Flotation '19

#Flotation19

Monday November 11th

08.00 Registration desk opens. Light breakfast of filled croissants, tea, coffee and fruit juice

08.50 Fundamentals Symposium opening remarks and presentation of MEI Award
B.A. Wills (MEI, UK)

09.15 *Technical Session 1*
Chairmen: Y. Ghorbani (Luleå University of Technology, Sweden) and M. Rudolph (Helmholtz Institute Freiberg for Resource Technology, Germany)

09.15 **Keynote Lecture: The scientific legacy of Joseph Kitchener- its impact in flotation and colloid science**
J. Ralston (University of South Australia, Australia)

Dr Joseph A Kitchener was born in 1916 in Grimsby, on the east coast of England. Some years later, Joe attended an excellent council grammar school in London, from 1926 to 1934. At the conclusion of his secondary education, he won an open scholarship to University College London, where he skipped the first year of the Bachelor's degree and obtained a First Class Honours degree in Chemistry in 1936. He completed a PhD in mid-1938, dealing with the photosensitization of solids, just three years and nine months after leaving secondary school. At UCL, the Head of the Department of Chemistry was F.G Donnan. N K Adam was a member of staff while Herbert Freundlich was an Honorary Research Associate. The intellectual milieu was rich and stimulating for the young scientist to thrive in. Following his doctoral studies, Joe was appointed to the staff of the Chemistry Department at Imperial College and by 1956 was Reader in Physical Chemistry. He was awarded a D.Sc in 1958 for his eminent contributions to the scientific literature, especially in ion exchange equilibria and kinetics. In 1961 the Department of Mining and Mineral Technology , led by Professor M.G Fleming, lured Joe away from Chemistry and conferred upon him the unique title of "Reader in the Science of Mineral Processing".

Joe was one of the foremost colloid scientists in the United Kingdom, indeed worldwide, during the 20th century. His work was characterized by remarkable insights and perception, coupled with exquisite timing. He knew exactly when to enter a field and when to leave to carve out a new area. Joe possessed a strong desire to understand the fundamentals of complex industrial systems, especially within the area of colloid science and its applications to mineral processing. Throughout his impeccable career at Imperial College, Joe influenced, guided and educated many international scientists and engineers as well as inspiring his colleagues.

His work in colloid science covered areas such as: the dewatering of fine particle dispersions; wetting films; rheological phenomena; the selective adsorption of additives such as collectors and flocculants on to mineral surfaces; electrochemistry of metal sulphides; and of course froth flotation! Joe made pioneering studies into the analysis of surface forces which control the colloid stability of mineral dispersions. This led directly to the first correct measurements of long range van der Waals forces between macroscopic bodies. These investigations were performed in parallel with those of Boris Derjaguin and his group in Moscow. He also was very interested in thin liquid

film and foam behaviour, integrating surface forces and film thickness measurements, along with structural effects. There was excellent cooperation with Alexei Scheludko and his research team in Sofia.

Joe completed forty years on the staff of Imperial College in 1978 at which point the College bestowed the coveted title of Senior Research Fellow upon him. He enjoyed this role until 1985, when he finally left Imperial College. Joe died peacefully in his home in Tewin Wood on March 9 2009 at the age of 93.

This keynote lecture traces the scientific legacy of a hugely gifted man and shows how it underpins a significant amount of modern research in mineral flotation and colloid science.

09.45 **Unlocking the true value of chemicals in mineral processing**
D.R. Nagaraj, R.S. Farinato, E. Arinaitwe and T. Bhambhani (Solvay Technology Solutions, USA)

As in many other technology areas, research and development in mineral processing chemicals have reached a plateau in contrast to mounting industry challenges related to decline in the ore grade and quality, HSE (health, safety and environmental) aspects, water and energy consumption, economic uncertainty, and rapidly eroding chemistry knowledge and expertise in the industry. This predicament can be attributed largely to a fading recognition of the critical role of chemicals in minerals extraction and their true value. While there is still additional but marginal entitlement that can be identified and achieved, without a step change in behavior, solutions to industry challenges will remain weak, incomplete and incremental, with additional entitlement being left on the table. Success in developing novel technologies and understanding the true value of chemicals will be greatly improved when we can confront the chemical complexity in mineral processing systems, in both the process and valuation sense. This in itself is one of the grand challenges facing the industry. Cooperative development is seen as necessary in order to penetrate through current performance ceilings, a situation which is increasingly important given the realities of having to produce minerals and metals economically in spite of declining ore grades and the need to fulfill HSE commitments. Unlocking the true value of mineral processing chemicals thus requires a sensible scheme for monetizing their benefits in the context of operational and HSE factors before, during and after their use. A critical overview, from an industry perspective, will be provided highlighting recent advances, current and emerging challenges, and some directions to address these challenges.

10.00 **Direct measurement of interaction force between solid surface and air bubble: relationship between interaction force and contact angle**
K. You, K. Kim, S. Han, and S. Kwon (Korea Institute of Geoscience and Mineral Resources, (Republic of Korea)

Estimating the hydrophobicity of a solid surface is important for flotation. Measuring the contact angle or interaction force between air bubbles and a solid surface has been widely used for evaluating the hydrophobicity of surfaces. However, the correlation between the contact angle and interaction force of bubble-particle was not fully explained because they are measured on the different measurement scale, respectively: contact angle was measured on a macroscale surface and interaction force of bubble - particle was measured on a microscale surface. In this study, we directly measured the macroscale surface–bubble interaction force in terms of attachment force and detachment energy. We then correlated our measured attachment force and detachment energy values with the contact angle. It was found that the attachment force (F_a) and detachment energy in phase 2 (E_2) reflect the hydrophobicity of mineral surface, and increase exponentially with increasing contact angle of the mineral surface.

10.15 **A novel flotation recovery model that includes CFD-computed turbulence intensity on particle-bubble collision efficiency**
A. Wang, S. Mitra, M.M. Hoque and G. Evans (The University of Newcastle, Australia)

In this study, a novel kinetic modelling framework is suggested to predict the desired mineral particles recovery based on flotation process. The collision efficiency used in this kinetic model is derived directly from a 3D computational fluid dynamics (CFD) model involving a single bubble-multiple particle aggregate without requiring a conventional empirical collision sub-model. The CFD model computes the collision efficiency over a wide operating range comprising bubble Reynolds number (60 to 400) and particle diameter (30 to 100 μm).

Additionally, the effect of fluctuating flow field (including presence of bubble wake) on collision efficiency is incorporated based on a large eddy simulation (LES) turbulence model in the turbulence intensity range from 4 to 20%. For a given attachment and detachment efficiency, recovery is computed as a function of gas volume fraction, bubble size, bubble-particle slip velocity, and pulp solids concentration and particle size. A theoretical estimation of bubble surface loading is provided to demonstrate its inverse effect on the slip velocity. The derived kinetic model is noted to predict significant reduction in the recovery when the effect of surface loading is included in the analysis.

10.30 Coffee, exhibition and poster viewing

11.30 **Mobile versus immobile bubble surfaces: a micro PIV study**
M. Eftekhari, K. Schwarzenberger (Institute of Fluid Dynamics, Germany), S. Heitkam (TU Dresden, Germany), A. Javadi (Institute of Fluid Dynamics, Germany and University of Tehran, Iran) and K. Eckert (Institute of Fluid Dynamics and TU Dresden, Germany)

Mobile bubble interfaces are known to provide higher particle-bubble collision efficiencies compared to immobile ones. However, it is still a matter of debate under which surface coverage the interface can still be considered as a mobile one. To address this question, we use a combination of profile analysis tensiometry and micro particle image velocimetry (μPIV). Both techniques are applied simultaneously to a fixed bubble, exposed to controlled flow seeded with fluorescent polystyrene microparticles (5 μm).

Interfacial properties are varied via irreversible adsorption of nanoparticle-surfactant complexes (colloidal silica + CTAB). Surface coverage can be adjusted by the compression of the bubble until a monolayer of nanoparticle-surfactant complexes covers the entire bubble surface. In this way, the transition of an interface from free-slip to no-slip boundary condition can be triggered. Using μPIV, the velocity profiles inside the hydrodynamic boundary layer are analyzed, and the mobility of the interface is quantitatively evaluated.

11.45 **Effects of frothers and the flow pattern of air supply on bubble size in a flotation column with diffused aeration**
Hangil Park, Chun Yong Ng and Liguang Wang (The University of Queensland, Australia)

In the present work, bubble size in a laboratory-scale flotation column equipped with a sparger was measured with different flow patterns of air supply in the presence of one of three common frothers: DF-250, PPG-425, and MIBC. A fast-switching solenoid valve was added to the air intake line of the column to convert the flow pattern of air supply from steady to oscillatory. The measured bubble sizes were compared to those with the solenoid valve taken off the air intake line. It was found that for each frother tested, use of the solenoid valve with proper selection of switching frequency and on/off time ratio can significantly reduce the bubble size and at concentrations lower than the critical coalescence concentration (CCC), the degrees of reduction on bubble size were larger than those at concentrations above the CCC.

12.00 **Mineralogical and surface chemical characterization of flotation feed and products after wet and dry grinding**
M. Peltoniemi, R. Kallio, A. Tanhua, S. Luukkanen and P. Perämäki (University of Oulu, Finland)

Wet processing after crushing is common practice in flotation but the need for more efficient water management has increased interest towards dry processing. In this study the effect of both wet and dry grinding on flotation of sulphidic and non-sulphidic ores were compared. Bench scale flotation tests were carried out and various microscopic and spectroscopic methods such as FESEM and XPS were used in characterization of flotation feeds and products. Bulk surface charge properties were tested with mass titration.

Clear differences in surface properties were observed, which encourages further research. Wet grinding was beneficial for the energy efficiency for both ores and promoted the selectivity of flotation particularly with sulphidic ore. The wear of the mill and grinding media seemed more extensive in wet grinding. Dry grinding produced more fine particles tightly attached to the surfaces, referring to the higher surface charge of the dry material especially with non-sulphidic ore.

12.15 **The effect of lattice impurities on the electronic structure and surface adsorption of sphalerite：a DFT study**
Ye Chen, Jianhua Chen, Yuqiong Li and Cuihua Zhao (Guangxi University, China)

Sphalerite is an important Zn-bearing mineral and the primary source of zinc metal. Natural sphalerite commonly contains impurities in the lattice, and the surface properties as well as the subsequent flotation behavior of sphalerite depend on the type and extent of impurities. Models of sphalerite (110) surface bearing typical impurities such as Fe, Mn and Cd, etc. have been built. And the influences of these impurities on the semiconducting properties of sphalerite have been discussed using density-functional theory (DFT). Moreover, the effects of lattice impurities on copper activation and CN adsorption on sphalerite surface have been studied. The results can provide important insight into the mechanism of copper activation and cyanide adsorption and the subsequently flotation behaviors of sphalerite.

12.30 **Studies of bubble approach effects on coalescence as a function of frother type and concentration**
N. Schreithofer, Z. Javor and K. Heiskanen (Aalto University, Finland)

Bubble coalescence in flotation is dependent on the bubble surface “stiffness” as has been discussed previously. The argument was that the general type of flow is determined by the general boundary condition of the surface tangential velocity. For a stiff boundary with $V_t=0$ the result is a parabolic Poiseuille flow and with a pure water $V_t\neq0$ a four times faster Plug Flow. An important variable that has been treated in bubble columns as a function of electrolyte concentration. Their results indicate three different regimes; a slow viscous drainage, a fast inertial drainage and an elastic bouncing regime where no coalescence takes place.

Microfluidistic techniques have been used to map the three regimes as a function of frother concentration. The frothers have been the same as in the previous studies: DF200, NF240 and DF 250.

The model of critical speed of approach v_c developed for electrolytes by Yaminsky et al. has been modified for frothers, especially their effect on the surface viscoelasticity.

12.45 Lunch

14.00 *Technical Session 2*
Chairmen: K. Heiskanen (Ouotec, Finland) and A. Morrison (JKMRC, Australia)

14.00 **Study on surface characteristics and flotation mechanism of pitchblende and uraninite**
L. Chun-feng, Liu Zhi-chao, Li Guang, Ma Jia, Qiang Lu-de and Tang Bao-bin (Beijing Research Institute of Chemical Engineering and Metallurgy, China)

Aiming at the problem of poor enrichment effect of uranium ore flotation, we conducted a systematical study on pitchblende and uraninite, which are widely distributed in uranium deposits. In this paper, the surface characteristics of uranium minerals and flotation tests of pure minerals were carried out, and the flotation mechanism of uranium minerals was discussed. By means of Zeta potential test,

we studied the variation of uranium mineral surface potential. By means of X-ray photoelectron spectroscopy(XPS) test, the composition and valence state of elements on the surface of uranium minerals were studied. After a series of flotation experiments of single uranium mineral, the most suitable collector and flotation conditions for pitchblende and crystalline uranium ore were screened out. Finally, the mechanism of the collector on the surface of uranium minerals is preliminarily discussed with the aid of Zeta potential test and infrared spectroscopy analysis.

14.15 **Attachment and detachment interactions between bubble and hematite/quartz particle**
Li Zhuang and Zhijun Zhang (China University of Mining and Technology, China)

In flotation, the bubble still has a moving velocity after attaching particle, and may collide with other bubbles, resulting in particle detachment. This paper studied attachment and detachment interactions between bubble and hematite/quartz particle of different sizes in water. Bubble–particle induction time measurements and vibration detachment experiments were performed by using a homemade induction timer. The effect of bubble withdrawal (rising) velocity and vibration amplitude on bubble–particle aggregate detachment was investigated. The results show that high bubble withdrawal (rising) velocity degrades bubble–particle aggregate stability and requires longer induction time. The difference in attachment properties between hematite and quartz particle is explained by Derjaguin–Landau–Verwey–Overbeek (DLVO) theory. The critical detachment force of particle is calculated from the maximum detachment amplitude. In addition, the effect of coarse particle on detachment is more significant.

14.30 **Influence of microturbulence on the bubble-particle interaction investigated with Positron Emission Particle Tracking (PEPT)**
A.-E. Sommer, K. Ortmann, T. Richter (Institute of Fluid Dynamics, Germany), M. Van Heerden, T. Leadbeater, K. Cole (University of Cape Town, South Africa), S. Heitkam (TU Dresden, Germany), P. Brito-Parada (Imperial College, UK) and K. Eckert (Institute of Fluid Dynamics and TU Dresden, Germany)

In a flotation cell, turbulence significantly affects the recovery rate. Microturbulence influences the motion of solid particles and thus, the probability of bubble-particle aggregation. We investigated the effect of microturbulence on bubble-particle interactions with positron emission particle tracking (PEPT). Single air bubbles (d_b=2.5mm) were captured generated on a needle in a water flow channel. Upstream, a mesh produced an isotropic turbulent flow with 5-15% turbulence intensity. Depending on the distance to the grid, the incident flow near the captive bubble (Re=600) was characterized by eddies of different length scales and magnitude. The liquid contained up to 0.3% PMMA particles (d_p=200-400µm) and up to six radiolabelled particles coated with PMMA (d_p=300-400µm). The trajectories of the labelled particles were recorded, allowing us to determine the average particle distribution in the turbulent field and describe the bubble-particle interactions. These results provide valuable information to enhance our understanding of key flotation phenomena.

14.45 **Pulp-froth interface phenomena investigated with Positron Emission Particle Tracking (PEPT)**
A. Norori-McCormac (University College London, UK), P.R. Brito-Parada, K. Hadler, J.J. Cilliers (Imperial College, UK) and K. Cole (University of Cape Town, South Africa)

It is usually assumed that the pulp and froth phases in flotation systems are distinct regions separated by their interface; while the pulp is characterised by a turbulent environment, the froth is considered a relatively quiescent region. In this paper, the behaviour of hydrophobic and hydrophilic particles is characterised with positron emission particle tracking (PEPT) in a 4 L continuous bench-scale flotation cell. Flow profiles of different angular slices of the vessel, determined from streamlines of the average particle velocity, suggest an interesting coupling of the pulp and froth phases. In particular, it was found that the rotational kinetic energy gained by particles in the pulp leads to rotational motion above the interface that extends into the froth phase. This work provides insight into the behaviour of particles near the pulp-froth interface and highlights the importance of PEPT as a tool to further our understanding of complex flotation phenomena.

15.00 **Particle flow dynamics and turbulence measured with positron emission particle tracking (PEPT)**
K. Cole (University of Cape Town, South Africa and Imperial College, UK), P.R. Brito-Parada, K. Hadler and J.J. Cilliers (Imperial College, UK)

The flow profile of a flotation vessel is a key factor in determining flotation performance. The energy input to the vessel via the impeller enables the mixing of slurry and air bubbles, which is required for particle and bubble interactions leading to attachment and the separation of valuable mineral particles in the froth. Positron emission particle tracking (PEPT) produces detailed and quantitative measurements of different particle classes inside flotation vessels, with the goal to improve fundamentally based computational models of physics phenomena. Flotation may be one of the most challenging applications investigated with PEPT, due to the variation in radiation transport through multiphase media, and that interactions such as attachment occurring on a length scale towards the spatial resolution of PEPT. This work presents the application of fluid dynamics to describe the flow profile of a laboratory scale flotation vessel and quantify the turbulent fluctuating velocity experienced by hydrophobic and hydrophilic tracer particles.

