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A BRIEF OVERVIEW OF THE PROCESS MODELING/SIMULATION AND DESIGN CAPABILITIES OF METSIM

John Bartlett[1], Alex Holtzapple[2] and *Curtis Rempel[3]

[1]*PROWARE*
Tucson, Arizona, USA

[2]*PROWARE*
Belo Horizonte, MG, Brazil

[3]*PROWARE*
Quesnel, BC, Canada
*(*Corresponding Author: Curtis.Rempel@usask.ca)*

ABSTRACT

METSIM is a powerful program capable of modelling and simulating every known metallurgical and inorganic chemical process. METSIM is used by companies throughout the world to design, simulate and control operations from mine to tailings and everything in between. At its absolute simplest, METSIM can be used to create a process flowsheet. METSIM modules and built-in unit operations cover mass and energy balances for either steady-state or dynamic simulations of mine, stockpile, heap leach, material handling, comminution, beneficiation, hydrometallurgy, pyrometallurgy, gas and steam handling, and tailings management processes. Data for the material being processed can include mineralogy, particle size analysis, grade by size or multicomponent size analysis, washability data, mechanical, physical and thermodynamic properties. METSIM is written in APL (A Programming Language). Unlike C++, APL is simple and easy to learn, allowing the user to program whatever they can imagine, without first obtaining a degree in computer science. METSIM can also interface with EXCEL and other software through dynamic data exchange (DDE), allowing data to be imported and exported for viewing, analyzing and controlling. METSIM can answer simple or complex metallurgical and process questions allowing the user to predict and engineer without the issues of clumsy and tortuous spreadsheets.

KEYWORDS

METSIM, Process design, simulation, control.

INTRODUCTION

METSIM is a powerful program capable of modelling and simulating every known metallurgical and inorganic chemical process. For more than 30 years, its developers have focused their efforts towards maintaining a program capable of modeling well-defined processes as well as theoretical developments. Given the flexible nature of the program's platform, users may select from over 200 pre-programmed unit operations or create APL subroutines to design their own. Currently, METSIM is used in over 50 countries for mass and energy balances for either steady-state or dynamic simulations of mine, stockpile, heap leach, material handling, comminution, beneficiation, hydrometallurgy, pyrometallurgy, gas and steam handling, and tailings management processes. New unit operations and processes are endlessly developed in industry and therefore will continue to drive METSIM to expand its capabilities.

THE BASICS

At its simplest METSIM can be used to produce flowsheets. Figure 1 below shows a simple crushing circuit flowsheet created in METSIM. The flowsheet contains typical unit operation symbols which are easily identified as screen, jaw crusher, conveyors and a stockpile. The unit operations included in METSIM cover the full range of common processes as well as several proprietary unit operations. Streams join the unit operations to indicate the direction of material flow. From here the level of detail is strictly under the control of the user.

