to be better positioned to accurately control the dilution rate (hence % solids) to the flotation plant feed. The galvanic interaction of steel grinding media will also be reduced due to the elimination of grinding balls in the mostly autogenous HPGR-VRM set-up, thereby preserving the mineral surface chemistry.

From an energy standpoint, the HPGR-VRM circuit, in Overflow mode, displayed the lowest specific energy consumption of the circuits considered. The effects of grinding pressure have shown that higher pressures tend to facilitate more sphalerite liberation in the -10/20um range. One needs to be cautious when making conclusions on the effects of size specific liberation on float recovery, as surface chemistry needs to also be well accounted for.

15.40 **Taking advantage of shapes of rock to reduce comminution energy**
R. Chandramohan, M. Powell and P. Holtham (JKMRC, Australia)

Understanding the fracture process of rock is of particular interest to the mining industry where, currently the main drive is to reduce the comminution energy. There is little work looking at the influence of shape on rock fragmentation and utilizing it to reduce comminution energy. It is hypothesized that particle shape and the way force is applied to the particle influence energy absorption and utilization in fracture. The implication is that energy reduction during comminution can be achieved by controlling and using the shapes of rock particles to advantage.

Controlled breakage tests have been conducted to verify the effects of shape ranging from single particle breakage to laboratory batch tests. The results are then compared with numerical simulations to quantify optimum breakage routes. Initial findings show that the rate of fines generation can be controlled by the shape of particles and the mode of loading.

16.00 Coffee

Thursday April 15th

08.30 *Technical Session 5*
Chairmen**:** W. van Drunick (Anglo Research, South Africa) and G. Davey (Metso Process Technology Support, UK)

08.30 **Interpretation of vibration signal of tumbling mills**
S.P. Das, D.P. Das, S.K. Behera and B.K. Mishra (Institute of Minerals & Materials Technology, India)

Size reduction in tumbling mills is a major cost driving factor in any mineral processing industry and for this reason it is imperative to optimize the mill operations. Key to optimization of tumbling mills is designing the right kind of diagnostic and sensing tools. We have been attempting to gather vibration signature of tumbling mills using wireless sensors. Effect of mill parameters such as mill speed, mill filling, feed size, ball load, slurry viscosity, etc. have been studied. We have used a ± 5g triaxial accelerometer to capture the mill vibration and have analyzed the signals using power spectral density (PSD) as well as averaging of filtered vibration signal in the Fourier domain. A common band pass filter is used to filter the vibration signal generated for different cases. Results of our work show that only Fourier transform based analysis does not provide sufficient information about the mill vibration. The study has been made in a 90 cm diameter tumbling mill to analyze coarse versus fine grinding under wet and dry conditions. The work is currently being extended to study industrial tumbling mills.

08.50 **Ball-charge optimization of cement mills**
P. Fleiger and S. Woywadt (Verein Deutscher Zementwerke e.V., Germany)

Nearly 60% of the electric energy used for cement production is spent on grinding processes. Ball mills still account for almost 60% of all installed mills while operating with an average efficiency significantly below 2%. A complete substitution of this mill-type is not to be expected over the next decades due to quality and financial reasons. Therefore mill-optimization implies high savings potentials (up to 10%). Especially the adaption of operating parameters like the ball charge represents an attractive approach due to the fact that almost no additional capital costs are required.

Because of limited possibilities for measuring during mill-operation only empirical models are available until today.

VDZ is developing a tool for the combined simulation of ball-kinematics and comminution in order to enhance general understanding of the grinding-process and to provide the opportunity for numerical optimization. Research is carried out with emphasis on practical aspects and direct industrial applicability by further using a semi-technical grinding-plant and a demonstration-mill.

09.10 **Total primary milling cost reduction by improved liner design**
J. Dahner (Magotteaux (Pty) Ltd, South Africa) and A. Van den Bosch (Magotteaux SA, Belgium)

Total milling cost are composed of energy, liner and grinding media cost.

In Primary milling, the grinding media is the most important part of the total cost. The grinding media cost can be drastically reduced by improving the impact condition inside the mill. These impact conditions inside the mill are influenced by shell liner design as well as feed and discharge end design and the type of discharge. The impact conditions improvement will bring a significant decrease in grinding media consumption. This decrease can be followed by another one as the softened impact condition will allow an alloy optimization of the grinding media.

Liner design can also improve the energy consumption as energy is not wasted to overthrow grinding media.

This paper will present some practical examples where the media and energy consumption can be or has been reduced by optimizing liner design.