15.15 Coffee

16.00 **New approach for flotation process modelling and simulation**
J. Yianatos, P. Vallejos (UTFSM, Chile), R. Grau and A. Yañez (Outotec, Finland)

The aim of this work consisted of developing a flotation model based on industrial data from modern and large mechanical flotation cells (up to 300 m^3). Using industrial data from different flotation plants a model was developed considering the metallurgical performance, residence time distribution and operational and hydrodynamic conditions. The model considers the behaviour of each cell in a flotation bank separately, using a distributed approach. The overall mineral recovery by true flotation was calculated in terms of the collection and

froth zone recoveries and the gangue entrainment into the concentrate was also evaluated. The mineral in the flotation feed was characterized by particle size and surface liberation classes to evaluate the metallurgical performance along the flotation bank.
This paper presents a new approach for flotation circuit modelling and simulation, which addressed the challenges for improving the froth behaviour by varying the cell design as well as the potential for circuit optimization.

16.15 **Flotation of fine quartz using microbubbles**
I. Filippova, S. Farrokhpay, L. Filippov (University of Lorraine, France) and N. Rulyov (TurboflotServices, Ukraine)

It is known that fine and ultrafine particles are difficult to float mainly due to the low bubble-particle collision efficiency. In this paper, the effect of microbubble carriers on flotation of fine quartz particles (below 50 µm and with 44% less than 20 µm) is discussed. The different air rates, collector and microbubble dosages were tested at batch flotation scale using an external microbubbles generator. It was found that when microbubbles were used, much less amount of collector (about half) was needed to achieve the same, or even slightly higher recovery. At the same time, the quartz flotation rate was also higher when microbubbles were used. The advantages of microbubbles may be attributed to the more efficient bubble-particle collision/attachment rate and to the preferential adsorption of collector on the bubble surface rather than fine particles. The interaction between microbubble-collector-quartz will be discussed and the involved mechanism will be identified.

16.30 **Flotation of fine particles using hydrophobized hollow glass microspheres**
S. Arriagada , C. Acuña and M. Vera (Federico Santa Maria Technical University, Chile)

This contribution presents a new technology to improve fine particles flotation (< 20 µm) performance based on the addition of hydrophobized hollow glass microspheres (patent submitted). The technology has been developed and validated using mineral ore (100% -500 mesh, mainly bornite). Batch flotation experiments were conducted under the following conditions a) standard reagents addition, b) standard reagents addition and hollow glass microspheres, c) standard reagents addition, without frother and hydrophobized hollow glass microspheres.

The results demonstrated that the flotation kinetics constant increased 1.4 times on average, and final recovery increases from ~65% up to ~90%. Additionally, the new technology shifted the grade-recovery curve, promoting better metallurgical performance. No frother was necessary to stabilize the froth zone while hydrophobized material was used.

In conclusion, the new technology shows a feasible approach to recover fine particles. The level of hydrophobization can be controlled by detailed functionalization procedure.

16.45- Sundowner in Vineyard Gardens
18.00 Accompanying guests welcome

Tuesday November 12th

08.00 Registration desk opens. Light breakfast of filled croissants, tea, coffee and fruit juice

08.45 *Technical Session 3*
Chairmen: S. Farrokhpay (University of Lorraine, France) and C.T. O'Connor (University of Cape Town, South Africa)

08.45 **The interactions of thiol collectors with frothers on pyrite, quartz, and chalcocite**
D. Pienaar, B. McFadzean, C.T. O'Connor (University of Cape Town, South Africa) and N. Schreithofer (Aalto University, Finland)

Dithiophosphate (DTP) is classically used as a co-collector in sulphide mineral flotation, where xanthate-DTP mixtures have been shown to synergistically improve mineral flotation performance Notwithstanding the improved recoveries observed, DTP does not behave as a conventional collector, since it does not adsorb onto the mineral surface under certain conditions. A recent investigation has indicated that DTP-frother mixtures synergistically improve sulphide mineral recovery, whereas DTP-xanthate mixtures did not improve recovery under the conditions used.

Residual DTP in solution, measured by UV-vis spectrophotometry, revealed that DTP does not adsorb at the mineral-water interface, even in the presence of frother, but surface tension tests showed that DTP has weak activity at the air-water interface. Isothermal titration calorimetery (ITC) showed an exothermic energy of association between DTP and frothers, indicating that there is some interaction between these two reagents in solution. Contact time and microflotation tests indicated that DTP-frother mixtures synergistically improved attachment probability and flotation recovery. It is proposed that this synergistic effect is due to DTP and frothers interacting at the air-water interface thus enhancing the kinetics of film thinning between bubble and particle.

09.00 **Investigations on the working mechanism of the nitrile based sulfide collector Tecflote**
E. Schach, M. Rudolph (Helmholtz Institute Freiberg for Resource Technology, Germany) and A. Lewis (Nouryon Surface Chemistry, Sweden)

Tecflote is a new group of nitrile-based collectors for sulphide flotation. The fact that it is insoluble in water results in some interesting implications for its actual working mechanism. It can be assumed that the Tecflote-molecules are adsorbed in the air water interface

getting first into contact with the mineral surface during the particle bubble collision rather than being already present on the mineral surface before. Therefore, the adsorption of Tecflote and the spreading of the three-phase contact line between the mineral surface and the air bubble must be related to each other. Different investigations including contact angle measurements, AFM studies, and micro flotation experiments are conducted to obtain a better understanding of the working mechanism of Tecflote. Due to the insoluble character, Langmuir-Blodgett technique is used to investigate the behaviour of Tecflote in the air-water interface and to deposit layers of Tecflote on mineral substrates for the above-mentioned studies.

09.15 **Cationic collector conformations onto oxide mineral interface: role of pH, ionic strength and ion valence**
S.K. Solongo, A. Gomez-Flores, J. You, H. Kim (Conbuk National University, South Korea) and G.W. Heyes (CSIRO Mineral Division, Australia)

Adsorption of collectors at solid-liquid interface to impart and enhance hydrophobicity is fundamental to mineral flotation. To enhance minerals' hydrophobicity, during adsorption a collector must conform on the mineral surface with its non-polar tail facing the aqueous phase. However, this conformation is subject to conditions prevailing in aqueous phase such as pH and nature of ions present. Molecular level understanding of this phenomena is beneficial for improving hydrophobicity by adsorption layer manipulation. In this study conformational changes of cationic collector Behenyl trimethyl ammonium chloride onto silica surface have been studied using an in-situ Quartz crystal microbalance with dissipation (QCM-D). Two electrolytes; NaCl and $CaCl_2$c have been used to investigate effects of ionic strength and ion valence. QCM-D data at different pH with or without background electrolyte reveals changes in collector conformations and structure of the adsorption layer. These conformation changes have been related to imparted hydrophobicity.

09.30 **5-(butylthio)-1,3,4-thiadiazole-2-thiol used as the selective collector for improved flotation separation of galena and sphalerite from pyrite**
Wanjia Zhang, Jian Cao, Wei Sun, Yuehua Hu and Zhiyong Gao (Central South University, China)

Xanthate is the most commonly used collector in sulfide mineral flotation, but suffers from the disadvantage of low selectivity. Sulfhydryl anion within xanthate molecule non-selectively bonds with metal ions on mineral surfaces. In addition, sulfur-containing functional groups (sulfhydryl anion and thiocarbonyl) in xanthate molecule are with an inferior selectivity. Over the past decades, the challenge of improving the selectivity of xanthate molecule to against pyrite has captured the attention of reagent chemists. In this work, we developed a new collector 5-(butylthio)-1,3,4-thiadiazole-2-thiol by modifying sulfhydryl anion into thioether through forming a heterocyclic framework containing diazole fragment. As a result, an increased number of chelation site and improved chelation ability of new collector molecule lead to a better selectivity compared with xanthate. Flotation tests proved that Pb-Zn concentrates against pyrite could be collected selectively by using new collector, indicating that 5-(butylthio)-1,3,4-thiadiazole-2-thiol has a promising industrial application potential in sulfide mineral flotation.

09.45 **A study on froth flotation of sphalerite using amphiphilic cellulose and frother mixture as froth stabilization agents**
T. Nuorivaara and R. Serna-Guerrero (Aalto University, Finland)

To counteract the challenges posed by the global decline of ore grades, it is necessary to further improve the flotation process in order to secure a steady stream of raw materials in the future. As a possible solution our group studied using a mixture of a commercial frother (DowFroth200) and an amphiphilic cellulose derivative (namely, hydroxypropyl methyl cellulose) as the frother system when floating a sphalerite model ore in laboratory scale flotation experiments.

The key findings from this study shows significant advantages on the use of the cellulose-frother mixtures, producing: i) improved separation efficiency; ii) maintaining high recoveries in highly alkaline pH and iii) maintaining high recoveries when the collector dosage was reduced to 25 % of its original value. These results suggests that the mixture provides a more robust chemical system resulting in improved flotation performance on a wide scale of conditions compared to that of pure DowFroth200.

10.00 **Assessing the combined effect of water temperature and complex water matrices on xanthate adsorption on chalcopyrite and pentlandite**
N.P Mhonde, N. Schreithofer, M.Mäkela (Aalto University, Finland) and K.C. Corin (University of Cape Town, South Africa)

The combined effect of dissolved ions and water temperature on the adsorption of a xanthate collector on chalcopyrite and pentlandite was investigated. Multilinear regression was employed to determine the combined effect of the various water constituents on the extent of xanthate adsorption on mineral surfaces. Cationic species improved the adsorption of the collector on sulphide minerals through xanthate adsorption activation. Thiosulphate ions generally have a negative effect on collector adsorption and the interaction of thiosulphate ions and cations effectively reduced collector adsorption on the sulphide minerals. With regards to temperature variation caused by seasonal variation, this study suggests that temperature can influence the adsorption of collectors in the flotation process and this should be approached on a case by case basis as it seems to differ with the type of mineral under investigation. The empirical modelling approach was sensitive enough to successfully model the interactions in complex water systems.

10.15 **Floatability study of hematite, magnetite, chamosite, diopside and epidote with amine type collectors**
C.H. Veloso (Université de Lorraine and ArcelorMittal Global Research & Development, France), L. Senez, A.C. Araujo (ArcelorMittal Global Research and Development, France) and L.O. Filippov (Université de Lorraine, France)

The role of the silicate mineralogy on the choice of collectors and depressants is considered in recent literature as a key factor to enlarge the iron ore resources. The floatability of single-minerals hematite, magnetite, chamosite, diopside and epidote using dodecylamine hydrochloride (DDA) and dodecyloxypropylamine (ETA) was studied by microflotation over a range of pH from 2 to 12 and concentrations

ranging from $1x10^{-6}$ M to $5.5x10^{-4}$ M. A separation window was observed for DDA at pH value between 4-5, in which iron oxides do not float and diopside has already achieved its plateau of floatability. This result is expected due to the difference in surface charge of these minerals, but this principle was not observed for the case of chamosite that presented a poor floatability at this same pH range. ETA has a stronger collection power conferred by the ether function, which allows to achieve higher floatability for all minerals. This can solve the problem of chamosite flotation, but no separation window is observed for ETA, meaning that even the iron oxides float in presence of this collector. The results were discussed in relation with the studies of adsorption of both collectors on the surface of the five minerals.

10.30 Coffee, exhibition and poster viewing

11.15 **Potential role of colloidal silica as a calcite depressant in scheelite flotation**
N. Kupka, B. Babel and M. Rudolph (Helmholtz Institute Freiberg for Resource Technology, Germany)

The main challenge in froth flotation of scheelite lies is the contamination of the concentrate by other calcium-bearing minerals, mainly calcite. To remedy this problem, sodium silicate is a depressant frequently used in the flotation of scheelite against calcite. Several authors acidified the water glass using oxalic acid or sulfuric acid to improve its performance. One suggested mechanism for this improved depression lies in the idea that the reaction between water glass and the acid results in the production of colloidal silica which in turn preferentially absorbs onto calcite.

In this article, the authors investigate the direct use of colloidal silica in scheelite flotation to test its potential role as a depressing agent including notably single-mineral and batch flotation as well as surface interaction studies. Additionally, the formation of colloidal silica with acidified water glass is discussed using Dynamic Light Scattering.

11.30 **Computational insights into the adsorption mechanism of gallic acid/ pyrogallic acid/tannic acid on calcium-bearing mineral surfaces**
Jianyong He, Wei Sun, Shangyong Lin Yuehua Hu (Central South University, China), Chenyang Zhang, Chenhu Zhang (Central South Univerity and Hunan Research Institute for Nonferrous Metals, China) and Guoqiang Wang (Nanjing University, China)

From a novel spatial geometry aspect, the adsorption mechanism of gallic acid (GA), pyrogallic acid (pyGA) and tannic acid (TA) were investigated via using the first principles calculations and the classical molecular dynamic (MD) approaches. The obtained geometry, ionization energies of proton and molecular orbitals of GA showed that the deprotonation of GA would preferentially occur at the 1-COOH and 4-OH sites. This could be the potential site for chelation of metal ions. The DFT results further indicated that the dissociated GA/pyGA could bind with the fluorite surface more strongly than the calcite surface, in both geometry and thermodynamics aspects. However, MD results showed that TA preferred to adsorb onto the calcite surface rather than the fluorite surface. The computational results were well consistent with the experimental results. At molecular level, this work reveals the adsorption mechanism of GA , pyGA and TA on fluorite and calcite, respectively. The obtained results puts emphasis on the influence of spatial geometry of a large molecule on its flotation performance, which sheds new light on the development of novel flotation reagents via considering the influence of the spatial structure of a molecule.

11.45 **Orfom® D8 depression of chalcopyrite during trial runs of Cu-Mo bulk concentrates**
S. Timbillah, R. LaDouceur, D. Laney, A. Das, and C. A. Young (Montana Technological University, USA)

Orfom® D8 is a low carbon-chain trithiocarbonate ($(NaOOC)CH_2SCSSNa$) with anionic functional groups at both ends. It was tested as an organic depressant in the differential flotation of molybdenite from chalcopyrite in the presence of either sodium isopropyl xanthate (SIPX) or potassium ethyl xanthate (KEX). Results show that it depresses chalcopyrite while molybdenite remains floatable. Orfom® D8 appears to adsorb specifically on chalcopyrite through its trithiol (CS_3^-) functional group via both chemisorption and metal complexation. Chalcopyrite becomes hydrophilic because the carbonate (COO^-) functional group protrudes from the surface. Because Orfom® D8 does not appear to bond with molybdenite, it remains hydrophobic. Orfom® D8 solution chemistry is detailed via its pKa constants and decomposition products. Results of successful trial runs of a large pilot plant facility are illustrated along with the economics comparing Orfom® D8 to traditional inorganic NaSH depressant.

12.00 **Sulphidisation and flotation of oxidised copper sulphides**
T. Moimane, Y. Huai and Y. Peng (The University of Queensland, Australia)

Sulphidisation, a process for conversion of an oxide to a sulphide surface, offers a way to improve amenability of oxidised sulphides to the flotation separation technology. However, it has proved to suffer from drawbacks such as low efficiency, failing to restore floatability of heavily oxidised sulphides and its surface reaction products seem to be sensitive to certain pulp chemistry conditions. Holistic understanding of the process can be a stepping stone in the quest to modify it for improved efficiency. Thus the present study seeks to understand the process; the surface reactions at play and products that form on oxidised copper sulphides, and how they are affected by specific pulp chemistry conditions, by employing a combination of techniques; flotation, surface analysis and electrochemical tests. This will facilitate identification of the problems that render the sulphidisation process inefficient, which can be used as a guideline to improve flotation of oxidised copper sulphides.

12.15 **Effect of hydrogen peroxide on the separation of copper sulfide minerals and arsenic-bearing copper minerals using flotation**
G.P.W. Suyantara, T. Hirajima, H. Miki, K. Sasaki (Kyushu University, Japan), S. Kuroiwa and Y. Aoki (Sumitomo Metal Mining Co. Ltd, Japan)

Effect of oxidation treatment using hydrogen peroxide on the separation of copper sulfide minerals (i.e., chalcopyrite and bornite) and arsenic-bearing copper minerals (i.e., tennantite and enargite) was investigated in this work. Floatability of each mineral significantly decreased following the oxidation treatment. However, flotation tests using mixed mineral of chalcopyrite and arsenic-bearing copper minerals indicate that the arsenic-bearing copper minerals had a higher floatability compared to that of chalcopyrite after the oxidation treatment followed by the addition of potassium amyl xanthate (PAX). Various surface characterizations using X-ray photoelectron spectroscopy, FTIR analysis, atomic force microscopy, and contact angle measurements were performed to understand the phenomenon. Moreover, the bench scale flotation was conducted to confirm the mixed flotation phenomenon and the results suggest that the oxidation method could deliver a satisfying separation of copper sulfide minerals and arsenic-bearing copper minerals.

