What! No Standard Procedures for Mineral Processing Laboratory Tests?

There appears to be a lack of standardization for routine mineral processing laboratory tests at many mineral processing operations and labs. The exact situation ranges from strong, well-documented and followed – to some documented and followed – to few, if any standards. Root causes include lack of awareness of importance, availability, access, etc.

Whether performing these tests in your own laboratory or using consultant or vendor facilities it is good practice to critically review and understand the procedures in use. This starts a good dialogue and has many positive impacts, e.g.,

- Verifying existence of standards. Lacking standards, how exactly are tests performed and repeated?
- Review of procedures and if they are being followed by lab staff.
- Vetting use of industry standards or not.
- Verifying the existence and adherence to of laboratory QA/QC procedures.

With this context, the state of standardization is surprisingly poor at many facilities:

- No written procedure
- Multiple written procedures
- Procedures not being closely followed
- Procedure modifications for ease of execution by technicians
- Use of non-standard procedures or equipment
- Poor sample preparation practice
- Difficulty in obtaining copies of Best Practices for running tests.
- Lack of experienced people to teach experimental procedures.
- Lack of QA/QC programs within laboratories.

Developing and maintaining a collection of such procedures will provide many benefits to mineral processing engineers. Below is discussion of the challenge and opportunity; including a listing of some useful, common procedures, a listing of available references and standards including selected links, and some thoughts on content for standards.

This site (https://www.911metallurgist.com/metallurgy/) seems a logical place to exchange ideas and standards. Your comments and questions are welcome, either on this site or emailed to me at: baseitz.mpe@gmail.com

This listing is not exhaustive. It is not intended to be. It would be good to receive input and discussion from readers about the gaps they see as well as to receive details of standards they use or have seen used.

Thanks,

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Seitz, R.A, 2015 Experimental Methods in Mineral Processing

1. Introduction

Mineral processing is a core technology for mining and production of metals, minerals, and inorganic chemicals, as is clearly demonstrated by the great success of its global implementation. As such it forms a crucial link in the services that the mining sector delivers to society. Over the last two hundred years developments have been largely empirical activity with theoretical understanding lagging industrial practice and related observations.

Demands on the efficiency of mineral processing plants have increased due to the processing of lower grade, more complex ores, an increasingly more stressed economic environment, and social licensing requirements (e.g., maximum use of resources with minimum harm to people and the environment and sharing of benefits). Therefore the need to accurately characterize the individual processes which comprise mineral processing plants has increased over recent decades. It is certainly a challenge to develop standardized methods for experimental work that can be easily repeated in different laboratories. In many cases the exact handling is important, but it is not easy to document into a practical protocol.

While conventional mineral processing plant operation was driven by value maximization, this text addresses the paradigm shift towards inclusion of social license by including reference to related experimental methods (e.g., characterisation of ARD - acid rock drainage). In this respect the text is very relevant for developed countries, as the new paradigm will heavily influence the future development of mineral processing plant management globally. The major goal of this work is to provide support to the stabilization and optimisation of these mineral processing facilities. Overall it can be concluded that the global application of existing knowledge and experience in mineral processing technology will represent a cornerstone in future production management.

The mineral processing profession is extremely practice-based, and therefore it has always had benefited from the development, sharing, and standardization of experimental methods. This seemingly simple activity has been strongly hampered by several factors:

i. Mineral process engineering is a typical interdisciplinary activity where understanding of chemical engineering, mechanical engineering, electrical engineering, and chemistry is required to develop and understand the processes. The challenge here is to integrate methods and approaches from these disciplines.

ii. Commercial forces have increasingly weighed against the sharing of information and development of common standards. A great example of this is the apparent change between the sharing of Bond's comminution work and present day.
iii. Ores and their treatment processes are by their nature difficult to define with exactitude. For instance it is virtually impossible to characterize all the individual aspects of an ore that impact processing behavior, the processes are based on complex physicochemical mechanisms which are only partially understood, and due to the complexity and variability of ores and the processes our understanding remains firmly rooted in empiricism.