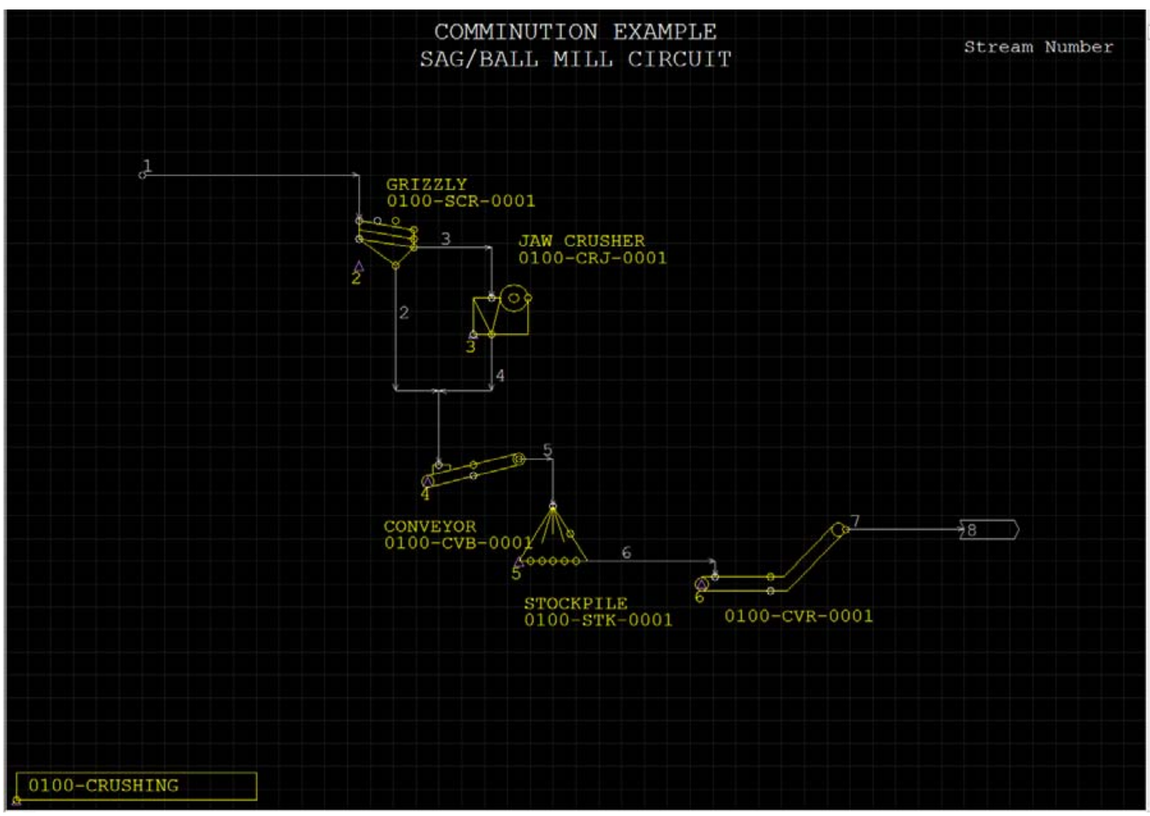


Figure 1 - METSIM Flowsheet

Components of the process, along with their physical and chemical properties, can be added to the model from a large database included in METSIM. Physical and chemical processes can be calculated within the unit operations. All unit operations have algorithms based on commonly accepted textbook calculations with which the output streams are calculated. Many unit operations contain proprietary algorithms for calculating complex units such as hydrocyclones. In the hydrocyclone unit operation the user can choose between the KREBS (gMax), Lynch, Plitt or Modified Plitt algorithms. If the user does not like the algorithm present in the unit operation, they can create their own using the APL programming language, or simply override the unit operation output and write directly to the stream. Although only one section of a larger model is shown in Figure 1, multiple sections can be added to encompass an entire operation from mine to tailings inclusive. METSIM can generate basic mass and energy balances for a single unit operation or model complex multi-unit, multi-component processes using algorithms involving multidimensional inputs. The level of complexity is in the hands of the user.

MODULES AND APPLICATIONS

METSIM is offered as a modular program, meaning that companies and individuals may purchase a simple mass balancing program for beneficiation and hydrometallurgical processes or may include modules for material handling, comminution, pyrometallurgy, gas and steam handling, and dynamic simulation for mines, stockpiles, heap leaching, and tailings management processes. Modules offered are shown in table 1.

Table 1 - METSIM Modules And Applications In Industry

MODULE	DESCRIPTION
BASE/MASS BALANCE MODULE	This module performs mass balance calculations around each unit operation and includes Chemical, Mineral Beneficiation and Hydrometallurgical models.
COMMINUTION & GRAVITY SEPARATION MODULE	This module includes Crushing, Grinding, Classification, Plant Material Balances, Gravity Separation, Dense Media, Coal Preparation, Washability and Liberation Models.
HEAT BALANCE MODULE	This module performs heat balance calculations around each unit operation and reports temperatures and the heat content for each stream. Heat losses and heats of reaction are also calculated and reported. It includes an extensive Thermodynamics Database and several Pyrometallurgical models.
DYNAMIC SIMULATION & HEAP LEACHING MODULE	Dynamic simulation capability is being added to each unit operation as there is a demand for it; all operations concerned in heap leaching have already been provided with dynamic simulation. The heap leach module performs mass balances around the heap leach process including chemical reactions, precipitation and evaporation, solids and water inventories, and process controls. The model is non-steady state and generates time dependent plots of all critical variables in the operation. It includes DDE and PID Controllers, Heap Leaching, Solar Energy/Weather Module w/Solar Pond. Used to model processes that are time dependent.
MINE MODULE	The Mine Module allows import of drill-hole data, the mine block model and the mining sequence. The feed to the waste dumps, heaps, stockpiles and plant can then be taken directly from the mine. This allows dynamic simulation over the life of the mine.
CONTOURING MODULE	Used for building complex mine, stockpile, heap leach, and tailings models from DXF contour files and for displaying detailed data graphically.
METCOST, OPERATING COST MODULE	The Operating Cost Module is designed to enable the user to use the data generated by the flowsheet model to generate tables of operating costs. Costs are output in spreadsheet format and can be itemized by flowsheet section, unit operation, and cost types. A series of routines are provided in a menu structure for input, calculation, editing and output. Operating costs can be determined, at any time following the calculation of a model. This module includes OPCOST, an advanced program for calculating mine capital and operating costs.