09.30 **Milling rate of chosen mineral materials in a ball mill under changing apparatus – process conditions**

T.P. Olejnik (Lodz Technical University, Poland)

The article presents the results of investigations concerning the analysis of milling kinetics of chosen rock materials for various sets of grinding media. Investigations were carried out for a mill operating on a semi—technical scale. Milling was conducted periodically, using steel and corundum grinding media. Diameter of steel grinding media was equal to 60 mm and diameters of corundum grinding media applied during grinding were equal to 40, 30, 20 and 10 mm. Millings were carried out with changing ball compositions determining forces allowing grinding media to affect the milled material and determining the change of grinding media contact point number. Mineral raw materials of varied crystallographic structure were subjected to milling. The process of milling was conducted for quartzite, granite and graywacke. Output fraction of milled material was of size 5 – 8 mm. Granulometric analysis of milled raw material was performed every 30 minutes, returning the sample for further milling. Results of milling allowed to define the kinetics of mean grain size change as well as disintegration rate of particular size classes. Equation of milling rate was extended using the basic Gardner-Austin model:

$$\frac{\Delta w_i(t)}{\Delta t} = -S_i w_i(t) + \sum_{j=1, i>1}^{i-1} S_j b_{i,j} \cdot w_j(t)$$

Based on the knowledge of granulometric composition we calculated mean grain size.

$$d_s = \sum_{i=1}^{n} d_{si} \cdot x_i$$

The obtained results allowed to determine the milling kinetics combining it with the basic apparatus-process conditions. It was found that disintegration rate depends on the filling degree of mill's chamber. Furthermore, we defined the basic dependencies (existing in the theory of statistic moments) for investigated millings. We also examined the influence of milling process conditions on disintegration rates of particular grain size classes and statistic moments of the first and second order.

09.50 **Modeling the residence time distribution of a large ball mill as a function of load volume and percent solids**

A.B. Makokha and M.H. Moys (University of the Witwatersrand, South Africa)

Researchers and industrialists generally agree that accurate models of mill load behaviour could be the key to accurate design and effective control of grinding mills. Previous researchers emphasized the value of acquisition of information that could help in calibration of mill power models. It is believed that the pattern of mill power draw correlates with mill capacity. Difficulties arise with large industrial mills where small changes in mill capacity cannot be detected through variation in a power draw pattern or the observed power draw pattern is due to other individual influences such as change in ore characteristics or slurry properties.

This work seeks to make available clear and detailed information of how the significant operational factors vary during the continuous state of mill operation and how these variations are reflected in the measured mill signals; so as to monitor and characterize the changes in mill operating conditions. This will provide a fundamental basis on which sound control schemes can be created for improved mill product quality and process performance. Two direct sensors one based on proximity and the other on conductivity have been developed and applied to measure the parameters which define the in-mill dynamics in an industrial scale mill. The behaviour of the mill was studied for a range of load volumes and percent solids. Residence time distributions were measured under a wide range of conditions. An empirical model is proposed that mathematically relates the measured parameters to key variables involved to give an intelligent interpretation of the data. This information will aid mill operators and process engineers to make timely decisions regarding mill control and optimisation, in order to enhance productivity whilst mitigating the mill operating costs. The combined use of measuring techniques as well as mathematical models is a key route to enhance understanding and develop control strategies for optimal mill performance.

10.10 **Coarse grinding applications using the Metso Vertimill®**
G. Davey (Metso Process Technology Support, UK)

Metso have recently supplied a number of Vertimill® stirred mills for milling duties normally performed by conventional ball mills due to the greater energy efficiency of the Vertimill®. With global energy costs increasing rapidly the use of energy efficient grinding processes are of growing importance.

The reduction in energy consumption by the use of stirred mills is now an established norm for fine and ultrafine grinding. However, the use of Vertimill® instead of ball mills has resulted in significant energy saving, as much as 30%, even at relatively coarse grind sizes. The testwork, engineering and subsequent operation of these plants will be covered in detail.

Is it possible to replace the ball mill completely by the use of stirred mills and would there be process and energy consumption benefits? A detailed analysis of various projects and potential payback will be assessed in the paper.

10.30 Coffee

11.10 **Optimisation of the secondary ball mill using an on-line ball and pulp load sensor – the Sensomag**
P. Keshav (Anglo Platinum, South Africa), B. de Haas, B. Clermont (Magotteaux, Belgium), A. Mainza (University of Cape Town, South Africa) and M. Moys (University of the Witwatersrand, South Africa)

The ball load and pulp load have a significant influence on the ball mill product size and production capacity. To improve the circuit performance at industrial scale these variables must be tweaked to levels where the plant can get grind and capacity benefits. In most of the grinding circuits the influence of these variables are not quantified because it is difficult to obtain precise measurements of the pulp load for an industrial scale mill and the conventional method of obtaining ball load measurements that involves crash stops is not attractive. A comprehensive set of work was performed on an industrial scale mill to quantify the effects of both ball and pulp load. A wide range of ball and pulp loads were tested and the findings are reported in the paper. The Sensomag, a sensor developed by Magotteaux, was used to obtain ball and pulp load measurements during the experimental work.

11.30 **Comparison of the overall circuit performance in the cement industry: high compression milling vs ball milling technology**
N.A. Aydoğan and H. Benzer (Hacettepe University, Turkey)

For cement grinding, tube mills having multi-chambers are traditionally used either in open or closed circuit operations. After the introduction of high compression grinding mills (High pressure grinding rolls (HPGR), vertical roller mill (VRM) and horomill), various circuit configurations have been developed for energy efficient grinding. In this study, in order to evaluate and compare the performances of these cement grinding technologies, industrial scale data were gathered from HPGR-Ball mill, VRM, Horomill and multi-chamber ball mill closed circuits.