12.30 **Flotation behaviour of malachite from calcite and quartz with chelating collector and its adsorption mechanism**
X.R. Zhang, Y.G. Zhua, L. Han, L. Lu and C.B. Li (BGRIMM Technology Group, China)

In this paper, a chelating collector S-carboxymethyl-O,O¡¯-dibutyl dithiophosphate (CMDT) is used in the flotation of malachite from quartz and calcite. Micro-flotation results showed that CMDT exhibited stronger adsorption and better selectivity for malachite in the separation from calcite and quartz than octyl hydroxamic acid (OHA), 8-Hydroxyquinoline and butyl xanthate, and a good separation results could be achieved for artificial mixed minerals between pH 6 and pH 9. The effects of Na2S and Cu2+ ions are also investigated. Its adsorption mechanism was studied by Zeta potential, FTIR and XPS analysis. Zeta potential results illustrated that CMDT showed a better affinity to malachite than calcite and quartz. FTIR spectra told us that CMDT was easier to adsorb on malachite surfaces than on calcite and quartz surfaces. XPS gave obvious evidences that there was a reaction occurred between CMDT and Cu2+ ions on malachite surface, and there was no adsorption on calcite and quartz surfaces.

12.45 Lunch

14.00 *Technical Session 4*
Chairmen: N. Schreithofer (Aalto University, Finland) and P. Brito-Parada (Imperial College, UK)

14.00 **Fundamental and flotation techniques assessing the effect of water quality on bubble-particle attachment of chalcopyrite and galena**
L.L. October, K.C. Corin, M.S. Manono, J.G. Wiese (University of Cape Town, South Africa) and N. Schreithofer (Aalto University, Finland)

Bubble-particle attachment has been studied in the most fundamental way from as early as 1934 by bringing a bubble into contact with a flat mineral surface and since then, techniques measuring this interaction have advanced. Water quality within flotation will impact the bubble particle attachment and as more operations recycle their water on site, an understanding of this process becomes vital. This study uses an Automated Contact Time Apparatus (ACTA) to assess the effect of water quality on bubble-particle attachment of selected sulphide minerals; galena and chalcopyrite, from a fundamental perspective. Classical microflotation tests are complemented with collector adsorption and mineral potential under degrading water quality to validate the ACTA and gain an understanding on the effect of water quality on bubble-particle attachment as well as subsequent flotation.

14.15 **Effect of ion exchange in copper flotation in the presence of bentonite when using saline water**
Siyu Song, Guohua Gu and Yanhong Wang (Central South University, China)

Clay minerals have a deleterious effect on flotation. In the previous study, use of saline water had a positive impact on the flotation recovery when dealing with copper ore containing substantial amounts of bentonite. The current study of mixed pure minerals further found that different cations had different effect on bentonite viscosity due to the compressed double layer effect. Besides, the effect of ion exchange plays an important role in copper flotation in the presence of bentonite, which led to both the internal and external structure of bentonite changed. Consequently, the discrepancies between flotation recovery and viscosity measurements. This study revealed the underpinning mechanism of copper flotation in the presence of bentonite by using different cations.

14.30 **Effect of seawater on bubble interactions with chalcopyrite and molybdenite surfaces**
G.P.W. Suyantara, T. Hirajima, H. Miki, K. Sasaki (Kyushu University, Japan), S. Kuroiwa and Y. Aoki (Sumitomo Metal Mining Co., Ltd., Japan)

The effect of seawater on copper-molybdenum (Cu-Mo) flotation attracts many attentions in recent years, mainly focus on altering the depressing effect of seawater on floatability of molybdenum ore. On the other hand, the interaction between bubble and particles during flotation is one of the key factors to understand the depressing effect of seawater. Therefore, this study aims to investigate the effect of seawater on bubble-particle interactions with chalcopyrite and molybdenite surfaces. In addition, the effect of emulsified kerosene, a typical molybdenite collector, in seawater on bubble-particle interactions was investigated. This study shows that the kerosene retarded the bubble surface mobility and reduced its rise velocity in seawater. Moreover, kerosene could accelerate the formation of three-phase contact (TPC) between the bubble and both mineral surfaces at the natural pH of seawater. However, the adsorption of seawater precipitate on both mineral surfaces at pH 11 rendered the surfaces hydrophilic, preventing the formation of TPC. Flotation tests using pure and mixed minerals were then carried out to assess the floatability of chalcopyrite and molybdenite under various pH conditions and its correlation with bubble-particle interactions study. It was found that the addition of emulsified kerosene could give a narrow window for selective flotation of chalcopyrite and molybdenite in seawater at specific pH value. The possible mechanism is proposed in this study to explain this phenomenon.

14.45 **Biodepression of copper-activated pyrite with *Acidithiobacillus ferrooxidans* in seawater flotation**

F. San Martín (Universidad Técnica Federico Santa María, Chile), W. Kracht, I. Valles (Universidad Técnica Federico Santa María and Universidad de Chile) and T. Vargas (Universidad de Chile, Chile)

Bacterium *Acidithiobacillus ferrooxidans* has shown to be a good depressant of pyrite in seawater flotation. At industrial scale, it is common the activation of pyrite with copper ions from other minerals. In the present study, microflotation experiments in a Hallimond cell were conducted to evaluate the depressant effect of *A. ferrooxidans* on Cu-activated pyrite in seawater flotation. The results showed that at pH 10, the recovery of pyrite activated with 1 mM of $CuSO_4$ conditioned with collector sodium isopropyl xanthate (4.7410^{-5} M), was 90 %. When Cu-activated pyrite was previously conditioned with the bacteria and the collector was added later, the recovery dropped to 50%. At pH 8, the recovery of pyrite activated with 1 mM of $CuSO_4$ was 95 %, which dropped to 80% by pre-conditioning with *A. ferrooxidans*. The results indicate that bacterium *A. ferrooxidans* is able to depress Cu-activated pyrite in seawater flotation at pH 10 and, to a lesser extent, at pH 8.

15.00 **Investigating the effect of particle properties on iron ore flotation using X-ray Micro Tomography**
M. Safari, D. Deglon (University of Cape Town, South Africa), S. Nadimi (Newcastle University, UK), L.L Filho (University of São Paulo, Brazil) and T. Souza (Vale Institute of Technology, Brazil)

This paper investigates the effect of particle physical properties on the reverse flotation of iron ore. Flotation is affected by both physical and chemical factors. The focus of this paper is on the physical properties of particle shape and morphology. The study uses results from the flotation of Timbopeba iron ore (Brazil, Vale) in a laboratory batch mechanical flotation cell. X-ray Micro Computed Tomography (µCT) is used to characterise particles in the flotation concentrate and tailings, within 1 µm resolution. The effect of particle shape, liberation, and roughness on the recovery of coarse quartz and hematite (+150 [illegible] true fl
the effect of these particle characteristics on floatability is discussed. The study uses a relatively recent quantitative approach for particle characterisation (high resolution µCT) to evaluate flotation.

15.15 **Electrochemical detection of thiosulfate in the presence of sulfate ion using stainless steel electrode modified by gold**
Z. Ertekin, K. Pekmez, M. Can and Z. Ekmekçi (Hacettepe University, Turkey)

A highly sensitive electrochemical electrode was fabricated by plating gold on surface of a stainless steel electrode for detection and measurement of thiosulfate ion in process water. Cyclic voltammetry and differential pulse amperometry were used for the characterization of electrochemical response towards thiosulfate ion. The electrode showed linear response and excellent sensitivity with the detection limits from 50 ppm to 900 ppm for $S_2O_3^{2-}$. The optimization of medium pH for $S_2O_3^{2-}$ ion was studied and found to be suitable for flotation water measurement. Effects of SO_4^{2-} as an interference ion were investigated and found that it did not interfere with $S_2O_3^{2-}$ detection where the signal changes were below 5%. The Au modified stainless steel (316L) electrode showed high reproducibility, repeatability, and stability.

15.30 **A novel method for analysing the floatability of quartz with renewable hexyl-amine cellulose nanocrystals using an automated contact timer apparatus**
R. Hartmann and R. Serna-Guerrero (Aalto University, Finland)

The current demand on mineral resources is steadily increasing urging for efficient and, simultaneously, environmentally friendly separation techniques, of which the flotation process is most frequently used. To address both challenges, this work presents the employment of hexyl amine cellulose nanocrystals as renewable reagent for the replacement of molecular amines in the flotation of quartz as well as a novel in-house engineered automated contact timer apparatus to analyse the mineral´s floatability. The novel induction timer allows the establishment of particle-bubble attachment probability distributions as a function of the reagent concentration, attachment time and the distance between the particle bed and bubbles, of which the latter one is of specific concerns. The results show a correlation between the initiation of non-compressive particle bubble attachments measured with the induction timer and a significant increase in the floatability of quartz using a lab-scale flotation cell in the presence of a sufficient cellulose concentration.

15.45 **Hydrophobic behavior of fluorite surface at alkaline solution and the application in flotation**
Ruolin Wang, Yuehua Hu, Haisheng Han, Wei Sun, Zhao Wei, Honghu Tang, Jianjun Wang (Central South University, China), A.V Nguyen (University of Queensland, Australia) and Zhizhong Shi (Hu Nan Shizhuyuan Non-ferrous Metal Limited Liability Corporation, China)

Normally fluorite was collected by fatty acid collectors at ph 5-11, rendering the surface to be hydrophobic. In this study, we found fluorite surface was naturally hydrophobic at high pH without any surfactant, which is beneficial for the selective flotation separation of fluorite from calcite. In flotation test, the recovery of fluorite remains a decreasing trend at alkalescent pH while increasing at high pH values. The results of contact angle show the hydrophobicity obviously increase at pH 13. X-ray photoelectron spectroscopy and atomic force microscopy analyses clearly indicated that fluorite surface is eroded by hydroxide ions or affected by hydroxylation. SFG spectrum confirmed that the orientation and hydrogen bonding structure of the water molecules are dramatically changed. Moreover, a new signal peak, 3667 cm^{-1}, appeared at strongly alkaline condition, which is normally identified to be free -OH and indicated the surface to be hydrophobic. Therefore, the surface structure of fluorite must undergo some significant changes, which will play an important role in the flotation of fluorite.

16.00 Coffee

18.00 Coaches leave for conference dinner at Kirstenbosch Botanical Gardens

Wednesday November 13th

07.45 Registration desk opens. Light breakfast of filled croissants, tea, coffee and fruit juice

08.35 Welcome to Applications Symposium
J. Wills (MEI, UK)

08.45 *Technical Session 5*
Chairmen: R. Kuyvenhoven (Sustainable Minerals Institute, Chile) and Q. Dehaine (Geological Survey of Finland, Finland)

08.45 **Keynote Lecture: Canadian achievements in flotation technology: a retrospective**
J.E. Nesset (NesseTech Consulting Services Inc. and Adjunct Professor, McGill University, Canada)

More than a century after its adoption and adaptation as a major mineral separation technology within the mining industry, significant new developments in flotation continue to appear. A number of important contributions have come from Canadians and a selection of these are highlighted in this presentation. This includes the developments that led to the successful milling of the highly complex Sullivan ore by Cominco starting in the early 1920's, to column flotation developed in the 1960's, to the staged flotation reactor (SFR) technology recently introduced by Woodgrove Technologies. The development of industrially-robust sensors at McGill has permitted new insights into the process, including the key relationships between bubble size and frothers. The application of these gas dispersion tools has resulted in significant process gains and some examples are highlighted. The joint development of the continuous mini pilot plant (MPP) by Canadian laboratories and equipment suppliers is also seen as a significant contribution to flotation technology as evidenced by its adoption by testing laboratories worldwide. Although not directly a flotation technology, the development of mass balancing and data reconciliation methods and software (e.g. Bilmat), begun modestly as a joint government-industry collaboration in the early 1970's, has evolved into an essential tool for testing, production accounting and resource management at mineral processing, mining and metallurgical sites. Some comments and historical perspectives are also offered in the keynote.

09.15 **Optimising your float circuit for changing ore conditions**
S. Morgan (Outotec, Australia) and B. Kgaswane (Outotec, South Africa)

It is very common for operators to be treating ore material that is significantly different to the plant design conditions. Typical reasons could be unrepresentative feed material used for the detailed design or there could be mine life extensions resulting in new ore types being processed. Most operators will adapt their flotation plant by reviewing the circuit configuration, flotation capacity and reagent suite. However, the flotation cell components are rarely reviewed to determine whether these are still suitable for the new feed conditions. For example, customising the launder configuration will improve froth mobility whilst optimising the rotor type and speed will improve the float cell hydrodynamics. These mechanical changes may seem minor but depending on the ore type can have a significant effect on the overall plant revenue.

This paper discusses the optimisation of flotation cells at various mine sites, and presents operational data highlighting its effect on plant performance.

09.30 **Evaluation of new flotation circuits design using a novel approach**
P. Vallejos, J. Yianatos (UTFSM, Chile), R. Grau and A. Yañez (Outotec, Finland)

This paper presents a new approach for flotation circuit design which addressed the challenges for improving the cell design and operation, as well as the potential for circuit optimization in terms of selecting the best compromise of cell size and number of cells per bank. For this purpose, a flotation simulator USM-FLOTMOD, built on industrial data from modern and large mechanical flotation cells, was developed.

The flotation simulator was previously validated using data from flotation plants testing and allowed the metallurgical prediction for new circuit arrangements, considering variable mineral and cells design characteristics, number and size of cells per row, and variable operating conditions. Then, the increase in flotation circuit efficiency using more flexible and more cost-effective designs was analysed and illustrated for alternative new scenarios. In this context, a re-evaluation of the current design rules used at present for plant design and operation and the use of new circuit arrangements are presented.

09.45 **Low-temperature effects on flotation efficiency- changes in process water quality, reagent regimes and tailings management**
Y. Ghorbani, P.I. Guntoro, C. Zwahlen, J. Rosenkranz, T. Karlkvist, (Luleå University of Technology, Sweden) and N.-J. Bolin (Boliden Mineral AB, Sweden)

There are many mining activities in extreme cold climate worldwide, including mining operations in Scandinavian countries such as Northern Sweden. Though substantial mineral processing and mining activities are carried out in different climate condition, the effect of low temperature (i.e. temperatures of around 5 to 10 °C) as an important operational variable has received only limited attention. Temperature has a pronounced effect on the physical, chemical, and physico-chemical properties of a pulp. Studying the flotation

separation in cold climate is part of the work plan within the Centre for Advancer Mining and Metallurgy (CAMM) at Luleå University of Technology (LTU). This review examines the current knowledge on the effect of low temperature on flotation performance in order to identify suitable flotation reagents/reagent regimes and hydrodynamic concepts adapted to mineral processing and tailing treatment in cold climate. Furthermore, the effect of water recirculation and low temperature on the behavior and footprint of different ions and residual additives such as SO_4^{2-}, Mg^{2+}, Ca^{2+}, as well as chemical reagents during the flotation process are studied.

10.00 Coffee, exhibition and poster viewing

10.45 **The same-level arrangement technology of flotation plant: fundamentals and practice**
Ming Zhang, Liang Cao, Zhengchang Shen, Ming Tan, Yihong Yang (BGRIMM Technology Group, China) and R. Melville (Roytec, South Africa)

Stepwise arrangement of flotation cells is the most common layout for flotation circuit in mineral processing industry. In such design, slurry flows from upstream to downstream by gravity and the middling products are returned to previous stages by pumps. This presentation will introduce an alternative solution in which slurry-suction flotation cells are adopted so that all the flotation cells can be placed on a same horizontal platform and no pumps are needed for middling product transferring. The technology of slurry-suction flotation cell will be described in details including unique features, working principle and the related fundamental problems. The comparison of capital investment, operating cost and metallurgical performance will be made between the conventional stepwise arrangement and the same-level arrangement technology based on industrial practice. As a typical application, Jinchuan Nickel Mine cut the footprint of its flotation circuit by 24% and reduced the building height by 3.2 meters.

11.00 **Effect of particle size and shape in ore flotation**
R. Farinato, D.R. Nagaraj (Solvay, USA), T. Bhambhani (Solvay and Columbia University, USA) and P. Somasundaran (Columbia University, USA)

In the flotation of sulfide ores, non-sulfide gangue is purported to report to the concentrate by entrainment. While it is long known that particle size affects entrainment, plant practice suggests that certain gangue minerals (e.g. mica) entrain more than others resulting in lower concentrate grades. Given the platy shape of mica, a study of the concurrent effect of shape and size on entrainment is warranted. Flotation tests were conducted on mixtures of a copper ore and sized mica or silica. The familiar entrainment vs particle size curve was reproduced up to a certain size, with more mica being recovered than silica. Beyond this size, the curve shifts upward, suggesting more entrainment of the coarse particles, which is along the lines of what is observed in plants- the coarse mica appears to be recovered rapidly. Additional experiments were conducted to shed light on the mechanisms. Potential pathways to mitigate this effect are discussed.