ENGINEERING MODULE	The Engineering Module sizes equipment, generates equipment lists, adds instrumentation, generates instrumentation lists, and simulates process control systems.

Combining all modules into a single model allows for simulation of nearly any process from beginning to end, and given the importance of recycle flow convergence, a single model to accomplish this feat is invaluable. METSIM has been, and is currently, used for the following applications, though it is not limited to this list.

- Copper, nickel, uranium, gold, and silver heap leaches
- Incinerators for military wastes at a superfund site
- Electric furnace for EAF dust
- Selenium decontamination process
- Chloride process for titanium dioxide
- HCl process for high purity alumina
- Rare earth solvent extraction processes
- Large-scale potash solar ponds
- 100,000 ton per day grinding circuit
- Potash, soda ash and phosphate plants
- Dynamic model of lead refining
- Sulfuric acid plants
- Aggregate and gravel plants
- Copper, moly, lead, zinc concentrators
- HCl leach and magnesium electrolysis
- Zinc and gold pressure leach plants
- FeCl3 leach plants for molybdenum
- NH3 leach process for brass scrap
- Placer and CIP gold cyanidation plants
- Uranium acid/carbonate leach plants
- Outokumpu and INCO flash smelters
- Copper, lead, zinc, nickel smelters
- Precious metal and copper refineries
- Dense media coal preparation plants
- Nickel hydromet and smelting processes
- Magnesium and aluminum processes
- Direct iron ore reduction processes
- Beryllium and indium processes

FEATURES

Although the focus of METSIM is accurate calculations and algorithms, a simple-to-use interface offers users of all abilities a platform for model creation. Features, such as those outlined below, are included with all modules. In conjunction with the modules listed above the features of METSIM make it an invaluable tool for de-bottlenecking and optimization tasks.

Mass balancing based on design criteria:
- Detailed equipment sizing and equipment lists;
- Steady-state simulation: mass and energy balancing;
- Parameterization to simulate existing/operating plants;
- Dynamic simulation for time-varying parameters.

Flowsheeting:
- Easy to add new unit operations;
- Unlimited number of unit operations and flow streams;
- Flowsheet and dynamic graphics;

- Capable of calculating single, multiple or all unit operations;
- Robust proprietary flowsheet convergence algorithm;
- Full graphical interface.

Chemistry:

- Extensive thermodynamic database;
- Chemical kinetics and phase equilibria;
- Eight solid, liquid, molten, and gas phases.

Process controls:

