



INTERNATIONAL
SEMI-AUTOGENOUS GRINDING
AND
HIGH PRESSURE GRINDING ROLL
TECHNOLOGY
2019



Outotec

MOLYCOP



CONFERENCE SPONSORS

The SAG 2019 Organization Committee and Conference Hosts, namely the Norman B. Keevil Institute of Mining Engineering at the University of British Columbia, the Canadian Mineral processing Division of the Canadian Institute of Mining, Metallurgy and Petroleum, and the Canadian Mining Industry Research Organization wish to recognize the conference and event sponsors.

Platinum



Gold



Silver



Copper



Friends



The SAG 2019 Organization Committee and Conference hosts, namely the Norman B. Keevil Institute of Mining Engineering at the University of British Columbia, the Canadian Mineral processing Division of the Canadian Institute of Mining, Metallurgy and Petroleum, and the Canadian Mining Industry Research Organization wish to recognize the conference and event donors.



Ausenco
FLSmidth
Gekko Systems
Hatch
KVM
Lynum Progressive
ME-Elecmetal
Metso
Minerals Engineering International
Molycop
Outotec

Polycorp
SAGMILLING.COM
SGS
Teck
Tega
ThyssenKrupp
Toms
Weir
Wood
WipWare

INTERNATIONAL SEMIN-AUTOGENOUS GRINDING AND HIGH PRESSURE GRINDING ROLL TECHNOLOGY 2019

EDITOR:

Liliana F. Hartwig
Technical Editor

Proceedings of an International Conference on Autogenous Grinding, Semi-autogenous Grinding and High Pressure Grinding Roll Technology held September 22–26, 2019 in Vancouver, B.C., Canada. This conference is made possible by the support from the Norman B. Keevil Institute of Mining Engineering of the University of British Columbia, the Canadian Mineral Processors of Canadian Institute of Mining, Metallurgy and Petroleum and the Canadian Mining Industry Research Organization.

The editor has tried to accommodate the spelling conventions of authors from predominantly English-speaking countries—including the British Isles, Canada, Australia, South Africa, New Zealand, and the United States. Contributions from majority non-English-speaking countries have been normalized to Canadian English spelling, in deference to the conference location and its organizers.



FOREWORDS

The SAG conferences began in Vancouver in 1989, bringing together world industry professionals who specialize in the technology of comminution, specifically autogenous and semi-autogenous grinding (AG/SAG) and high-pressure grinding rolls (HPGR). This targeted conference draws from a wealth of world leading technical experts specializing in the art and science of comminution.

The organizing committee is very excited to be hosting this event at a new venue which we believe will greatly enhance the attendee experience. All proceedings, tradeshow, salon, poster sessions, and peripheral amenities will be located on a single floor allowing for ease of movement and networking.

This conference takes pride in the fact that it is operator influenced and oriented, which is mandated in the organization's goals. The theme of the SAG 2019 conference [R]EVOLUTION reflects incremental and step-change improvements in SAG and HPGR technology that is occurring in industry. Over 200 abstracts were submitted, of which 87 papers have been selected for presentation.

In addition to four full days of technical presentations there will be three panel discussions hosted in the evenings. During the day, concurrent with the presentations will be poster sessions and, continuing from the past conference, a sold-out trade show with vendor salons showcasing technologies and consultants who work in the world of comminution.

For the first time a mobile application will be available allowing attendees to view dates, times, and abstracts, and plan their own personalized itineraries on their personal devices.

There are many individuals and groups that contribute to the continued success of this conference, encompassing authors, presenters, the organizers, and the generous sponsors. They are all gratefully acknowledged for their work to put this program together. A thank you also to the student volunteers without whom this would be more difficult to coordinate. We hope they take this opportunity to network and learn more about our exciting industry.

Support from members of the Norman B. Keevil Institute of Mining Engineering at the University of British Columbia is greatly appreciated. Similarly, the support of our other host organizations is acknowledged—the journals *International Mining* (IM) and *Mining Engineering International* (MEI)—as is that of MEI's Dr. Barry Wills and Amanda Wills. Lastly, we would like to thank our committee, including our Vice-Chairs, Mr. Paul Staples and Mr. Kevin Scott, Finance Chair, Mr. Mark Adams, our website and registration Chair, Mr. Alex Doll, our Field Trip Chair, Ms. Katherine Ray, and the efforts of all the active local and international committees.

Greg Rasmussen

Vice President, Sales and Operations – North America
Gekko Systems

Malcolm MacLachlan

Program Manager
Dept. of Mining Engineering, University of British Columbia

Linda Duncan

Technical Representative, Mining
Quadra

Paul Staples

VP and Global Practice Lead
Ausenco



LOCAL ORGANIZING COMMITTEE

Greg Rasmussen, Chair

Gekko Systems Inc., Vancouver, BC

Paul Staples, Vice-Chair

Ausenco, Vancouver, BC

Kevin Scott, Vice-Chair

Equinox Gold Corp., Vancouver, BC

Bern Klein, Past Chair

Norman B. Keevil Institute of Mining Engineering
University of British Columbia, Vancouver, BC

Adrian Dance

SRK Consulting, Vancouver, BC

Alex Doll, Registrar

AGD Consulting, Logan Lake, BC

Berge Simonian

Centerra Gold, Fort St. James, BC

Bianca Foggiatto

Ausenco, Vancouver, BC

Brendan Costello, Technical Chairman

Sedgman Pty, Vancouver, BC

David Frost

DRA Global, Toronto, ON

David Meadows

Bechtel Mining and Metals, Phoenix, Arizona, AZ

Debbie Staples

Unit Electrical Engineering, Kaleden, BC

Fisher Wang

UBC Mining, Vancouver, BC

Irma Gabric

Thermo Fisher Scientific, Vancouver, BC

James Yue

Fluor, Vancouver, BC

Jeff Drozdiak

Ridgway & Company, Barristers and Solicitors, Duncan, BC

John R. Davidson

FLSmith, Vancouver, BC

Joshua Sobil

Siemens, Vancouver, BC

Katherine Ray

Molycop, Kamloops, BC

Kelly McLeod

JDS Energy & Mining Inc., Vancouver, BC

Laurie Reemeyer

Wood, Vancouver, BC

Liliana F. Hartwig

Technical Editor Consultant, Lund, BC

Linda Duncan

Quadra Chemicals, Vancouver, BC

Malcolm (Mac) MacLachlan

UBC Mining, Vancouver, BC

Mark Adams, Donations Chairman

Outotec, Vancouver, BC

Michael Samuels

TMAC Resources, Toronto, ON

Persio Rosario

Hatch, Vancouver, BC

Reem Roufail

University of Waterloo, Ontario



INTERNATIONAL ORGANIZING COMMITTEE

Alison Keogh, CEED, Australia
 Alex Jankovic, Hatch, Australia
 Andre McKen, SGS, Canada
 Andrew Gardula, Koeppern, Australia
 Arkady Senchenko, TOMC Institute, Russia
 Bert Huls, Huls Consulting, USA
 Brett Morgan, Russell Mineral Equipment, Australia

Brian Putlan, OMC, Australia
 Craig Sams, Outotec, USA
 David Carr, Oceanagold, New Zealand
 David Way, JKTech Pty, Australia
 David Meadows, Bechtel, USA
 Doug Farnell, Farnell-Thompson, Canada
 Ed Wipf, EdRockMan, USA
 Edward Rybinski, Freeport-McMoRan, USA
 Ekkhart Matthies, Weir Minerals, Germany
 Emre Altun, METU, Turkey
 Fatih Wirfiyata, PT Newmont NUSA Tenggara (Batu Hijau), Indonesia
 Francois Robichaud, Agnico Eagle Mines, Canada
 Greg Lane, Ausenco, Australia
 Helmut Liepold, Siemens, Germany
 Holger Plath, thyssenkrupp, USA
 Homero Delboni Jr., HDA Serviços, Brazil
 Ivan Mullany, Newmont Goldcorp, Canada
 Jaime E. Sepúlveda, J-Consultants, Chile
 James Connelly, Barrick Gold, Canada/South Africa

Jim Vanderbeek, Freeport McMoRan, Peru
 Joe Pease, CRC Ore, Australia
 Jonathon Brown, Fluor, Canada
 Jorge Torrealba, BBA, Canada
 Justo D. Enriquez-Serrano, FMI, Peru
 Levi Guzman, Molycop, Peru
 Luis Marcelo Marques Tavares, Universidade Federal do Rio de Janeiro, Brazil
 Maarten van de Vijfeijken, STM, Switzerland
 Malcolm Powell, University of Queensland, Australia
 Marcelo Perrucci, ABB, Switzerland
 Mark Richardson, Contract Support Services, USA
 Michel Brissette, Freeport McMoRan, USA
 Paul Cousin, Agnico Eagle Mines, Canada
 Peter Amelunxen, Aminpro, Peru
 Peter Radziszewski, Metso, Canada
 Phil Thompson, FLSmidth, Canada
 Rob Henderson, Amerigo Resources, Canada
 Robert McIvor, Metcom Technologies, USA
 Samad Banisi, Shahid Bahonar University of Kerman, Iran
 Sami Hindstrom, Outotec, Finland
 Simon Hille, Goldcorp, Canada
 Stephen Morrell, SMC Testing, Australia
 Steve Walters, CRC Ore, Australia
 Ted Bearman, Bear Rock Solutions, Australia
 Toni Kojovic, SimSAGE, Australia
 Walter Valery, Hatch, Australia



SAG CONFERENCE AWARD FOUNDATION

With the support of numerous donors and the sellout attendance for the SAG conferences, past conferences generated a positive revenue stream. After the successful SAG 2006 the SAG Committee created the SAG Conference Award Foundation to support undergraduate students studying programs in Canadian universities that provide instruction in mineral processing methods and to support postgraduate students where their studies focus on the development and expansion of knowledge in the field of comminution. The first awards were presented in 2008.

2011

Undergraduate	Cameron Bruin	University of British Columbia
	Jeff Shaw	Laurentian University
	Roger Ren	McGill University
Postgraduate	David Cataford	Laval University

2012

Undergraduate	Adam Dreihar	University of British Columbia
	Adrian Bill	McGill University
Postgraduate	Zorigtkhuu Davaanyam	University of British Columbia

2013

Undergraduate	Dominic Carvelas	Dalhousie University
	Michael MacArthur	Queen's University
	Yiyang Li	McGill University
	Nishant Sharma	University of British Columbia
Postgraduate	Amit Kumar	University of British Columbia

2014

Undergraduate	Nik Naserifard	Dalhousie University
	William Yin	Queens University
	Henrique Coppini	The University of Toronto
	Sheelah McCarthy	McGill University
Postgraduate	Benjamin Legare	Laval University
Polytechnique	Teri Herbert	British Columbia Institute of Technology

2015

Undergraduate	Arthur Stokreef	Queen's University
	Hilary Smith	University of Alberta
	Anthony Clapperton	Laval University
	Jim MacKay	University of British Columbia
Postgraduate	A. Kalonji-Kabambi	Laval University
	Michael McClintock	University of British Columbia
Polytechnic	Alex Briand	CEGEP de Sept-Îles
	Reid Simpson	BCIT



2019

Vancouver, British Columbia, Canada

2016

Undergraduate	Lowell Knapp	University of Toronto
	Hillary Williams	McGill University
	Taylor Greer	University of British Columbia
	David Georges-Filteau	Laval University
Postgraduate	Stefan Nadolski	University of British Columbia
	Christopher Marion	McGill University
	Edgar Manuel Pérez García	Laval University
Polytechnic	Gary Chow	BCIT
	Jimmy Morin	CEGEP de Sept-Îles

2017

Undergraduate	Michelle Hoang	University of Toronto
	Alex Thivierge	Laval University
	Sandra Jean Ranson	Queen's University
	Bailee Johnson	McGill University
Postgraduate	Edgar Manuel Perez-Garcia	Laval University
	Gilberto Rodrigues da Silva	McGill University
	Fisher (Chengtie) Wang	University of British Columbia
Polytechnic	Layne Kaufman	BCIT
	Aurelie Pandosy	CEGEP de Sept-Îles

2018

Undergraduate	Arthur Stokreef	Queen's University
	Hilary Smith	University of Alberta
	Anthony Clapperton	Laval University
	Jim MacKay	University of British Columbia
Postgraduate	Michael McClintock	University of British Columbia
	A. Kalonji-Kabambi	Laval University
Polytechnic Undergraduate	Alex Briand	CEGEP de Sept-Îles
	Reid Simpson	British Columbia Institute of Technology

Award Trustees:

Bryan Rairdan
Michael Samuels
Keith Merriam
Alex Doll
Mark Adams

2019

Vancouver, British Columbia, Canada



SAG 2019 FIELD TRIP

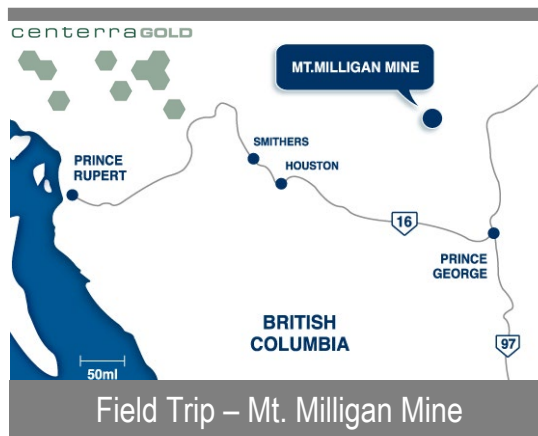
Mt. Milligan Tour

September 27 & 28, 2019

The SAG Conference 2019 field trip includes a tour of the mill and mine at Centerra Gold's Mt. Milligan Mine near Prince George, BC. A bus will depart the JW Marriott (conference hotel) at 06:00 with travel via charter plane to Prince George with an arrival of 08:30. The group will disembark and will be taken by bus from the airport to the mine site. Lunch will be provided either at the site or on the bus to the site.

After the tour of North America's largest SAG mill, 40 feet in diameter, the bus will leave the site to overnight in Prince George at the one of its newest hotels, the Courtyard Marriott. Cocktails, dinner, and entertainment will be included in the evening's program.

Breakfast will be provided at the hotel, and the bus will depart from the hotel at 09:00 to tour two local manufacturing facilities that work with the Mt. Milligan Mine. Lunch will be provided at the hotel or on the bus.



Once this final tour is complete, the bus will transport the group to the airport for the charter flight home, arriving in Vancouver around 18:00. Another bus will transport the group from the Vancouver airport to the hotel.

Field Trip Chair
Katherine Ray
Molycop Canada

MOLY COP



2019

Vancouver, British Columbia, Canada



COPYRIGHT

All materials published as part of SAG 2019 are the Copyright of the Canadian Institute of Mining and Metallurgy (CIM)

2019

Vancouver, British Columbia, Canada



TABLE OF CONTENTS

Sunday, September 22, 2019

TIME	EVENT	LOCATION
12:00	Registration	Granville Rooms
17:00	Welcome Reception	Parq Level 6

Monday, September 23, 2019

TIME	EVENT	LOCATION
6:30	Author's Breakfast	Stanley Rooms
6:30	Delegate's Breakfast	Parq Grand Ballroom
8:00	Welcome Remarks, Greg Rasmussen, Chair	
	Welcome to the 7 th International Semi-autogenous Grinding and High-Pressure Grinding Roll Technology Conference 2019. The conference theme is (R)EVOLUTION, to reflect both incremental and step change improvements in SAG and HPGR technology.	
9:00 to 17:00	SAG Conference Trade Show	Kitsilano Ballroom
9:00 to 17:00	SAG Conference Poster Session	Outside Kitsilano Ballroom
8:20	Session 1 – Energy Efficiency	Parq Grand Ballroom
10:00	Morning Coffee	Pre-Function Area
10:15	Session 2 – Optimization and Start-up	Parq Grand Ballroom
12:15	Lunch	Pre-Function Area
13:15	Session 3 – Testwork	Parq Grand Ballroom
15:00	Afternoon Break	Pre-Function Area
15:15	Session 4 – GeoMet and Mine-to-Mill	Parq Grand Ballroom
17:15	Refreshment Break	Parq Grand Ballroom

Sponsored by:



PANEL 1 – Leadership in Resource Development

Comminution in Sustainable Resource Development

18:15 in the Parq Grand Ballroom



2019

Vancouver, British Columbia, Canada

Tuesday, September 24, 2019

TIME	EVENT	LOCATION
6:30	Author's Breakfast	Stanley Rooms
6:30	Delegate's Breakfast	Parq Grand Ballroom
9:00 to 17:00	SAG Conference Trade Show	Kitsilano Ballroom
9:00 to 17:00	SAG Conference Poster Session	Outside Kitsilano Ball Room
8:00	Session 5 – Comminution Design	Parq Grand Ballroom
10:00	Morning Coffee	Pre-Function Area
10:15	Session 6 – Optimization and Start-up	Parq Grand Ballroom
12:15	Lunch	Pre-Function Area
13:15	Session 7 – Liners	Parq Grand Ballroom
15:00	Afternoon Break	Pre-Function Area
15:15	Session 8 – Modelling and DEM	Parq Grand Ballroom
17:15	Refreshment Break	Parq Grand Ballroom

Sponsored by:



PANEL 2 – Women in Comminution

Gender Diversity in the Workplace

18:15 in the Parq Grand Ballroom

2019

Vancouver, British Columbia, Canada



Wednesday, September 25, 2019

TIME	EVENT	LOCATION
6:30	Author's Breakfast	Stanley Rooms
6:30	Delegate's Breakfast	Parq Grand Ballroom
9:00 to 17:00	SAG Conference Trade Show	Kitsilano Ball Room
9:00 to 17:00	SAG Conference Poster Session	Outside Kitsilano Ball Room
8:00	Session 9 – Optimization and Start-up	Pre-Function Area
10:00	Morning Coffee	Parq Grand Ballroom
10:15	Session 10 – Drives and Maintenance	Pre-Function Area
12:15	Lunch	Pre-Function Area
13:15	Session 11 – Liners	Pre-Function Area
15:00	Afternoon Break	Parq Grand Ballroom
15:15	Session 12 – Comminution Design	Parq Grand Ballroom
17:15	Refreshment Break	Parq Grand Ballroom