11.15 **Flotation froth state classification and monitoring for industrial processes**
E.C. Nienaber, Z.C. Horn, A.L Haasbroek, L. Auret (Stone Three Digital, South Africa) and J.W.D. Groenewald (Anglo American Platinum Ltd, South Africa)

Undesired flotation froth properties and inefficient flotation operation can have many root causes. Reagent dosing, pulp levels, air flow, particle sizes, particle compositions, and mineral liberation affect the froth phase and steer the process away from a metallurgical optimum. Nonlinearity of flotation effects (and their interactions) coupled with non-observability of many flotation variables results in typical control
systems being unable to ameliorate inefficient operation. However, visual cues can be obtained from flotation froths and, in conjunction with other measured process variables, provide means with which froth phenomena can be characterized for control and monitoring.

In this study we prepare a framework for froth state classification using readily available online measurements of cell operation (pulp level, aeration rate, etc.) together with variables inferred from flotation froths e.g. froth height, bubble size, and froth velocity. The relevant flotation variables may then be used to create proxy states which broadly classify flotation/froth behavior: below-lip, collapsed, sliming, normal, overly stable, and froth high. The proposed framework is used to determine classification rules and potential corrective actions for different cells within a South African flotation plant.

11.30 **Applying digitalization and artificial intelligence concepts in minerals processing – next level towards increased productivity**
T. Bertsch (Festo AG & Co. KG, Germany)

In Minerals Processing higher accuracy and precision in slurry level control is achieved already today by applying modern automation. Results are more stable processes and increased yield in flotation cells. But digitalization and artificial intelligence (AI) tools will enable to improve the productivity even further. Productivity can be improved by various means, e.g. distributed control or new digitalized and intelligent field components, which enable autonomous control of parts of the process. Digitalization and AI installed on edge result in higher productivity and is the basis for condition monitoring, cloud services as well as the implementation of predictive maintenance concepts.

The presentation will show the features of these new technologies and discuss the impact on life cycle costs, means investment as well as operational costs, for new plants as well as for modernization projects to upgrade existing plants. The related impact on staff qualification and consulting will be presented as well.

11.45 **Rougher flotation cell pulp level control to increase recovery**
M. Ferra (REXA Inc. USA)

Flotation is used in mining to produce concentrates of copper, gold and several other valuable ores. In 2017, a copper mine near Globe, Arizona improved their rougher cells productivity using technically advanced electro-hydraulic actuators in the flotation process by enabling excellent tank pulp level process stability. The new actuators controlled the dart valve position to allow pulp to leave the cell. Tank cell pulp level can change due to feed and discharge fluctuations from neighbouring tanks. When traditional pneumatic actuators are used, they have sluggish response times and overshoot due to the inherent physical property of air being compressible. Electro-hydraulic actuators have the benefit of hydraulic stiffness to deliver accurate and repeatable (0.1%) dart valve positioning. The froth layer has more opportunity time to maximize mass transfer into the launderer. The results are an increase in copper recovery by 2-4%.

12.00 **Real-time flotation monitoring with time-gated Raman spectroscopy**
B. Heilala, M. Mikkonen and M. Tenhunen (Timegate Instruments Oy, Finland)

The beneficiation processes are lacking tools for faster, on-line analyses and process monitoring to give insight for mineralogical changes. Recent studies and industrial piloting tests have proved that time-gated Raman can be an exceptionally powerful real-time process monitoring tool. This novel technology allows mineralogical measurements from different kind of mining samples, also from ones containing water. Detecting changes in real-time in both slurries and froths open new possibilities for process optimization by turning the monitoring results into meaningful concentration and mineralogical information which enables improved process control and optimization for the mining industry. Continuous on-line and at-line time-gated Raman measurements can also be used to produce quantitative information for precise beneficiation process control, process optimization and quality control. Introduction to this novel technology and some of its practical applications are presented in this paper and in several real-world industrial case studies.

12.15 **Effects of mechanical cell height on flotation response- a pilot scale study**
L. Malm, S.C. Chelgani, A. Sand and J. Rosenkranz (Luleå University of Technology, Sweden)

The size of flotation cells has increased over the last three decades and progresses have been made to optimize the performance of existing flotation cells. There is still lack of understanding of the relationship between the cell dimensioning and flotation performance. In this study the effect of mechanical cell height on flotation efficiency is explored. Two identical pilot scale cells but with different heights (1.5 and 1 m) were used to process a copper sulfide ore. The control parameters included the impeller speed, froth height and residence time. The results indicated that the 1 m cell had higher total recovery than the 1.5 m one, while it showed a lower grade. Size by size particle assessments demonstrated the same pattern as the total recovery and grade. The most effective parameter on flotation efficiency was the froth height in the 1.5 m cell and in the 1 m cell was impeller speed.

12.30 **Is there a maximum size for an efficient flotation cell?**
S.J. Neethling and P.R. Brito-Parada (Imperial College, UK)

Flotation cells have increased in size at a near exponential rate for a number of decades, driven by a need to keep operating and capital costs down while simultaneously meeting the coupled challenges of an ever-increasing demand and falling grades. We will demonstrate that as cells get larger they become more carrying capacity constrained, which implies a transition from typical first order kinetics towards zero order behaviour. A theoretical model for this transition is developed, with the behaviour being characterised by a single dimensionless group which depends upon floatability, the concentration of floatable species, particle size, particle density and, importantly, flotation cell size. As there is a strong cell size dependency on this transition, it is virtually impossible to study at the laboratory scale. Methods for identifying problematic zero order behaviour from industrial data are therefore discussed together with some examples. The new model's ability to describe this behaviour is also demonstrated.

12.45 Lunch

14.00 *Technical Session 6*
Chairmen: Zhiyong Gao (Central South University, China) and K. Cole (University of Cape Town, South Africa)

14.00 **Developing a semi-empirical model of the HydroFloat™ Cell: part 1: a hindered settling classification model**
K. Demir, W.J. Whiten, A. Morrison, K. Runge, C. Evans (JKMRC, Australia) and J. Kohmuench (Eriez Manufacturing Company, USA)

HydroFloat™ is a fluidized-bed flotation cell, which has been demonstrated to recover significantly coarser particles than that achieved via conventional flotation. Flotation recovery of coarse particles has many benefits for the mining industry, most notably a cost benefit in terms of grinding and throughput. Currently there is no model to predict HydroFloat™ cell performance for use in simulation evaluations. A potential modelling approach being developed in this study which treats the HydroFloat™ cell as a hindered settling classifier and incorporates a flotation parameter, which changes particle buoyancy. MATLAB code has been written which partitions the cell into different zones and predicts mass flow based on settling equations. Laboratory-scale experimental testing has been conducted using particles of different density, size and shape to test the assumptions associated with this approach. In this paper, which will be the first in a series outlining the development of this HydroFloat™ modelling approach, the settling classification model will be discussed and validation data presented.

14.15 **The hydrodynamics of a fluidised bed flotation device using positron emission particle tracking**
A.J. Morrison (University of Queensland, Australia), M. van Heerden (University of Cape Town, South Africa) and J. Sweet (Anglo American plc, South Africa)

Novel flotation devices such as the Eriez HydroFloat™ achieve improved coarse particle recovery through a fluidised bed region that acts as a barrier to sparger-induced turbulence in the upper part of the cell. While gas- or liquid-fluidised beds are well represented in the literature, flotation devices such as the HydroFloat™ are fluidised with a mixture of both gas and liquid, complicating the momentum transfer in their beds. In order to predict the performance of fluidised bed flotation devices in response to control variables such as air, water and feed flow rates, it is necessary to understand the hydrodynamic response of the fluidised bed to these variables. For this work, positron emission particle tracking (PEPT) was used to compare the behaviour of solid particles inside an aerated and non-aerated laboratory-scale fluidised bed flotation device under a range of different operating conditions.

14.30 **Froth recovery in a two-product flotation device**
G.J Jameson and C. Emer (University of Newcastle, Australia)

The phenomenon of drop back has been proposed to explain why the discharge of hydrophobic particles in the froth from a flotation cell is less than expected. It is assumed that some particles detach from bubbles in the froth and drop back into the flotation cell. In this paper, an alternative explanation is presented, in which particles don't necessarily drop out of the froth. Instead, they never enter the froth in the first place.

Experiments will be described, in which coarse coal particles 0 to 2000 µm in diameter were floated in a continuously operated fluidised bed froth flotation cell. Bubble clusters were observed, some of which rose into the froth layer, others forming a thick layer beneath the froth. The cluster layer was withdrawn and separated on a sieve bend with a passing size of 500 µm. The fraction of >500 µm particles in the froth discharge was 40%, so clearly the froth was able to transport the coarse particles as product in the overflow launder. The froth carried approximately 60% of the total product, the remainder being extracted as coarse particles on the sieve bend.

A theory to predict critical conditions for a loaded bubble to pass into the froth will be presented. A video clip of the phenomenon will be shown.

14.45 **The impact of a hydrodynamic cavitation device on the flotation of PGM fines**
V. Ross (Mintek, South Africa) and A. Singh (GoldOre Pty Ltd, South Africa)

The use of hydrodynamic cavitation devices (HCDs) to improve the recovery of valuable mineral from fine and oxidised feed material has been clearly demonstrated by research studies and plant application. In these reactors, the nucleation of ultrafine (nano) bubbles on the surfaces of fine valuable particles during contacting in a venturi aids their agglomeration and subsequent recovery by micro- and macro-bubbles during flotation. This, together with enhanced cleaning of particle surfaces, leads to increased kinetics and concentrate grades.

This paper details further investigations on the Mach HCD, using a UG2 PGM ROM feed from the Bushveld Complex. Fractional analysis showed that increases in recovery and grade compared to the baseline were obtained in the -20 um fraction, supporting the current theory. The changed hydrodynamic conditions also reduced mass pull and entrainment, and resulted in an increased selectivity between PGMs and chromite.

15.00 **Mineral separation at high throughput using a new Reflux Flotation Cell pilot skid**
J.E. Dickinson, K. Galvin (University of Newcastle, Australia), B. Dabrowski, L. Christodoulou and D. Lelinski (FLSmidth, USA)

The Reflux Flotation Cell (RFC) decouples the relationship between water recovery and gas flux, addressing the need for improvement in feed throughput, recovery, and product grade. The "segregation" between the particle-laden bubbles and the downwards tailings flow is strengthened using a system of parallel inclined channels positioned below an inverted fluidized bed of bubbles. Through collaboration between the University of Newcastle and FLSmidth, a portable skid consisting of two RFC units supported by a program logic controller, was established for piloting site trials for the very first time. Feed volume fluxes of 1-4 cm/s were examined, and inverted fluidization water used to achieve effective counter-current washing and gangue rejection down through the concentrated bed of particle-laden bubbles. Site trials, commenced at a North American copper mine, have delivered first stage recoveries of 87% ± 5% of the "recoverable" particles using cell retention times of only 20 to 60 seconds.

15.15 Coffee

16.00 **Performance of 630m^3 TankCell® at Buenavista del Cobre Cu-Mo concentrator**
J. Suhonen, R. Grau, A. Yañez, T. Miettinen (Outotec, Finland), A. Tapia (Buenavista del Cobre, Grupo México, Mexico) and T. Mattsson (Outotec, Canada)

The first two Outotec e630 TankCells®, with 630 m³ of effective flotation volume were commissioned at Buenavista del Cobre (BVC) Cu-Mo concentrator plant in Northern Mexico as the first cells in two existing rougher lines. Commissioning was finished in March 2018. Since start-up, the plant has reported increased copper recoveries while maintaining the final grade.

The two cells have been in continuous operation for more than one year and have been providing excellent metallurgical results at low energy consumption. After the start-up, the gas dispersion abilities of both cells considering superficial gas velocities and bubble sizes were measured in parallel with continuous metallurgical sampling. This paper provides a review of the cell operation at BVC. Furthermore, the gas dispersion results are compared to values obtained from flotation cells of different sizes.

16.15 **Hydrodynamic and metallurgical evaluation of the 680m^3 flotation cell in industrial application**

Yihong Yang, Dengfeng Han, Zhengchang Shen and Shuaixing Shi (BGRIMM Technology Group, China)

Flotation machines are getting bigger and more efficient. The KYF-680 Machine, a new generation forced-air flotation cell, has been developed by BGRIMM in the recent years and the capacity of 680m^3 makes it the largest cell in the world in the present. The first unit has been installed, tested and is currently operating at the DeXing Copper Mine in China to reprocess the tailing. The global recovery rate of the flotation plant has been increased by 1.48 percent. The rotor of the machine is characterized by inclined blades and high specific speed, which increases pumping capacity while reduces energy consumption. Rotor-stator assembly was elevated to the tank's waist level to optimize the large-scale flow pattern and hence improve coarse particle recovery. The design principles and hydrodynamic characteristics will be presented with the emphasis on flow control technology and the effects on the metallurgical performance.

16.30 **Development and evaluation of the FLSmidth newWEMCO™ flotation mechanism**
M. Walker, B. Sadler, J. Downey L.F. Echeverri, I. Coltrin, L. Christodoulou, D. Stevens and D. Lelinski (FLSmidth, USA)

FLSmidth introduces the patented newWEMCO™ flotation mechanism, the newest philosophy for flotation technology designed to retrofit into existing WEMCO® flotation machines.

The hydrodynamic and metallurgical responses of the newWEMCO™ mechanism were evaluated in the laboratory and a pilot plant. It is designed to be retrofitted into 250m^3 and 300m^3 machine sizes. The newWEMCO™ technology has shown superior metallurgical performance as well as a significant increase in energy efficiency at all stages of testing. The increased performance of the newWEMCO™ design is due to a change in the rotor profile and a complimentary profile for the disperser.

16.45- Sundowner in exhibition area
18.00 Accompanying guests welcome

Thursday November 14th

08.15 Registration desk opens. Light breakfast of filled croissants, tea, coffee and fruit juice

09.00 *Technical Session 7*
Chairmen: J. Yianatos (UTFSM, Chile) and P. Amelunxen (Hudbay Minerals, Canada)

09.00 C**ontact-demonstrated improvements in gold and base metal flotation performance using a Jameson Cell**
V. Lawson and A. Price (Glencore Technology, Australia)

While the Jameson Cell technology has been around for 30 years, it has been applied mainly to coal or base metals. Glencore Technology ("GT") has now accumulated significant plant data over the years, including now published gold recovery results, which have shown that the Jameson Cell can achieve up to 15%-20% improvement in fine gold recovery over conventional circuits. The Jameson Cell, with its high contact efficiency, enables excellent bubble-particle contact for fine free particles and has demonstrated its exceptional ability to float liberated particles. Jameson Cells at the head of roughing and cleaning circuits allow you to recover the fine gold lost due to the inability of other flotation technologies to recover this difficult fine fraction.

09.15 **Industrial application of the high-intensity StackCell flotation technology**
J.N. Kohmuench, H. Thanasekaran, N-S. Yap and A. Weber (Eriez, USA)

To improve plant efficiency, the traditional approach in mineral processing has been to exploit economies of scale and to build increasingly larger unit operations. In flotation, this has been evident by the design and installation the large tank-style conventional cells that can exceed 600 cubic meters in volume. Unfortunately, this approach is flawed in that there is a significant reduction in energy efficiency as the conventional tank designs become larger. While some equipment suppliers have tried to circumvent these inefficiencies with improved rotor designs, others have utilized an altogether different approach to meet the industry requirements while delivering on better performance and a much higher energy efficiency. This approach utilizes a separate, high-energy bubble-particle contacting zone coupled with a larger chamber for froth/pulp phase separation. This staged method ensures that the energy is focused only on contacting and not wasted on pumping or creating turbulence need for suspending particles. This technology was recently tested and successfully installed at two plants in Australia with positive results. Pilot and full-scale data show that the focused energy greatly improves the kinetics of the separation. An overview of the technology is provided along with data and results from these applications.

09.30 **Improved PGM flotation in a pneumo-mechanical cell**
V. Ross (Mintek, South Africa)

The processing of the UG2 reef in the Bushveld Complex in South Africa presents some specific challenges, in limiting the levels of chromite in flotation concentrates to enhance smelter operation, and to improve the recovery of ultrafine (typically <10 micron) liberated PGMs. Conventional ways of suppressing the chromite such as by means of froth washing are not effective, the industry being dominated by mechanical cells.

This paper describes the results of laboratory tests on a run-of-mine UG2 ore, in which the performance of a novel, pneumo-mechanical flotation cell was assessed against that of conventional mechanical laboratory flotation cells operated under equivalent conditions. The results not only indicated an improved PGM kinetics and recovery, but also a reduced mass pull compared to the mechanical cells of more

than 40%, thus doubling the concentrate grade. This was accompanied by a significant improvement in the selectivity between PGMs and chromite.