General usage of HPGRs in cement industry is as pre grinder; in this study, HPGR circuit presented as case study is closed circuit pre grinding system with a close circuit ball mill. The other case studies, VRM, Horomill and single stage closed circuit ball mill circuits, don’t include any pre grinding systems.

The grindabilities of the raw materials of all circuits were varying in a narrow range of 13-15 kWh/t. The results show that high compression grinding mill circuits are more energy efficient than conventional single stage multi chamber ball mill circuits. In terms of the performance of the individual equipments on energy use were compared in each stage and high compression systems are found to be high performance units.

11.50 **Simulation assisted capacity ımprovement of cement grinding circuit: case study cement plant**

H. Dundar, H. Benzer, N.A. Aydogan, O. Altun, N.A. Toprak, O. Ozcan, D. Eksi and A. Sargın (Hacettepe University, Turkey)

Extensive sampling campaign was performed around the cement grinding circuit of a cement plant in Turkey, for different production types of cement, as CEM I 42.5, CEM II 32.5 / 42.5 / 52.5, for the modelling and simulation purposes. During the sampling surveys; samples were collected from around the circuit for the steady state condition of the operation and, following a crash stop, from inside the mill. The size distributions of the samples were determined down to 2 microns by the combination of sieving and laser sizing methods. By using the size distributions around the circuit and control room data mass balance studies were performed. Then equipments in the circuit; ball mill, air classifier and dust filter, were modelled individually by using the appropriate model structures. After modelling the circuit, simulation studies were performed for capacity improvement, mainly by the ball size optimization. By implementing the proposed optimization, the capacity of the circuit was increased up to 12.5-35.5% for different production types, hence; the overall specific energy consumption of the circuit was reduced, as predicted in simulation studies.

12.10 **Analysis of a stator earth fault protection system of a grinding mill converter-fed synchronous motor**

R. Vargas and J. Pontt (Technical University Federico Santa María, Chile)

Until recently, the application of cycloconverter-fed gearless mill drives for wet grinding had been considered a mature technology. However, in recent years, some large grinding mills driven by gearless drives have presented unexpected insulation failures in the ring motor concerning the stator windings.

Operation and maintenance depends on the proper technology management and new risks emerge with the systems scaling-up. The continuous process of mine-to-mill integration depends on reliable electrical systems and productive availability with electric protective functions depending on the proper signal detection for surveillance of the motors operation. A too sensitive protection is not functional because it produces undesirable nuisance trips with unnecessary downtimes. An insensitive protection is also bad because of the danger of non detection of a real failure.

Concentrator environments in mountains at high altitude impose stringent conditions, Traditional parasitic second order effects may be not treated as negligible, like thermal expansions, electromagnetic effects and EMC emissions. In this frame, harmonics and partial discharges of windings in medium voltage converter-fed machines build additional leakage current background that masks eventual phase insulation failures or produce nuisance trips.

One important operational topic is the protection degree of the electrical protection system under ground-fault conditions of the motor, because of downtime costs associated given the case the motor had a phase to ground fault. This work presents a study and discussion based on modeling and simulation for assessing the limitations and range of application of a 100% earth fault protection configuration, considering the operation of this protection acting also as earth leakage protection.

12.30 **Synchronous electric drives for grinding mills**

M. Ploc (GE Energy, Canada) and M. Clatworthy (GE Energy, Australia)

The grinding process in the mining industry has seen an increased throughput to accomplish greater production and lower overall production costs.

Up to 8-9 MW, a single motor can be connected to drive the mill through a pinion and ring gear.
Above the single-pinion drive limit, the dual pinion approach was developed to allow two drive motors to be used. This allowed the mill input power to be increased to 16-18 MW. Recent developments in clutch and ring gear materials and design are allowing greater input powers of up to 20 MW to be considered.

To avoid damage to the ring gear by uneven load sharing between the two motors, it is critical that the two machines accurately share load. This is typically achieved by either drives capable of controlling

load torque between motors or using a GE proprietary control system that accurately controls the load torque from each motor.

Beyond the current limits of the dual-pinion system, the industry currently uses the ring motor. This design employs a single, shaft-less synchronous motor. The motor stator is located around the periphery of the mill and the rotor poles are fixed to an annular extension of the mill shell.

There is no standard type of drive suitable for all grinding mills. Tradeoffs exist between the initial capital costs, operating costs, and process optimization. A complete cost analysis of the various drive technologies available that includes initial cost, net present value of the project operating costs, and maintenance costs should be made on each project to determine the optimal technology.