Sponsored by:



PANEL 3 – Student Mentorship

Addressing the Age Gap in Mining

18:15 in the Parq Grand Ballroom



2019

Vancouver, British Columbia, Canada

Thursday, September 26, 2019

TIME	EVENT	LOCATION
6:30	Author's Breakfast	Stanley Rooms
6:30	Delegate's Breakfast	Parq Grand Ballroom
9:00 to 12:00	SAG Conference Trade Show	Kitsilano Ballroom
9:00 to 17:00	SAG Conference Poster Session	Outside Kitsilano Ballroom
8:00	Session 13 – Comminution Design	Parq Grand Ballroom
10:00	Morning Coffee	Pre-Function Area
10:15	Session 14 – Process Control	Parq Grand Ballroom
12:15	Lunch	Pre-Function Area
13:15	Session 15 – Process Control	Parq Grand Ballroom
15:00	Afternoon Break	Pre-Function Area
15:15	Session 16 – Fine Grinding/Crushing	Parq Grand Ballroom
17:15	Refreshments	Parq Grand Ballroom

Thursday Evening

TIME	EVENT	LOCATION
18:15	Closing Banquet Dinner	Parq Grand Ballroom

Friday, September 27 and 28, 2019

TIME	EVENT	LOCATION
Departure: Friday Return: Sunday	SAG 2019 Field Trip	Mt. Milligan Site

2019

Vancouver, British Columbia, Canada



TECHNICAL SESSIONS



SESSION 1

Energy Efficiency

Monday, September 23 at 8:30



SESSIONS 2, 6, & 9

Optimization & Start-up

2 – Monday, September 23 at 10:15

6 – Tuesday, September 24 at 10:15

9 – Wednesday, September 5 at 8:00



SESSION 3

Testwork

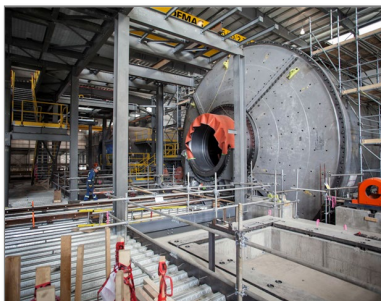
Monday, September 23 at 13:15



SESSION 4

GeoMet & Mine-to-Mill

Monday, September 23 at 15:15



SESSION 5, 12, & 13

Comminution Design

5 – Tuesday, September 24 at 8:00

12 – Wednesday, September 25 at 15:15

13 – Thursday, September 26 at 8:00



SESSIONS 7 & 11

Liners

7 – Tuesday, September 24 at 13:15

11 – Wednesday, September 25 at 13:15



SESSION 8

Modelling and DEM

Tuesday, September 24 at 15:15



SESSION 10

Drives and Maintenance

Wednesday, September 25 at 10:15



SESSION 14 & 15

Process Control

14 – Thursday, September 26 at 10:15

15 – Thursday, September 26 at 13.15



SESSION 16

Fine Grinding/Crushing

Thursday, September 26 at 15:15

2019

Vancouver, British Columbia, Canada



Monday, September 23, 2019 – Parq Grand Ballroom

SESSION 1: Energy Efficiency		
<i>Session Chair: TBD</i>		
Time	Paper Title, Author(s)	Paper #
8:20	Where are the Opportunities in Comminution for Improved Energy and Water Efficiency? <i>Lane, Hille, Pease, & Pyle</i>	1
8:45	Reducing Energy and Water Consumption Through Alternative Comminution Circuits, <i>Lind, Murray, Boylston, & Arce</i>	2
9:00	A Summary of Energy Efficiency Opportunities for the Red Chris Comminution Circuits, <i>Nadolski, Haycock, Li, Seiler, & Kumar</i>	3
9:15	Quantifying the Additional Energy Consumed by Ancillary Equipment and Embodied in Grinding Media in Comminution Circuits, <i>Ballantyne</i>	4
9:30	Question Period	
10:00	Break	

SESSION 2: Optimization and Start-up		
<i>Session Chair: TBD</i>		
Time	Paper Title, Author	Paper #
10:15	Continuous Improvement at Sentinel (with Remote Grinding Support), <i>Butar, Becker, Putland, Lovatt, & Kock</i>	5
10:30	Maintenance and Optimization Practices in the New Afton Grinding Circuit, <i>Katchen & Madsen</i>	6
10:45	Optimisation of Asanko's Obotan SABC Circuit to Achieve Project 5 Mt/a, <i>Bradford, Gift-Agbey, Grobler, Frost, & Morgan</i>	7
11:00	Pre-Crushing of SAG Feed: Friend or Foe, <i>Starkey, Reeves, & Senchenko</i>	8
11:15	The Contrarian's Guide to SAG Mill Optimisation, <i>Sherman</i>	9
11:30	Benchmarking Comminution Circuit Performance for Sustained Improvement, <i>Ballantyne & Giblett</i>	10
11:45	Question Period	
12:15	Lunch	



2019

Vancouver, British Columbia, Canada

SESSION 3: Testwork		
Session Chair: TBD		
Time	Paper Title, Author	Paper #
13:15	Testwork Variability – Implications for Grinding Circuit Design, <i>Vizcarra & Wong</i>	11
13:30	Bond's Work Index: What It Is and What It Isn't, <i>Doll & Simonian</i>	12
13:45	Comparative Study of Mechanical Properties of Pebbles within an Autogenous Grinding (AG) / Semi-Autogenous Grinding (SAG) Circuit, <i>Jacobson & Fabbri</i>	13
14:00	A Review of 10 Years of HPGR Pilot Tests at the University of British Columbia, <i>Wang & Klein</i>	14
14:15	The Value of Daily HIT Ore Hardness Testing of SAG Feed at the Meadowbank Gold Mine, <i>Kojovic, Bergeron, & Leetmaa</i>	15
14:30	Question Period	
15:00	Break	

SESSION 4: Geomet and Mine-to-Mill		
Session Chairs: TBD		
Time	Paper Title, Author	Paper #
15:15	Simulating the Impact of Ore Competence Variability on Process Performance – Case Study of a Large Copper Mine, <i>Faramarzi, Kanchibotla, & Morrison</i>	16
15:30	Advanced Mine-to-Mill Used to Unlock SABC Capacity at the Barrick Cortez Mine, <i>Powell, Bozbay, Kanchibotla, Bonfils, Musunuri, Jokovic, Hilden, Young, & Yalcin</i>	17
15:45	Augmenting Traditional Mine-to-Mill with Cloud-Based Simulation and Reconciliation Capabilities, <i>Carrasco, Gahona, La Rosa, Shapland, Beaton, & Amini</i>	18
16:00	Drill-to-Mill Plant Optimization at Altynalmas Pustynnoye Gold Mine, <i>Esen, Daniel, Dzhalolov, Bachramov, Geronimo, & Kalmatayev</i>	19
16:15	Maintaining Consistent Performance from Two Identical SAG Mills Receiving Different Size Distribution, <i>Draba, Bepswa, Mainza, & Anyimadu</i>	20
16:30	Investigation of a Novel HPGR and Size Classification Circuit, <i>Pearce, Gagnon, Klein, MacIvor, Makni, Wang, & Kumar</i>	21
16:45	Question Period	
17:15	Refreshments	
18:15	Panel – Leadership in Resource Development “Comminution in Sustainable Resource Development” <i>Sponsored by Newmont Goldcorp</i>	

2019

Vancouver, British Columbia, Canada



Tuesday, September 24, 2019 – Parq Grand Ballroom

SESSION 5: Comminution Design

Session Chairs: TBD

Time	Paper Title, Author	Paper #
8:00	Selection of HPGR Technology for the Côté Gold Project: Evaluation of the Impact on Cost and Metallurgy, <i>Makni, Lapointe, Croteau, & Sato</i>	22
8:30	The Metcalf Concentrator HRC™ 3000: Performance at Variable Specific Force, <i>Zervas</i>	23
8:45	HPGR at Tropicana Gold Mine – Case Study, <i>Gardula, Das, Viljoen, Tickner, & Piscicelli</i>	24
9:00	Milling in Raffinate at the Mutoshi Mine, <i>Bordi & Green</i>	25
9:15	HPGRs in Minerals: What Do More Than 50 Hard Rock HPGRs Tell Us for the Future? (PART 2 – 2019), <i>Burchardt & Mackert</i>	26
9:30	Question Period	
10:00	Break	

SESSION 6: Optimization and Start-up

Session Chair: TBD

Time	Paper Title, Author	Paper #
10:15	Dynamic Modelling of a SAG Mill-Pebble Crusher Circuit by Data-Driven Methods, <i>Li, Evertsson, Lindqvist, Hulthén, Asbjörnsson, & Bonn</i>	27
10:30	SAG Mill Ball Charge Modelling at Mount Milligan, <i>Simonian, Yue, & Rawat</i>	28
10:45	Design, Construction, and Operating Experience of the SAG-VERTIMILL® Circuit at Semafo's Boungou Mine in Burkina Faso, <i>Houde & Boylston</i>	29
11:00	The Impact of Expanding Screening Capacity of the Kansanshi SAG Mill Discharge on the Overall Circuit Performance, <i>Phiri, Ngosa, Chongo, Scagliotta, & Heath</i>	30
11:15	Zinkgruvan Zinc Lead and Copper Concentrator Throughput Upgrade, <i>Elphinston, Fredriksson, Brandt, & Vasara</i>	31
11:30	Resetting the Batu Hijau SAG Milling Circuit to Process Low-Grade Stockpile Ore, <i>Condori, Wirfiyata, & Dwi</i>	32
11:45	Question Period	
12:15	Lunch	



2019

Vancouver, British Columbia, Canada

SESSION 7: Liners		
Session Chair: TBD		
Time	Paper Title, Author	Paper #
13:15	Implementing the First Thunderbolt Skyway with Insideout Technology at Cobre Panama, <i>Ikaheimonen, Rubie, Gwynn-Jones, & Bohorquez</i>	33
13:30	Continuous Improvement in SAG Mill Liner Design to Increase Hard Rock Throughput, <i>Taghimohammadi, Grignon, Sherman, & Virani</i>	34
13:45	The Design and Evaluation of SAG Mill Liner Trials, <i>Toor, Valery, Brennan, & Duffy</i>	35
14:00	Grates Plugging in High Diameter SAG Mills: An Overview on Operational Analysis, <i>Olmedo & Rioseco</i>	36
14:15	The Dynamic Influence of Ball Mill Wearing Profile in Mill Performance, <i>Torrealba, Dupont, & Allaire</i>	37
14:30	Question Period	
15:00	Break	

SESSION 8: Modelling and DEM		
Session Chairs: TBD		
Time	Paper Title, Author	Paper #
15:15	A Particle Scale Model for Simulation of SAG Mill Process Performance: Model Components and Application to Pilot and Industrial Scale Mills, <i>Sinnott, Cleary, & Morrison</i>	38
15:30	Linking the Packed Bed Test to Full Size HRC™ HPGR Performance, <i>Qiu, Vien, Mular, Alkac, & Pate</i>	39
15:45	Model-Based Laboratory / Plant Scale-up of HPGR Circuit Performance, <i>Sepúlveda, Tobar, & Figueroa</i>	40
16:00	The Natural Selection Function and Its Application to Crushing and Grinding, <i>Vien</i>	41
16:15	Evaluating the Energy Performance of an SABC Circuit with Pre-Crusher Under a Dynamic Operating Condition, <i>Gong, Liu, Wang, Klein, Sun, & Kou</i>	42
16:30	Using Modelling to Optimise a Single-Stage SAG Circuit Operated in Closed Circuit with High Frequency Fine Screening Technology, <i>Frausto, Ballantyne, Runge, Mwale, Powell, & Mainza</i>	43
16:45	Question Period	
17:15	Refreshments	
18:15	Panel – Women in Comminution, <i>Sponsored by Fluor</i>	

2019

Vancouver, British Columbia, Canada



Wednesday, September 25, 2019 – Kitsilano Ballroom

SESSION 9: Optimization and Start-Up

Session Chairs: TBD

Time	Paper Title, Author	Paper #
8:00	Four Years into Operation – A Review of the Commissioning, Ramp-up, and Current Performance of the Las Bambas Concentrator in Peru, <i>Meadows, Lamb, & Carpio</i>	44
8:30	Design and Start-up of the Merian SABC Circuit, <i>Davies, Giblett, & Dwi Payana</i>	45
8:45	The Recent Advances of Raglan's Comminution Circuit, <i>Rosario, Nathan, Tse, Wang, & Proulx</i>	46
9:00	Improvement of CIS Standard Iron Ore Circuit by HPGR, <i>Heinicke & Hubert</i>	47
9:15	Optimisation Opportunities at Newmont Goldcorp's Peñasquito Operation, <i>Lind, Erwin, Chandramohan, Tweed, Lane, Staples, Hille, Foggiatto, Awmack, & Patterson</i>	48
9:30	Question Period	
10:00	Break	

SESSION 10: Drives and Maintenance

Session Chair: TBD

Time	Paper Title, Author	Paper #
10:15	The HofAlign Girth Gear, <i>Hofmann & White</i>	49
10:30	ABB Ability™ – Digitalization of Predictive Maintenance for Grinding, <i>Madi & Perrucci</i>	50
10:45	Using the “Two Mills One Drive” Concept to Save Operational Costs, <i>O'Neill</i>	51
11:00	Asset Health Analytics of a Gearless Mill Drive, <i>Tischler</i>	52
11:15	Continuous Improvements in Mill Relining at Escondida, <i>Martinez, Rubie, Bohorquez, & Gwynn-Jones</i>	53
11:30	Increased Throughput from Liner Design Initiatives in the Aktogay 40 ft SAG Mill, <i>Faulkner, Lozovoy, Kumar, & Lee</i>	54
11:45	Question Period	
12:15	Lunch	



2019

Vancouver, British Columbia, Canada

SESSION 11: Liners Session Chair: TBD		
Time	Paper Title, Author	Paper #
13:15	Design of Gigantic Composite Liners for Large SAG Mill Applications, <i>Bustamante, Mori, & Toro</i>	55
13:30	Comparative Study of Mill Discharge Systems using Coupled DEM SPH Simulations, <i>Murariu</i>	56
13:45	Optimizing Pulp Lifter Design Using SPH Simulation: Tritton Story, <i>Weerasekara & Town</i>	57
14:00	Field Validation of an Updated Work Approach Applied to Ball Mill Megaliner™ Design, <i>Jara, Suazo, & Martinez</i>	58
14:15	SAG Mill Grinding Media – Is Bigger Really Better? <i>Cornish, Conger, & Pax</i>	59
14:30	Question Period	
15:00	Break	

SESSION 12: Comminution Design Session Chairs: TBD		
Time	Paper Title, Author	Paper #
15:15	Optimizing Ball Mill Selection for a HPGR Ball Mill Circuit, <i>Wong, Mackert, Lipiec, Remmers, Burchardt, & Vanderbeek</i>	60
15:30	Reducing Edge Effect and Material Bypass Using Spring-Loaded Cheek Plates in HPGR Grinding, <i>van der Ende, Knapp, & van der Meer</i>	61
15:45	HPGR: Why Skewing is a Requirement for Operational Applications, <i>Knapp, Hannot, & van der Meer</i>	62
16:00	Application of the Eccentric Roll Crusher to SAG Milling, <i>Beland, Drescher, Lipiec, Silberman, Wong, & Szczelina</i>	63
16:15	Estimating Ultrafine Screening Performance and Efficiency, <i>Bosman, Morgan, & Cunningham</i>	64
16:30	Redesigning SAG Mill Recycle Crusher Operation, <i>Powell, Evertsson, & Mainza</i>	65
16:45	Question Period	
17:15	Refreshments	
18:15	Panel – Student Mentorship: Addressing the Age Gap in Mining <i>Sponsored by Ausenco</i>	

2019

Vancouver, British Columbia, Canada



Thursday, September 26, 2019 – Kitsilano Ballroom

SESSION 13: Comminution Design

Session Chairs: TBD

Time	Paper Title, Author	Paper #
8:00	An Assessment of the Energy Efficiency and Operability of the World's Largest Autogenous Grinding Mills at Boliden's Aitik Mine, <i>McElroy, Powell, Tillberg, Hilden, Yahyaei, Linna, & Johansson</i>	66
8:30	Single-Stage Autogenous Grinding Revisited, <i>de Paiva-Bueno, Foggiatto, & Lane</i>	67
8:45	Single-Stage SAG Mills – What are the Important Design Considerations to Avoid Common Pitfalls? <i>Mainza, Nyakunhwa, & Powell</i>	68
9:00	Toward a Simple Approach Determining Single-Stage SAG Mills' Aspect Ratios (D/L), <i>Kalala</i>	69
9:15	Hard Rock – Crush It or Let it Break Itself? <i>Putland & Sciberras</i>	70
9:30	Question Period	
10:00	Break	

SESSION 14: Process Control

Session Chair: TBD

Time	Paper Title, Author	Paper #
10:15	A Structured Approach for Implementation of APC at FMI Cerro Verde, <i>Ortiz de Zavallos, Yopez-Monroy, Nunez-Chirinos, Supomo, & McKay</i>	71
10:30	Advanced Control Optimization and Digital Twin in Comminution for Better Mineral Throughput and Size Classification, <i>Nazari & Carricajo</i>	72
10:45	Sound-based Advanced Process Control of a SAG Mill at Sumitomo Minera San Cristobal, <i>King, Vidal, & McKay</i>	73
11:00	Wireless Sensors Used to Determine Operational Variables in Grinding Mills, <i>Duarte, Martínez, Castillo, & Mascaró</i>	74
11:15	BEST POSTER PRESENTATION TBC	75
11:30	BEST POSTER PRESENTATION TBC	76
11:45	Question Period	
12:15	Lunch	