09.45 **Froth stability and flotation performance: the effect of impeller design modifications**
D. Mesa and P. Brito-Parada (Imperial College, UK)

Turbulence in mechanical flotation cells, achieved via an impeller, plays a key role in keeping particles in suspension, dispersing air bubbles and promoting particle-bubble collision. However, the turbulent regime can also affect the pulp-froth interface, destabilising the lower regions of the froth and affecting the overall flotation performance. Yet, the effects that pulp zone design modifications have on the froth are poorly understood.

In this work, we study the impact of impeller design modifications on the performance of a large laboratory-scale flotation tank. To this end, two different impeller designs, with and without a stator, were assessed under a range of operating conditions (air flowrate, impeller speed and froth depth) to determine changes in pulp and froth variables. The results show that the use of a stator significantly improves froth stability and flotation performance. The findings are discussed with a focus on linking pulp and froth zone phenomena.

10.00 **Investigating the effect of physical parameters on iron ore flotation in mechanical flotation cells**
M. Safari, D. Deglon (University of Cape Town, South Africa), F.S. Hoseinian (University of Technology, Iran), L.L. Filho (University of São Paulo and Institute of Technology Vale, Brazil) and T. Souza (Institute of Technology Vale, Brazil)

This paper investigates the effect of physical parameters on the reverse flotation of hematite in mechanical flotation cells. Physical parameters include froth height, impeller speed, superficial gas velocity and solids concentration. The study uses results from the flotation of Timbopeba iron ore (Brazil, Vale) in a laboratory batch flotation cell and associated results from industrial mechanical flotation cells. The study investigates the effect of physical parameters on the flotation of quartz and entrainment of hematite over a broad range of particle sizes. Results show that froth height, impeller speed, superficial gas velocity and solids percentage have a significant effect on both flotation and entrainment. Results also show that hematite losses are due to a combination of fine hematite entrainment and coarse hematite flotation i.e. the presence of floatable hematite.

10.15 **Selective recovery of copper and zinc sulphides in the presence of pyrrhotite and hard process water**
D. Aguilar (CIDT Peñoles, Mexico), J.J. Frausto (Metso Minerals, Canada), L. Méndez (Minera Sabinas, Mexico), D. Castruita and J. Arguijo (CIDT Peñoles, Mexico)

Water is of prime importance to the mining industry; therefore, the recycling of the process water is a good practice in mine sites to minimise the use of fresh water. Sometimes this affects the recovery of valuable minerals since the recycled water contains reagents remnants and undesired ions. Additionally, if the water has hard water type properties and a problematic mineral specie is present, i.e. pyrrhotite, the selective separation of the valuable minerals from the gangue becomes challenging. This paper presents the results of a laboratory scale flotation program focussed on developing a reagent scheme to selectively recover copper and zinc sulphides in the presence of pyrrhotite when using hard water. The process water was identified as a source of calcium and sulphate ions. A reagent scheme was developed to improve the selectivity of the valuable minerals with respect to pyrrhotite while treating the process water at the same time.

10.30 Coffee

11.15 **The impact of grinding chemistry on sulphide and oxide copper mineral flotation at Lubumbe Mine, Zambia**
A. Mhone (ZCCM Investments Holdings Plc, Zambia), C.J Greet (Magotteaux Australia Pty Ltd, Australia) and A. Bauristhene (Magotteaux (Pty) Ltd, South Africa

The conversion of a concentrator from one grinding media type to another is a major undertaking in terms of both financial and technical risk. So, a strategy of completing sufficient laboratory and field tests to mitigate this risk, and give the operation confidence that advancing to plant trial will give a high probability for success.

The objectives of this paper are two fold: to provide the reader with a strategy for mitigating risk prior to undertaking a plant trial; and to provide a statistical basis for analysing plant trial data. That is, when employing an electrochemically inert grinding media in the primary grinding circuit it is possible to change the surface chemistry of the system leading to a reduction in reagent consumption and an improve the metallurgical response of the ore.

This paper tracks the change in grinding media consumption, reagent consumption and copper recovery as the plant converted from forged steel to high chrome media. These changes are correlated to the shift in pulp chemistry.

11.30 **The reduction the negative effects of aluminosilicate minerals on copper and gold flotation by a new process route**
W.J. Rodrigues, W. Silva, V. Rhodes, P. Gonzaga, L. Mahlangu and S. Engelbrecht (Clariant Southern Africa (Pty) Ltd, South Africa)

The presence of aluminosilicates has a deleterious effect on mineral processing operations such as grinding, flotation, dewatering and tailings due to these silicates influence slurry rheology, adhesion to surface of mineral particles and reagent consumption. In this current study, the objective was to identify mechanisms that improve the flotation performance of sulphide minerals. The flotation response of gold-bearing pyrite and arsenopyrite and chalcopyrite with a high aluminosilicate content was investigated. Solely traditional sulphide collectors have not
been achieving a satisfactory metallurgical recovery. Hence a new range of reagents has been developed by Clariant. These reagents have presented ability to improve the copper and gold recoveries and concentrate grade of sulfide ores with high aluminosilicate content issues.

Addition of Clariant products to the flotation of ore with high silicate content achieved the gold recovery of 80%, while xanthate and dithiophosphate did not exceeded 40% of metallurgical recovery. Furthermore, the copper recovery from ore with silicate gangue issues reached 93% through Clariant collector dosage. These results support the efficacy of Clariant products to improve the copper and gold recovery even though the high aluminosilicate content.

11.45 **A comparison of native starch, oxidized starch and CMC as copper-activated pyrite depressants**
B. Fletcher, W. Chimonyo and Y. Peng (The University of Queensland, Australia)

The separation of pyritic gangue from chalcopyrite during copper flotation can be made more efficient by using depressants such as starch and carboxymethyl cellulose (CMC). The non-toxicity of these naturally sourced biopolymers makes them attractive reagents for improving the sustainability of mineral processing operations. Generally, starch is less expensive, but CMC is often more effective. The choice of what to use in a particular flotation system depends on the operational and economic benefits each can offer. In this study, the performance of a CMC, native wheat starch and an oxidized version of the wheat starch are compared in batch flotation of pyrite (copper activated) and chalcopyrite. These results are explained in terms of mineral surface/polymer interactions using adsorption isotherm and X-ray photoelectron spectroscopy (XPS) data. The influences of polymer properties such as intrinsic viscosity, molecular weight distribution, chain conformation and functional group type and degree substitution are also incorporated.

12.00 **Challenges and opportunities for cobalt recovery at copper plants**
R. Kuyvenhoven (Sustainable Minerals Institute, Chile) and B. Townley (Universidad de Chile, Chile)

Recent developments in electromobility are increasing the demand for raw materials such as cobalt, graphite and lithium. The Chilean mining industry, that historically focussed on copper only, is responding to this change-of-scenario with an increased interest in recovering cobalt as by-product in the copper production process. Cobalt can be found in Iron Oxide Copper Gold (IOCG) type ores at fairly low grades, between 50-500 ppm approximately. In most cases, cobalt is present as solid solution within the crystalline structure of pyrite or chalcopyrite. Hence, concentration of the pyrite fraction, that typically reports to the tailings of the cleaner-scavenger stage in the copper flotation circuit, offers an opportunity for recovery of cobalt at relatively low cost, as the only process requirement is to add a pyrite specific flotation stage at neutral pH to produce a relatively cobalt-rich pyrite concentrate.

In addition to the potential economic benefit of recovering cobalt, the production of a pyrite concentrate decreases the environmental burden of the tailings by significantly reducing its potential to generate acid. One of the main issues that mining companies search to confirm upfront, is which cobalt grade the copper ore and/or pyrite concentrate should have, in order to assure economic feasibility of cobalt recovery. More specifically, the challenge that arises is to characterise the cobalt species from a mineralogical point of view and the cobalt distribution between pyrite and chalcopyrite, so that the likely cobalt grade and recovery of the final pyrite concentrate can be calculated correctly without overestimating the cobalt potential.

12.15 **Processing of a complex carbonated-rich Cu-Co mixed ore via reverse flotation**
Q. Dehaine (Camborne School of Mines, UK and Geological Survey of Finland, Finland), L.O. Filippov, I.V. Filippova (Université de Lorraine, France) and H.J. Glass (Camborne School of Mines, UK)

Over one half of current global cobalt production arrive from Cu-Co sediment hosed deposits of the Democratic Republic of Congo (DRC). These deposits are usually composed of the supergene oxide ore blanket grading into a sulphide ore at depth. The transition between the two ore types usually host both Cu-Co oxides and sulphides mineralisation which are extremely difficult to recover through conventional flotation processes. Such ores can be even more complex to process as carbonate minerals such as dolomite and magnesite may represent a significant proportion of the gangue. This study investigates the flotation behaviour of such a complex carbonate-rich mixed oxide-sulphide ore where copper is hosted in sulphides (bornite, chalcopyrite, chalcocite) and oxides (malachite, chrysocolla) while cobalt is hosted in oxides (heterogenite, kolwezite and Cu-asbolane) and one sulphide (carrollite). A two-step flotation process including a sulphide flotation stage at neutral pH and a carbonate flotation stage at acid-pH allowed to increase the copper and cobalt recovery to 80%. The obtained Cu and Co product are carbonate-poor and may economically be processed through an acid leaching route.

12.30 **Analysis of the rougher-scavenger bank using Tecflote™ S11 at Boliden Aitik, Sweden**
A. Lewis, M. Svensson (Nouryon, Sweden), N.-J. Bolin, L. Malm (Boliden Mines, Sweden) and O. Lima (Nouryon, Brazil)

Tecflote S11 is a patented sulfide collector used in a plant trial at the Boliden Aitik copper concentrator, north Sweden. The insolubility of the collector results in a mechanism for collector particle attachment to be significantly different to that of conventional thiol collectors requiring major changes to how the plant was operated but not changes in plant equipment. The strong rejection of pyrite and silicate gangue and resulting increase in copper grade in the rougher resulted in a reduction in mass pull from the bank and an increase load to the rougher-scavengers of copper-pyrite composites. These composites were recovered using PAX as a scavenger collector. TOF-SIMS data showed that the Tecflote was selective to the chalcopyrite mineral; sieve analysis and MLA data showed that Tecflote is better than PAX for floating the fine particles, which were originally reporting to final tails.

12.45 Lunch

14.00 *Technical Session 8*
Chairmen: J. Finch (McGill University, Canada) and V. Ross (Mintek, South Africa)

14.00 **Investigation of the impacts of various aspects of water quality on performance at Sentinel in the improvement process of its water management system**
I. Muzinda and N. Schreithofer (Aalto University, Finland)

The Sentinel copper mine owned by First Quantum and located in the North West province of Zambia was commissioned in 2014 and achieved commercial production in 2016. In order to understand the impact of water quality on process plant performance, a structured protocol was employed with results being considered in further development of the water management system. This paper outlines the protocol followed to evaluate this with specific emphasis on the impact of water quality on performance from comminution to flotation.

The importance of knowing these aspects during the design stage will be emphasised, firstly to avoid losses in performance that are realised during the commissioning and early production years of a project and secondly to allow for the incorporation of specific design aspects addressing water quality from the onset. This knowledge can thereby save operations from costly retrofits or modifications in response to performance drops or environmental breaches.

14.15 **Impact of aqueous species and fine colloidal matter in process water on flotation performance at Rio Tinto Kennecott's Copperton Concentrator**

T. Bhambhani, G. Castillo, D.R.Nagaraj, R.S. Farinato (Solvay Mining Solutions, USA), J. Moyo and C.McClung (Rio Tinto Kennecott, USA)

The Rio Tinto Kennecott Cu-Mo-Au-Ag operation has pockets of skarn ores, which have been treated periodically. Processing of this ore type typically results in lower Cu and Mo recoveries as well as plant upsets, both when the ore is treated by itself or in conjunction with the non-skarn ores. Mineralogical studies of these skarn ores suggest higher concentrations of deleterious gangue with no significant difference in the valuable mineral composition (mostly chalcopyrite) or the degree of liberation of the value minerals. The gangue mineral composition led to the hypothesis that aqueous species in process water emanating from non-sulfide gangue are responsible for the poor recoveries. The present investigations using flotation tests, spiking experiments, and water chemistry studies indicate that the changes in water quality are attributed to both fine colloidal matter, as well as soluble mineral species, resulting in poor flotation performance. Restoration of flotation performance with modifiers is also discussed.

14.30 **Pyrite flotation: is it stockpile oxidation or oxidation of fresh particle surfaces during plant processing that has a greater impact?**

S. Xu, W. Skinner (University of South Australia, Australia), M. Zanin (University of South Australia and MZ Minerals, Australia) and S. Brito e Abreu (JKMRC, Australia)

Many flotation plants are facing a challenge when processing stockpiled sulfide ores due to heavily oxidised surfaces of the ores. Although these oxidised sulfide ores will be crushed and ground before flotation processes and fresh particle surfaces are generated, stockpiled sulfide ores still exhibit low flotation response. This paper investigates the effect of simulated stockpile oxidation and oxidation of fresh particle surfaces during grinding on the floatability of pure pyrite particles using ToF-SIMS, XPS and EDTA extraction techniques. The grinding experiments were performed in a Magotteaux Mill® system which allows the control and monitoring of the grinding chemistry. Hydrophobicity (contact angle distribution) changes of the pyrite particles during and after grinding were determined by ToF-SIMS. This work highlights the importance of the concept–contact angle distribution (rather than average contact angle) of particles in flotation studies. This work also demonstrates the important links between comminution chemistry and flotation.

14.45 **Impact of flotation hydrodynamic factors on the recovery of silver and lead at Minera Fresnillo**

J.J. Anes (Flottec LLC, Canada), J.O. Godínez, M.L. Franco (Flottec México, Mexico) and A. Tolentino (Minera Fresnillo, Mexico)

The application of flotation hydrodynamics to plants began more than 20 years ago, however there are few applications using this technology to control their performance. This study describes the initial phase of a project aimed at developing a practical application of hydrodynamic concepts to control metallurgical performance in a plant. This research was executed by Flottec Mexico at Minera Fresnillo, one of the largest silver producers in the world. Reagent types and dosages were held constant during this study as its focus was to link gas hold up (Eg), gas superficial velocity (Jg), froth level and frother dosage (ppm) to Pb and Ag recoveries in the first cell of the lead rougher circuit. Principles of experimental design (DOE) and Six Sigma were utilized in the testing and data analysis. This phase of work resulted in the formulation of a control algorithm for optimizing rougher metal recovery and concentrate grade.

15.00 **Intensification of the flotation separation of potash ore using ultrasound treatment**

L.O. Filippov, I.V. Filippov (Université de Lorraine, France and National University of Science and Technology, Russia), T.P. Lyubimova (Institute of Continuous Media Mechanics and Perm State University, Russia) and O.O. Fattalov (Perm State University, Russia)

The effect of sonication on the selective flotation and separation contrast between sylvite KCl and halite NaCl in saturated salt solutions was investigated. The flotation experiments were performed on the potash ore samples from Verkhnekamskoye deposit (Russia) using the primary amine as collector. Different particle size (0.5-1mm, 0.25-0.5 mm, 0.1-0.25 mm) with similar contents of the main components K (26-29%) and Na (16.5-18%) and the same mineralogical composition were studied.

The pulp treatment was performed with an ultrasonic generator at power ranges varying from 10 to 75 W. The maximum recovery of sylvite was obtained for the size fraction of 0.25–0.5 mm (93.99%) while the sylvite recovery was low from the coarse-grained fraction (0.5–1 mm). The lowest flotation selectivity was observed for the fine-grained ore sample (0.1–0.25 mm). The combined ultrasonic treatment of this sample during conditioning and flotation reduced the recovery of NaCl in the potash concentrate almost two times (from 17.9%. to 9.9%) and increased the KCl recovery from 89.9% to 95.9%. The enhanced flotation selectivity between KCl and NaCl under sonication was attributed to the increased detachment of weak hydrophobic NaCl particles from air bubbles according to particle size and mode of treatment. Thus, a balance has been established between the particles size, the collector consumption, the power of the ultrasound treatment and the way of sonication (during the conditioning with reagents or/and flotation) to optimize the separation contrast between NaCl and KCl.

15.15 Coffee

15.45 **Flotation of spheroidized graphite from spent lithium ion batteries**
A. Vanderbruggen and M. Rudolph (Helmholtz-Institute Freiberg for Resource Technology, Germany)

Recycling of lithium ion battery (LiB) has attracted a lot of attention and is particularly focusing on the valuable metals such as cobalt, nickel and lithium. Despite the growth in graphite consumption and the fact that it is counted as a critical material, there is little previous work focusing on graphite recycling. This original research presents a graphite recycling approach using flotation. This process is able to separate battery electrode materials while preserving their functional integrity in order to reintegrate them in the value chain of LiB production. Two valuable products, one of graphite and one with the valuable metals are recovered using a batch mechanically agitated Outotec flotation cell. Batch flotation study shows that pre-treatment, especially the intensive mechanical pre-treatment improves the process. The graphite recovery is +98 % with a grade of 85 wt. %. This research aims to reach closed-loop system for spheroidized graphite from spent LiB.