12.50 Lunch

14.00 *Technical Session 6*
Chairmen: A. Mainza (University of Cape Town, South Africa) and J. Favier (DEM Solutions Ltd, UK)

14.00 **Less invasive vibrations measurement for monitoring and surveillance of grinding mills with gearless drives**
J. Pontt, U. Ramos, F. Rojas, W. Valderrama and M. Olivares (Technical University of Santa Maria, Chile)

Since the first application of gearless mill drives in wet grinding, experience was gained with high-power drives and the GMD's were considered a mature technology. Therefore, in last decade, looking for economy of scale, a natural growing in size and power for bigger SAG and Ball mills were scaled-up, with mill-diameters of 38 and 40 feet. However, in recent years, some large grinding mills driven by gearless drives have presented unexpected failures in the ring motor concerning the stator and rotor systems. Although the phenomena involved in such failures had complex nature, commonly the manifestation is of mechanical kind. In such events there was not neither sufficient instrumentation nor experience for avoiding such failures. Of course, downtimes are very costly especially when the failure happens in the SAG mill, which is the critical equipment in the grinding line.

In this work, a system for measurement mechanical dynamical signals is proposed for being installed within the stator and rotor of a ring motor, highlighting the displacements and vibrations monitoring and surveillance of operation. Issues regarding accessibility, location and applications are discussed.

It is expected that with the application of the proposed system, more knowledge and experience can be gained for monitoring and surveillance of Grinding Mills with Gearless Drives in order to avoid costly downtimes by having timely detection of any abnormal operating condition.

14.20 **Comparison of wet and dry centrifugal based classification efficiency**
H. Benzer, O. Altun (University of Hacettepe, Turkey) and A. Mainza (University of Cape Town, South Africa)

Classification is one of the most important unit operations of any comminution circuit. The design and choice of the classification device has the potential to render the circuit inoperable. There have been many attempts to improve the classification efficiency for devices used in both dry and wet comminution processes. This work compares the efficiency of classifiers used in dry and wet comminution circuits. The comparison of classifiers efficiencies was performed using partition curve parameters from experimental data collected from laboratory and industrial units under a normalised criterion. The circuits where different scales of dry and wet classifiers are employed were analysed. The effect of operating parameters of the separation efficiencies of wet and dry classifiers were studied and will be reported in the article. The implications of operating these devices at various levels of efficiency on the overall comminution circuit were studied for both wet and dry comminution processes. The results tend to indicate that the fish hoek effect is very pronounced in cases were the viscosity is high for both wet and dry classifiers. The both wet and dry processes the quantity and quality of the recycle load appear to have a huge influence on the grinding efficiency of the circuit.

14.40 **Implementing strategies to improve mill capacity and efficiency through classification by particle size only, with case studies**
N.J. Barkhuysen (Derrick Corporation, South Africa)

Recent advances in fine screening technology allow for the efficient classification of mill products by means of particle size separation only, the advantages are numerous, including improved throughput, reduced power consumption, coarser grind and reduced reagent consumption. The paper will review the history of fine screening from early 20th Century to modern day technology and will detail the economic benefit obtained through modern day, fine particle, classification techniques by means of the patented Stack Sizer^{TM} technology. Several case studies will be presented to demonstrate the effectiveness of the technology.

15.00 **DEM modelling of liner and lifter wear in grinding mills**
M.S. Powell, N.S. Weerasekara (JKMRC, Australia), S. Cole, R.D. LaRoche and J. Favier (DEM Solutions Ltd, UK)

Wear of grinding mill liners and lifters plays a major role in the overall efficiency and economics of mineral processing. Change in the shape of lifters as they wear has a significant influence on grinding efficiency, and the annual cost of maintenance and mill down-time depends on the life of both liners and lifters. The Discrete Element Method (DEM) is a computational method for simulating the dynamics of particle processes. Previously limited in application by industry to 2D models of grinding mills, full 3D simulation, which provides a far better prediction of bulk particle dynamics in a grinding mill, is now possible using the latest commercial DEM software tools such as EDEM. This paper presents an analysis of 3D simulation of a grinding mill carried out using the EDEM software package customised to predict the rate of wear of lifter geometry and to enable progressive updating of worn lifter geometry profiles. The analysis employs methodology developed to determine key grinding efficiency metrics such as segregation, collision energy spectra, and power draw as a function of charge properties, mill configuration and operating conditions. The developed approach provides a means of predicting the effect of lifter and liner wear on grinding mill performance.

15.20 **Prediction of mill structure behaviour in a tumbling mill**
P. Jonsén, B.I. Pålsson (Luleå University of Technology, Sweden), K. Tano (LKAB, Sweden) and A. Berggren (Boliden Minerals, Sweden)

Computational demands and the lack of detailed experimental verification have limited the value of Distinct Element Method (DEM) modelling approaches in mill simulation studies. This paper presents the results of a study in which the deflection of a lifter bar in a pilot ball mill is measured by an embedded strain gauge sensor and compared to deflections predicted from finite element (FE) simulations. The flexible rubber lifter and the lining in a tumbling mill are modelled with the finite element method (FEM) and the grinding medium modelled with DEM. The deflection profile obtained from DEM-FE simulation shows a reasonably good correspondence to pilot mill measurements. To study the charge impact on the mill structure two different charges are used in the simulations. The approach presented here is a contribution to the validation of DEM-FE simulations and an introduction to the description of a bendable rubber lifter implemented in a DEM-FEM mill model. It opens up the possibility to predict contact forces for varying mill dimensions and liner combinations. FEM is especially valuable in this case, since there are readily available libraries with material models. This is a follow-up work to previous preliminary result from a mono-size ball charge interaction study.