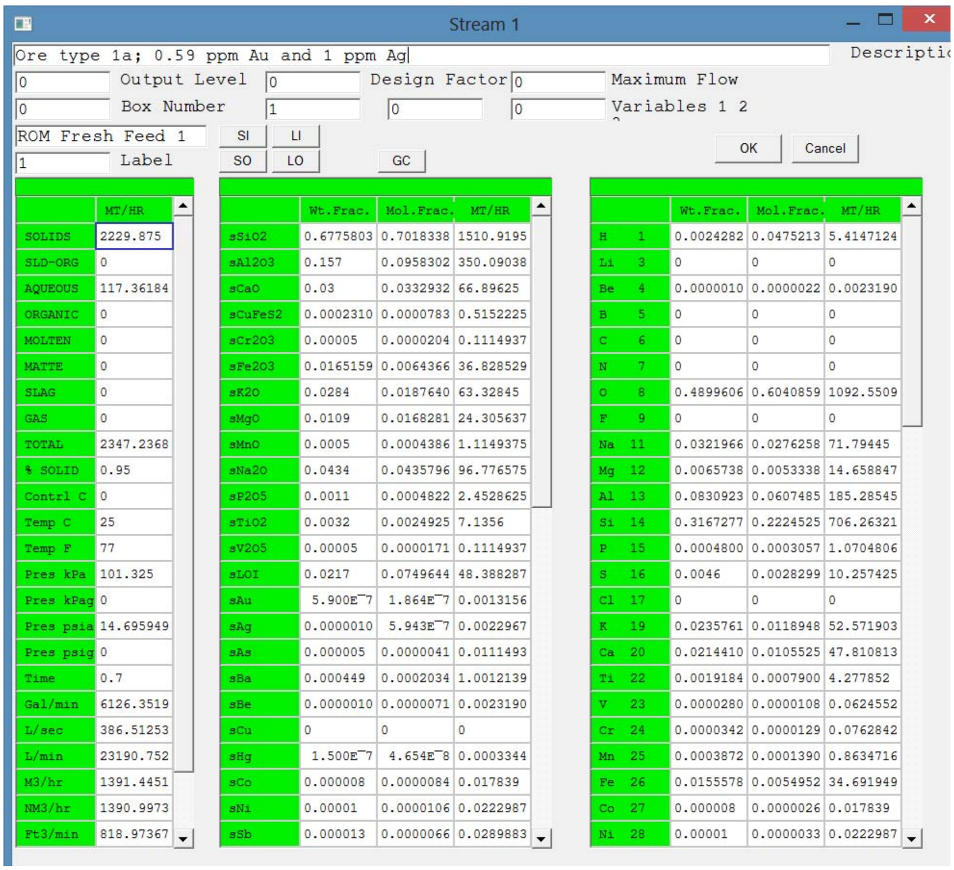
- Feedback, feed forward, pH and PID controllers;
- Logic/expert systems;
- User-defined equations and algorithms.

Compatibility:

- Spreadsheet interface to Excel via dynamic data exchange;
- DXF interface with AutoCAD.

MATERIAL AND PROCESS DESIGN DATA

Detailed data for the material being processed, including mineralogy, particle size analysis, grade by size or multicomponent size analysis, washability data, mechanical, physical and thermodynamic properties may be included for all flow streams. Process data may include equipment sizing, control strategies, equipment availabilities, chemical reaction efficiencies, heat losses/gains, reagent and material costs, meteorological data, and any other item that impacts the process. An example of mineralogical data within a flow stream is shown in figure 2.


Stream 1

Ore type 1a; 0.59 ppm Au and 1 ppm Ag | Descripti

0 Output Level 0 Design Factor 0 Maximum Flow

0 Box Number 1 0 0 Variables 1 2

ROM Fresh Feed 1 | SI | LI | OK | Cancel

1 Label | SO | LO | GC

	MT/HR
SOLIDS	2229.875
SLD-ORG	0
AQUEOUS	117.36184
ORGANIC	0
MOLTEN	0
MATTE	0
SLAG	0
GAS	0
TOTAL	2347.2368
% SOLID	0.95
Contrl C	0
Temp C	25
Temp F	77
Pres kPa	101.325
Pres kPag	0
Pres psia	14.695949
Pres psig	0
Time	0.7
Gal/min	6126.3519
L/sec	386.51253
L/min	23190.752
M3/hr	1391.4451
NM3/hr	1390.9973
Ft3/min	818.97367

	Wt.Frac.	Mol.Frac.	MT/HR
sSiO2	0.6775803	0.7018338	1510.9195
sAl2O3	0.157	0.0958302	350.09038
sCaO	0.03	0.0332932	66.89625
sCuFeS2	0.0002310	0.0000783	0.5152225
sCr2O3	0.00005	0.0000204	0.1114937
sFe2O3	0.0165159	0.0064366	36.828529
sK2O	0.0284	0.0187640	63.32845
sMgO	0.0109	0.0168281	24.305637
sMnO	0.0005	0.0004386	1.1149375
sNa2O	0.0434	0.0435796	96.776575
sP2O5	0.0011	0.0004822	2.4528625
sTiO2	0.0032	0.0024925	7.1356
sV2O5	0.00005	0.0000171	0.1114937
sLOI	0.0217	0.0749644	48.388287
sAu	5.900E¯7	1.864E¯7	0.0013156
sAg	0.0000010	5.943E¯7	0.0022967
sAs	0.000005	0.0000041	0.0111493
sBa	0.000449	0.0002034	1.0012139
sBe	0.0000010	0.0000071	0.0023190
sCu	0	0	0
sHg	1.500E¯7	4.654E¯8	0.0003344
sCo	0.000008	0.0000084	0.017839
sNi	0.00001	0.0000106	0.0222987
sSb	0.000013	0.0000066	0.0289883