16.00 **Novel flotation reagents for the beneficiation of spodumene**
D. Chipfunhu (BASF, Australia), A. Michailovski (BASF SE, Germany) and S. Dickie (BASF, New Zealand)

Lithium demand for battery manufacturing has exploded in the recent past due to increased battery energy storage demand. Spodumene is the main hard rock lithium bearing mineral. Gravity concentration and flotation are the main methods of concentrating spodumene to a grade suitable for producing lithium hydroxide or carbonate. Flotation is mainly carried out using fatty acids as collector. Fatty acid has slow adsorption kinetics onto spodumene requiring very long conditioning times, is relatively unselective and requires very large dosages. BASF Mining Solutions has developed a novel collector for spodumene flotation that is very selective against iron, silica and alumina-based minerals. The new collector achieved rougher lithia grade of 5.2% compared to 3.7% for fatty acid in laboratory flotation testing. When tested with pulp from a working plant where proper slimes removal and magnetic separation were conducted, the rougher concentrate BASF collector was 6.5% lithia compared to 5.2% for fatty acid. The overall lithia recovery was similar.

16.15 **Recovery of apatite from mine tailings by froth flotation**
R. Jolsterå, E. Niva, E. Öberg, E. Widetun, K. Taavoniku and V. Töyrä (Loussavaara-Kiirunavaara AB, Sweden)

At LKAB's two main mine sites in northern Sweden, apatite-magnetite ores are mined and beneficiated, where the main product being iron ore pellets. In the current situation, the apatite reports to the tailings pond together with the rest of the gangue minerals. The phosphorus grade in the tailings varies typically between 4.1 to 5.7 % P_2O_5. As a part of a larger initiative that focus on recovering valuable materials from tailing streams LKAB now investigates the possibility of recovering the apatite from the mine tailings by froth flotation.

The apatite is mainly of fluorapatite type, however, apatite from one site has an elevated amount of chlorapatite present. The scope of this work is to investigate how changes in pulp chemistry and flotation circuit design can minimize impurities such as calcium containing carbonates and amphiboles in the final apatite concentrate. Different fatty acid collectors have been tested in laboratory scale and several different flotation circuits have been tested and evaluated in pilot scale.

16.30 **Parisite flotation from carbonatite REE-ore**
R.G. Merker (Merker Mineral Processing, Germany), T. Heinig, A. Balinski, R. Möckel (Helmholtz Institute Freiberg, Germany) and P. Quang Van (Hanoi University of Mining and Geology, Vietnam)

Rare earth bearing fluoro carbonates (REFK) are one of the most important sources of rare earth elements (REE) globally, with bastnaesite being the most studied mineral of this group in terms of flotation. However, in contrast, the REFK mineral parisite has very little reference in the literature with respect to its flotation behavior.

A carbonatite REFK ore comprised of mainly parisite and associated Ba-Sr-minerals from Vietnam was investigated by Helmholtz institute Freiberg Germany (HIF). The Authors present information herein regarding this deposit material used and the beneficiation test program undertaken, as well as propose a multi-stage flotation technique comprising the following process steps:

Crushing and sensor-based pre-sorting,
Milling and sizing,
Conditioning and cold rougher REE-flotation,
Re-grind and hot cleaner flotation.

With preliminary bench-scale flotation tests, parisite mineral concentrates of more than 40 % REO could be produced at a high recovery. Additional investigation results are presented with respect to:

Differing flotation response of the REFK,
Leaching of gangue carbonates to enrich REFK.

The work represents a significant advancement in the field, as it is the first time that floatability differences between individual REFK could be proven and numbered by automated mineralogy.

16.45 Conference summary
J.A. Finch (McGill University, Canada)

17.00 Closing Remarks and Invitation to Flotation ’21. Presentation of Glencore and Magotteaux Prizes
A.J. Wills (MEI, UK)

17.10 Farewell wine function, Vineyard Gardens
Accompanying guests welcome

POSTERS

Fundamentals Symposium
Displayed November 11th-12th

The behaviour of surfactant- and solid-stabilized emulsions for mineral flotation- a critical review
Liang Cao, Xumeng Chen and Yongjun Peng (The University of Queensland, Australia)

In mineral flotation, oily collectors are often used to enhance the surface hydrophobicity of minerals. However, oily collectors are insoluble and difficult adsorbing on minerals and therefore the emulsification of oily collectors in flotation is important. In emulsion, the interfacial properties between oil and water can be modified by the adsorption of surfactants, solid and electrolytes. In flotation, the emulsification of oily collectors can potentially be affected by the presence of frothers, minerals particles and electrolytes. Therefore, this paper is to provide a thorough review on the behaviour of surfactant-stabilized and solid-stabilized emulsions in flotation. Firstly, this paper presents a brief review on the mechanisms of emulsification, related to steric repulsion, electrostatic forces and thin film stabilization, determining the formation and stability of emulsions. Then, this paper reviews the bulk and interfacial properties of surfactant-stabilized and solid-stabilized emulsions. The last section reviews the effect of electrolytes on the emulsions.

Effects of froth properties on dewatering of flotation products
Na Zhang, Xumeng Chen and Yongjun Peng (The University of Queensland, Australia)

The presence of stable froth in flotation product has a detrimental effect on the downstream dewatering process, which is a challenge in processing plants of many commodities, such as coal, copper and phosphate. The stable froth is not only related to the properties of mineral particles but can also be affected by water salinity and the presence of clay minerals. In this article, the effects of stable froth on the dewatering of flotation products were presented. It starts with a brief review of the dewatering of flotation products, followed by our recent research on the froth properties including froth structure, stability and rheology, and then the effects of stable froth on both thickening and filtration of flotation products. Furthermore, future directions to increase the dewatering efficiency of flotation products are recommended.

The critical degree of bornite surface oxidation in flotation
T. Moimane, Y. Huai and Y. Peng (The University of Queensland, Australia)

Surface oxidation of copper sulphides is well-documented in literature and it is well known that its effect on flotation can be either beneficial or detrimental. ‘Mild oxidation’ is known to enhance mineral floatability while the net effect of ‘significant oxidation’ is mineral depression. However, how much is ‘mild’ or ‘significant’ oxidation in quantitative terms? Thus it is crucial to quantitatively define oxidation degree and relate it to flotation performance. Surface characterisation of a series of oxidised bornite was carried out using XPS. The degree of oxidation was quantified as the ratio of hydrophilic and hydrophobic surface species and correlated with flotation recovery. A quantitative relationship between bornite oxidation and flotation was established and a critical oxidation degree, beyond which bornite flotation becomes impossible, was identified. A comparative case between bornite, chalcocite and chalcopyrite is also presented. This work will provide insights on how to better handle ores of various oxidation degrees and susceptibilities.

Starch chemical modification in selectively depressing graphite in flotation
W. Chimonyo, B. Fletcher and Y. Peng (University of Queensland, Australia)

Low and uneconomic quantities of graphite associated with valuable copper sulphides pose significant flotation separation problems in the minerals industry. This is attributable to intrinsic hydrophobicity of these minerals which enables easy flotation of graphitic gangue simultaneously with valuable copper sulphides. As widely reported, environmentally benign, cheap and ubiquitous natural polymers such as starch can be used to depress graphite during flotation. However, starch consists of diverse multilevel structural features and poly-hydroxyl functionality which makes it less specific to achieve selective depression. As a result continuous research is eminent to utilize starch’s chemical versatility and modify it to eliminate deficiencies which lower its depressive capacity. A better understanding of the influence of altered functional characteristics and molecular structures on adsorption capacity, morphology and depression mechanisms will lead to

identification of further opportunities for innovative development of more specific starch derivatives. This paper reviews the current fundamental knowledge on starch chemical modification with a view to improve selective depression of graphite.

Lead adsorption on copper sulphides and the relevance to its contamination in copper concentrates

T. Hamilton and Y. Peng (University of Queensland, Australia)

Certain complex copper sulphide ores contain trace levels of heavy metal contaminants, most of which can be separated from the copper sulphide minerals during flotation. Some of these elements, however, are not separated during the flotation process and are in fact concentrated. The heavy metal investigated in this study is lead. It is hypothesised that lead in the orebodies is interacting with copper sulphides and this interaction is contributing to heavy metal rejection inefficiency. In this study, X-ray Photoelectron Spectrometry (XPS) has been used to confirm an interaction between lead and copper sulphide minerals in which lead forms as lead sulphide-like compound on the surface of copper sulphide minerals. Copper sulphide minerals with lead adsorbed on their surfaces have been subjected to fine grinding and flotation. The tendency of the lead to report to fine particles during grinding and their behaviour in flotation is discussed.

Neutron radiography of the froth zone in a flotation cell

S. Heitkam (TU Dresden, Germany), J. Sygusch, M. Rudolph (Helmholtz Institute Freiberg for Resource Technology, Germany), T. Lappan, S. Eckert (Institute of Fluid Dynamics, Germany), P. Trtik, D. Mannes (Paul Scherrer Institut, Laboratory for Neutron Scattering and Imaging, Switzerland) and K. Eckert (TU Dresden and Institute of Fluid Dynamics, Germany)

In mineral flotation the froth zone plays a crucial role for the recovery rate and grade of the separation process. Reduced froth stability could enhance particle clustering and drop-back while high liquid fractions result in extraction of pulp and contained gangue particles.

This contribution deals with neutron radiography of the froth zone of a model flotation cell. Neutrons are attenuated strongly by water and sub-millimeter gadolinium particles. This allows for measuring the liquid content and velocity of the froth as well as for tracking the hydrophobic particles along froth zone and overflow.

Experiments are conducted in a flat flotation cell of 50 cm height and 10 cm width, varying the concentration of the frother methyl isobutyl carbinol (MIBC), the filling level and the gas flow rate. The data allow to deduce the influence of froth stability and froth residence time on pulp extraction, particle accumulation and particle drop-back.

Alternative activator for sphalerite flotation

E. Cakir and O. Bicak (Hacettepe University, Turkey)

Sphalerite is the most abundant zinc sulphide mineral in sulfide ore deposits. Unlike the other sulfide minerals, it has poor floatability and requires activation by copper or lead ions. Copper sulphate ($CuSO_4$) is the most widely used activator for flotation of sphalerite.

ZNFlooter (ZnFL) produced in liquid form by Metal-Kim which is considered as an alternative activator for sphalerite flotation. This reagent contains copper amine complex and less amount of sulphate compared to copper sulphate. In this study, activation performance of ZnFL was compared with CuSO4. Rougher kinetic flotation and open cleaner flotation tests were conducted to reveal the effectiveness and usage of ZnFL on three different ore that contains sphalerite by comparing selectivity, grade and recovery of zinc concentrates.

The effect of surface coverage on the rising behaviour of particle-laden bubbles

P.R. Brito-Parada, P. Wang, J.J. Cilliers and S.J. Neethling (Imperial College, UK)

A systematic investigation of the influence of surface coverage on the dynamics of rising bubbles was carried out using high-speed photography and image analysis. Results show that attached particles strongly dampen the oscillations observed in aspect ratio and decrease its velocity and acceleration. The overall velocity of a bubble was found to be directly correlated to its aspect ratio and inversely correlated to its particle coverage, while the acceleration and the aspect ratio and its change are inversely correlated. Interestingly, the trend observed in the oscillation and the oscillation period is similar for different levels of particle coating. A drag modification factor that quantifies the drag influence of particles on bubble velocity was identified from force analysis and a modified drag coefficient introduced to predict, for the first time, the behaviour of rising bubbles covered by particles. These correlations obtained are essential to enhance the modelling of flotation phenomena.

Experimental and computational investigations on L-cysteine as an environmentally-efficient flotation reagent in the selective separation of molybdenite from chalcopyrite

Zhigang Yin, Zhijie Xu, Jianyong He, Chenhu Zhang, Qingjun Guan, Shangyong Lin, Xiangsheng Lai, Wei Sun, Yuehua Hu (Central South University, China), Chenyang Zhang (Central South University and Hunan Research Institute for Nonferrous Metals, China), Jingxiang Zou and Daixiong Chen (Nanjing University, China)

In this work, L-cysteine was introduced as an environmentally-efficient flotation reagent in the selective separation of molybdenite from chalcopyrite. Its flotation performance and adsorption mechanism onto chalcopyrite were also investigated by flotation experiments, zeta potential, FTIR spectra, TOF-SIMS measurements and first principle calculations. The flotation results indicated that L-cysteine exhibited stronger depressing capacity than the conventional chalcopyrite depressants of Na_2S, NaHS and sodium thioglycolate, suggesting it could become a promising potential depressant in the selective flotation separation of Cu-Mo. The results of zeta potential, FTIR spectra and

TOF-SIMS measurements demonstrated that L-cysteine might chemisorb on the Cu atom of chalcopyrite surface via –SH and $–NH_2$ groups to form a stable L-cysteine-Cu chelate compound. In addition, the dimer of L-cysteine specie was also observed on chalcopyrite in the presence of oxidant. The first principle periodic calculations further supported the experimental characterizations, the calculated reaction energy for L-cysteine with Cu on the (001).

Selective separation of fluorite from calcic minerals using cymoxanil derivatives

Wanjia Zhang, Jian Cao, Wei Sun, Yuehua Hu and Zhiyong Gao (Central South University, China)

The flotation separation of calcium-containing minerals from each other still remains a significant challenge in mineral processing field. Active hydroxyl is a common functional group of widely used flotation collectors (such as oleic acid, benzohydroxamic acid and phosphates), which is a versatile claw to stably bond with active metal sites on mineral surfaces. However, the accurate site recognition by single functional group to different calcium-containing mineral surfaces has been proved difficult to achieve. Benzohydroxamic acid was a successful precedent, and excellent selectivity was obtained though the synergistic chelation of such multi-function-group as carbonyl, secondary amine and hydroxyl with active metal sites on the mineral surfaces. On the basis of "multi-function-group chelation" strategy, two cymoxanil derivatives of 2-cyano-N-(ethylcarbamoyl) acetamide and (E)-2-(3-ethylureido)-N-hydroxy-2-oxoacetimidoyl cyanide were developed by molecular modification of benzohydroxamic acid. Flotation tests showed that cymoxanil derivatives have a promising industrial application potential in the reverse flotation of fluorite from scheelite.

Positron emission tomography (PET) measurements of liquid content in a laboratory flotation vessel

K. Cole, M. Mahlangu, S. Peterson, M. R. van Heerden (University of Cape Town, South Africa) and M. G. Spangler-Bickell (Nuclear Medicine Unit, IRCCS Ospedale San Raffaele, Italy)

Positron emission tomography (PET) is an imaging technique used in medicine to detect cancer tumours and investigate physiological function. It has also been applied in a mineral processing context, to measure the liquid content in flowing foams in relation to bubble coalescence. However, the impact of the results was limited by the simplicity of the image reconstruction techniques and the vessel design, which was restricted to 2D and a two-phase foaming liquid. This work presents the development of an advanced image reconstruction technique, namely maximum-likelihood expectation-maximisation (MLEM), which has been reconfigured from a medical application to the PET detector configuration at the University of Cape Town. This has enabled the reconstruction of more complex PET measurements for froth flotation, such as extending the results to 3D and multiphase media to determine the distribution of water in a 3D and three-phase flotation system.

Floatability of micaceous minerals and apatite using pataua palm tree oil

J.A.E. de Carvalho, A.B.Henriques, P.R.G. Brandão, R.Z.L. Cançado, P.S. Oliveira and G.R. da Silva (University of Minas Gerais, Brazil)

Micaceous minerals are commonly found in phosphate ores, representing a challenge to selectively recover apatite. Aiming at identifying new flotation reagents for the separation of micaceous minerals from apatite, this study investigates the floatability of these minerals in the presence of pataua palm tree oil collector and starch, as depressant. Samples of muscovite, phlogopite, biotite, and apatite had its surface properties and the collector adsorption examined using microflotation, electrophoresis, X-ray powder diffraction, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), X-ray photoelectron spectroscopy (XPS), and Fourier transform infrared spectrometry (FTIR).

Synergy between cationic alkyltrimethylammonium bromides (C_nTAB) and nonionic n-octanol surfactants in foamability and floatability of quartz

A. Wiertel-Pochopien, J. Zawala (Polish Academy of Sciences, Poland), E. Larsen and P.B. Kowalczuk (Norwegian University of Science and Technology, Norway)

The paper presents a systematic investigation on the influence of mixtures of three cationic n-alkyltrimethylammonium bromides (C_nTAB, n=8, 12, 16) and non-ionic n-octanol (C_8) surfactants on foamability and floatability of quartz. The foaming data indicated that a synergetic effect occurred for the mixed systems, which resulted in the increased foam height and stability compared to the performance of one-component solutions. Similar synergistic effects were observed for quartz flotation. The strongest effect was observed for C_{16}TAB, and it was significantly reduced with shorter carbon chain lengths (n=12, 8). To elucidate the mechanism of observed effects, the adsorption coverage at the bubbles surface, just after their formation in the solution, was calculated using the Ward-Tordai equation based on adsorption isotherms. It was found that the synergetic effect between investigated surfactants exists only, if the adsorption coverage of C_nTAB molecules was lower than the corresponding coverage for C_8.