2019

Vancouver, British Columbia, Canada

SESSION 15: Process Control		
Session Chair: TBD		
Time	Paper Title, Author	Paper #
13:15	Challenges of Using Advanced Control Tools (ACT) System at the Sarcheshmeh Copper Complex SAG Mill Circuit, <i>Bashiri, Maleki-Moghadam, Akbari, Yazdani, & Banisi</i>	77
13:30	Methodology for Assessing the Benefits of Grind Control Using PST Technology for True Online Particle Size Measurement, <i>Maron, O'Keefe, Sepúlveda, & Cirulis</i>	78
13:45	Online Optical Monitoring of the SAG Mill Chamber, <i>Sepúlveda & Duarte</i>	79
14:00	SAG and Ball Mill Online Ball Charge Level Measurement by Sound, <i>Churata</i>	80
14:15	Teck's HVC Adaptive Cruise Control for Secondary Grinding, <i>Nuñez & Hahn</i>	81
14:30	Question Period	
15:00	Break	

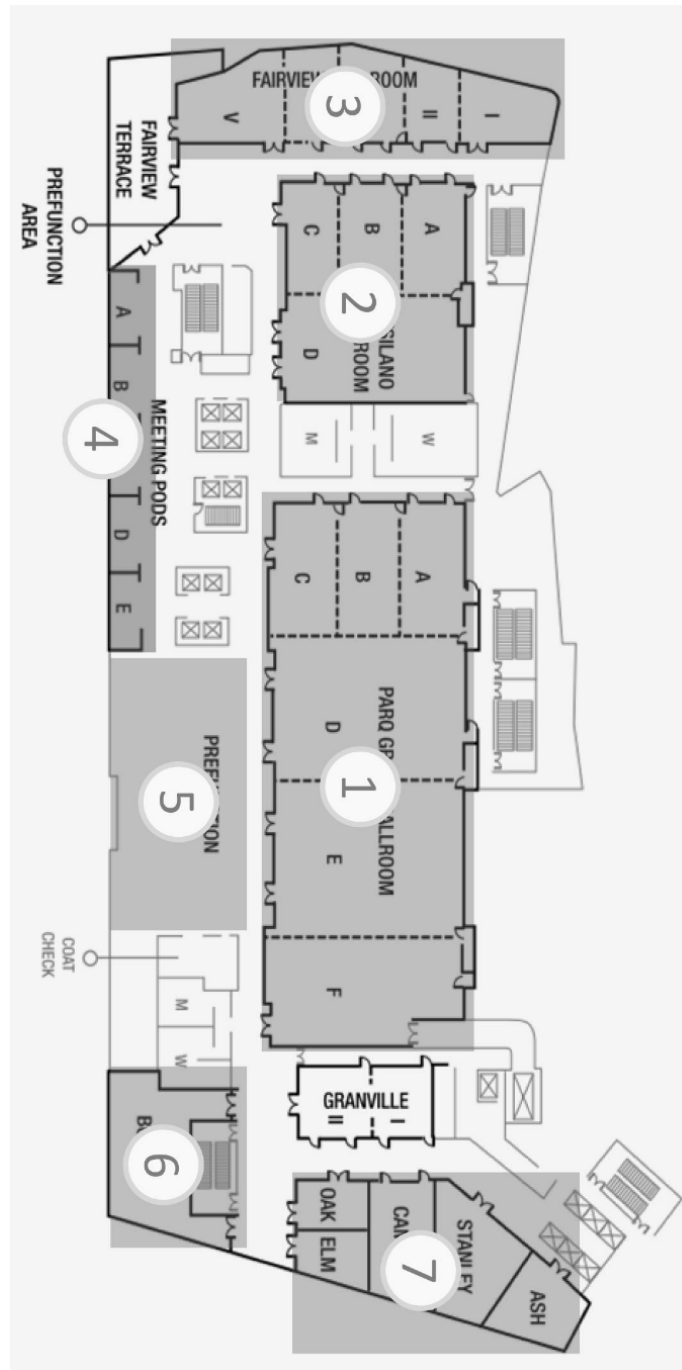
SESSION 16: Fine Grinding/Crushing		
Session Chairs: TBD		
Time	Paper Title, Author	Paper #
15:15	A Review of Published Full-Scale Stirred Mill Results, <i>Larson</i>	82
15:30	Improving Single-Stage SAG Circuit Efficiency and Product Quality Through Finish Grinding in the Towermill, <i>Palaniandy, Yahyaei, & Ishikawa</i>	83
15:45	Design and Operation of the Vertical Shaft Impactor in Fine Crushing Applications, <i>Lewis-Gray & Rasmussen</i>	84
16:00	A History of IsaMill Progress at the Teck Red Dog Mine, <i>Larson, Lacouture, & Anderson</i>	85
16:15	A Method for Ball Mill Media Sizing for Different Upstream Processes, <i>Bartholomew, McIvor, & Arafat</i>	86
16:30	Contributing to a Better Understanding of Grinding Media Wear – Exploring the Impact of Different Parameters, <i>Radziszewski & Martins</i>	87
16:45	Question Period	
17:15	Refreshments	
18:15	Closing Banquet Dinner	

2019

Vancouver, British Columbia, Canada



EXHIBITORS





WHERE ARE THE OPPORTUNITIES IN COMMINUTION FOR IMPROVED ENERGY AND WATER EFFICIENCY?

08:20, Paper #1

Greg Lane, Simon Hille, Joe Pease, & Matt Pyle

In this paper, the authors review the opportunities for improved energy and water efficiency in comminution circuit design and operation. Specifically, the authors discuss methods for improving throughput and/or energy and water efficiency for semi-autogenous grinding (SAG)-based and high-pressure grinding rolls (HPGR)-based circuits.

For existing plants, best practice is to start from the correct base to ensure the current circuit operates to its best efficiency. This discussion covers instrumentation and calibration; correct cyclone components and maintenance, ball size, and grinding control loops; routine checks; and key performance indicators (KPIs) to keep the comminution circuit running optimally.

For upgrades to existing projects and new projects, topics include:

- Blast design and reducing run-of-mine (ROM) particle size
- When do ore sorting, dense medium separation (DMS), and coarse particle flotation add value?
- Targeting size reduction with the correct size media in milling – multi-stage milling
- Coarse waste rejection
- Autogenous and pebble milling to reduce media consumption
- Improved classification efficiency:
 - screens vs. cyclones
 - efficient cyclone operation
- Compression crushing to fine sizes with the use of dry grinding and classification
- Water conservation opportunities and their project impacts.

Examples of flowsheets and technologies that can reduce energy consumption and improve energy and water efficiency are provided based on recent projects. These are supported by case studies based on brownfield optimisation work.

Notes:



Vancouver, British Columbia, Canada

08:45, Paper #2

Mineral processing consumes significant power, primarily in comminution, as well as significant amounts of water through hold-up in conventional tailings facilities. Reducing power and water consumption in comminution circuits can contribute to reduced operating costs and improved sustainability. Metso and Newmont Goldcorp have been working on alternative comminution circuits that are both energy-efficient and present the possibility for using less fresh water as compared to conventional comminution circuits.

Specific energy and water consumption in the novel circuits are compared against a traditional SABC circuit.

[illegible]



09:00, Paper #3

Stefan Nadolski, Russ Haycock, Kevin Li, Santiago Seiler, & Amit Kumar

A comprehensive energy study was carried out for the Red Chris mill, which processes copper-gold ore at a rate of 30,000 tonnes per day (t/d) and is located in Northern British Columbia. The study focused on identifying opportunities for energy conservation in the semi-autogenous grinding (SAG)-ball mill and regrind circuits. Mill surveys were carried out to calibrate mill models, such as those in JKSimMet, for simulation of alternative operating scenarios. Energy benchmarking methods were used for all circuits, including a Vertimill regrind circuit, to evaluate nominal energy performance and compare circuit configurations.

For the SAG and ball mill circuits, considerable flexibility in the material handling system allowed alternative flowsheets to be assessed. Evaluated energy conservation measures included implementation of SAG mill charge monitoring technologies to allow for mill speed reduction, diversion of pebble crusher product to the ball mill circuit, sensor-based sorting of pebble crusher feed, and modification of media sizes.

The regrinding circuit consists of a grate-discharge ball mill and a Vertimill, which is operated with a separating tank. Circuit surveys and energy benchmarking through use of an Eliason laboratory stirred mill test showed that the Vertimill separating tank was ineffective as a size classifier. Overall, the paper presents a summary of energy benchmarking efforts and evaluation of identified energy conservation opportunities.

Notes:

[illegible]



2019

Vancouver, British Columbia, Canada

QUANTIFYING THE ADDITIONAL ENERGY CONSUMED BY ANCILLARY EQUIPMENT AND EMBODIED IN GRINDING MEDIA IN COMMINUTION CIRCUITS

09:15, Paper #4

G. Ballantyne

Assessment of comminution energy intensity has traditionally been confined to the crusher and mill motor power consumption. However, a measure of ancillary equipment power and the embodied energy consumed through media wear is required to compare disparate equipment types and circuit configurations fairly, as they can contribute a significant (average 45% increase) proportion of energy to the comminution circuit. Conveyors and slurry pumps use electrical energy to move ore between comminution and classification equipment in mineral processing circuits. Steel balls and rods are regularly used as grinding media in tumbling mills to assist with ore breakage. The consumption of this media through wear processes can be viewed as a form of embodied energy consumption, as the mining, smelting, casting, and shipping of media consumes a substantial quantity of “embodied” energy.

The comminution energy curve database has been developed at the Julius Kruttschnitt Mineral Research Centre over recent years to capture comprehensive energy data for comminution circuits. The database also contains limited data for both ancillary equipment power and embodied energy of grinding media. However, as the database does not contain ancillary and embodied energy data for all the circuits, simplified models were required to populate circuits where these figures were not known. In the comminution circuits studied from the database, the average additional specific power attributable to pumps, conveyors, and media was 1.6, 0.6, and 3.4 kWh/t, respectively. These figures were highly dependent on the type of comminution circuit. New energy curves were generated that included the ancillary equipment power and embodied energy in the grinding media. The resulting energy curves allow mines to be benchmarked on specific comminution energy as well as media wear and ancillary equipment power draw.

In this paper, the authors will present two case studies that explore the effect of circuit type on electrical comminution energy as well as embodied and ancillary energy consumption. The first case study looks at the transition of a circuit from autogenous (AG) through semi-autogenous (SAG) and pre-crushed barely-autogenous (BAG) milling. Each circuit change achieved an increase in throughput, but the result of this decision also increased the specific comminution energy, the embodied energy, and the ancillary equipment power. The second case study explores the change in the trade-off between SAG and high pressure grinding rolls (HPGR) circuits when the increase in conveying requirement and change in media wear are considered when comparing comminution circuit options. These two case studies demonstrate the importance of including ancillary equipment power and the embodied energy of the grinding media wear in the assessment of comminution energy efficiency

Notes:



CONTINUOUS IMPROVEMENT AT SENTINEL (WITH REMOTE GRINDING SUPPORT)

10:15, Paper #5

Ramlan Butar, Mike Becker, Brian Putland, Ivka Lovatt, & Fred Kock

Continuous improvement is a major key performance indicator (KPI) for many metallurgical operations. Improvement never happens by itself and is rarely attributed to a single party or person, but is rather the culmination of different factors, ideas, and efforts towards the overall improvement of a system, which is ultimately driven by culture. Nameplate capacity of 55 million tonnes per annum (Mt/a) has been achieved at the Sentinel Copper Project (First Quantum Minerals Limited) through the continual efforts of the team, steadily improving throughput and tightened operational control of the process. This paper provides some background on the project, challenges faced, and explores the observations, recommendations, and changes made at Sentinel involving site personnel, vendors, and external experts. Specific focus is given to the continuous comminution circuit operating data analysis, evaluation, and feedback reporting processes utilized and the positive improvements resulting from the ongoing relationship.

Notes:

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



Vancouver, British Columbia, Canada

10:30, Paper #6

The New Afton concentrator began commercial operation in 2012 with a tertiary grinding circuit commissioned in Q2-2015. Grind size has been improved relative to milling rate both before and after the tertiary circuit addition. Mill availability has also improved, reaching 97.5% in 2018. Availability has been increased through the integrated application of nine main elements of Reliability engineering combined with effective maintenance management. Mill production planning integrates grind size and recovery models, costs, and the grade distribution of the ore to optimize net present value (NPV) over the life of mine. Stability in milling rate and grind size has been achieved through live-pile management, expert control systems, selective use of the pebble crusher, and optimization of the semi-autogenous grinding (SAG) liner design, grinding media, and SAG discharge screen-deck apertures.

[illegible]



OPTIMISATION OF ASANKO'S OBOTAN SABC CIRCUIT TO ACHIEVE PROJECT 5 Mt/a

10:45, Paper #7

R. Bradford, W. Gift-Agbey, E. Grobler, D. Frost, & P. Morgan

Asanko gold mine in Ghana started processing ore from the Nkran pit in January 2016 at a production nameplate of 3 million tonnes per annum (Mt/a). The flowsheet is a conventional semi-autogenous grinding (8.6 m Ø x 4 m, originally 5.6 MW) ball mill (5.8 m Ø x 9.1 m 5.6 MW) and pebble crusher (SABC) with gravity-gold and carbon-in-leach (CIL) recovery. The nameplate production was comfortably achieved, so much so, that the SABC circuit was capable of processing more than the downstream section of the plant. Consequently, a program of de-bottlenecking was initiated to rectify volumetric capacity constraints. This program was later referred to as Project 5 Million (t/a) or P5M. Having completed the de-bottlenecking exercise, it became evident that the SABC circuit could not reach 5 Mt/a, on hard rock from Nkran. The new challenge was, therefore, to increase the capacity of the milling circuit through a focused comminution initiative that would address the following: geometallurgical treatment plan; upfront fragmentation requirements; installation of feed and mill monitoring equipment; and integration of a knowledge-based control strategy. In this paper, the authors take the reader through the various measures implemented to increase the milling rates and to create a stable/sustainable control philosophy. As a result of the implementation of advanced mill performance monitoring technology (MillSlicer) and the collaboration between a team of experts in comminution, control, and operations, the Asanko process plant feed tonnage has increased from 3 Mt/a to 5 Mt/a.

Notes:



Vancouver, British Columbia, Canada

11:00, Paper #8

In the mineral processing sector, a common approach to expanding a SAG mill circuit is the addition of secondary or tertiary crushing to reduce the size of the mill feed. The addition of pre-crushing can increase the throughput of an existing SAG mill circuit by 10% to 30% or more, depending on the nature of the ore and the crushing equipment selected. In this paper, the principal author will discuss his experiences with the application of pre-crushing in SAG mill circuits over a 50+ year career, both at the design stage and as a retrofit expansion, and discuss some of the opportunities/challenges discovered along with potential high-energy mitigation strategies.

Starkey has used pre-crushing in commercial projects for over 20 years so these ideas are sound and not new.

[illegible]



THE CONTRARIAN'S GUIDE TO SAG MILL OPTIMISATION

11:30, Paper #9

Mark Sherman

Twenty years ago, the author reported on the results of using unorthodox mill shell lifter geometry and the charging of large grinding balls to the Alumbreira SAG mills. Since then, the author has continued to develop SAG mill shell liner and grate designs, based on the learnings from Alumbreira and other sites. The key findings from the intervening twenty years of liner modification have culminated in a contrarian approach to the design of these elements, where the desire for the optimum media trajectory has been replaced by a shell liner design that can sustain full speed operation immediately after a mill reline, and a grate's pebble ports have been replaced with longer but narrower slots. The contrarian approach changes implemented by the author at three sites have generated at least a 15% increase in SAG mill throughput rate, increased SAG mill liner life, and improved pebble crusher performance. This paper presents the results from two Australian sites whilst another paper in these proceedings presents the results achieved at Suriname's Rosebel gold mine (Taghimohammadi, Grignon, Sherman, & Virani, 2019).

Notes:

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



2019

Vancouver, British Columbia, Canada

BENCHMARKING COMMINUTION CIRCUIT PERFORMANCE FOR SUSTAINED IMPROVEMENT

11:30, Paper #10

G. Ballantyne & A. Giblett

Newmont has a demonstrated history as a leading investor in comminution technology developments. Most notably the cornerstone high pressure grinding rolls (HPGR) demonstration plant at the Lone Tree operation in 2003, which contributed to paving the way for the subsequent acceptance of HPGR technology in the hard rock mining industry. Newmont endeavours to evaluate grinding circuit performance at its global operations, allowing continuous improvement of operating facilities and practical insights to be applied to new plant designs. This approach was demonstrated by a global mine-to-mill operations review in 2009, incorporating circuit sampling and standard ore characterisation testwork to facilitate the assessment of circuit performance efficiency and increased circuit productivity. This effort, and an ongoing commitment to performance analysis, has resulted in a performance-based dataset defining 15 individual comminution circuits. The database further provides a useful basis for comparing the available techniques to define circuit comminution efficiency.

In this paper, the authors will review various methods for assessing comminution circuit efficiency in the context of the Newmont database, including the Bond, Morrell, and size specific energy (SSE) methodologies. The authors will show that SSE method generates a relative efficient measure that allows equipment performance to be assessed in isolation and is in that sense comparable to the Morrell approach, whereas the published Bond approach is better suited to overall circuit analysis. The combination of these three methods allows a comprehensive understanding of the effectiveness of each comminution circuit, highlighting improvement opportunities, and providing a baseline from which the potential of new technologies can be measured.