Due to the poorly defined nature of the mineral processing system, practice and research have tended to progress slowly and they heavily depend on standardized methods that may not be exact but, when used in a standardized way, are very helpful and useful to compare experimental results. Past examples with broad use today include the Bond Grindability Tests, Laboratory Flotation Tests, and Thickening / Settling Tests.

Probably the most limiting factor in achieving maximum performance from processing facilities is the lack of qualified, well-trained professionals, with awareness of prior developments and practices and able to comprehend scientific research results and transfer them into practice. It is therefore of prime importance to make this body of knowledge, proven experiences in mineral processing technology applications and current available scientific advances easily accessible globally. This is one of the drivers for the development of this work, which represents a contribution to help overcome the existing capacity development challenge.

There has been a trend for some time that industrial practice and scientific research have been growing apart from each other and exposure to the fundamentals of mineral processing has almost vanished from Western Universities. Part of the reason for this are the global implementation of an academic assessment method that primarily focuses on the impact of publications on the progress in scientific research, economic forces leading to the closure of smaller programs, and social forces reducing the interest of students in entering the mining industry. Applied research results with an impact on mineral processing practice are not yet being sufficiently rewarded as their impact is not always reflected by citations in scientific journals.

This text and related references are expected to contribute to bridging the gaps between the technology and science, and their practical application by providing a reference to experimThere is a gap in ental methods and enhancing the dialogue and co-operation between practitioners and scientists. Practitioners are encouraged to understand the scientific background of all processes relevant for plant operation, while scientists are encouraged to address practical problems using scientific methods.

Since the mid-1960s, the knowledge and understanding of mineral processing has advanced and moved away from empirically-based approaches to a fundamentally-based first-principle approach embracing chemistry (general, physical, organic, surface) and multiple engineering disciplines (chemical, mechanical, electrical), often involving laboratory work and techniques. The result has been vast progress in understanding the complex and interdisciplinary aspects of the physicochemical processes and systems involved. Some of these experimental methods and techniques have matured to the point that they have been accepted as reliable tools in mineral processing research and practice.

For sector professionals, especially the new generation of young engineers and scientists entering the mineral processing profession, the quantity, complexity and diversity of existing practices together with these developments can be overwhelming, particularly where access to basic and advanced level laboratory courses in mineral processing has not occurred. In addition, information on experimental methods is scattered across the technical literature and only partially available in the form of textbooks and guidelines. This text seeks to address these deficiencies. It assembles and integrates the experimental methods developed by practitioners and scientists around the world and broadly applied in mineral processing practice and research. To reduce the problems covered above it will be valuable to develop a text providing reference to guidelines and textbooks and in some cases summarizing experimental methods, and to catalogue videos showing the critical methods actually being demonstrated in the laboratory.

Focusing on the more relevant experimental methods in mineral processing leads to coverage across the areas listed below:

- General
- Laboratory
    - Sampling
    - Sample Preparation
    - Calibration
- Particle Characterisation
    - Analytical
    - Microscopy
    - Size analysis
- Comminution
- Screening and Classification
- Flotation
- Gravity Separation
- Magnetic Separation
- Ore Sorting
- Solid-Liquid Separation
    - Filtration
    - Thickening

The *Experimental Methods in Mineral Processing* text forms part of an approach to developing competency in mineral processing, and as such, is intended to be used together with textbooks, guidelines, videos, etc. The text is intended for use by mineral process engineering practitioners and scientific researchers. The internet provides access to an interdisciplinary team of experts capable of providing and reviewing inputs about the key experimental methods. However, it has so far not been used in this manner. The text provides a contribution to establishing a common body of knowledge with professional language, enhancing global communication between mineral processing professionals. Descriptions of the experimental methods will be linked with available online presentations, video-based materials, etc. for the training of students, researchers, engineers, lab technicians, and plant operators, demonstrating commonly accepted experimentation procedures and their application for lab-, pilot-, and full-scale mineral processing plant operations. Each procedure will to address the following (5W/1H -- What, Why, When, Where, Who, How). These ‘W’ areas will be covered in the text with links to guidelines and procedures that provide additional details of the ‘Ws’ and specifics about how.