Influence of solid particle properties on froth stability

M. Kruszelnicki, I. Polowczyk (Wroclaw University of Science and Technology, Poland) and P.B. Kowalczuk (Norwegian University of Science and Technology, Norway)

In this study the influence of particle size, shape and hydrophobicity on froth properties was studied by dynamic froth experiments using a Dynamic Froth Analyzer (DFA100). The research was focused on so-called wet foams, in which the spherical shape bubbles are separated from each other by liquid films. The properties of froth generated with non-ionic surfactant (Tripropylene Glycol n-Butyl Ether) solution and containing either glass beads (size ranging from approx. 10 to 350 μm, sieved into minor fractions) or quartz as model solid particles was determined. The obtained results showed that there was a strong relationship between investigated particle properties and the froth

stability, determined by its height, structure, and liquid content changes in time. It was found that for spherical particles with intermediate hydrophobicity (contact angle ca. 60°) and 70-110 μm size the froth reached its maximum height. The behaviour of particles in to foam films was also examined and discussed.

The effect of structure features of oxidized starches on the depression of chalcopyrite and graphite

W. Chimonyo, B. Fletcher and Y. Peng (The University of Queensland, Australia)

Graphite association with valuable copper sulphides is problematic during concentration by flotation. In this study, different mechanisms of starch oxidation to depress graphite in a quest to improve separation from chalcopyrite during flotation was investigated. Sodium hypochlorite (NaClO), hydrogen peroxide (H_2O_2) and periodate ($NaIO_4$) were the oxidants used to systematically oxidize native wheat starch. Each oxidation protocol varies the degree of debranching and chain cleavages resulting in different molecular weight polydisperse polymer fractions. This is coupled with differing in proportion and type of carbonyl functional groups formation and surface charge characteristics. It was hypothesised that a critical level of oxidation exists to yield optimal depression of graphite but minimal depression of chalcopyrite. Adsorption isotherms, Zeta potential, Atomic Force Microscopy (AFM) and XPS measurements studies were conducted to ascertain the direct influence of differently oxidized starches on the depressive mechanisms during flotation.

The emulsification of oily collector by flotation frothers in fresh water and saline water

Liang Cao, Xumeng Chen and Yongjun Peng (The University of Queensland, Australia)

Frothers have to be used in mineral flotation forming small bubbles and stable froths. As surfactants, frothers may also emulsify the oily collector used to enhance the surface hydrophobicity of target minerals. In this study, two commonly used frother types (aliphatic alcohol and polyglycol-type frothers) with different structures were selected to study their effects on the emulsification of oily collector dodecane. For a comparison, de-ionised water was tested in parallel with saline water to investigate the effect of electrolytes on the emulsification process. Emulsification tests revealed that in de-ionised water aliphatic alcohol frothers contributed to the coalescence of dodecane droplets preventing the emulsification under agitation, while polyglycol-type frothers promoted the emulsification of. In saline water, both aliphatic alcohol and polyglycol-type frothers improved emulsions under agitation. Interfacial tension at the interface, zeta potential and viscosity of the oil droplets were measured to study the interfacial characteristics of emulsions.

A contribution to the implication of crystallographic orientation of cassiterite crystals on surface properties in flotation

Haosheng Wu and M. Rudolph (Helmholtz Institute Freiberg for Resource Technology, Germany)

Atomic force microscopy (AFM) with the colloidal probe and needle-type topography techniques were employed. The high-resolution force spectroscopy measurements were explored between a silica sphere (non-functionalized or hydrophobized) attached to a tip-less contact-mode AFM cantilever and SnO_2 (110), SnO_2 (100) and SnO_2 (001) surface in aqueous solution. Differences in surface charge as a function of orientation are explained in terms of differences in both the coordination number and density of cationic and anionic sites on the surface. It is believed to play an important role on adsorption behavior of organic reagents (e.g. collectors). For a proof of concept, we used Aerosol® 22 as a collector for cassiterite flotation to functionalize different sample surface at pH 3. The contact angle measurements as well as the topography visualizations from AFM show that the adsorption of Aerosol® 22 is the most abundant on SnO_2(110) followed by SnO_2(100) and SnO_2(001) in the concentration range from 10^{-6} M to 10^{-4} M. The result matched with simulation studies of other groups. However, in addition and to the contrary, in this paper it is concluded that the anisotropic surface charge may be the crucial factor for the adsorption behavior.

Study on the effect of sulfide mineral spatial structure on its floatability by ligand field theory

Jianhua Chen (Guangxi University, China)

In mineral flotation, the crystal structure of minerals determines the properties of minerals and influences the reaction of reagent on mineral surface. The coordination number and coordination properties of transition metal ions could affect the electron orbitals and electronic arrangement of metal ions, which in turn affect the interaction between flotation reagent and metal ions on the mineral surface. The effect of spatial geometry on the sulfidization of smithsonite surface was studied using a close-packed model. The effect of crystal filed stabilization on flotation of pyrite with different crystal structures was investigated. Theπ-back-bonding was used to explain why xanthate can only float pyrite but not float hematite. The ligand field selection can explain the mechanism of hydrophilicity of pyrite and hydrophobicity of galena, and an interaction model of flotation reagent and mineral surface based on the ligand field theory was proposed. The results of the study are important for the design of flotation reagents based on mineral spatial structure.

On the use of an automated contact timer apparatus for the quantitative assessment of wettability for microparticles

R. Serna-Guerrero and R. Hartmann (Aalto University, Finland)

The time required for the attachment (t_{att}) between solid particles and bubbles in an aqueous phase is known to be a reflection of the wettability of the solid surfaces. Although plenty of research has been performed on the use of induction timers, they have been limited to the estimation of relative floatability in specific systems.

Using a novel Automated Contact Timer Apparatus (ACTA), a first attempt at quantifying the wettability of microparticles was carried out. Bubble-particle attachment experiments were performed using silica beads with various degrees of hydrophobicity. From experimental data

and based on the well-known form of bubble-particle agglomeration efficiency, values of contact angle were calculated with similar values than those measured directly on planar surfaces.

The particle size effect in low rank coal reverse flotation

Yonggai Li and Jianzhong Chen (China University of Mining and Technology, China)

The particle size composition of minerals is a very important influence factor for flotation technological indexes. Different minerals have their own optimum flotation particle size range. The mineral particles with different size have different flotation behavior. This research studied the particle size effect from three different points. (1) The effect of subbituminous coal and silica with different particle size on the performance of reverse flotation; (2) The flotation behavior of coal and silica with different particle size in reverse flotation; (3) The effect of ultra-fine coal on the flotation behavior of silica and the performance of reverse flotation. The results show that when the particle is composed of coarse coal or middle size coal with fine silica, good reverse flotation performance could be obtained. The average particle size of concentrates of reverse flotation is larger than that of tailings. The existence of ultra-fine coal could deteriorate the recovery of silica and the separation efficiency of reverse flotation.

The effect of various monovalent and divalent ions on the behaviour of gangue during the flotation of a sulfidic PGM bearing ore

M. Manono, K. Corin and J. Wiese (University of Cape Town, South Africa)

Mineral concentrators are becoming increasingly aware of the importance of the quality of water they feed into their milling and flotation circuits. It is speculated that different inorganic constituents of process water may yield different flotation results owing to electrolyte-reagent-mineral interactions occurring in the pulp phase which are speculated to be specific to ion type, reagent type and mineral or ore type. This thus requires an understanding of different specific ion effects on both the pulp phase and froth phase phenomena such that process water chemistry can be monitored and controlled in a manner that does not negatively affect flotation performance. Previous research has shown that inorganic electrolytes may impact mineral hydrophobicity and floatability and could in turn affect froth stability, entrainment and thus mineral grades and recoveries. In this study, the floatability of a Merensky ore is tested on a bench scale in various single salt solutions, *viz*., $CaCl_2$, $CaSO_4$, $Ca(NO_3)_2$, $MgCl_2$, $Mg(NO_3)_2$, $MgSO_4$, NaCl, $NaNO_3$ and Na_2SO_4 in order to examine specific ion effects on gangue recovery. Coagulation and zeta potential tests are conducted in order to ascertain specific ion effects on gangue depression. The findings of this work have shown that the NO_3^- ions resulted in greater depression of gangue compared to the Cl^- and SO_4^{2-} ions. It was also shown that the divalent Ca^{2+} and Mg^{2+} showed a stronger depression of gangue compared to the monovalent Na^+.

Bubble-particle interactions of flotation in an agitated tank: CFD simulations with DLVO and XDLVO

A. Gomez-Flores, S.K. Solongo, J. You, H. Kim (Conbuk National University, South Korea) and G.W. Heyes (CSIRO Mineral Division, Australia)

Flotation kinetics inside a flotation tank were modelled using computational fluid dynamics (CFD). The flotation process consisted of three sub-processes defined as probabilities: collision, attachment and detachment that depended on local values of flow properties inside the tank. The Derjaguin, Landau, Verwey and Overbeek (DLVO) theory has been used to calculate the interaction energies (van der Waals and electrostatic) between a bubble and a particle. The DLVO theory was extended (XDLVO) to include the hydrophobic interaction. In this study, the DLVO theory was included in the calculation of the probabilities of attachment and detachment. The DLVO and XDLVO have not been used before to conduct CFD modelling of flotation kinetics. Relative hydrophobic silica particles of 30, 120, 480 µm diameter were floated in the tank agitated at 840 rpm.

Sodium carbonate/sodium silicate depressing system in flotation: a multi-scale approach

Y. Foucaud, I.V. Filippova, L.O. Filippov, S. Lebègue and M. Badawi (Université de Lorraine, France)

Sodium silicate (Na_2SiO_3) is one of the most common reagents used in the froth flotation process, in which it is an efficient dispersant as well as a powerful gangue minerals depressant. Due to its high affinity with a lot of minerals, mostly silicates, it adsorbs on their surfaces and prevents the adsorption of the collector, maintaining them hydrophilic. Hence, Na_2SiO_3 is widely used in the flotation separation of rare earth minerals, zinc minerals, iron minerals, scheelite, fluorite, apatite, and many other minerals. For decades, authors have demonstrated higher efficiency of Na_2SiO_3 when it is used in combination with sodium carbonate (Na_2CO_3), a common pH regulator. Among many well-known depressants, this system presented the best efficiency for many ores, including the Tabuaço scheelite-bearing skarn studied herein. However, the mechanisms resulting in these strong positive synergistic effects are not well understood at the moment. Hence, the response surface methodology (RSM) was applied to this ore, considered as a case study, to optimize the depressing conditions and to study deeply the flotation behavior of this system. Strong synergistic effects between the two reagents were exhibited by the RSM, mostly affecting the scheelite, fluorite, and calcium-bearing silicates recoveries. This was attributed to surface carbonation of the minerals by Na_2CO_3, subsequently leading to a better depression by Na_2SiO_3. Overall, a 1:1 ratio between the two reagents displayed the best results in terms of WO_3 grade and recovery. To gain understanding in the molecular mechanisms responsible for the aforementioned synergistic effects, spectroscopic studies (FTIR, XPS) were combined with state-of-the-art molecular modelling (DFT at 300 K) on fluorite, an archetype of calcium minerals.

Interpreting the shape of the flotation rate distribution from size-by-size kinetic tests

L. Vinnett (McGill University, Canada, and Universidad Técnica Federico Santa María, Chile), C. Marion and K.E. Waters (McGill University, Canada)

A size-by-size kinetic characterization of copper-lead from a complex ore is presented. The time-recovery curves are fitted to the Gamma model to obtain the maximum recovery R_∞ and the flotation rate distribution $F(k)$. This model can represent from L-shaped functions to deterministic rate constants. Different grinding times are evaluated to obtain different conditions for R_∞ and $F(k)$. The finest (-20μm) and coarsest fractions (+75μm) present slower responses. However, the different shapes (L-shaped for the -20μm and mounded for the +75μm classes) indicate that a low percentile (*e.g.* 20%) along with a location parameter for $F(k)$ allow for a better kinetic interpretation for the evaluated minerals.

A physico-chemical study into selective flotation of wollastonite from silicates

N. Buthelezi and K.E. Waters (McGill University, Canada)

Wollastonite is a calcium silicate mineral which is used in a variety of industries including ceramics, plastics, frictional materials, electrical and thermal insulators, pharmaceutical and paper industries. Flotation of wollastonite ores that contain silicate minerals as gangue, specifically feldspar, diopside and quartz is challenging and seldom discussed in literature. In this study, microflotation tests, zeta potential measurements, X-ray photoelectron spectroscopy (XPS) and bubble-particle attachment studies were employed to assess the interaction of wollastonite, quartz and diopside with dodecylamine (DDA) and tannic acid (TA). Microflotation tests on quartz and wollastonite using $3.17x10^{-3}$mM DDA as a collector yielded high flotation recoveries at pH 5 to pH 9. Whilst, microflotation tests performed on diopside using $3.17x10^{-3}$ mM DDA at pH 5 to pH 9, yielded poor flotation recoveries. An increase in DDA concentration resulted in high recoveries for all minerals including diopside. Tannic acid (TA) was used as a depressant for diopside at higher DDA concentration. TA was an effective diopside depressant for a defined TA concentration range. Microflotation results suggest that wollastonite and quartz can be selectively floated from diopside using DDA, and TA could be used to improve the selectivity. XPS analysis, zeta potential tests and bubble-particle attachment studies complemented the results obtained from microflotation tests. Zeta potential measurements and XPS were also used to deduce reagent adsorption mechanisms.

Reducing negative effects of oxidation on flotation of sulphide ores

S. Ozcelik and Z. Ekmekci (Hacettepe University, Turkey)

Surface oxidation of sulfide minerals affects significantly flotation performance, particularly Cu-Zn sulfide ores containing secondary copper minerals. Surface oxidation may occur during ore formation, in stockpile and even during concentration. In this study, effects of surface oxidation of Gediktepe Cu-Zn sulfide ore (from Turkey) on copper flotation performance were investigated. Various methods were used to reduce Cu-Zn selectivity problem and produce a copper concentrate with acceptable zinc content. The best results were obtained by using high intensity conditioning in presence of Na2S, dewatering and stage addition of depressants such as sodium metabisulphite and zinc sulphate during copper rougher flotation.

Applications Symposium

Displayed November 13th-14th

Direct detection of the pulp-froth interface using the ultrasound transit time technique

T. Richter, S.Heitkam and K. Eckert (TU Dresden, Germany)

The position of the pulp-froth interface in a flotation cell is an important parameter in froth flotation processes which needs to be controlled in situ. For this purpose, we employ a non-invasive technique, the so called ultrasound transit time technique (UTTT).

In UTTT, a transducer sends Ultrasound pulses of several MHz through the pulp. The pulses are reflected at the pulp-froth interface. The echoes are recorded by the emitting transducer and the time-of-flight is computed.

The vertical position of this interface is calculated by multiplying the time-of-flight with the speed of sound of the pulp. The latter is determined simultaneously by a second transducer, using a target plate which is placed at a known height in the pulp, simultaneously. Based on detailed measurements, the capabilities of the method are evaluated for a pulp-air and a pulp-froth interface in a lab-scale setup. The accuracy is found to be equal to better than 3%.

Hydrodynamic characteristics and control methods of the transportation zone in flotation cells

Dengfeng Han, Shuaixing Shi, Ming Tan and Yihong Yang (BGRIMM Technology Group, China)

The hydrodynamic characteristics of a flotation cell's transportation zone have significant impact on its metallurgical performance, especially on coarse particles recovery efficiency. However, how to define and optimize the transportation zone was seldom investigated by researchers. In this paper a method will be introduced to define the boundary of the transportation zone by PIV measurement and numerical simulation. To avoid particle dropping back and improve coarse particle recovery rate in large flotation cell, the transportation zone can be extended upwards to reduce the floating distance of bubble-particle aggregates by two ways: (1) increase the uphill shooting angle of the jet, (2) elevate the entire rotor-stator assembly. These two technologies have been proved to be effective in both laboratory and industry. The relevant hydrodynamic and metallurgical response will be described and analyzed in details.