The results of this analysis were also plotted on the comminution energy curves, a free platform provided by the Coalition for Eco Efficient Comminution (CEEC) and the Julius Kruttschnitt Mineral Research Centre (JKMRC). The energy intensity of each Newmont site was assessed using four individual energy indices.

In this paper, the authors will discuss the insights generated from each analysis method and demonstrate their relative merits as observed for the operations studied in this assessment.

Notes:



TESTWORK VARIABILITY – IMPLICATIONS FOR GRINDING CIRCUIT DESIGN

13:15, Paper #11

Tim G. Vizcarra & Bevin Wong

JKTech has completed a comparative testing program of Bond tests as an addition to its “round-robin” quality control program for JK Drop Weight (JKDW) and SMC tests. Over seventy Bond tests of representative splits of quarry material were undertaken by over thirty participating laboratories. To JKTech's knowledge, this represents the largest comparative study of Bond testing reported in the literature.

The scale of the exercise meant that the variability due to systematic differences between laboratories, as well as the inherent experimental error of the test, could be decoupled. These “errors” in the Bond test are often under-appreciated in design, and the results are discussed in the context of implications for mill sizing. Other major factors that drive ball milling efficiency, which are not accounted for by the Bond equation but are strongly evident in the JKTech database, are also presented.

Notes:

This image shows a single sheet of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page. There are approximately 20 lines visible. The paper has a slight shadow on the right side, suggesting it's resting on a surface.



Vancouver, British Columbia, Canada

13:30, Paper #12

Bond's work index is one of the mostly widely used metrics of mineral grindability. In spite of its ubiquity, users are often not aware of the nuances of the work index family: what are its strengths and weaknesses. Moreover, the operating work index frequently gets confused for a specific energy consumption (SEC) in documents such as National Instrument (NI) 43-101 reports. Understanding where the work index fits into the family of power-based grinding metrics will help operators correctly apply the work index and avoid making mistakes.

A revised definition of work index is offered that makes clear the distinction between SEC and work index.

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



COMPARATIVE STUDY OF MECHANICAL PROPERTIES OF PEBBLES WITHIN AN AUTOGENOUS GRINDING (AG) / SEMI-AUTOGENOUS GRINDING (SAG) CIRCUIT

13:45, Paper #13

D.A. Jacobson & D. Fabbri

Pebbles discharged from an autogenous grinding (AG) or semi-autogenous grinding (SAG) mill are often considered to have unique properties as compared to the full feed stream to the primary mill. These particles that "survive" the mill have been assumed to be of harder, more competent composition. The competence of the pebbles has a significant effect on the surrounding processes, and this affects the selection/optimization of the process flow. However, many projects only have ore properties obtained from raw ore or core samples, and often the pebble handling is designed based on this testwork with possibly assumed factors for increased hardness. This study used three separate approaches to compare the pebble properties to raw ore properties. The first approach looked at a broad database for Impact Crushability (IC) Work index of raw ore (390 validated results) and the derived IC Work index from pebble crusher operating data (60 validated results) to compare "typical" crushing work indices encountered.

The second approach compared operating data at plants where both secondary crushers and pebble crushers are used, and the similarity of these crushers allows for comparison of the energy used in crushing raw ore versus pebbles. The third approach was direct lab testing and analyzed 32 samples from ten mine sites with focus on the mechanical properties (hardness, competence) of sampled pebbles in relation to the sample of raw ore directly prior to the mill. Depending on site, size of pebbles, and which tests were available, test results specific towards hardness (IC Work index or SMC) were used to relate raw ore entering the mill with the pebbles that are discharging at a snapshot in time. The results showed that pebbles generally are more competent and more consistent in hardness than the raw ore entering the primary mill, with measured or derived IC Work index that was elevated by 5% to 37% (on average) depending on the measurement method. Direct laboratory testing of at ten sites gave an average pebble hardness value that was 24% greater than the raw ore during the crash stops. While no all-inclusive model is considered valid, the results are valuable to show the mechanical properties of pebbles and the range from site to site or even within the same orebody. The variance between pebble properties and the rest of the material stream aids in determination of pebble crusher selection/operation, whether to process the pebbles in a separate stream, and with design of mill grates and discharge trommels/screens.

Notes:



Vancouver, British Columbia, Canada

14:00, Paper #14

In 2008, the Norman B. Keevil Institute of Mining Engineering commissioned a 0.75 m by 0.22 m Köppern high pressure grinding rolls (HPGR) at the Centre for Coal and Mineral Processing (CMP) Laboratory at the University of British Columbia (UBC). In the past 10 years, over 200 pilot tests were conducted on a wide range of ore samples including copper, iron, gold, silver, tungsten, nickel, and diamond received from 26 different mineral deposits. The data generated from these pilot tests were primarily used for HPGR sizing and process design and also provided opportunities for advanced research, from which a suite of small-scale testing procedures was developed for HPGR modelling and simulation (Davaanyam, 2015; Nadolski, 2012). In this paper, the authors summarize the results of the pilot-scale HPGR tests performed to date and discuss the observed effects of feed properties and operating conditions on HPGR performance and their implications for circuit design. Based on the statistical analysis, a number of empirical models were developed for the prediction of HPGR power draw, net specific energy consumption, specific throughput, and product size distributions.

[illegible]



THE VALUE OF DAILY HIT ORE HARDNESS TESTING OF SAG FEED AT THE MEADOWBANK GOLD MINE

14:15, Paper #15

Toni Kojovic, Yanick Bergeron, & Karl Leetmaa

In November 2017, Agnico Eagle Mines Limited (AEM) initiated a program to evaluate the value of routine ore hardness testing using semi-autogenous grinding (SAG) feed samples in forecasting the SAG Mill/Ball Mill (SAB) grinding circuit performance. Daily samples were collected over a two-month period and submitted for Hardness Index Tester (HIT) evaluation to provide estimates of the competency (Axb) and grindability (Bond ball mill work index [BMW_i]). The statistical analysis of the ore hardness and WipFrag online sizing data suggest a strong correlation that confirmed the well-known expectation that feed size and hardness do affect the grinding performance, even in a secondary crushed feed situation. This means introducing routine HIT testing at site will enable the operations to maximize the throughput for a set grind target and verify if the grinding circuit is performing optimally for the actual feed, rather than feed predicted from mine planning and scheduling.

Notes:

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



2019

Vancouver, British Columbia, Canada

SIMULATING THE IMPACT OF ORE COMPETENCE VARIABILITY ON PROCESS PERFORMANCE – CASE STUDY OF A LARGE COPPER MINE

15:15, Paper #16

Farhad Faramarzi, Sarma S. Kanchibotla, & Robert Morrison

For decades the minerals industry has been challenged by inherent variability of ore deposits. Quantifying this characteristic of orebodies is becoming increasingly important because the mining industry needs to extract resources with lower grades and more complexities. Ore comminution is the most energy-intensive process in almost all mines and requires designs specifically tailored to aid maximizing the value chain. Although ore variability is frequently debated as a major source of uncertainty in process performance, most of the current ore testing methods do not capture this variability and plant designs and process performance predictions are based on using average values for ore characteristics.

This paper presents an innovative ore characterization approach to quantify ore breakage variability. The new approach extends the standard JK drop weight test (JKDWT) and is therefore called the extended drop weight testing (ExDWT) approach. This characterising strategy has been applied to samples from three domains at a large copper mine. The Julius Kruttschnitt Minerals Research Centre (JKMRC) breakage model is used to describe the competence variability of each domain based on the collected samples in terms of two major components, called hard and soft. These ore characterization results were used in JKSimMet® software to estimate comminution equipment model parameters. The estimated model parameters were transferred into the simulation and optimization platform, integrated extraction simulator (IES) to estimate through constraint-based simulations the impact of ore competence variability on the semi-autogenous (SAG) mill performance of a semi-autogenous ball-mill-crushing (SABC) circuit configuration in a copper processing plant. Simulation results from analysis of breakage variability can potentially assist with more robust plant designs and optimization through a better understanding of the extent of variability of ore competence and its associated uncertainties.

Notes:



ADVANCED MINE-TO-MILL USED TO UNLOCK SABC CAPACITY AT THE BARRICK CORTEZ MINE

15:30, Paper #17

*Malcolm Powell, Ceren Bozbay, Sarma Kanchibotla, Benjamin Bonfils, Anand Musunuri,
Vladimir Jokovic, Marko Hilden, Jace Young, & Emrah Yalcin*

In expanding the mine to process considerably more competent ore sources, this semi-autogenous-ball mill-crusher (SABC) circuit with a single ball mill is not just throughput constrained but will shift to being permanently ball mill limited. The application of a fully integrated processing objective that relies on close cooperation between mine, dispatch, and mill is required to address this challenge. Moving beyond the general perception of mine-to-mill, a deeper processing knowledge is applied along the mining chain, considering blasting as the first stage of comminution and recovery. Grade department and dilution are considered at the mining stage and modelled with the new Sustainable Minerals Institute (SMI) blast movement simulator, linking with the block model data. Based on field trials, blast design and blending strategies are developed to couple with new operating strategies at the mill.

It has been found that accounting for blast movement for the higher intensity blasts could generate additional value of over \$1 million per high-intensity blast. Strategies to shift the workload and debottleneck the milling circuit were proposed and proven during the milling trials, demonstrating an increase in throughput of 16% is achievable. A number of process improvement opportunities, including changing the semi-autogenous (SAG) mill control strategy, have been identified to enhance current productivity and ensure long-term capability to process the considerably more competent future ores. In a departure from traditional once-off applications of mine-to-mill changes, on-site technology transfer is being embedded in online tools to sustain advanced mine-to-mill capability in the daily planning and operation.

Notes:



Vancouver, British Columbia, Canada

15:45, Paper #18

Mine-to-mill (M2M) optimisation is a mature methodology that has demonstrated significant benefits to operations globally. One drawback to the approach is that the audits conducted to calibrate the blasting and comminution models only capture an instant in the operation's life. This can limit scenarios where there are complex ore paths or long-term schedules to be considered.

Notes:

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



DRILL-TO-MILL PLANT OPTIMIZATION AT ALTYNALMAS PUSTYNNOYE GOLD MINE

16:00, Paper #19

S. Esen, M. Daniel, B. Dzhalolov, B. Bachramov, J. Geronimo, & A. Kalmatayev

JSC AK Altynalmas engaged Esen Mining Consulting Pty Ltd (EMC) to conduct a drill-to-mill plant optimization project to determine what opportunities exist to increase the mill throughput and improve the overall mine and concentrator performance. The scope of the project included in-situ ore body characterization, drill and blast improvements, run-of-mine (ROM) fragmentation measurement and modelling, and crushing and milling optimization. Pustynnoye Gold Mine's crushing circuit includes a jaw crusher and two secondary cone crushers operating in closed-circuit with classification screens. The grinding circuit consists of a semi-autogenous (SAG) mill with a pebble crusher followed by two ball mills. The SAG mill is unusual, with a low aspect ratio similar to the ball mills. The ball mills currently produce a final grind size of P_{80} of 75 microns (μm).

Pustynnoye Gold Mine plans to increase the throughput from 2.1 to 2.5 Mt/a and possibly more in future expansions. In order to deliver this capacity increase, management initiated a drill-to-mill project in July 2018.

EMC'S drill-to-mill methodology has delivered significant benefits to the mine: increased fines from blasts (approximately 11% more -10 mm fines; reduced ROM F_{80} from ~500 mm to ~150 mm; increased dig rates (about 25% to 30%); improved wall control; reduced ore loss/dilution; and increased crusher throughput (16.2%); increased mill throughput (11.6%). This paper explains the methodology followed and presents the results.

Notes:



Vancouver, British Columbia, Canada

16:15, Paper #20

The Sadiola Hill Gold Mine (Sadiola Hill) comminution circuit consists of two parallel semi-autogenous grinding (SAG) mills that are in series with a closed-circuit re-grind ball mill. The SAG mills are each operated in open circuit with a dedicated hydrocyclone cluster. The cyclone underflow streams supply feed to the re-grind ball mill. The milling circuit prepares fresh feed for a conventional agitation leach and carbon-in-pulp (CIP) plant, which requires a consistent feed to maintain steady recoveries. The two SAG milling lines receive crushed feed from a common bin that supplies two independent feed belts to the SAG mills. Segregation in storage and during extraction from the bin results in different particle size distributions being fed to the two production lines. In this paper, the authors discuss how a consistent product is obtained from the two identical SAG mills at Sadiola Hill while receiving different particle size distribution material.

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There are no margins, text, or other markings on the paper.



INVESTIGATION OF A NOVEL HPGR AND SIZE CLASSIFICATION CIRCUIT

16:30, Paper #21

Patrick Pearce, Claude Gagnon, Bern Klein, Rob MacIvor, Sami Makni, Fisher Wang, & Amit Kumar

The aim of the Crush It! Challenge is to accelerate transformative solutions to reduce energy usage in the mill. Natural Resources Canada supported competition for innovative energy-efficient comminution with a contribution of \$10 million. In total, 65 proposals were submitted from which 12 were selected as semi-finalists and 6 were subsequently selected as finalists by an external Challenge Jury. Each finalist is eligible to receive up to Cdn\$800,000 to advance their concepts that will be judged in December 2020 when one will be selected and award Cdn\$5 million for advancement toward commercialization. This paper profiles one of the six shortlisted proposals titled “Development of a Novel HPGR and Size Classification Comminution Circuit to Replace Ball Mills.”

Wet ball milling in closed circuit with hydrocyclones exclusively fills the role of the final stage of comminution before the mineral separation circuit in the minerals industry. This includes those recently constructed plants that use Crushing-HPGR-Ball Milling as an alternative to the most common SAG-Ball Milling circuit. The premise of this work is that high-pressure grinding rolls (HPGR), in closed-circuit with some form of classification/dewatering, can effectively replace ball milling in the final grinding step ahead of mineral separation.

Notes:



Vancouver, British Columbia, Canada

08:00, Paper #22

IAMGOLD'S Côté Gold Project is a Greenfields open pit gold mining project located approximately 125 km southwest of Timmins, Ontario, Canada. Côté's mineralization is free-milling. However, grindability testing on several samples from the Côté Lake deposit indicates that the majority of the material is very competent and resistant to SAG milling. A typical SAG mill configuration, even with high ball loads, would not enable processing of this material in an energy-efficient manner. Testwork conducted at COREM using HPGR technology confirmed that this option provided metallurgical and economic advantages over SAG milling in a traditional flowsheet. In addition to lower operational costs, the use of HPGR technology induced micro-cracking of the samples tested which enhanced cyanidation leach kinetics. Therefore, HPGR was selected over SAG milling in the comminution flowsheet. This paper summarizes the results from the comminution and cyanidation testwork program that led to the selection of HPGR technology.

This image shows a single sheet of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page. There are approximately 20 lines visible. The paper has a slight shadow on the right side, suggesting it's resting on a surface.



THE METCALF CONCENTRATOR HRC™ 3000: PERFORMANCE AT VARIABLE SPECIFIC FORCE

08:30, Paper #23

George Zervas

In 2014, Freeport-McMoRan Morenci operations (Metcalf Concentrator) commissioned the first 3 m diameter flanged tire design HRC™3000 high-pressure grinding roll (HPGR) crusher. The unit was installed as part of the tertiary crushing circuit. In 2017, performance evaluation at variable specific forces was completed.

With limited industry experimentation on large-scale operating HPGR equipment, validation of HPGR performance relationships and parameters presented by Klymowsky and Morrell was needed, particularly their applicability to a large-scale flanged tire design.

A series of seven circuit surveys was executed, complete with reliable mass balances and process data collection as the basis for this study. Specific force variability consisted of 2.5, 3.0, 3.5, and 4.0 N/mm² test conditions. For each survey, the following ore characterization was performed on the fresh (circuit) feed: a Bond ball mill work index, a SMC test, and packed bed testing (PBT).

Results of the study validate relationships between specific force, operating gap, and specific throughput on a large plant scale. Circulating load and fresh feed capacity effects related to applied specific force are established with the optimum specific force of 3.5 N/mm² identified for this circuit. Energy efficiency proved to decrease at greater specific forces. Net specific energy ranges of 1.22 to 1.97 kWh/t and 0.79 to 1.42 kWh/t were measured across the circuit and the HRC™3000 itself, respectively, over the span of seven surveys.

This paper presents plant-scale performance data for the first 3 m diameter HRC™3000 circuit installed at Freeport-McMoRan Inc. operations.

Notes:



Vancouver, British Columbia, Canada

08:45, Paper #24

At SAG 2015 AngloGold Ashanti Australia Ltd and Koeppern presented a case study on the first year of high-pressure grinding rolls (HPGR) operation at the Tropicana Joint Venture's (AngloGold Ashanti Australia 70% and manager, Independence Group NL 30%) Tropicana Gold Mine (TGM). It is nearly six years since the mine was commissioned. This case study update describes process optimisation that was undertaken by AngloGold Ashanti with assistance of Koeppern Machinery Australia (KMA). The result of the optimisation is an increase in mine productivity of over 30%. The presentation describes the challenges in all areas of operation—process control, studded lining performance and wear rates, mechanical availability, and maintenance. During the six years of operation, the HPGR demonstrated it was the correct choice, with the project being an unquestionable success story.

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There are no margins, text, or other markings on the paper.



09:00, Paper #25

Chemaf has engaged Outotec to deliver copper and cobalt process technologies to the Mutoshi Mine, located in the Democratic Republic of Congo. The Mutoshi project will make use of milling in raffinate as a major part of the project water balance and process optimization. As such, included in this delivery will be a 6.5 m diameter by 9.4 m effective grinding length (EGL), 8.1 MW acid-resistant semi-autogenous grinding (SAG) mill.