What comprises a standard?

A model based on the ASTM or ISO seems a good starting point. This comprises:

- Title
- Scope
- Reference Materials
- Terminology Definitions
- Summary of Test Method
- Significance and Usage
- Apparatus
- Reagents and Materials
- Sampling and Specimens
- Calibration of Apparatus
- Preparation of Samples / Specimens
- Procedure(s)
- Calculations
- Precision and Bias of Results
- Reporting
- Version Control (who originated, who has edited and why, with associated dates)

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2. Necessary Procedures and Related References

General

Bottleneck identification	Weibull DCC

	Observational Hydraulic
System / Process design	Flowsheet Control Philosophy

Coleman, R.L., Metallurgical testing procedures, **Mineral Processing Plant Design**, Eds. A.L. Mular and R.B. Bhappu, SME, 1978, 135

Connelly, D., Metallurgical testing & flowsheet development, Mining Resources 2007, AusIMM, 2007, presentation.

McNulty, T.P., Overview of metallurgical testing procedures and flowsheet development, **Mineral Processing Plant Design, Practice, and Control**, Eds. A.L. Mular, D.N. Halbe, and D.J. Barratt, SME, 2002, 119

Saich, S.J., Was that metallurgical testing program any good, for process design and financial evaluation, **Procemin 2010**, Santiago, Chile, 2010, presentation.

Spedden, H.R., Section 30: Sampling and Testing, SME,

Laboratory

Sampling	Sample collection practices and procedures
Sample Preparation	Riffling
Particle characterisation	Analytical Microscopic – Panning & Microscopy (optical & SEM) Sieving Bulk Density Specific Gravity
Calibration	pH Meter Calibration & Measurement Procedure Eh Meter ‘Calibration’ & Redox Measurement Procedure On-Stream and Batch XRF analysers
Preparation of Reagents	

Sampling

Sampling in mineral processing plants is key to process management and value maximization through metallurgical understanding and process control. There are reference readings and videos available to assist in the learning and application of these concepts.

Minnitt, R. and Pitard, F., **Sampling in the Minerals Industry: Introduction to Sampling Theory and Sampling Practice**, Course Notes, 2015.

Sampling for Mineral Processing (7 parts)

Part 1. Introduction – 5:47 (https://www.youtube.com/watch?v=XZhDqWCq9Bg)

Part 2. Sampling Basics – 8:00 (https://www.youtube.com/watch?v=OcanIxkEjRQ)

Part 3. Sampling Errors - 7:17 (https://www.youtube.com/watch?v=yIooljYxIUs)

Part 4. Metallurgical Samplers – 7:40 (https://www.youtube.com/watch?v=rz-mnq-xeEs)

Part 5. Process Control Samplers – 5:24 (https://www.youtube.com/watch?v=qc91UdOBVRc)

Part 6. Mass Balancing – 10:11 (https://www.youtube.com/watch?v=ss_ICMQi9JE)

Part 7. Recovery and NSR – 12:01 (https://www.youtube.com/watch?v=A5KBUCOe1c8)

Sample Preparation

HRU – Lesson 5 – Sample Preparation and Processing – Technical Level: Intermediate 19:25

https://www.youtube.com/watch?v=fzL5JI80AHw

HRU – Lesson 6 – Processing Test Results and Liberation – Technical Level: Intermediate 22:45

https://www.youtube.com/watch?v=8x0XmZIIs7Y

HRU - Lesson 7 - Can I Make Money Gold Mining? Technical Level: Intermediate 28:47