15.40 Coffee

16.10 **Understanding fine ore breakage in a laboratory scale ball mill using DEM**
P.W. Cleary (CSIRO Mathematical and Information Sciences, Australia) and R.D. Morrison (JKMRC, Australia)

Most DEM analyses of ball and stirred mills reported to date have considered only media motion and its interaction with the mill lifter configuration. For SAG mills, a large fraction of the feed material can already be well represented in DEM models. But for other mill types with much finer feed, the number of feed particles has been prohibitive until now to include them directly in the calculations. Here, we model a periodic section of a lab scale ball mill, including the coarser ore particle sizes directly in the DEM model. This provides the opportunity to better understand the effect of media on the interstitial

bed of powder and of the effect of the powder on the media. The effect of the powder fill level (varied between 0 and 150% of the pore space in the media charge) will be evaluated. The distribution of the powder, its effect on power draw and the way in which it contributes to the pattern of energy utilisation will be assessed. The simulation results are compared with experimental results from a test at similar ball loading and rotation rate and for several size fractions of ore at a range of powder fill fractions. The results provide estimates of the probability (per unit time) of collision between media and ore particles (the "Selection" function) and the intensity of each collision which can be translated into an estimate of severity of breakage using the JKMRC breakage model (the "Breakage" function).

16.30 **Is fine grinding an appropriate technology for the optimal extraction of refractory gold ores?**

D. Capstick (Deswick Mining Consultants (Pty) Ltd, South Africa)

Refractory gold ores by their very nature are complex, difficult and costly ores to process. Historically these gold deposits have often yielded low recovery rates and have required a sophisticated and costly technology to extract any meaningful value. It is a commonly aired opinion, that as the mining community strives to discover more world class gold deposits the ores will become more refractory in nature and therefore offer a greater challenge to process.

Over the years, refractory ores have been treated by employing roasting, bioleach, pressure oxidation and fine grinding with varying degrees of success. Often these processes have either been environmentally unsound such as roasting, or attracted a high CAPEX and operating costs such as bioleach and pressure oxidation.

This paper describes the application of a fine grind Deswik technology on a number of Zimbabwean greenstone refractory projects. Fundamentally an understanding of the base mineralogy of the deposits and having the ability to effectively release and recover that gold from the gangue material is the key to providing an effective and sustainable technical solution.

This paper describes our experience in designing, developing and manufacturing a processing solution in more than eight gold projects, highlighting the milling and leach parameters and costs. The paper also clarifies the operating parameters, business benefits and potential economic returns of investing in this technology.

16.50 **Investigation on the residence time and fine grinding at Float Characteristic Test Rig**

F. Francis, J. Kabuba, E. Muzenda and M. Mollagee (University of Johannesburg, South Africa)

The objective of this project is to investigate the possibility of improving the Platinum Group Metal (PGM) recovery by reducing the secondary cleaner tails grade to below 2g/t. Two test works were conducted; one was to investigate the possibility of reducing the secondary cleaner tails grade to 2g/t by increasing floatation residence time with Float characteristic Test Rig (FCTR) and another was to reduce to same grade by grinding the secondary cleaner tails using ultra fine technology and floating at FCTR. The samples collected from both test work were sent for PGM analysis and for grind analysis using Malvern. From the grind analysis there was 9.9% grind improvement when the secondary clear tails (SCT) was milled. From the PGM analysis the mass balance was performed using solver programme to determine the mass flow rate, mass pull and total recovery which indicate the SCT reduction when milling and float.

17.10 **The effect of the design of a secondary grinding circuit on platinum flotation from a UG-2 ore**

L. Maharaj, J. Pocock and B.K. Loveday (University of KwaZulu-Natal, South Africa)

Platinum concentrator plants experience significant losses in their overall Platinum Group Elements (PGE) recoveries due to the inefficiencies of their secondary grinding and flotation processes. This project involves an investigation of selective grinding of the platinum-bearing silicate particles present in UG-2 platinum ores found in the Bushveld Igneous Complex (BIC).

The batch-scale laboratory test work consisted of external classification of the UG-2 ore feed material with a spirals concentrator, followed by ball milling and flotation in a 5 litre cell with a Denver

flotation machine under fixed conditions. The UG-2 ore was separated into a low density silicate-rich fraction and a high density chromite-rich fraction using the spiral and thereafter mixed in various volumetric feed ratios of silicates to chromite followed by milling and flotation to assess the platinum mineral recovery.

These tests indicated that under batch conditions, the secondary rougher flotation recovery may be improved by more than 10% as compared to the conventional tests and that the use of an external classification device, i.e. a spirals concentrator followed by milling may be a more efficient solution to achieving selective grinding of platinum minerals.

The potential for new milling technology to improve the recovery of PGE minerals beyond 90% would be of significant benefit to platinum producers.