The SAG mill rotating body incorporates technologies from Outotec's extensive acid-resistant milling library. The utilization of advanced design capabilities, manufacturing techniques, and proprietary Outotec technologies has seen the large acid-resistant mill designed and manufactured four months ahead of schedule.

This paper details the Mutoshi comminution circuit design as well as the advantages and challenges associated with milling in raffinate.

Notes:

[illegible]



2019

Vancouver, British Columbia, Canada

HPGRs IN MINERALS: WHAT DO MORE THAN 50 HARD ROCK HPGRs TELL US FOR THE FUTURE? (PART 2 – 2019)

09:15, Paper #26

Egbert Burchardt & Thomas Mackert

Smaller scale beneficiation and concentration plants with a couple of hundred tonnes per hour capacity, as well as large concentrators like Cerro Verde, Mogalakwena, Boddington, Salobo, Sierra Gorda, and Karara have utilized high pressure grinding rolls (HPGR) technology and have operated successfully for more than a decade.

In addition, HPGRs have been installed or retrofitted respectively in semi-autogenous ball mill-crusher (SABC) circuits and were additionally installed in conventional crushing and grinding plants to improve production.

All these installations contributed to a broad knowledge base for current and future applications.

This paper reviews a selection of these installations in terms of:

- Actual performance production results, which created the basis for establishing sound sizing procedures for future HPGR/ball mill comminution circuits
- Process/mechanical and plant layout/design
- Operation and maintenance procedures
- HPGR design improvements to reduce operating cost and increase both availability and throughput.

In this paper, the authors present the conclusions of this review, which indicate suitable means of maximizing the reliability and economics of future HPGR installations.

This paper is an update of the SAG 2011 paper:

“HPGRs in Minerals: What do existing operations tell us for the future?” (Burchardt, 2011)

Notes:



DYNAMIC MODELLING OF A SAG MILL-PEBBLE CRUSHER CIRCUIT BY DATA-DRIVEN METHODS

10:15, Paper #27

Haijie Li, Magnus Evertsson, Mats Lindqvist, Erik Hulthén, Gauti Asbjörnsson, & Graham Bonn

In a semi-autogenous grinding (SAG) mill and pebble crusher circuit, the behaviour of the comminution process is non-linear and time-varying due to wear and variations in the feed material. To describe such a complex system, data driven models were introduced, along with a case study of a SAG mill circuit in Copper Mountain, British Columbia, Canada. This paper presented a mill power draw model using several regression algorithms like Artificial Neural Networks (ANN), K-Nearest Neighbours (KNN), Random Forest (RF), and Gradient Boosting method (GBM). The results were then combined by weighted mean squared errors to perform a more accurate ensemble model. The second method considered the comminution process as a time series problem, so the original dataset was re-structured, and a forecasting SAG power model was proposed by using Long Short-Term Memory algorithm (LSTM). This LSTM forecasting model applied 20 minutes of historical data to predict 2-minute SAG power draw in advance. It was shown that both the presented methods gave promising results for SAG mill power prediction.

Notes:

[illegible]



Vancouver, British Columbia, Canada

10:30, Paper #28

The 40 ft diameter SAG mill at Mount Milligan Mine (MTM) has been in operation since 2013. For the first few years, the SAG mill charge was measured during scheduled downtime and the charging schedule updated accordingly. In late 2017, investigations of the comminution circuit concluded that the SAG mill was not consuming its maximum power draw capability when operating at a 14% to 16% ball charge and 68% to 74% critical speed. Therefore, liner design changes were made to allow for mill speed operation closer to 78% to 81% critical speed. Additionally, the ball charge target was adjusted to 20%.

Notes:

[illegible]



10:45, Paper #29

Martin Houde & Alan Boylston

SEMAFO's greenfield Boungou gold mine in Burkina Faso achieved its first gold pour on June 28, 2018, just 40 months from the project's notice to proceed. The Boungou ore body contains approximately 1.5 million ounces (Moz) of gold in resources and reserves at an average head grade of 4.1 grams per tonne (g/t). Life-of-mine (LOM) is at least seven years at the nominal throughput rate of 4,000 tonnes per day (t/d).

SEMAFO acquired the Boungou project as a concept study in 2015. Following acquisition, an intensive value engineering exercise was undertaken to identify an optimal comminution flowsheet, with specific consideration being paid to operating flexibility, expansion potential, and capital and operating costs. Of the eight alternative flowsheets studied, a semi-autogenous grinding (SAG)-Tower Mill-Pebble Crusher (SA-TM-C) circuit was found to have the most positive impact on project economics. Note that the term “Tower Mill” (two words) used in this paper refers to a generic vertically oriented stirred mill, and not necessarily to the TowerMill (one word) trademarked by Eirich GmbH.

In this paper, we present the results of the value engineering study that supported the selection of the SA-TM-C circuit. SEMAFO's experience during the construction and start-up are also discussed, and plant performance is compared against the design.

Notes:

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



Vancouver, British Columbia, Canada

11:00, Paper #30

The sulphide ore circuit semi-autogenous grinding (SAG) mill at Kansanshi Mine is a 9.75- m diameter and 6.1-m long mill and was designed to discharge onto a vibrating screen, which was adequate for the design throughput of 1,350 and 1,500 tonnes per hour (t/h) nominal and maximum, respectively. However, due to continuous improvements on the crushing and milling circuits, the circuit throughput exceeded the design capacity of the screen, leading to reduced screening efficiency and hampering further throughput improvement initiatives. A study was undertaken to determine the best way to increase the screening area. Retrofitting a trommel screen between the mill discharge and the vibrating screen was chosen as the best alternative. Space limitations meant that the trommel had to be very short, with a relatively large diameter to give sufficient screening area. This in turn meant a large drop exiting the mill and consequently high slurry velocities onto the feed end of the trommel. Computational fluid dynamics (CFD) was used to model the flows out of the mill and through the trommel, allowing various target plates, baffles, and spiral designs to be assessed. The final design was a balance between slowing down the flow sufficiently to hold it in the trommel long enough for the trommel to work, but without backing it up so much that it flooded the trunnion and caused back-flow into the mill. This paper gives details into the performance of the trommel since installation.

[illegible]



ZINKGRUVAN ZINC LEAD AND COPPER CONCENTRATOR THROUGHPUT UPGRADE

11:15, Paper #31

Mark Elphinston, Erik Fredriksson, Kenneth Brandt, & Ante Vasara

The Zinkgruvan Mining concentrator in central Sweden was upgraded in 2010 to create a separate line for the mine's copper ore. That line was further modified in 2011 to process zinc-lead ore in between the copper milling campaigns. In May 2017, an autogenous grinding (AG) mill was commissioned to allow continuous parallel operation with the existing grinding circuit for both zinc-lead and copper ores. This would become Zinkgruvan's second AG mill. Zinkgruvan is part of the Lundin Mining group.

The AG mill selected by Zinkgruvan Mining was a 1.8 MW, 5.1 m x 7.0 m dual drive Sala mill manufactured in 1974. The mill had been located at Boliden's Garpenberg mine where it became redundant after an expansion in 2014.

Outotec was engaged to provide relocation, refurbishment, installation, and commissioning services. The upgraded and refurbished AG mill consists of the original mill shell, heads and gear with new upgraded Outotec hydrostatic main bearings, trunnions, ring gear guard, feed and discharge assemblies, base plates, and foundation items. Outotec also supplied a modernized control philosophy with installation and commissioning performed by the Outotec service centre in Sweden.

This paper will be structured by first outlining the benefits and flexibility provided to Zinkgruvan's flowsheet by the addition of an AG mill. Secondly, it will discuss the benefits and outcomes afforded to Zinkgruvan's project through the selection and refurbishment of the existing mill. Third, the authors will discuss the mechanical audit methodology, design of the modernized components, and refurbishment process. Finally, the paper will conclude by demonstrating how the project has been successful for both Zinkgruvan and Outotec with feedback on the two years of operation since commissioning.

Notes:



Vancouver, British Columbia, Canada

11:30, Paper #32

The benefits of resetting the Batu Hijau SAG circuit are reported in this paper along with the challenges encountered during the process, such as ore characteristics and material handling.

Notes:

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



IMPLEMENTING THE FIRST THUNDERBOLT SKYWAY WITH INSIDEOUT TECHNOLOGY AT COBRE PANAMA

13:15, Paper #33

Timo Ikaheimonen, Peter Rubie, Stephen Gwynn-Jones, & Joel Bohorquez

First Quantum Minerals Ltd (FQML) is currently commissioning the world's first THUNDERBOLT SKYWAY system and INSIDEOUT Technology for improving the safety and speed associated with mill relining at Cobre Panama. FQML, as an industry leader and early adopter, partnered with Russell Mineral Equipment (RME) to implement these new technologies, which will enable mill relining to be completed without people inside of the mill.

The SKYWAY system at Cobre Panama is designed to work with the two Metso SAG mills, and one Outotec SAG mill on site. The major structural components are called the towers and rails and are specific to each mill and plant layout. The modules that convey the THUNDERBOLT Hammers and relining personnel are standardized and can be re-used between each SKYWAY system. This paper discusses the way in which the SKYWAY system has been integrated into the greenfield plant design.

The choice to implement THUNDERBOLT SKYWAY and INSIDEOUT Technology at Cobre Panama was based on both performance and safety benefits. The performance benefits for the system were predicted using RME's MILL RELINE DIRECTOR simulation capability. This paper contains the results of the analysis that predicts the relining duration at Cobre Panama, and compares this performance to the durations that would have been achieved with traditional relining methods.

Notes:



Vancouver, British Columbia, Canada

13:30, Paper #34

Rosebel Gold Mine (RGM) has increased its comminution circuit hard ore throughput from 4.3 to approximately 7.3 million tonnes per annum (Mt/a) via several expansion initiatives and circuit optimizations to allow for sustained throughput rates at increased hard rock ore ratio. Investigation into the performance of the 30-foot (ft) Semi-Autogenous Grinding (SAG) mill identified that the SAG mill's liner design was sub-optimal for processing hard rock ores. The increase in throughput rate was achieved by developing aggressive lifter designs, which project the largest amount of grinding media onto the toe of the mill charge. The change from the original design of 60 lifter rows to 40, and then 30 rows with the appropriate face angle for use with a larger grinding ball, allowed the increase of the SAG mill's rotational speed from 70.0% to 75.6% critical speed, which increased hard ore throughput rates. This paper describes the changes to the SAG mill's set-up including lifters, grates, and grinding balls.

[illegible]



THE DESIGN AND EVALUATION OF SAG MILL LINER TRIALS

13:45, Paper #35

Paul Toor, Walter Valery, Lachlan Brennan, & Kristy Duffy

Development of SAG liners has always been of considerable interest to mill operators as liners significantly affect plant performance (throughput, grind size), material costs and plant downtime. Thus, operators commonly trial different liner shapes, profiles, and configurations. However, there is little to be found in the way of guidance on how to conduct such trials and evaluate the benefits. Conducting liner trials involves a significant investment and the risk is usually considered high. There is potential for loss of production if the trial liners underperform or if they need to be removed prematurely due to reduced wear life or poor performance.

In terms of data analysis to evaluate the benefits of trial liners there are some inherent difficulties. Firstly, it is impractical to conduct an on-off trial, hence there is generally only one data set for analysis. Furthermore, the liner shape is dynamic due to wear, with the progression in wear yielding differing mill performance in terms of throughput, power draw, and size reduction over the life of the liner. Thus, a before and after comparison may provide an overly simplified and erroneous result. Finally, the fact that the service life of a liner is in the order of months means that both the wider plant and the ore being processed are often subject to significant variation over the course of a trial. This means that comparisons between liners can only be made by rigorous statistical analysis or process modelling if reliable conclusions are to be drawn.

This paper aims to provide guidance for conducting SAG liner trials and tools and techniques to evaluate the results. This will allow mill operators to minimize the risk associated with liner trials and provide increased confidence in any conclusions and recommendations.

Notes:

[illegible]



2019

Vancouver, British Columbia, Canada

GRATES PLUGGING IN HIGH DIAMETER SAG MILLS: AN OVERVIEW ON OPERATIONAL ANALYSIS

14:00, Paper #36

Sergio A. Olmedo & Cristian Rioseco

During the operation of large diameter semi-autogenous grinding (SAG) mills, mainly 40 ft and 38 ft some of these mills have experienced problems with worn grinding media balls trapped in the grates slots and causing blockage. This can result in shutdowns, reduced equipment availability, and loss of concentrate production.

Researchers have studied parameters and operational variables that are most likely causing this issue, and which of these have a higher probability of affecting operations. The authors have examined a wide body of operational information about 40 ft SAG mills in South America in hopes of identifying the main variables and completing a comparative evaluation. At the same time, the authors have implemented analysis methodologies for grates and grinding media, in order to identify a feasible solution.

One possibility explored involves simulations using the discrete element method (DEM) to estimate the pressure applied to the entire surface of the grate under different operational conditions in a SAG 40 ft mills. Technical workshops on this topic developed for operators of 40 ft SAG mills are underway in Chile as participants aim to find solutions applicable in their facilities. In this paper, the authors summarize the operational practices and conditions likely to result in plugging, as well as the progress of studies seeking to explain causes and preventative measures.

Notes:



14:15, Paper #37

A ball mill with new (NL), mid-worn (MWL) and worn liners (WL) was evaluated under typical grinding circuit conditions. Additionally, a mill survey with new liners at lower mill speed (NLLS) was evaluated. An extra 10% to 20% in energy savings (working index efficiency at approximately similar P_{80}) could be found by adapting the mill's operational parameters (speed) based on liner profile, but this energy savings cannot be evaluated independently of the evaluation of the grinding circuit functional performance equations (in this study, the reference was t/h of -75 μm).

Notes:



2019

Vancouver, British Columbia, Canada

A PARTICLE SCALE MODEL FOR SIMULATION OF SAG MILL PROCESS PERFORMANCE: MODEL COMPONENTS AND APPLICATION TO PILOT AND INDUSTRIAL SCALE MILLS

15:15, Paper #38

M. D. Sinnott, P. W. Cleary, & R. D. Morrison

This particle scale model is based on a full 2-way coupling of the discrete element method (DEM) and smoothed particle hydrodynamics (SPH) methods. Motion and breakage of resolved coarser particles within a SAG mill are performed by the DEM component. Fine particles in the feed or from breakage of coarser particle fractions combine with the water to form a slurry, which is well represented using the SPH component of the model. The changing solids loading in the slurry, controlled by the progressive generation of fine particles from the coarse rock breakage, controls the slurry rheology. The slurry size distribution is discretized allowing the transport and dispersion of fine material to be tracked at each point in the slurry by solutions of coupled advection-diffusion equations in the SPH part of the model. Grinding of the finer particles in the slurry due to collisions and shear of the coarser particles (rocks and grinding media) is performed by solving a local population balance model for each SPH particle. This allows, at least in principle, the prediction of the breakage and transport of coarser material and the transport of the finer material within the grinding and pulp chambers of a semi-autogenous grinding (SAG) mill including discharge performance of the mill. The ability of this particle-scale model to predict performance (meaning throughput, product size distribution, resident particle size distribution, net power draw, wear) for a SAG mill is explored for a Hardinge pilot mill and industrial scale 36 ft SAG mill, which is based on scaling up the Hardinge mill. The model includes axial transport components such as rock feed, water addition, internal slurry transport, and mixing flow through the grate, and flow within and out of the pulp chamber.

Notes:



LINKING THE PACKED BED TEST TO FULL SIZE HRC™ HPGR PERFORMANCE

15:30, Paper #39

Xiangjun Qiu, André Vien, Mike Mular, Dilek Alkac, & Bill Pate

The industry would benefit from a small-scale (~1 kg) lab test capable of predicting the performance of the HRC™ high pressure grinding rolls (HPGR), a flanged roll HPGR. An ore characterization test at this small scale is an economical means to predict HRC™ performance with respect to an entire range of ore types within a given deposit. The packed bed test (PBT), also known as the piston and die test, is the most promising candidate to fulfill this need due to its small sample size requirement and mode of compression being virtually identical to that of the full-size HRC™. In this paper, the mechanics of the HRC™ are represented using the principles of plasticity theory to obtain the stress distribution across the surface of the tires. We present a semi-mechanistic model which uses the constitutive relationships obtained from augmented PBT data to obtain the contact stress distribution by solving the governing system of equations for the force balance and the yielding condition. The results of the PBT are used to estimate the HRC™ power and throughput from the plastic rolling resistance model (PRR, generally referred to as the performance model). The results of the PBT and the performance model are also used to predict the product size distribution using the natural selection function (Vien, 2019) population balance model (PBM, generally referred to as the breakage model). Both the performance model and the breakage model have been validated with circuit surveys of the HRC™3000 installed at Freeport-McMoRan's Metcalf concentrator.

Notes:



Vancouver, British Columbia, Canada

15:45, Paper #40

High-pressure grinding rolls (HPGR) are getting more attention from comminution process designers. For brownfield expansions or new greenfield investment projects, existing laboratory scale tests – like the so-called Piston Press Tests (PPT) – are being used to generate large amounts of empirical data to populate their respective geometallurgical databases. Based on this laboratory-scale data, designers must face the challenge of establishing reliable scale-up criteria to predict the anticipated performance of the new full-scale HPGR installation.

The resulting EXCEL-based simulator can also be applied to the analysis and optimization of any existing or future operations.