https://www.youtube.com/watch?v=49a-IUH1sOA

HRU - Lesson 9 Simplified Liberation and Separation Test 2 11:11

https://www.youtube.com/watch?v=aameYZ__1Sg

HRU - Lesson 10 Crushing and Grinding: Technical Level Intermediate 37:09

https://www.youtube.com/watch?v=Qev2FDB3lmA

Calibration

Mettler Toledo Laboratory, pH tutorial - theory, measurement, electrode maintenance 38:54

https://www.youtube.com/watch?v=gtcCLldrcg4

Yokogawa Analytical, Understanding ORP Basics 46:50

https://www.youtube.com/watch?v=ZHGMxj-Smtk

Particle Characterisation

Analytical

Microscopy

Butcher, A.R., A practical guide to some aspects of mineralogy that affect flotation, **Flotation Process Optimisation: A Metallurgical Guide to Identifying and Solving Problems in Flotation Plants**, Ed. C.J. Greet, AusIMM, 2010, 83-

Sutherland, D. and Gu, Y., Guiding process development using automated mineralogical analysis, **Mineral Processing Plant Design, Practice, and Control**, Eds. A.L. Mular, D.N. Halbe, and D.J. Barratt, SME, 2002, 270

Size Analysis

ASTM Standards

WSTyler, How To Perform a Test Sieve Analysis - W.S. Tyler Test Sieves 5:43

https://www.youtube.com/watch?v=-4qqqwzDWvI

1. Test sieves
2. Test sieve shakers
3. Sample materials & preparation
4. Running the test
5. Recording results & analysis

Comminution

Crushing (impact, abrasion)	
Primary Grinding Procedures (Bond, SMC, …)	GMSG – Bond, Morrell
Drop Weight Test Sample selection and preparation.	
Regrind (rod mill, ball mill, vertical stirred mill, horizontal stirred mill)	

Grind calibration for existing plant	
Abrasion	Bond Abrasion Mill and other tests
Attrition tests	
Operating Work Index Calculation	
Mill Charge Measurement	Load monitoring

Amelunxen, P., et al., The SAG grindability index test, Minerals Eng., vol. 55, 2014, 42-51.

Bond, F.C., Crushing and grinding calculation, British Chemical Engineering,

GMSG, 20150505_Bond_Efficiency-GMSG-ICE-v1-r04: Determining the Bond Efficiency of industrial grinding circuits, 2015.

http://www.globalminingstandards.org/wp-content/uploads/2016/02/20150505_Bond_Efficiency-GMSG-ICE-v1-r04_08_Apr_2016.pdf

Morrell, SMC test – which papers

GMSG, 20150821_Morrell_Method-GMSG-ICE-v01-r01: Morrell method for determining comminution circuit specific energy and assessing energy utilization efficiency of existing circuits, 2015.

http://www.globalminingstandards.org/wp-content/uploads/2016/08/20150821_Morrell_Method-GMSG-ICE-v01-r01-.pdf

Mosher, J. and Bigg, T., Bench-scale and pilot plant tests for comminution circuit design, **Mineral Processing Plant Design, Practice, and Control**, Eds. A.L. Mular, D.N. Halbe, and D.J. Barratt, SME, 2002, 123

Mosher, J. and Tague, C.B., Precision and repeatability of Bond grindability testing,

Mwanga, A., Rosenkranz, J., and Lamberg, P., Testing of Ore Comminution Behavior in the Geometallurgical Context—A Review, Minerals, vol. 5, 2015, 276-297.

Napier-Munn, Chapter 4. Rock Testing – Determining the Material Specific Breakage Function,

Rowland, C.A., Testing for the selection of comminution circuits to prepare concentration feed, Proc. AusIMM, No. 289, 1984, 79-91.

Starkey, which papers

Wyslouzil, D.M., Standard laboratory-pilot plant tests for equipment selection, **Design and Installation of Comminution Circuits**, Eds. A.L. Mular and G.V. Jorgensen II, SME, 1982, 228-

Screening and Classification

Screen efficiency	

Anon, Advantech, Test sieving: Principles and procedures. A discussion of the uses, capabilities, and limitations of testing sieves as analytical tools, Advantech Mfg., 2001.