Cyanide-free flotation route to process the complex sulphide ores of Tellerhäuser deposit (Saxony, Germany)

I.V.Filippova, H.A. Blanco and L.O. Filippov (Université de Lorraine, France)

One of the main challenges addressed by the European FAME project was to explore alternative processing routes to upgrade European strategic dormant deposits into economically viable operations. Advanced research work using combined approach of depth mineralogical analysis and the development of new flotation reagent regimes led to the definition of optimized flowsheets for the processing of the blend (skarn+schist) ore of the Tellerhäuser ore deposit (Saxony, Germany). Two different protocols were studied for selective sulphide flotation: "direct" selective flotation consisting in performing a step by step selective sulphide flotation; "two stages" selective flotation consisting in a preliminary bulk flotation of sulphides followed by selective Cu and Zn flotation after collector desorption. The developed CN-free process returned concentrate recoveries of 81.3%, 91.9% respectively for Cu and Zn at grades of 23.4 % and 53.7 % for the same elements. Not only high Cu and Zn grades and recoveries were achieved, but also As and Fe were concentrated in the final tails of the process with 12 % As at a very high recovery level 96.2%.

Testing a new collector for cassiterite flotation

I. Bremerstein (UVR-FIA GmbH, Germany) and C. Rudolph (Zschimmer & Schwarz GmbH & Co KG, Germany)

Currently styrene phosphonic acid (SPA) is one of the successfully used collectors for cassiterite flotation.

Convinced that cassiterite flotation gains in importance several other collectors were investigated. One is the PHIZS collector - a synergistic mixture of aliphatic phosphonic acids. The performance of this collector is investigated.

The investigations were carried out on a skarn ore from Erzgebirge in Germany containing cassiterite but also some sulphides. The test material was taken from processing a 120-t- bulk sample of the ore in the test center of UVR-FIA GmbH in Freiberg/ Germany. The experiments give promising results: the recovery of tin is at about 80 %.

An improved bubble load measurement device and its innovative application

Dengfeng Han, Liang Cao, Ming Zhang and Zhengchang Shen (BGRIMM Technology Group, China)

The bubble load measurement devices have been widely used as operation diagnosis tool in flotation circuit, however there are still some deficiencies to be overcome for the existing devices. This presentation will introduce an improved bubble load measurement system as well as an innovative measurement method, which can achieve continuous and stable sampling with less interference and high accuracy. Measurement and comparative analysis were carried out in two parallel flotation banks. In the first bank, the bubble load of rougher and scavenger are only 9.99g/L and 2.64g/L respectively at the shallow location. While in the second bank, the corresponding indices reach to 16.25g/L and 8.47g/L. The change of bubble load with height was investigated for the first time. The result shows that in the upper portion of the cell the bubble load increases with height in rougher cells, while it decreases with height in scavenger cells. Results and analysis will be given in details.

The interaction of grinding media and collector in pyrite flotation at alkaline pH

Yufan Mu, Yupu Cheng and Yongjun Peng (The University of Queensland, Australia)

Pyrite is often floated with gold to maximize gold recovery, and its flotation performance is related to the grinding media type. The interaction of three types of grinding media (forged, 15% chromium and 30% chromium steel) and xanthate in pyrite flotation was investigated at pH 8.5. At the same xanthate dosage, the highest pyrite recovery was achieved with forged steel although it generated significant iron contamination on pyrite surface. An increase in xanthate dosage cannot effectively improve pyrite recovery with chromium steel. This is contrary to the case at pH 5.0 where 30% chromium steel generated the highest pyrite recovery. This is because at pH 5.0 xanthate oxidation preceded over pyrite oxidation and a high pulp potential generated by chromium steel facilitated dixanthogen formation, whilst at pH 8.5 pyrite oxidation preceded over xanthate oxidation and a high pulp potential generated by chromium steel facilitated pyrite oxidation instead of xanthate oxidation.

Maximizing recovery and grade with increased throughput using a single stage of flotation

M.J. Cole, K.P. Galvin and J.E. Dickinson (University of Newcastle, Australia)

The Reflux Flotation Cell (RFC) utilises the Boycott Effect to decouple the water recovery from the gas flux, in principle permitting higher throughput per unit area of vessel without compromising on grade and recovery. This study is the first to examine the delineation between grade and recovery as a function of feed throughput using a single RFC stage. Experiments involved fine coal tailings as a representative "binary" feed of hydrophobic and hydrophilic particles. Coal Grain Analysis, an optical imaging technique, was used to assess the maceral makeup of the feed, and validate the RFC experimental results, along with tree flotation analysis. By preserving a downwards net flux of wash water, a high recovery and grade were achieved over elevated feed superficial velocities of 3 and 5 cm/s, with an overall positive shift in the flotation recovery-ash curve close to the coal-grain analysis result.

Comparison of online and offline pulp sensor metrics in an industrial setting

Z.C. Horn, E.C. Nienaber, L. Auret and E. Wolfaardt (Stone Three Digital, South Africa)

Pulp-phase dynamics strongly impact on flotation performance, yet flotation control and monitoring are usually limited to surface level froth characteristics. An online pulp-phase sensor promises a better understanding of flotation process dynamics and performance. However, the accuracy and commercial benefit of in-pulp sensors need to be demonstrated through rigorous experimental design and testing under representative conditions. A three factor Box-Behnken design is proposed to test airflow, pulp level, and frother reagent addition on pulp-phase measurements. Experimentation is limited by plant resources, but should ensure representative state measurements, state stabilisation, and robustness to process disturbances. Reasonable process limits must be considered in factor level selection to prevent process instability or unacceptable product loss. Correlation of online pulp-phase measurements to offline pulp sensor measurements is analysed and discussed.

Simulation of flotation plant performance under varying process water composition

B. Michaux, M. Rudolph and M. Reuter (Helmholtz Institute Freiberg for Resource Technology, Germany)

As the mining industry is facing an increasing number of issues related to its fresh water consumption, significant efforts are being deployed in research and in industry to develop innovative methods tackling such problems. In this context, recent developments have been made with mineral processing simulation platforms, allowing the inclusion of water chemistry effects on the simulation of a flotation plant performance.
Based on laboratory-scale flotation experiments and a sampling campaign in a fluorite flotation plant, the recent developments in the field of process simulation were used to simulate the performance of the flotation plant under varying process water composition. Based on those simulations, the implementation of different water-saving strategies, such as an intensification of process water reuse in the processing plant, were investigated and suggestions on the rearrangement of the water circuit could also be made.

The impact of microbial load on the flotation response of a PGM bearing ore

M. Smart, S.T. Harrison and K. Corin (University of Cape Town, South Africa)

In water scarce regions, the demand for water within the concentrator is often met using recycled water sources. The quality of recycled water depends heavily on the level of remediation applied to the water as well as the location of the addition point on site. The persistence of microbes in these waters and their impact on flotation is currently poorly understood. By studying the microbial load within the flotation circuit waters of a PGM concentrator, the growth and death of microbes in response to flotation conditions was investigated. Factors such as the addition of flotation chemicals possibly acting as carbon source for growth or those toxic to certain microorganisms was considered. The specific properties of the microorganisms present within the flotation waters and those attached to the mineral surface such as heterotrophic, autotrophic or mixotrophic growth habit will affect their persistence and growth in the flotation circuit. These properties are currently being investigated for the microbial consortia within circuit waters. An understanding of the microbes and their growth or decline in the flotation circuit is required to best advise or facilitate disinfectant methods should these microbes impact the recovery of the PGMs.

Ore dissolution test protocol for estimating water quality changes in minerals processing plants– towards closed water circulation

L.L. Thi, N. Schreithofer and O. Dahl (Aalto University, Finland)

To save freshwater resources and comply with environmental regulations, minerals processing operations are transitioning to partially or fully closed water circulation. The dissolution of the ore and addition of reagents however, leads to changes in water composition, that may cause compromised flotation performance, maintenance and environmental challenges and costly modifications are often required in order to cope with these challenges.

The experimental methodology presented aims to predict the tendency of accumulation of elements and compounds in the process water during comminution, flotation and storage in tailings facilities and establishes relationship between laboratory results and historical plant water quality data.

The results obtained with Boliden Kevitsa ore and on-site waters showed a good corellation between the water matrix of the actual process water and that obtained in the ore dissolution tests. Thus the methodology could serve as an aid for the prediction of the water matrix variation when designing closed water circulation systems at existing and new plants.

Evaluation of the undeslimed flotation feed for the iron ore industry

N.P. Lima (Vale S.A., Brazil) and B. McFadzean (University of Cape Town, South Africa)

The removal of slimes in reverse flotation iron ore circuits is common practise to mitigate the detrimental effects of slimes on reagent consumption, increased froth stability and hematite losses through entrainment. The mean amount of slimes on the beneficiation plants is 12% of the total feed, representing almost 11% of iron losses. The typical desliming circuit comprises 2 or 3 stages of cyclones, representing 5% of Capex for greenfield projects and 15% of energy consumption of the beneficiation plants.

This paper presents a review of the characterization of slimes and their effect on the reverse flotation process. Furthermore, bench scale and pilot tests were carried out with different slimes. The results show the possibility to obtain high quality concentrates with undeslimed flotation feeds with optimised pulp chemistry. More importantly, it was shown that the combined effect of pulp density and fine particle

size has a large effect on froth stability. Deeper investigation into the effects of undeslimed iron ores on froth stability, viscosity and entrainment should be done to better understand and manage their effects.

Mineralogical quantification of floating and entrained gangue

B. McFadzean, M. Becker (University of Cape Town, South Africa) and J. Sweet (Anglo American, South Africa)

Platinum-bearing UG2 ore contains mostly hydrophilic gangue minerals chromite (~65%) and pyroxene (~23%), with talc being the only floatable gangue mineral (~1%). Therefore, it is to be expected that chromite and pyroxene report to the concentrate by entrainment only, whereas talc may report to the concentrate by true flotation in the absence of sufficient depressant. However, it was found that large quantities of pyroxene were reporting to a Western Limb UG2 concentrate that could not be accounted for by entrainment alone.

A continuous hybrid flotation cell was used for flotation tests to generate deep froths that could mimic plant-scale entrainment functions. Mineral flows were quantified using QEMSCAN and these were decoupled into entrained and floatable fractions. It was found that about half of the gangue in the concentrate reported there by true flotation and half by entrainment. The large amount of pyroxene reporting by true flotation was due to finely disseminated talc throughout the pyroxene particles. This type of study is extremely useful in decision making around gangue management on an operational plant.

Use of oscillatory air supply to improve column flotation of coking coal in highly saline water in the absence of collector and frother

Junyu Wang, Hangil Park, Chun Yong Ng and Liguang Wang (The University of Queensland, Australia)

Flotation tests were carried out for a coking coal sample in 0.5 M NaCl solution in the absence of collector and frother using a laboratory-scale flotation column with oscillatory air supply, which was separately generated via two different devices: a fluidic oscillator and a solenoid valve. Conversion of the flow pattern of air supply from steady to oscillatory via either of these devices significantly improved the flotation performance, which was linked to enhanced bubble surface area flux. There was no statistically significant difference in the flotation performance achieved using these two oscillatory air generation devices.

Characterization of a stockpiled sulphide copper ore and evaluation of its metallurgical response

L. Tavares, L. Gois, D. Couto and A. Avelar (Vale, Center of Mineral Development, Brazil)

Aiming at optimizing the life of mine and the project economics, the low grade ore is often stockpiled and reclaimed only in the end of mine life, when the high grade ore is exhausted. The decision to build stockpiles of low grade ore is based on economical evaluation and, in general, the drop of metal recovery due to partial oxidation, in the case of sulphide ores, is not properly taken into account. In this study, a low grade copper sulphide ore that has been stockpiled since 2006 was characterized to evaluate the metallurgical performance. The samples collected in the stockpile were submitted to size by size characterization (chemical analysis, mineralogy, oxidation measurement with EDTA) and bench scale flotation tests, with the objective to evaluate the weathering effect on the metallurgical recovery. The results indicated that oxidation effect was responsible for drastic drop of copper recovery, especially in the finer size fractions.

Measuring the vertical water content profile of lab scale two-phase flotation froths using conductivity

M.R. Lepage, L. Visconti, and K.E. Waters (McGill University, Canada)

A conductivity sensor is developed that is able to measure the vertical water content profile of flowing flotation froths with a vertical measurement resolution of 10 mm. The sensor is designed to automatically scan both the maximum froth height at equilibrium (froth equilibrium height), the froth to collection zone interface, and collection zone gas hold up. In this study, the sensor is applied to measure the water content profile of different frothers (MIBC, poly propylene glycol 425, propylene glycol butyl ether, propylene glycol propyl ether) at different frother concentrations and input gas rates at their respective froth equilibrium heights. The water content in the froth is dependent on the coalescence rate and the drainage of water from the froth. From this, the water content profile can give insight into the bubble size and stability of the froth zone under different operating conditions and frother types.

Development of monitoring algorithm of flotation from froth features extracted by machine vision system

K.H. Kim, G.H. Kim, K.S. You (Korea Institute of Geoscience and Mineral Resources, Korea) and Y.H. Ko (Chung-Nam National University, Korea)

In the flotation process, the froth is a good factor that represents the state of the process. Thus, skilled engineers have been judged the state of flotation process through the observation of the froth, and have adjusted the various parameters of the process. Since the 1990s, various studies have been conducted to apply machine vision system and image processing technologies for objective and accurate judgement of the flotation conditions. Therefore, in this study, we constructed a two-channel machine vision system and tried to extract and analyze various features of froth. Using the 3 liter bottom driven flotation cell and transparent Perspex cell, top surface image and side image of froth were measured at the same time. From the top surface image of froth, color feature was extracted using Gaussian Mixture Models (GMMs) and bubble detection algorithm was developed using local normalization and random seed expansion technique. Using the extracted and analyzed features from top surface image, the correlation with grade of the concentrate and bubble size distribution were confirmed. And the relationship between the thickness of froth observed by side image and various operating conditions such as airflow rate and additives were investigated. In conclusion, we tried to develop the system that can monitor the flotation process in real time by combining two image features.

Improving recovery of iron using column flotation of iron ore slimes

E. Matiolo, H. Couto, H., A.S. Freitas, R.N. Almeida (CETEM/MCTIC, Brazil), N. Lima and K. Silva (VALE, Brazil)

In general, itabirite processing plants in the Brazillian southern system, produce slimes in the hydrocyclone desliming stage containing particle sizes of approximately 99% <45 µm, 25%> 10 µm, 45% <5 µm and 15% <1 µm, 3% of solids by weight and between 35% and 45% of Fe. It is estimated that Fe losses in concentration plants range between 8 to 20% of the total waste in these industrial operations. This work is aimed at evaluating the technical feasibility of concentration of two samples of slimes from two different processing plants in operation in the Brazillian southern system (Minas Gerais state) using column flotation technology. The results indicate that the two samples are ameanable for concentrating using column flotation under specified conditions. The results are discussed regarding the effect of variables such as collector type and dosage, circuit configuration, mineralogical composition of the ore samples and addition of depressant.

Analyzing the effect of different frothers on gas dispersion in a cavitation sparger using electrical resistance tomography

P. Holdsworth, R. LaDouceur and C. Young (Montana Technological University, USA)

Axial dispersion in column flotation is critical for optimizing particle-bubble interaction and maximizing recovery. The effect of different flotation frothers on axial gas dispersion rates in a column flotation cell were measured using electrical resistance tomography (ERT). Gas holdup can be measured using ERT and utilized in the determination of axial gas dispersion rate in the column. The ERT is constructed with two sensor planes making it possible to simultaneously capture gas holdup values at and immediately above the cavitation sparger. Three frothers of varying strengths were used to investigate axial dispersion rates. Experimental conditions were modified by altering the superficial gas rate, frother concentration, and sparger pump speed. Utilizing a two-phase (gas-liquid) system, the effects of varying experimental conditions were captured and are represented using concentration tomograms. There is a strong positive correlation between axial dispersion rate, frother strength, and machine operating parameters.

A comparison of fatty acid collectors for spodumene flotation

C. Marion, R. Li, J. Paris, R. Langlois, N. van Noord, O. Kökkılıç, K. Waters (McGill University, Canada) and J. Quinn (Jarret Quinn Consulting Inc., Canada)

Lithium has become one of the major target elements for the hi-tech sustainable lifestyles expected by the growing global population. It is a key component in lithium-ion batteries, which are essential for laptops, smartphones, and the ever-increasing desire for electric vehicles. Traditionally, lithium has been obtained from brines, however, the expected increase in demand will require new deposits to be found and exploited – namely hard rock deposits. This study compared the use of two different fatty acid-based collectors (CustoFloat 7080 and 7080c) for the flotation of a North American spodumene deposit. Zeta potential measurements and single mineral microflotation experiments were used to provide a surface chemical understanding of each reagent's interaction with spodumene and the major gangue minerals in the ore (mica and feldspar). They were then tested and compared for the recovery of spodumene from the ore itself. Although zeta potential and microflotation tests suggested the collectors adsorbed to some extent with all three minerals, it was suggested that they had a higher affinity to spodumene. Real ore flotation work confirmed these findings; producing a spodumene product with a > 6 % Li_2O grade in both cases. CustoFloat 7080 offered marginal improvements in grade (6.1 % Li_2O) compared to CustoFloat 7080c (6.0 % Li_2O); however, CustoFloat 7080c provided a greater Li_2O recovery.