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



THE NATURAL SELECTION FUNCTION AND ITS APPLICATION TO CRUSHING AND GRINDING

16:00, Paper #41

André Vien

The product size distribution resulting from comminution is usually described using a population balance model (PBM) that employs a selection (rate of breakage) function and a breakage (appearance) function to describe how fast each particle size class breaks and the resulting daughter particle size distribution, as described by many authors. The term in parenthesis is the corresponding terminology used by the *Julius Kruttschnitt Mineral Research Centre* (JKMRC) and in JKSImMet. It has long been known to JKSImMet users that, for a ball mill, the breakage function does not need to be modified for different cases. Adjusting the selection function will suffice to fit the data. This paper details that this is possible because the solution to the grinding equation is not unique. This led to the search of a breakage function/selection function pair that may be a more natural solution to the grinding equation compared to other possible solutions. Such a pair was found and is described herein. Examples of its application to ball milling, cone crushing, and roll crushing (Metso's HRC™ high pressure grinding rolls [HPGR]) are presented.

Notes:



Vancouver, British Columbia, Canada

16:15, Paper #42

The addition of a pre-crushing stage to semi-autogenous-grinding (SAG)–ball mill-crushing (SABC) circuits is gaining popularity in the mining industry. Industrial experiences show that this practice is able to increase the performance of the SAG mill. Variations in ore competence, hardness and/or liberation size are usually found between different geo-units within one ore deposit. The comminution circuit may perform differently in terms of throughput and product quality, as the property of the feed ore varies. This study investigated the energy performance of an SABC circuit with pre-crusher under a dynamic operating condition.

Notes:

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



USING MODELLING TO OPTIMISE A SINGLE-STAGE SAG CIRCUIT OPERATED IN CLOSED CIRCUIT WITH HIGH FREQUENCY FINE SCREENING TECHNOLOGY

16:30, Paper #43

J.J. Frausto, G.R. Ballantyne, K. Runge, A.N. Mwale, M.S. Powell, & A.N. Mainza

Comminution is perhaps the most energy-intensive step of the mineral processing value chain. Therefore, maximising the use of the energy available in this stage is crucial for sustainability. The development of new or improved technologies and their early adoption in circuit design provides an opportunity to improve the efficiency of the mining industry. For instance, there are many existing plants that have SAG mills installed in a single-stage grinding configuration, the easiest way to maximise energy utilisation may be retrofitting improved classifiers. Classification plays a key role both in overall energy utilisation, energy per ton of ore processed, as well as grinding performance, suitability of product for downstream recovery, for single stage SAG milling circuits. In that regard, recent developments in fine screening technology offer the opportunity to explore their installation in single stage SAG mill applications. This paper presents a modelling study to develop strategies for single stage SAG mills closed with high frequency fine screens. The study aims to quantify the potential benefits of installing fine screening technology with existing single stage SAG circuit operations. This alternative circuit design is proposed as an option for small-scale operations, as well as a potential path for an expansion. The benchmark is expressed in terms of throughput and energy efficiency.

Notes:

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



Vancouver, British Columbia, Canada

08:00, Paper #44

MMG led the consortium that acquired the Las Bambas mine in 2014. The mine location is at an elevation of over 4,300 metres above sea level (masl) and is a very remote site with significant logistical requirements. The mine has three deposits; namely Ferrobamba, Chalcobamba, and Sulfobamba. The Las Bambas construction was launched in 2012 and the concentrator commissioning commenced in the last quarter of 2015. Within seven months of first ore feed the concentrator ramped up, exceeded the nameplate capacity of 140,000 tonnes per day (t/d), and has subsequently performed more than satisfactorily in the past three years. The comminution circuit features two 60" x 113" primary gyratory crushers connected by a large overland conveying system to two grinding lines, each having one 12.2 m dia. by 7.6 m flange-to-flange gearless semi-autogenous grinding (SAG) mill and one 7.9 m dia. by 12.2 m long gearless ball mill and two cyclone clusters. Three MP1000 pebble crushers are in closed circuit with the two SAG mills. This paper reflects on the construction and commissioning of the mill, the operating performance relating to the comminution equipment, and the plans to enhance the circuit performance as additional ore sources come online.

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



DESIGN AND START-UP OF THE MERIAN SABC CIRCUIT

08:30, Paper #45

Scot Davies, Aidan Giblett, & Nengah Dwi Payana

The Merian Gold Project (the Project), located in north-eastern Suriname, commenced commercial production in October 2016. The Project is operated by Newmont Goldcorp Suriname, with the government of Suriname indirectly participating in a fully funded 25% equity ownership stake. The Merian plant is designed to produce 400,000 ounces per annum (oz/a) to 500,000 oz/a during the first five years of operation, while processing on average 12 million tonnes per annum (Mt/a) of open pit ore through a conventional gold recovery flowsheet. Actual gold production in 2018 was 526,000 oz from 14.2 million tonnes (Mt) milled. Overall mine life is currently 13 years with reserves of 5.0 million ounces (Moz) on a 100% basis as of December 31, 2018 (124 Mt at 1.25 g/t).

The process plant incorporates primary crushing, SABC milling, gravity concentration, conventional cyanidation, carbon adsorption, elution, and tailings storage. The SABC grinding circuit has a 10.36 m diameter x 5.79 m length (flange to flange) variable speed Metso SAG mill with an installed power of 13 MW (twin 6.5 MW). A 7.31 m diameter x 12.83 m length (flange to flange) Metso trunnion overflow ball mill with an installed power of 13 MW (twin 6.5 MW) is operated in closed circuit with 650 mm cyclones to provide a 75 microns (μm) product to leach circuit.

The design and construction of the Merian Processing Plant represented a new approach for Newmont Goldcorp Corporation (Newmont Goldcorp) with a focus on lean design and accelerated schedule, resulting a unique set of challenges for the team to work through. Equipment selection for the SABC comminution circuit presented some challenges with significant variations in ore competence between surface saprolite and deeper fresh rock, requiring a degree of scalability to be built into the plant design and mine plan. The lean design focus introduced compromises into the overall plant layout, while an accelerated project development schedule impacted the ore characterization program and required a robust approach to risk management. The plant, by necessity, was commissioned on 100% saprolite feed from the Merian 2 pit, material, which presents a number of difficulties unrelated to grinding energy requirements and grinding efficiencies. Notwithstanding the challenges, the milling circuit at the Merian Gold Mine was successfully commissioned, and a number of efficiency improvements have been made to further improve plant reliability and realise significant capacity upgrades.

Notes:



Vancouver, British Columbia, Canada

8:45, Paper #46

The Raglan Mine, part of the Glencore Group, is located in Northern Quebec and commenced production in 1997. The process plant was initially designed to process underground ores at 0.85 Mt/a. Throughout the years, Raglan has made modifications to the process plant such as converting the autogenous grinding (AG) mill to a semi-autogenous (SAG) mill that achieved the capacity of 1.3 Mt/a in 2008. In 2013, an expansion study was launched to develop new underground mines to expand the overall life of mine. New opportunities were identified in 2016 to debottleneck the milling circuit such as introducing a new Vertimill™ in tertiary grinding to ensure that the circuit could handle variable ore hardness at the new target throughput of 1.5 Mt/a. In late 2018, the new tertiary grinding circuit was commissioned, and production is now in line with the new desired throughput and final grind. In this paper, the authors discuss the modifications related to the comminution circuit expansion at Raglan and focus on the solutions considered and challenges encountered in the design, commissioning, and operation of this circuit.

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There are no margins, text, or other markings on the paper.



IMPROVEMENT OF CIS STANDARD IRON ORE CIRCUIT BY HPGR

09:00, Paper #47

Felix Heinicke & Artur Hubert

During the past decades, it was standard to build iron-ore circuits in Commonwealth of Independent States (CIS) countries using 3-stage crushing followed by ball mill grinding. The optimization of those plants regarding throughput finds its limits in cases where no additional grinding equipment was installed that had the ability to reduce the transfer size to the ball mill. From other applications, the high-pressure grinding roll (HPGR) is known to do this job very efficiently at low energy consumption and low wear costs. This contribution presents the results of eight HPGR that were commissioned in 2016 and 2017 in a magnetite processing plant in Russia. It will also address start-up optimization work and material research to reach the present throughput increase of 12.5%. As a consequence, this technology attracted the attention of many major iron ore producers and thereby can be seen as pioneering and leading to optimization of other CIS standard iron ore circuits.

Notes:

[illegible]



2019

Vancouver, British Columbia, Canada

OPTIMISATION OPPORTUNITIES AT NEWMONT GOLDCORP'S PEÑASQUITO OPERATION

09:15, Paper #48

Peter Lind, Kevin Erwin, Rajiv Chandramohan, Dale Tweed, Greg Lane, Paul Staples, Simon Hille, Bianca Foggatto, Jaime Awmack, & Ben Patterson

Newmont Goldcorp's Peñasquito operation, located in the state of Zacatecas in northwest Mexico, is currently undergoing a series of optimisation works to increase throughput through the comminution circuit. Primary crusher product feeds the comminution circuit, comprising a parallel train of two SAG mills, pebble crushers and four ball mills. Additional feed is augmented through the primary comminution circuit from a separate circuit consisting of a secondary crusher and an HPGR.

As part of the optimisation plan, Ausenco, Peñasquito, and Newmont Goldcorp Technical Services defined clear strategies classified into short-, medium-, and long-term opportunities in preparation for the future competent ore sources. The comminution circuit at Peñasquito was operating below its full potential due to some unit operations not fully drawing installed power as well as material handling bottlenecks limiting individual circuit throughput.

Some of the critical comminution optimisation strategies included:

- De-constraining the SAG mill throughput with optimized operational load set points and revised process control
- Redesigning the SAG mill liners for optimum load and speed control
- Optimising crushing and HPGR operation for maximised throughput rates at the minimised product size distribution.

Ausenco's comminution optimisation tool, Ausgrind, was used to benchmark and analyse plant data with empirical models, predict circuit performance for varying ore characteristics, evaluate SAG mill liner wear, and predict the life for varying operating parameters. Variances between the actual and the predicted values were assessed in detail to identify missed opportunities and help guide operations with re-defined operating parameters to maximise throughput and productivity.

Notes:



THE HofAlign GIRTH GEAR

10:15, Paper #49

Karl Hofmann & Leighton White

Due to the size of girth gears required to transmit the necessary torque to permit rotation on a mill, a gear is often split into a number of segments for logistic, handling, and fitment purposes. Girth gear segments are bolted together with a traditional flange arrangement creating local areas of high stiffness about the circumference of the gear, contrasted with local areas of high flexibility in the areas where flanges are not present. To counter the effect of having variation in stiffness about the circumference of the gear, mill gears are typically manufactured with gussets about the radius of the gear to stiffen the complete circumference of the gear rim.

Stiffening the gear discourages flexibility, causing misalignment leading to poor contact with the mating pinion. In service, motion causing pinion misalignment generates heavy contact in localised areas of a gear tooth. High stresses in the material as a result of heavy localised tooth contact cause tooth deflection and leads to premature gear failure due to surface deterioration (pitting) and fatigue, in addition to contributing to the inability to efficiently transmit high torques before inevitably failing.

There is nothing new about eliminating the gussets from a girth gear; however, it is generally implemented on spur gears that do not exhibit a helix angle. The HofAlign Girth Gear will provide all of the loading benefits associated with helical girth gears with the ability to dampen and in many cases eliminate the adverse effects of gear mesh misalignment.

Notes:

[illegible]



Vancouver, British Columbia, Canada

10:30, Paper #50

In the past decade, the maintenance paradigm has shifted from corrective and preventive maintenance to predictive maintenance for improving reliability and availability of assets in the mining industry. Predictive maintenance, in contrast to the former paradigms, continuously monitors assets and offers condition-based maintenance. In order to develop reliable condition-based maintenance, a significant amount of data must be collected, managed, and analyzed, using big data technologies, advanced signal processing, and machine learning techniques. In this paper, we explain a cloud-based condition-monitoring platform for ABB grinding applications, using some industry prediction examples that benefit from Microsoft Azure services and ABB Ability™.

[illegible]



USING THE “TWO MILLS ONE DRIVE” CONCEPT TO SAVE OPERATIONAL COSTS

10:45, Paper #51

Ormond O'Neil

State-of-the-art grinding technology requires a variable-speed semi-autogenous grinding (SAG) mill and a fixed-speed ball mill. This involves using a variable-speed motor for the SAG mill and a wound-rotor induction motor (WRIM) for the ball mill. The “two mills one drive” concept uses standard off-the-shelf induction motors to drive both mills, both in single-pinion and dual-pinion applications.

How the system works: the drive first starts the ball mill for fixed-speed online operation. When the ball mill reaches the required speed, the drive switches to the SAG mill for start-up and variable-speed operation. Reliable frozen charge detection is available for both starts.

The key advantage for mill operators is the simple motor design. Squirrel-cage induction motors (SCIMs) do not produce carbon dust from the brushes, do not have any wear of slip rings and brushes, and do not require any special maintenance or repair capabilities. The maximum benefit can be obtained if one spare motor fits both mills.

Notes:

[illegible]



2019

Vancouver, British Columbia, Canada

ASSET HEALTH ANALYTICS OF A GEARLESS MILL DRIVE

11:00, Paper #52

Kurt Tischler

Today's standard approach to the maintenance of equipment is still heavily focused on reactive and preventive maintenance. Reactive maintenance is an undesirable procedure because unplanned downtime and loss of production are the consequence. Diagnostic analysis avoids repetition of the specific situation, but this is a reaction and not a proactive approach. Preventive maintenance is a series of planned maintenance activities, scheduled during pre-planned dates for downtime of the equipment. Preventive maintenance aims to avoid unplanned outage of equipment by applying the experience of the supplier and of the maintenance staff.

The proactive approach of asset health analytics targets predictive maintenance. Predictive maintenance is based on prescriptive analytics. It detects potential problems of the equipment before they occur and before the equipment must be shut down to avoid damages. With the prior knowledge of an undesirable development, predictive maintenance is planned at one of the next scheduled mill maintenance dates or an alternative date where maintenance can be scheduled. Furthermore, predictive maintenance avoids unnecessary work, costs and downtime, executed just because the activity is on the schedule for preventive maintenance.

The goal of the Siemens asset health analytics of gearless mill drives (GMD) is to replace reactive and preventive maintenance by predictive maintenance. It consists of three pillars:

1. Fingerprint methodology
2. Mathematic modelling
3. Artificial intelligence.

The fingerprint methodology compares current measurements with memorized typical measurements of a healthy condition of the GMD. The measurement data are pre-processed (e.g., frequency analysis of vibrations) and the data sets are assigned to operating points creating the fingerprints with time stamps. Asset health analytics compares the current fingerprint with the fingerprint of the healthy condition and analyzes any deviation regarding their characteristic patterns.

Mathematic modelling applies theoretical models, used for the design of the GMD, to evaluate the current operating conditions by comparing the results of the model with current measurements.

Artificial intelligence employs advanced pattern recognition and anomaly detection techniques to identify any deviation from normal behaviour at a very early stage.

Notes:



CONTINUOUS IMPROVEMENT IN MILL RELINING AT ESCONDIDA

11:15, Paper #53

Reynaldo Martinez, Peter Rubie, Joel Bohorquez, & Stephen Gwynn-Jones

Escondida's Los Colorados concentrator has been operating since 1990, with Laguna Seca Line 1 expansion coming online in 2002, and Line 2 in 2015, and is continuously improving the practices and safety of relining the mills on site. This paper summarises some of the improvement methods that Escondida has trialled with Russell Mineral Equipment (RME).

In 2014, Escondida engaged RME to complete a MILL RELINE DIRECTOR (MRD) Filmed Study to investigate ways of improving concentrator performance and utilisation. RME deployed specialist technicians and cameras to record four relines of Laguna Seca SAG number 4 to reveal practical pathways to reducing mill relining duration. Three significant opportunities were identified to achieve this. The first of these recommendations to be implemented concerned improvements to the discharge end liner design, which resulted in a reduction in reline duration of approximately 30 hours. The MRD simulation predicted a duration that was within a few hours of the actual duration. This paper contains the results of these simulations and compares them to the actual performance achieved.

In 2018, Escondida partnered with RME to complete INSIDEOUT Technology trials with the ultimate goal of allowing the mill to be relined without personnel inside. These trials were focused on testing specific aspects of the INSIDEOUT Technology and studying if there was any impact on relining speed. This paper contains the results of these trials, demonstrating that the INSIDEOUT Technology allows relining to be completed with no significant time penalties compared to traditional relining, and with no personnel inside of the mill.

Notes:



2019

Vancouver, British Columbia, Canada

INCREASED THROUGHPUT FROM LINER DESIGN INITIATIVES IN THE AKTOGAY 40 FT SAG MILL

11:30, Paper #54

C. Faulkner, N. Lozovoy, S. Kumar, & J. Lee

The Aktogay Mine is a large open pit mine located in southeastern Kazakhstan in East Kazakhstan province approximately 250 kilometres (km) from the Kazakhstan – China border. Aktogay is KAZ Minerals' second major growth project. The Aktogay orebody consists of an oxide deposit on top of a larger sulphide deposit, the latter containing some valuable molybdenum as a by-product. The Aktogay project has a measured and indicated oxide ore resource of 74 million tonnes (Mt) with a copper grade of 0.37%, and a sulphide ore resource of 1,558 Mt at a copper grade of 0.33%. The sulphide ore extracted from the Aktogay Mine is processed at the concentrator on site with a production life of over 50 years (to be shortened to c.28 years after the construction of the second concentrator, which is underway). The first concentrator was commissioned in late 2016 with a 40 ft diameter x 26 ft long semi-autogenous grinding (SAG) mill and two 28 ft diameter x 44 ft long ball mills supplied through FLSmidth.

The 40 ft SAG mill was supplied with a traditional bi-directional OEM lining system manufactured from chrome molybdenum steel and liners were installed utilising a 4,500 kg RME 7-axis reline machine. Since mill start-up in December 2016, the SAG mill was monitored on a regular basis to determine liner performance and wear patterns to understand the critical areas of the mill lining that were driving maintenance relines. During the first two sets of OEM liners, the tonnes increased from 2,034 t/h to 2,343 t/h, but remained well short of the target name plate 3,102 t/h.