Friday April 16th

08.30 *Technical Session 7*
Chairmen: A. Kwade (Technische Universität Braunschweig, Germany) and J. Pontt (Technical University Federico Santa María, Chile)

08.30 **Towards a mechanistic model for slurry transport in tumbling mills**
I. Govender, G.B. Tupper and A.N. Mainza (University of Cape Town, South Africa)

A new modelling approach to slurry transport in dynamic beds based upon combining space and time-averaged Navier-Stokes equations with a new type of cell model is described. The resulting Ergun-like equation is used to correlate pressure drop with time-averaged distributions of the porosity, superficial fluid velocity and solids velocity for data derived from positron emission particle tracking (PEPT) experiments in a scaled industrial tumbling mill fitted with lifter bars, pulp lifters and a discharge grate and run with particles and re-circulating slurry.

08.50 **New developments in dry grinding with Jet-mills using air and steam**
U. Enderle (NETZSCH-Feinmahltechnik GmbH, Germany)

The presentation gives a summary of the most common Jet-milling technologies and their latest developments based on test results. The benefits of steam over compressed air regarding the finest particle sizes that can be achieved and the improved economics when using hot compressed air in Jet mills will be discussed.

- By use of steam in combination with a modern classifier jet mills can now grind economically to particle sizes which are normally only achieved by using agitated bead mills..
- By using the heat generated in compressed air, jet-mills with internal classifier can replace mechanical mills for certain applications.

09.10 **Shifting from the norm: coarse grinding in stirred mills**
K. Barns, G. Anderson, D. Smith and H. De Waal (Xstrata Technology, Australia)

The IsaMill™ was developed by Mt Isa Mines and Netzsch Feinmahltechnik to transform the efficiency of ultrafine grinding technology in the early 1990. While the IsaMill™ evolved as an energy efficient grinding device the unique inert grinding environment of the IsaMill™ led it to become the enabling technology for a number of low grade complex ore bodies that would otherwise have been uneconomical. In the early 1990's the M3000's 1.1MW motor made it the mineral industries first large scale, large tonnage ultrafine grinding machine. To date the 3 mW M10 000 IsaMill™ is still the largest inert grinding stirred milling technology in the minerals processing industry.

With scale up to 3MW, adoption of IsaMill™ technology has shifted from its birth place in the realm of complex, fine grained ore bodies into mainstream coarse applications. With this shift the benefits of high energy efficiency, high power intensity (and resulting small installation footprint) and inert grinding is now available in mainstream grinding applications.

This paper examines the arrival of IsaMill™ technology into coarse grinding applications and the benefits it is having in both the PGM and base metals industries.

09.30 **Using the IsaMill technology in mainstream grinding applications**
B. Chaponda, A.N. Mainza (University of Cape Town, South Africa), B. Durant (Anglo Platinum, South Africa) and C. Walstra (Xstrata Technology, South Africa)

Most of the ore bodies being treated now contain finely disseminated mineral complexes. These usually require finer grinds to achieve good mineral liberation and improve flotation response. Conventional grinding equipments have serious energy ramifications in grinding to very fine sizes and hence stirred mills were found to be a realistic option. Due to the relative successes in finer grinding stirred mills are now being introduced for main stream grinding applications. However, there is need to evaluate machine and operating variables that can assist in achieving benefits obtained in fine grinding when these units are applied in main stream grinding.

Studies to investigate effects of operating parameters on specific energy consumption and product fineness were performed on the M4 IsaMill. The parameters analysed were stirrer speed, grinding media size and load, feed size, solids concentration and feed flow rate. The results obtained from the testwork show that stirrer speed, media load, feed size and flowrate have significant effects on both specific energy consumption and product fineness. The promising results appear to indicate that stirred mill can be utilized for main stream grinding applications.

09.50 **Selection criteria of stirred milling technologies**
B.R. Knorr (Metso Minerals Industries, Inc., USA)

The stirred milling technologies currently available on the market can be divided into two sub-categories: gravity-induced and fluidized. Gravity-induced stirred mills initiate a ball charge motion via rotational movement of a screw to provide a size reduction mechanism. In contrast, fluidized stirred mills use a rotational movement to fluidize a media-slurry mixture, resulting in a size reduction mechanism. While these two categories have both been generalized as “stirred mills”, they operate under very different principles.

This paper provides a summary of findings on the recommended selection criteria for both sub-categories of stirred milling technologies. Using a database of testing conducted on both gravity-induced and fluidized stirred mills, a comparison is drawn between the two sub-categories of stirred milling. These results are used to provide a guideline for when to utilize each technology. In addition, the benefits of incorporating both technologies into a two-stage fine grinding circuit are explored.

10.10 **Stress model as basis for optimization and scale-up of bead milling processes**
A. Kwade (Technische Universität Braunschweig, Germany)

Grinding processes can be modelled by the stress model developed in Braunschweig some years ago: According to the stress model product fineness is constant, if the product is stressed with the same stress intensity equally often (i.e. with the same stress number) by the same stress mechanism (e.g. impact). Based on the general model it can be derived, that for an equal mill type constant product fineness is achieved if stress energy and specific energy input are kept constant.