Anon., AIChE, Particle Size Classifiers. A Guide to Performance Evaluation, AIChE Equipment Testing Procedure, 1980.

Anon., ASTM, U.S.A. Standard Sieves ASTM Specification E-11, 2009.

Gatenby, A., Sieve testing – standards, certification and calibration, CSC Scientific Co., Inc.

ISO

ISO 2395:1990 Test sieves and test sieving – vocabulary. Standard ISO guide defining terminology used in the context of sieving.

ISO 2591-1:1988 Test sieving – Part 1: Methods using test sieves of woven wire cloth and perforated metal plate.

ISO 3310-1:1990 Test sieves – technical requirements and testing – Part 1: Test sieves of metal wire cloth.

ISO 3310-1:1990 Test sieves – technical requirements and testing – Part 2: Test sieves of perforated metal plates.

ISO 3310-1:1990 Test sieves – technical requirements and testing – Part 3: Test sieves of electroformed sheets.

ISO 4701:1999 – Determination of size distribution by sieving.

Flotation

One Product Flotation Rate	
One Product Cleaner Test	
Two Product Flotation Rate	
Two Product Cleaner Test	
Two Product Locked Cycle Test	
Three Product Flotation Rate	
Three Product Cleaner Test	
Three Product Locked Cycle Test	

Amelunxen, P.A. and Amelunxen, R.L., Aminpro's Methodology for Executing, Interpreting and Applying Kinetic Flotation Tests in Scale-Up. Part 2, **VI International Mineral Processing Seminar – Procemin 2009**, Santiago, Chile, 2009.

Amelunxen, P. and Runge, K., Innovations in froth flotation modeling & testing, **Mineral Processing and Extractive Metallurgy, 100 Years of Innovation**, Eds. Anderson, C., Dunne, R., and Uhrie, J., pp. 177-192, SME Press, 2014

Amelunxen, R.L. and Amelunxen, P., Aminpro's Methodology for Executing, Interpreting and Applying Kinetic Flotation Tests in Scale-Up. Part 1, **VI International Mineral Processing Seminar – Procemin 2009**, Santiago, Chile, 2009.

Barbery, G., Bourassa, M., and Maachar, A., Laboratory testing for flotation circuit design, **Design and Installation of Concentration and Dewatering Circuits**, Eds. A.L. Mular and M.A. Anderson, SME, 1986, 419-

Lotter, N.O., Whiteman, E., and Bradshaw, D.J., Modern practice of laboratory flotation testing for flowsheet development – A review, Minerals Eng., vol. 66-68, 2014, 2-12.

Runge, K.C., Laboratory flotation testing – an essential tool for ore characterisation, **Flotation Process Optimisation: A Metallurgical Guide to Identifying and Solving Problems in Flotation Plants**, Ed. C.J. Greet, AusIMM, 2010, 155-

Sandoval, G., Amelunxen, R., Barriga, D., Berrios, P., and Amelunxen, P., Review of flotation batch test procedures and scale-up: implications for entrainment, **27th International Mineral Processing Congress,** Santiago, Chile, 2014

Thompson, P., The selection of flotation reagents for flotation circuit design, 136

Williams, S.R., Ounpuu, M.O., and Sarbutt, K.W., Bench and pilot plant testwork for flotation circuit design, **Mineral Processing Plant Design, Practice, and Control**, Eds. A.L. Mular, D.N. Halbe, and D.J. Barratt, SME, 2002, 145

Gravity Separation

Heavy liquid procedures	
Gravity table test	

Aubrey, W.M., Jr. and Stone, R.L., Laboratory testing for gravity concentration circuit design, **Design and Installation of Concentration and Dewatering Circuits**, Eds. A.L. Mular and M.A. Anderson, SME, 1986, 433-