During 2017, through a continuous improvement program, potential improvements to the liner system were identified that could increase mill performance as well as address high wear areas of the liners that were driving liner replacement. A decision was made to investigate and carry out Discrete Element Modelling (DEM) on the benefits of converting the SAG mill to a Uni-directional mill and take advantage of the Bradken Vortex discharge system, whilst customising the feed end of the mill lining to improve wear performance and maximise reline efficiencies. A Uni-directional shell liner design has been initiated for phase two of the transformation to be implemented in 2019.

The SAG mill was relined in April 2018 incorporating the new design enhancements. These initiatives also included a 15% reduction in the quantity of liners installed which delivered an immediate improvement in mill availability. The first three months of operation after installation of the Bradken Vortex discharge system resulted in mill throughput increasing by 28.5% from 2,343 t/h to an average of 3,012 t/h. Further reduced wear and mill uptime benefits are expected to be realised over time as a result of utilising premium materials in the manufacture of certain products during the liner redesign. Introduction of the advanced 3D liner wear monitoring and reporting package is also expected to deliver data that will be used to improve liner profiles and life cycles. The 3D data captured during the highly accurate terrestrial laser mapping process is used to engineer the next generation liner design.

The paper outlines the approach used to identifying and implement design changes used in the optimisation of the Aktogay 40 ft SAG mill lining system and summarises the operational performance improvements realised and the future design initiatives being investigation.

Notes:



DESIGN OF GIGANTIC COMPOSITE LINERS FOR LARGE SAG MILL APPLICATIONS

13:15, Paper #55

Juan Bustamante, Ernesto Mori, & Javier Toro

A Chilean Copper mine with a 40-foot (ft) diameter SAG mill processing 4,300 t/h was facing very low availability due to repeated, unexpected shutdowns for liners failing because of cracks. Several kinds of alloys and designs were provided but results were out of control producing low production levels. Reasons of the critique are related to the mill operating with high ball charge levels and ball size up to 6.25-inch diameter, producing cracks on liner, bolt breakage, and more.

Failure analysis on steel liners and some hybrid designs showed that the failure mechanisms were related mainly to the third ring of the shell, and produced by the direct impact of grinding media on the liners. The amount of impact energy was beyond the design capacity of the liners used; therefore, the failures were happening uncontrollably after the second month of operation and randomly throughout the remaining liner lifetime.

The 6.25-inch ball size was producing adiabatic cracks because the of the huge amount of energy transmitted to the liner over a very short time. There was no time to dissipate this amount of energy by the mechanical deformation of the steel, which led to cracking and liner failure.

Due to the design of the shell liner, the cast liner was designed considering a huge mass of lifter bar with shell plate incorporated at the both ends adding another problem due to the differences of thickness between lifter and shell plate portions making more complicated the manufacturing of cast liners.

Cast manufacturers tried to avoid the cracks by using alloys more ductile, but that sacrificed the wear life and also produced cold welding due to impacts, making liner removal a very tough task.

Some hybrid solutions were applied to try to solve the problem, but failures continued due to the wrong design concept that lacked the capacity to absorb the impact energy.

A complete analysis and study of forces applied, and the evaluation of impact energy was done by Tega and a novel floating design was developed, combining the best characteristic of every material in the different zones of the liner according to the mechanical behaviour expected. DEM and FEM simulation demonstrated the solution was the right one and several in-field trials were conducted to validate the solution, with optimal results.

This paper follows the complete process of the study, analysis, solution, validation, and in field trials to improve the availability of the mill using a state-of-the-art composite material solution for the toughest applications on the largest SAG mills.

Notes:



2019

Vancouver, British Columbia, Canada

COMPARATIVE STUDY OF MILL DISCHARGE SYSTEMS USING COUPLED DEM SPH SIMULATIONS

13:30, Paper #56

Dr. Vasile Murariu

The performance of grinding mills depends on many factors including design and operational parameters, which include liner profiles, grate design and grate open area, pulp lifter design, mill's rotational speed, ore hardness, etc. Many times, the grinding process inside the mill produces enough fine material, but the full discharge of the fines is limited by the discharge system. Radial pulp lifter designs with higher recirculation loads in the pans combined with grate designs that allow increased amounts of ore to be recirculated back into the mills are often the primary cause for an efficiency drop in the mill. Most of the time, these situations are accompanied by higher mill power consumption, increased wear, and slurry pooling. This paper presents the comparative analysis of several grinding mill discharge systems using Metso Minerals Inc. Discrete Element Method (DEM) coupled with Smoothed Particle Hydrodynamics (SPH) code.

The analysis focuses on a slice of the mill, the conical discharge system, the discharge grates, the discharge pulp lifters, and the trunnion. We compare, in this study, different pulp lifter designs including radial, curved, and twin chamber by evaluating several key characteristics of the discharge systems for each design under the same initial conditions. These key performance parameters are discharge rates for solids and water, hold-up amounts in the pans for solids and water, and flowing rates of the solids and water through the grates in both directions (from inside the mill into the pans and from the pans back into the mill). This ability to accurately simulate the mill discharge system in combination with a slice of the operating charge is a new simulation capability and provides for a more representative evaluation of the mill conditions. The model has been calibrated against plant data for a 32-foot (ft) autogenous mill (AG) with radial discharge pulp lifters.

The analysis method used in this study could be a very useful tool for the operators and mine managers to decide which type of discharge system will perform better under certain operational parameters and what changes might be implemented to improve a mill's performance.

Notes:



OPTIMIZING PULP LIFTER DESIGN USING SPH SIMULATION: TRITTON STORY13:45, Paper #57

N.S. Weerasekara & S. Town

The pulp lifter is an integral component of autogenous (AG) and semi-autogenous (SAG) grinding mills, because it controls the mills' throughput, performance, and efficiency. The slurry transport from the AG/SAG mill through grate apertures into the discharge trunnion is the main function of the pulp lifter. This process develops complex flow behaviours in this area of the pulp system. Efficient and effective discharge of pulp/slurry from the mill is the key objective of the pulp lifter design.

Smoothed particle hydrodynamics (SPH) is a relatively new numerical method to solve equations of fluid dynamics by replacing the fluid with a set of particles. SPH has the computational advantage, particularly in problems involving fragments, drops, or stars that the computation is only where the matter is, with a consequent reduction in calculation. The SPH method is capable of dealing with problems such as free surface, deformable boundary, moving interface, wave propagation, and solid simulation. However, all these applications require excessive computation time if a fully three-dimensional simulation is to be carried out. Therefore, multi-CPU systems will require considerable computation time and effort. Graphics processing units (GPUs), on the other hand, are designed to treat a high data flow and to render pixels, so from a computational point of view they are highly efficient. GPUs appear as an accessible alternative to accelerate SPH models using a powerful parallel programming model where the graphics card is used as the execution device. This new technology makes numerical simulation of real-life engineering problems using SPH realizable and faster.

The traditional Computational Fluid Dynamics (CFD) methods generally struggle to model complex flow behaviour in applications/components like pulp lifters. This work aims to understand the complex slurry flow behaviour in the pulp lifter sections and its interface to the mill performance using SPH. This understanding is then used to build a computational framework for modelling industrial pulp lifters and investigating unique problems associated with their design and performance.

Aeris Resources Tritton Copper Mine Operation, in Australia conducted a grinding circuit survey to evaluate current circuit performance and investigate opportunities to increase throughput while maintaining a target P_{80} of 75 microns (μm). It revealed that there is opportunity to optimize the existing pulp lifter design. This paper will present the design optimization of the Tritton SAG mill pulp lifters using SPH, its benefits, and the investigated performance improvement thus far.

Notes:



Vancouver, British Columbia, Canada

14:00, Paper #58

The purpose of this paper is to demonstrate the impact that this new methodology will have on the existing tools, including field data collection, design analysis, simulation tools, and process data evaluation as well as how it all works together to facilitate design optimization.

Notes:



SAG MILL GRINDING MEDIA – IS BIGGER REALLY BETTER?

14:15, Paper #59

B. Cornish, W. Conger, & R. Pax

Rock breakage in grinding mills is a complex process, given the wide variety of ore characteristics, equipment, and operating variables. Fortunately, semi-autogenous grinding (SAG) mill operators need not fully understand and measure the breakage mechanisms; they merely need to know that they exist in different forms and how to improve their rate of occurrence. In the SAG milling environment, there is evidence that rock breakage rates can be increased by using larger grinding media, and the improvement can be measured as a combination of throughput rate, specific energy consumption, and pebble production rate. In this paper several case studies are presented that demonstrate SAG milling improvements due to increased rock breakage, with larger grinding media featuring as a critical component.

Notes:

[illegible]



Vancouver, British Columbia, Canada

15:15, Paper #60

In the last decade several high pressure grinding roll (HPGR)-ball mill circuits have been successfully commissioned and brought into operation. As the proportion of properties with highly competent ore deposits rises, the selection of HPGR-ball mill circuits for comminution will become more common. The ball mill portion of the design is predominantly influenced by models based on fine crushing or rod milling. Because semi-autogenous grinding (SAG) mills and HPGR-type crushers reduce particle size due to different breakage mechanisms, the resulting particle size distribution (PSD) curves can have different slopes and shapes (even though they may share the same P_{80}) influencing the selection of the downstream ball mill circuit.

Notes:

[illegible]



REDUCING EDGE EFFECT AND MATERIAL BYPASS USING SPRING-LOADED CHEEK PLATES IN HPGR GRINDING

15:30, Paper #61

R. van der Ende, H. Knapp, & F. van der Meer

In high pressure grinding rolls (HPGR), size reduction is achieved through interparticle comminution, by applying compressing force on a packed particle bed. The particle bed is created by choke-feeding material between two counter-rotating rolls. Cheek plates or flanges keep the feed material between the rollers and prevent it from flowing over the roller edges.

Most HPGRs use fixed cheek plates or flanges that do not move with the rollers. These cheek plates require a certain clearance distance from the roller edges. This distance generates an excessive “edge effect” or proportion of material bypassing the rolls and, consequently, the grinding process.

Enduron® HPGRs are equipped with cheek plates that are forced to a position parallel and close to the rolls’ edge by a spring system. The force on the cheek plates is controlled by the spring system, which is designed to maintain a pre-set minimum gap, even in the event of the rolls skewing. Combined with sealing zones and wear protection, the cheek plates ensure the feed material is always kept between the counter-rotating rollers.

As a result, the edge effect, the bypass, and the wear, are reduced and the grinding efficiency increases.

This paper evaluates the effects that cheek plates have on the HPGR’s grinding efficiency. To effectively examine this, we executed grinding tests with and without cheek plates, and the evaluation of the grinding result carried out by particle size analysis.

Notes:



2019

Vancouver, British Columbia, Canada

HPGR: WHY SKEWING IS A REQUIREMENT FOR OPERATIONAL APPLICATIONS

15:45, Paper #62

Henning Knapp, Stephan Hannot, & Frank van der Meer

High pressure grinding rolls (HPGR) are an energy efficient solution for comminution of industrial minerals and metal ores. The technology is successfully applied in an expanding field of applications throughout the minerals industry. HPGRs compress and grind the particle bed in the operating gap between two counter-rotating rolls. The equipment provides a high capacity, low energy alternative for applications with conventional tertiary and quaternary crushing and grinding, with size reduction reaching from 100 mm feed down to 25 microns product. In this process, maintaining a controlled and evenly distributed operating pressure between the rolls is very important. Due to feed segregation, the pressure distribution along the roll's surface can become uneven, resulting in a coarser product. This paper will show that the pressure distribution can become severely uneven. As it is difficult to eliminate feed segregation, the HPGR design should compensate and adapt for the uneven pressure distribution as much as possible. This paper will present that the best approach to compensate and adapt for the uneven pressure is to allow the rolls to skew relative to each other. This will be further supported by operating data from operational HPGR installations. Coarser products are also caused by an inadequate pressure distribution: the much-discussed edge effect. To minimize the consequence of the edge effect, an optimized ratio for the roll length to roll diameter will be calculated. Furthermore, the design philosophy behind application of cheek plates will be detailed. This cheek plate is used to retain the material between the rolls, reducing the edge effect while still allowing roll skew. Together these design considerations help optimize HPGR's performance.

Notes:



Vancouver, British Columbia, Canada

16:15, Paper #64

Ultrafine screen technology (as found in Derrick®'s Stack Sizer® and Metso's UltraFine Screen) provides high classification efficiency at relatively fine sizes compared to other classification technology (such as hydrocyclones). A review of operating data reveals that the performance of the technology differs from a traditional screen (i.e., where classification success is highly dependent on-screen solids' bed depth and percent of material near the aperture size). In the case of an ultrafine screen, performance is more driven by the ability of the slurry to flow through the screen panel. A performance equation for an ultrafine screen that combines aperture size, material is proposed that uses the oversize of the screen and the screen combines slurry % solids by volume and an investigation head pressure at the top of the screen and slurry viscosity.

This image shows a single sheet of white paper with horizontal blue ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



REDESIGNING SAG MILL RECYCLE CRUSHER OPERATION

16:30, Paper #65

Malcolm Powell, Magnus Evertsson, & Aubrey Mainza

Recycle crushing is used extensively to boost SAG mill throughput, by rapidly reducing the competent pebbles that would otherwise build up in a SAG mill. Although applied with considerable success, it is the authors' observation that these crushers are generally poorly utilised: operating well below installed power, switching on and off, and set at large closed side settings. Application of good design and control practice has the potential to increase crusher efficiency in terms of reduction ratio and thus in turn increase SAG mill throughput and unload overloaded ball mills to open up circuit capacity. Examples of operating practice and potential are provided to illustrate this.

Notes:

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



Vancouver, British Columbia, Canada

08:00, Paper #66

The new Aitik autogenous grinding (AG) milling circuit was based on the successful original milling plant at Aitik, with a focus on low life-of-mine operating costs. At the heart of this is eliminating steel grinding media, maximizing the use of gravity flow, and using spiral classifiers instead of hydrocyclones. The two 22.5 MW AG mills, 11.6 metres (m) (38 feet [ft]) diameter by 13.7 m (45 ft) long, are the largest mills by volume operating in the world. Each AG mill feeds a 10 MW pebble mill via a unique coupling of flow and pebble feed with the pebble mill product recycling to the spiral classifier that is closed with the AG mill. The massive size of the AF circuit and unique layout make this an interesting case study in alternative plant layout and operation compared to the strong trend towards finer feed, high ball load and multiple ball mills per semi-autogenous grinding (SAG) mill. Operating capability, data on specific energy, throughput, and plant stability are presented as a comparative case study.

[illegible]



SINGLE-STAGE AUTOGENOUS GRINDING REVISITED

08:30, Paper #67

Marcos de Paiva-Bueno, Bianca Foggiatto, & Greg Lane

This paper presents an assessment and trade-off study of high-pressure grinding rolls (HPGR)-based vs. autogenous grinding (AG)-based milling options for a 65 kt/d copper/gold project. The study relied on pilot trials to determine the applicability of potential single-stage (SS) AG flowsheet options and their energy efficiency. The results showed that the SS-AG option has a higher installed capital cost when compared with the HPGR-based option, mainly because large AG mill shells are required to compensate for the lack of steel grinding media. However, the SS-AG option has lower operating costs when compared the HPGR circuit, mainly due to no grinding media costs.

Notes:

[illegible]



Vancouver, British Columbia, Canada

08:45, Paper #68

Single stage SAG mills are attractive when there is limited capital for the project, so a lower capital investment is sought for start-up of the operation, or for when the initial ore will be considerably softer for a number of years. With increasing confidence in the operation of large SAG mills, single stage AG/SAG mills were installed by various companies in what were considered to be cost-effective comminution circuits. Unlike most of the comminution circuits that involve multiple grinding stages, single stage SAG mill circuits rely on one mill to achieve the desired product fineness at the defined throughput. The major drawback with single stage circuits is the lack of flexibility in the circuit because the same unit controls both throughput and the fineness of grind. For a new installation, there is need for people familiar with single stage SAG mill applications on the design team and for thorough ore characterisation data to ensure that the designed mill can meet the required throughput at the desired product fineness for the mined ore. The mill in this type of application should be designed with flexibility in operating set points to accommodate wide variations in the ore that can be processed on the plant. There are several challenges that should be considered when designing single stage SAG mills to ensure that they meet both the target throughput and product fineness. This paper will provide insights into the challenges encountered in the design and operation of single stage SAG mills and how these can be addressed at design and operation stages of the plant.

[illegible]



TOWARD A SIMPLE APPROACH DETERMINING SINGLE-STAGE SAG MILLS' ASPECT RATIOS (D/L)

09:00, Paper #69

Johnny T. Kalala

Over the past decades, a considerable amount of research was focused on improving predictions of semi-autogenous grinding (SAG) mill power requirements in mineral processing. Significant improvements have been made in terms of: i) understanding testwork required to accurately determine power consumption, ii) understanding parameters influencing SAG mill power draw, iii) developing models to predict the size reduction process and power consumption as a function of operating conditions, iv) automation and control, and v) geometallurgy.

Improved understanding of SAG mills over the past 20 years has resulted in a growing number of single-stage SAG mill (SSSAG) circuit implementations for projects having ore characteristics, target grind, and throughput previously considered only suitable only for standard semi-autogenous ball-crusher (SABC) or semi-autogenous ball (SAB) circuits.

Although the power requirement for SSSAG mills can be determined using equations such as those developed by Morrell (2006) or Barratt (1989), from testwork such as the Minnovex SAG power index (SPI) and the Starkey SAG design testwork, or even from pilot testwork, determining the SSSAG mill aspect ratio defined as mill diameter/mill length is not straightforward.

The author has developed a simple and sound approach to determine the SSSAG mill aspect ratio. The approach takes into account the ore characteristics (hardness and particle size distribution), the circuit configuration (with or without pebble crusher), the feed and target grind, and the plant capacity. The approach is tested against the current database of successful and unsuccessful SSSAG mill operations. The author drew conclusions based on observed results.