Based on this stress energy concept and on the relationship between Power number and Reynolds number the operation of a stirred media mill can be optimized regarding specific energy input and throughput by adjusting grinding media size and density as well as stirrer tip speed. In comparison to other model based methods this methods allows the forecast of results with totally different operation parameters of the mill. However, the optimization strategy depends on the grinding material as it will be shown by some examples. Moreover, by considering the different stress energy distribution and mean stress energies as well as the different energy transfer efficiencies of different mill sizes a more precise scale-up of stirred media mills is possible.

10.30 Coffee

11.10 **Tracking the motion of media particles inside an ISAmill using PEPT**
A. van der Westhuizen, I. Govender, A. Mainza (University of Cape Town, South Africa) and J. Rubenstein (Xstrata Technology, Canada)

Stirred milling is continually gaining acceptance in the mineral processing industry as a more energy efficient method of comminution. This is particularly the case for the IsaMill™, a high intensity stirred mill with a horizontal configuration and internal classification. These features along with the unique grinding mechanisms make for optimal energy efficiency. Use of Positron Emission Particle Tracking (PEPT) to trace the motion of a media bead in a simplified M20 IsaMill™ has enabled further understanding of the internal mechanisms which occur inside the real mill. The simplified M20 IsaMill™ has the same inner dimensions and disc sizes but is a closed unit without any flow through, no rotor and only 3 discs. The PEPT system has the advantage of being able to obtain detailed charge motion measurements in opaque and aggressive environments such as those encountered in grinding processes.

In previous studies PEPT has been used to analyse the motion of the media charge at low concentrations moving at slower speeds in grinding systems such as ball mills and vertical stirred mills.

The application to high speed horizontal stirred mills is novel. The paper covers the first phase of the PEPT-IsaMill™ program. The work reported here includes a discussion on the proof of concept and development of the methodology for high speed particle tracking. The experimental work included tracking glass beads (3 mm) and MT1 ceramic media (3.5 mm) over a range of volumetric fillings and rotational speeds. An analysis of the resultant trajectory field in terms of velocity, acceleration, porosity and shear distribution is presented for the range of operating conditions investigated.

11.30 **Fluidized mill media selection considerations**
M. Gallimore (Metso Mining and Construction Technology, USA)

Media selection is critical for efficient and cost effective, fluidized mill operation. Choice of media affects operating costs in terms of specific energy and media consumption.

This paper provides a summary of a Metso Stirred Media Detritor media bench top testing program evaluating key media parameters, such as specific gravity, roundness, and size. The media tested are sand and ceramic. The sand media are both glacial and sub-angular, whereas the ceramic media are highly spherical. These tests illustrate the significance of proper media selection for energy efficiency. Data from operating facilities show efficiency improvements by using an appropriate media for the given application.

While energy efficiency is an important consideration in media selection, other operating costs such as media consumption and media cost, are factors. Operational data is also presented to compare these parameters.

11.50 **Effect of media size and mechanical properties on milling efficiency and media consumption**
B.Y. Farber (Zircoa Inc., USA), B. Durant and N. Bedesi (Anglo Platinum Corp., South Africa)

The effect of media size and properties on milling efficiency, media wear, and power consumption will be discussed. A predictive model was developed and has been verified by analyzing results of laboratory and large scale production trials in a mineral grinding application. Recent developments in high density media capabilities for a range of feed types and particle sizes will be presented.

12.10 **A methodology for characterising in-situ viscosity profiles in tumbling mills**
N. Mangesana, I. Govender, A.N. Mainza and J.-P. Franzidis (University of Cape Town, South Africa)

A methodology for characterising viscosity profiles in tumbling mills based on in-situ shear rate data from Positron Emission Particle Tracking (PEPT) experiments is presented. Experiments were carried out in a laboratory scale mill fitted with lifter bars, pulp lifters and a discharge grate, and run with labelled particles within a re-circulating slurry. Shear rates were derived from the time-averaged velocity distributions of selected slurry tracers. These were combined with rheometer experiments at the same slurry solids concentrations to construct the appropriate rheograms (shear stress versus shear rate) from which the viscosity distribution was estimated. The paper presents both the methodology for the shear rate modelling and the rheometer experiments.

12.30 **Grinding circuit optimization by model predictive control**
T. Marx (ABB, Switzerland)

Over the years the minerals industry has invested in more efficient mills and associated drives solutions to reduce the specific energy consumption of the grinding process and to improve the material throughput through the grinding circuit. Variations in material size and composition still are the limiting factors for a stable grinding circuit operation and operators have to react quickly to fast changing materials and overall conditions. In this paper we will discuss how Advance Process Optimization, applying Model Predictive Control (MPC), can be used for grinding circuits to stabilize and optimize the process with the result of a further reduction in specific energy consumption and quality improvement of the grinding result.

12.50 Lunch

14.00 *Technical Session 8*
Chairman: M.S. Powell (JKMRC, Australia)

14.00 **Characterising porosity of multi-component mixtures in rotary mills**
K Sichalwe, I Govender and A.N. Mainza (University of Cape Town, South Africa)

Porosity characterisation presents a significant challenge in modelling of slurry transport in rotary mills due to the aggressive environment. A method of measuring the porosity of mill charge, using the Positron Emission Particle Tracking (PEPT) technique, is presented. The packing density of each size component is proportional to the residence time distribution of its representative tracer particle, based on the ergodicity of the system. The charge porosity is computed as a linear combination of the packing densities of individual components and modelled as a function of mill geometry and operating parameters.