Laplante, A.R. and Spiller, D.E., Bench and pilot plant testwork for gravity concentration circuit design, **Mineral Processing Plant Design, Practice, and Control**, Eds. A.L. Mular, D.N. Halbe, and D.J. Barratt, SME, 2002, 160

Magnetic Separation

Davis Tube Magnetic Separation Test	
LIMS test – wet, dry	
HIMS test – dry	
WHIMS	

Norrgren, D.A. and Mankosa, M.J., Bench and pilot plant testwork for Magnetic concentration concentration circuit design, **Mineral Processing Plant Design, Practice, and Control**, Eds. A.L. Mular, D.N. Halbe, and D.J. Barratt, SME, 2002, 176

Wernham, J.A., M.J. Ross, J.N. Orlich, and D.A. Norrgren, Laboratory testing for magnetic concentrator circuit design, Design and Installation of Concentration and Dewatering Circuits, Eds. A.L. Mular and M.A. Anderson, SME, 1986, 454-

Electrostatic Separation

Electrostatic separation lab test	

Lawver, J.E., J.B. Taylor, and F.S. Knoll, Laboratory testing for electrostatic concentration circuit design, **Design and Installation of Concentration and Dewatering Circuits**, Eds. A.L. Mular and M.A. Anderson, SME, 1986, 454-

Ore Sorting

Ore Sorting lab test	

Filtration

Filter leaf test	
Pressure filter test	
Filtration Test for Horizontal Belt Filter Simulation	
Rotary drum and rotary disc filter tests	

Krum, T., Bench and pilot plant testwork for filtration circuit design, **Mineral Processing Plant Design, Practice, and Control**, Eds. A.L. Mular, D.N. Halbe, and D.J. Barratt, SME, 2002, 207

Thickening and Clarification

Settling test procedures	

Ford, H.L., Flocculant testing, **Chemical Reagents in the Mineral Processing Industry**, SME, 255-260.

Keane, J.M., Laboratory testing for design of thickener circuits, **Design and Installation of Concentration and Dewatering Circuits**, Eds. A.L. Mular and M.A. Anderson, SME, 1986, 498-

Pocock, B.K., Smith, C.B., and Welch, G.D., Bench and pilot plant testwork for thickening and clarification circuit design, **Mineral Processing Plant Design, Practice, and Control**, Eds. A.L. Mular, D.N. Halbe, and D.J. Barratt, SME, 2002, 201

Tailings?

Acid rock drainage	

Material Handling – Wet (Slurry and Froth Pumping)

Froth stability measurement	

Pump Selection (Step 1 of 5) - Applied Fluid Dynamics - Class 053 4:51

https://www.youtube.com/watch?v=hk78NIpy3C4

Pump Selection (Step 2 of 5) - Supplier's Pumps - Applied Fluid Dynamics - Class 053 5:03

https://www.youtube.com/watch?v=icy-J6QsuMU

Pump Selection (Step 3 of 5) - Adjusting the System's Curve - Applied Fluid Dynamics - Class 053 6:13

https://www.youtube.com/watch?v=QlQJgcXhO10

Pump Selection (Step 4 of 5) - Operation Point - Applied Fluid Dynamics - Class 053 3:18

https://www.youtube.com/watch?v=lVGTMgI-w0k

Pump Selection (Step 5 of 5) - Optimizing the Operation Point - Applied Fluid Dynamics - Class 05 7:18

https://www.youtube.com/watch?v=OzS5okcuHDU

Pump Curve Diagram Construction / Applied Fluid Dynamics - Class 046 14:32

https://www.youtube.com/watch?v=WZHCSVLx7lg

Material Handling – Dry (Conveying, Bins & Hoppers, Transfer Points)

Shear Testing	
Segregation Testing	
Tests for Bins & Hoppers	
Angle of Repose	

McGlinchey, D., Ed., Characterization of Bulk Solids, Blackwell Publ., CRC Press, 2006.

http://www.blackwellpublishing.com/content/BPL_Images/Content_store/WWW_Content/9781405116244/9781405116244.pdf