Notes:



Vancouver, British Columbia, Canada

09:15, Paper #70

Many ore bodies are getting harder, more abrasive, and lower in grade. One of the issues designers face is minimizing capital and operating costs when treating such ores. Designers often look to secondary or tertiary crushing followed by grinding in a semi-autogenous grinding mill with recycle crusher followed by a ball mill (SABC) or ball mill only circuit when treating extreme ores ($A_{xb} < 30$, $B_{Wi} > 18$ and $A_i > 0.5$). This approach is capital intensive and for abrasive ores often results in a circuit with high maintenance and operating costs.

Lastly, the learnings from these circuits are used to explore the part that autogenous grinding circuits may play in future comminution circuits.

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There are no margins, text, or other markings on the paper.



A STRUCTURED APPROACH FOR IMPLEMENTATION OF APC AT FMI CERRO VERDE

10:15, Paper #71

Rafael Ortiz de Zevallos, Miguel Yopez-Monroy, Johaire Nuñez-Chirinos, Ari Supomo, & Jeff McKay

Cerro Verde operation, a Freeport-McMoRan affiliate, has successfully implemented advanced process control (APC) at its SX/EW leaching, C1 concentrator, and C2 concentrator. One of the keys to this success was the use of two corporate concepts called a cookbook and dynamic constraint control (DCC). The use of a cookbook for strategy design is intended to gather all the information about best practices in control of a circuit from the implementation team. To promote buy-in to the process, members of operations and engineering staffs contribute to defining the objectives, constraints, and methodology of controlling the circuit. Cerro Verde is a great example of how this process can lead to well-functioning and well-accepted APC at a state-of-the-art operation. Based on its success in C2 concentrator grinding, this process has been applied to other Cerro Verde processes and has led to improvements in the process control. This paper describes the process of cookbook and DCC development at Cerro Verde.

Notes:

[illegible]



Vancouver, British Columbia, Canada

10:30, Paper #72

In this paper the authors discuss a unique, dynamic solution for optimizing the comminution area in real time. The proposed technology is a combination of model-based predictive controller (MPC) techniques, optimization methods, and a real-time digital twin of the comminution area for mineral processing.

Our control strategy has been developed, tested, and implemented in numerous semi-autogenous grinding (SAG) mills and ball mills. The result for different mine sites showed an increase in throughput of between 2% and 5%, specific energy consumption reduction of about 15%, and process variability reduction up to 60%.

[illegible]



SOUND-BASED ADVANCED PROCESS CONTROL OF A SAG MILL AT SUMITOMO MINERA SAN CRISTOBAL

10:45, Paper #73

Dave King, Silvia Vidal, & Jeff McKay

Minera San Cristobal S.A. (MSC) is a Bolivian mining company and a fully owned subsidiary of the Japanese Sumitomo Corporation since 2009.

The San Cristobal mine is located in the province of Nor L pez, in the municipality of Colcha K in the department of Potos . Considered the most important mining project in Bolivia, MSC operates using the latest technology, high standards in employee training, strict occupational industrial health and safety controls, environmental preservation, and sustainable development.

MSC currently operates at 250,000 tonnes per day (t/d) mining and 52,000 t/d milling capacity at an elevation of about 3,800 metres above sea level. It has become a leading global lead and zinc producer.

Usually, SAG mills operate near installed horsepower to maximize throughput by controlling the bearing pressure and the speed. However, in the case of MSC, traditional control was changed to allow control mainly by sound. This has been the key to the success in improving throughput at MSC.

MSC has a fully developed Metso OCS-4D  advanced process control (APC) system controlling SAG mills, ball mills, flotation, and thickening processes. Expert supervisory control strategies have been used for many years to improve throughput and reduce power consumption. The most unique characteristic of the MSC APC is that the SAG control is purely based on sound emissions. It looks at SAG sound levels at various locations around the mill and adjusts feedrate, mill speed, and mill density to achieve maximum production. As such, it is perhaps the only operating mill to accomplish this feat. In this paper, the authors discuss the development of sound-based control and its application at MSC, as well as the increased efficacy as a result of this control.

Notes:



Vancouver, British Columbia, Canada

11:00, Paper #74

Important advances in aircraft industry sensor technology allow development of two process-variable measurement systems. The first is an on-line charge level and geometric distribution determination system for semi-autogenous grinding (SAG) mills; the second is a mechanical stress measurement system for the ball mill structure. Both systems are being tested in concentrator plants in Chile, and preliminary results show that they can significantly improve plant safety and availability.

This image shows a single sheet of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page. There are approximately 20 lines visible. The paper has a slight shadow on the right side, suggesting it's resting on a surface.

2019

Vancouver, British Columbia, Canada



TBD

11:15, Best Poster Presentation #75



2019

Vancouver, British Columbia, Canada

TBD

11:15, Best Poster Presentation #76



CHALLENGES OF USING ADVANCED CONTROL TOOLS (ACT) SYSTEM AT THE SARCHESHMEH COPPER COMPLEX SAG MILL CIRCUIT

13:15, Paper #77

Omid R. Bashiri, Mostafa Maleki-Moghadam, Abbas Akbari, Mostafa Yazdani, & Samad Banisi

The use of control systems, particularly, in grinding circuits where AG or SAG mills are employed has experienced significant progress in recent years. The Sarcheshmeh copper complex grinding circuit consists of a SAG mill (9.75×4.88 m), a ball mill (6.71×9.91 m) and a cluster of 15 hydrocyclones (66 cm diameter) working in a closed circuit. The Outotec advanced control tools (ACT) system has been installed with the objective of achieving optimal performance for the grinding circuit. The operating concept of ACT is to control the process above the basic automation system. ACT control decisions can be based on traditional crisp rules, fuzzy logic, or even advanced process models. Feed size distribution, charge shape (toe and shoulder positions), charge level, and cyclone overflow size distribution are among some other common parameters that could be measured. The ACT system uses state logic controls or fuzzy logic along with history values, and internal variables to perform the overall control of the circuit. The appropriate values with regards to SAG mill (weight, power speed, feed rate, and pebble production rate), ball mill (weight and power) and cyclone cluster (pressure, number of cyclones, density, and pump speed) should be assigned by the operators as control limits. In the logic limits section, proper values for SAG mill (weight very high, pebble high, weight rate of change), ball mill (power very low, power low, weight high) and sump (high level) must be also defined. Based on the experience and complexity of the circuit, states are defined (e.g., SAG mill weight too high, decrease speed). The main challenge was to choose the appropriate values for the control and logic limits and set points. Three major problems of the control system were inability to control pebble (recycled, reject) tonnage, preventing increasing the feed rate above a certain value, and a slow response to variations. To overcome these problems, the control and logic limits, and set points were obtained from the monthly variations of the parameters. Upon resolving some operational issues, the ACT system was put in practice which resulted in increase of the throughput from 900 to 1,150 t/h, and control of the pebble tonnage within a desired limit (190 t/h). Furthermore, a decrease in the mill weight variation and maintaining the mill weight close to the set point led to a significant reduction in the number of broken liners.

Notes:



2019

Vancouver, British Columbia, Canada

METHODOLOGY FOR ASSESSING THE BENEFITS OF GRIND CONTROL USING PST TECHNOLOGY FOR TRUE ONLINE PARTICLE SIZE MEASUREMENT

13:30, Paper #78

Robert Maron, Christian O'Keefe, Jaime Sepulveda, & Dylan Cirulis

Despite the recognized significance of ground product fineness on both line capacity and downstream process performance (typically flotation), less than 10% of mineral ore concentrators today use particle size measurements in automatic control applications for the final product particle size.

Although “near-line” particle size measurement instrumentation has been in place for several decades, its availability and low measurement frequency have typically been inadequate for reliable use in automatic control. CiDRA Minerals Processing Inc. has developed a novel and robust technology that provides a highly reliable and low maintenance system for “on-line” measurement of the particle size in the overflow of individual cyclones. The CYCLONEtrac™ Particle Size Tracking (PST) system is based around a wetted sensor design with no moving parts that provides a real-time trend of the desired target grind size parameter. The system does not require sampling and associated sample transfer piping that is prone to plugging, thus avoiding high maintenance requirements.

Investment decision makers require convincing reliable estimates of the expected economic value that automatic grind control projects will deliver. Based on actual plant operating records accumulated over long periods of time, the evaluation approach described here assesses and highlights the significant potential process improvement to be expected from CYCLONEtrac PST technology.

This paper presents the key operating criteria that permit increasing mill throughput and optimizing the production of valuable metal by identifying the optimal grind size. As increasing throughput requires operating closer to the process physical boundaries, accurate real-time particle size measurements, such as those provided by the PST System, become essential for achieving the maximum potential value of every operation. For further illustration, data from three different copper grinding/flotation plants are shown and compared.

Notes:



ONLINE OPTICAL MONITORING OF THE SAG MILL CHAMBER

13:45, Paper #79

Germán A. Sepúlveda & Leonardo E. Duarte

Most of the SAG mill instruments that give on-line information about the load and liner condition provide estimations through indirect measurements. The main reason for this is the harsh environment inside the mill in which the instruments must be placed; however, it is hard to keep such instruments working, for the same reason. Trying to work around the status quo, ETT has worked side-by-side with SAG mill operators of some of the largest copper plants in the world, in the north of Chile, to install cameras looking into the mill chamber, with good and promising results. This paper describes our concept, experimental validation, industrial design, and the implementation process, especially image quality and the algorithms that facilitate it.

This development (patented in six countries) has been based on four main points: 1) choosing camera locations that maximize their view and minimize the effects of the mill environment, 2) finding the right way to protect these cameras with minimal effect on performance, 3) choosing the cameras with the best wavelength and optical performance, as well as ruggedness, and 4) selecting the hardware and software platform to acquire and process the images.

Before reaching a robust design, several lessons were learned from the testing stage, mainly small details. At this point we can reduce mill inspection down-time to just two minutes of low-speed operation. The images obtained are processed with algorithms to monitor and measure the wear conditions of liners and grate, and the dynamic characteristics of the load.

This development offers new “sight” for operational control of a SAG mill, as well as adequate information to validate load movement models. Since this device is being complemented with additional sensing technologies, we are still periodically discovering new applications of this development.

Notes:



Vancouver, British Columbia, Canada

14:00, Paper #80

In order to increase throughput of comminution circuits, semi-autogenous grinding (SAG) mills are traditionally operated to their fullest capacity in terms of energy consumption. San Cristobal Mine (SCM) has a different operational approach by breaking the paradigm to “less energy = high production = high efficiency” using sound to control the mill speed and feed rate, while also maintaining an optimal ball charge level. This helps to maximize the efficiency, increase throughput, and reduce energy consumption.

Notes:

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.



TECK'S HVC ADAPTIVE CRUISE CONTROL FOR SECONDARY GRINDING

14:15, Paper #81

Eduardo Nuñez & Michael Hahn

In the last few years, Teck's HVC operation has embraced a culture of automated process control. As part of this vision, it was decided to perform an exhaustive grinding process control audit where all instruments and controls were inspected, calibrated, and upgraded. These improvements highlighted inefficiencies in the secondary grinding circuit already faced with ore variability, primary grinding limitations, steel charge instability, and liner wear issues. In order to improve the efficiency of the circuit, an extensive program was implemented including the development of soft sensors, a real-time steel charge schedule, overload detection, and an adaptive "cruise control" program with "steering assist." These enhancements have improved the particle size produced from the grinding circuit by 7.5%, in addition to capturing tangible energy savings.

Notes:

This image shows a single sheet of white paper with horizontal blue ruling lines. The lines are evenly spaced and run across the width of the page. There are approximately 20 lines visible. The paper has a slightly aged or off-white appearance.



Vancouver, British Columbia, Canada

15:15, Paper #82

While stirred mills in regrind and fine grinding duties have become more accepted, there continue to be questions about the testwork used for scaleup and comparisons. One reliable reality check for any future application is simply comparing a design to an already operating mill in a similar duty. This paper will attempt to summarize, explain, and compare all available published full-scale results from the different stirred mills in metalliferous applications.

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There are no margins, text, or other markings on the paper.



IMPROVING SINGLE-STAGE SAG CIRCUIT EFFICIENCY AND PRODUCT QUALITY THROUGH FINISH GRINDING IN THE TOWERMILL

15:30, Paper #83

Samayamutthirian Palaniandy, Mohsen Yahyaei, & Hidemasa Ishikawa

This paper studies the possibility of installing a gravity-induced stirred mill, such as the TowerMill, in finish grinding duty for single-stage semi-autogenous grinding (SSAG) mill circuit expansion to cope with feed type variation. SSAG mill circuit survey data was obtained from the published literature. A SSAG mill circuit was modelled in the JKSimMet software and the circuit was simulated when the feed type varied (increase in the feed size and ore hardness). The simulation results show that the circuit product became coarser, where the P_{80} increased from 73 μm to 116 μm . A medium-size 700 HP TowerMill was introduced in the finish grinding duty to recover the grind size back to 75 μm . The proposed circuit SAG-TowerMill circuit was simulated and successfully achieved the targeted grind size. The TowerMill grinding duty is called finish grinding duty as the contribution of comminution energy to the circuits is less than 15% of the total circuit energy consumption. A hypothetical gold dissolution study shows that the SAG-TowerMill circuit gold dissolution is more than the base case with the SSAG mill only. The payback period for the finish grinding circuit expansion was approximately ten months. This study indicates that using a TowerMill in finish grinding duty could be an option for SSAG mill circuit expansion.

Notes:



2019

Vancouver, British Columbia, Canada

DESIGN AND OPERATION OF THE VERTICAL SHAFT IMPACTOR IN FINE CRUSHING APPLICATIONS

15:45, Paper #84

Alexander (Sandy) Lewis-Gray & Greg Rasmussen

Vertical Shaft Impactors (VSI) are high-capacity and extremely efficient fully autogenous vertical shaft crushing machines designed to operate as second- or third-stage crushers in coarse mineral processing. The initial use of VSI crushers has been in aggregates (gravel and sand production), but over the last 15 years, Gekko Systems has successfully applied the technology in fine crushing applications in mineral processing. The VSI uses rock-on-rock crushing to liberate minerals at the grain boundaries (Gray, Davies, & Theletsane, 2014).

The first principle is “unconstrained” versus “constrained” crushing. Constrained crushing sees the ore passed between opposing surfaces (cone, jaw crusher) imparting energy into the rock to break it.

It is proposed that unconstrained crushing sees the energy imparted to the ore and the ore is then subjected to pressure so that it is pulled apart. In the VSI the ore is accelerated through an impellor to impart energy that is then thrown into a cloud of other particles and a wall of stationary ore. The ore is free to break along any inconsistencies such as grain boundaries and mineral boundaries. To date, both laboratory work and plant outcomes show this method is effective in liberating minerals at their natural grain size with very low energy consumption and little fines generation (Gray et al., 2014).

Gekko Systems is presently utilizing the VSI crushing technology in four operating sites. This paper will go through testwork completed for the sites, the scale-up (predictable specific energy) with correlation to known conventional SAG testing procedures, the benefits of adapting to the VSI technology at sites, and continued development. Continued development on the VSI crushers includes further optimizing and new rotor designs that will incorporate long-life components for extended maintenance cycles.

Both capital expenditure (CAPEX) and operational expenditure (OPEX) will be discussed with the key strengths and weaknesses of the total VSI installation being reviewed. The VSI offers a unit with high “Energy Density” and low capital and operating cost coupled with the greatest ability to accept variable feed characteristics of any of the crusher families.

Notes:



16:00, Paper #85

In December 2011, Teck's Red Dog Operation commissioned two 1.5 MW M3000 IsaMills as part of a project to improve their zinc metallurgy. This paper examines the history, including initial performance, characterization of a feed that has managed to be both abrasive and viscous at the same time, reviews improvements to the mill flexibility through an operating vessel size upgrade and the optimization of the internal component configuration for improved wear life. Red Dog has also completed a program for grinding media optimization. Recently, Red Dog finalized testwork and design on a value improvement project (VIP#2) that will install the world's first M15000 IsaMill in 2019 into their grinding circuit to ensure throughput and grind size targets are maintained as harder ores are processed in the near future.

Notes:

[illegible]



Vancouver, British Columbia, Canada

16:15, Paper #86

The size distributions of the material feeding a ball milling circuit, even those possessing a common 80% passing size, vary widely depending on the upstream process: semi-autogenous grinding (SAG), rod milling, stage crushing, or high pressure grinding rolls (HPGR). In addition, the grindability of HPGR product material may be altered by said process. These characteristics affect the optimum media sizing for the downstream ball mill. A method to evaluate and select the ball charging size(s) for these different circuit feed characteristics is described. It utilizes “ball mill grinding efficiency” from the functional performance equation, and energy-based cumulative grinding rates measured both in the plant and in a torque-metered pilot test mill.

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There are no margins, text, or other markings on the paper.



CONTRIBUTING TO A BETTER UNDERSTANDING OF GRINDING MEDIA WEAR – EXPLORING THE IMPACT OF DIFFERENT PARAMETERS

16:30, Paper #87

Peter Radziszewski & Sudarshan Martins

It is recognized that steel media wear can represent up to 50% of the operating costs in a given tumbling mill. Over the years, a number of works have explored the development of different ways and means to understand steel media wear and model and predict it. The focus of the present work is to explore the impact of different parameters, beyond the typical ones of ore abrasiveness, feed size, and slurry acidity, on grinding media wear. Parameters examined are related to microstructure, hardness, abrasion, and impact toughness of steel media as well as slurry density, silica content, slurry temperature, and water quality supported by experimentation and field data. A discussion will address some issues highlighted by the results that may contribute to predictive wear model development as well as indicate possible directions for future research.

Notes:

[illegible]