14.20 **Validation of a DEM-CFD model for simulating particle-slurry flow in a stirred mill**
C.T. Jayasundara, R.Y. Yang, A.B. Yu (University of New South Wales, Australia), I. Govender, A. Mainza, A. Westhuizen (University of Cape Town, South Africa) and J. Rubenstein (Xstrata Technology, Canada)

High speed stirred mills have been increasingly used in the mineral industry due to their relatively higher energy efficiency. A numerical model based on the combined discrete element method (DEM) and computation fluid dynamics (CFD) was developed to simulate particle and slurry flow in a stirred mill. Information such as power draw, flow pattern, velocity field and particle-fluid interaction has been obtained from the simulations. To validate the proposed model, the simulation results were compared with those from Positron Emission Particle Tracking (PEPT) experiments performed under similar conditions. Average velocity and acceleration in the radial direction and power draw under different mill loadings and mill speeds were compared. The results showed reasonable agreements confirming the validity of the model. Attempts were then made to investigate the microdynamic properties based on the simulation results. The present study shows the numerical model has promising potential for improving our understanding of the grinding mechanisms in stirred mills.

14.40 **An investigation of fluid flow through the dynamic porous bulk of a tumbling mill using SPH, DEM and Positron Emission Particle Tracking**
I. Govender, A.N. Mainza (University of Cape Town, South Africa) and P.W. Cleary (CSIRO Div. of Mathematics and Information Sciences, Australia)

The flow of slurry through the dynamic porous charge in a tumbling mill is investigated using Positron Emission Particle Tracking (PEPT), Smoothed Particle Hydrodynamics (SPH) and the Discrete Element Method (DEM). The solid and slurry flow related quantities (porosity, velocity distribution of balls and slurry) are experimentally determined from time-averaged trajectory fields of selected PEPT tracer particles in a steady state tumbling mill with re-circulating slurry. The solid charge measurements are compared to predictions of the solid motion made using DEM. The slurry distribution and flow pattern from PEPT are then compared to the simulated slurry behaviour found using SPH fluid passing through the dynamic porous charge predicted by the DEM model. Several different charge conditions are compared to give a clear indication of the extent of agreement between the two approaches for understanding solid and slurry charge behaviour.

15.00 **Predicting patterns of slurry flow in a 3D pilot SAG mill**
P.W. Cleary, P.J. Owen (CSIRO Mathematics, Informatics and Statistics, Australia) and R.D. Morrison (JKMRC, Australia)

For processes in which slurry flow does not dominate particle behaviour, a dynamic “porous bed” can be derived from DEM (discrete element method) analysis and combined with SPH (smoothed particle hydrodynamics) to estimate fluid flows within a dynamically moving particulate matrix. The DEM simulation provides averaged porosities and velocities which interact with the SPH fluid particles via an appropriate inter-phase drag. This approach has previously been used for SAG mills only in two dimensions. This paper extends the method to a three dimensional analysis of an industry standard 1.8 m diameter by 0.6 m long AG/SAG pilot mill. This provides detailed information on the internal flow of slurry within a SAG mill, including the prediction of dry regions and of slurry pooling. Carrying out

these simulations in 3D also allows the pulp flow patterns into and out of the mill via pulp lifters to be investigated.

15.20 **Predicting charge and slurry behaviour in a full scale Isamill**
P.W. Cleary, G. Pereira and M.D. Sinnott (CSIRO Mathematical and Information Sciences, Australia)

The Isamill is a horizontal stirred media mill used for fine and ultrafine grinding of slurry transported rock particles. In this paper we will present four types of models of a full size industrial scale Isamill, including the grinding chamber, feed, classifier and discharge. The models used are a dry DEM model, a slurry SPH model, a one way coupled DEM and SPH model and a fully 2-way coupled DEM-SPH model. These models allow the various influences of the media and the slurry on the motion of the charge to be determined. The power draw prediction is in line with installed power for this size mill. The DEM collision energies provide information on the spectrum of collisions available to fracture the fine particles. The performance of the slurry classifier will also be explored.

15.40 **Enlightened circuit design is essential to the take-up of new equipment**
M. Powell (JKMRC, Australia)

This paper postulates that unless novel and improved equipment is properly designed into novel circuit layouts, we will not capture the full potential benefit, or even possibly lose the benefit altogether. The use of the HPGR is used as the primary example, demonstrating how the operational and energy efficiency benefits can be all but lost and clouded over by excessive peripheral equipment and associated dust issues. The potential to leverage off the differences in operation of an HPGR and SAG mill are also used to demonstrate the potential of innovative and flexible circuit design. Other examples of how to utilise the outputs of the innovations being presented in this conference will also be presented. The emphasis will be on developing the circuit for the equipment at the same time as evolving new and innovative equipment, for it is nothing without a complete circuit.

16.00 Coffee and Wine