		Wt.Frac.	Mol.Frac.	MT/HR
H	1	0.0024282	0.0475213	5.4147124
Li	3	0	0	0
Be	4	0.0000010	0.0000022	0.0023190
B	5	0	0	0
C	6	0	0	0
N	7	0	0	0
O	8	0.4899606	0.6040859	1092.5509
F	9	0	0	0
Na	11	0.0321966	0.0276258	71.79445
Mg	12	0.0065738	0.0053338	14.658847
Al	13	0.0830923	0.0607485	185.28545
Si	14	0.3167277	0.2224525	706.26321
P	15	0.0004800	0.0003057	1.0704806
S	16	0.0046	0.0028299	10.257425
Cl	17	0	0	0
K	19	0.0235761	0.0118948	52.571903
Ca	20	0.0214410	0.0105525	47.810813
Ti	22	0.0019184	0.0007900	4.277852
V	23	0.0000280	0.0000108	0.0624552
Cr	24	0.0000342	0.0000129	0.0762842
Mn	25	0.0003872	0.0001390	0.8634716
Fe	26	0.0155578	0.0054952	34.691949
Co	27	0.000008	0.0000026	0.017839
Ni	28	0.00001	0.0000033	0.0222987

Figure 2 - METSIM Stream Properties Window Showing Mineralogical Data in the Solids Fraction

Inclusion of particle size distributions (PSDs) by mineral is possible using the multicomponent particle size (also known as grade by size) feature. In the graph shown in figure 3, multicomponent size distributions are shown by individual PSDs plotted for NaCl, KCl, CaSO4, and insolubles for a plant feed stream. Changes to the multicomponent size analysis due to unit operations such as flotation, screening and crushing are calculated and tracked throughout the model.

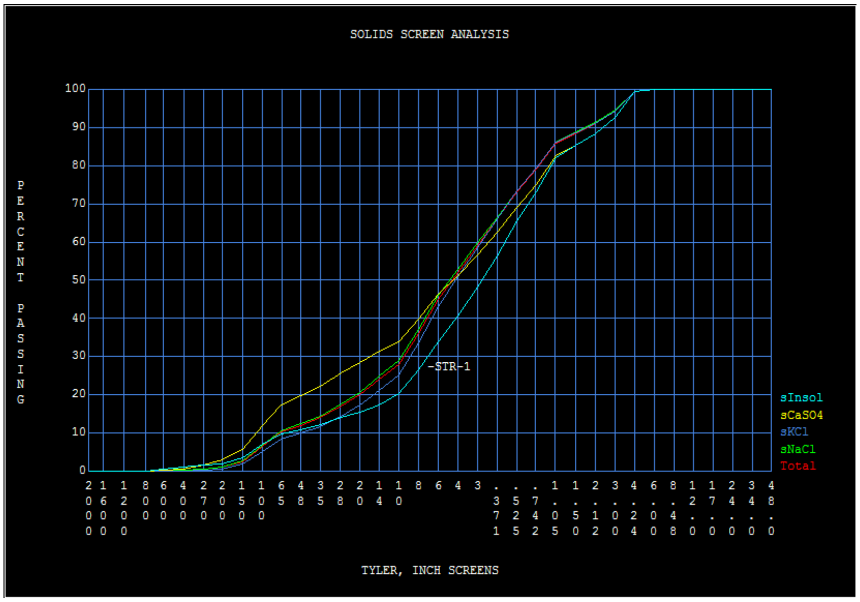


Figure 3 - METSIM Multicomponent Size Analysis (Grade by Size)

Meteorological data may greatly affect any process that is exposed to nature which includes nearly all processes. Figure 4 summarizes the type of meteorological data that METSIM is able to manage. Meteorological data is crucial in the correct modelling of heap leach, tailings pond and evaporation pond processes for obvious reasons.

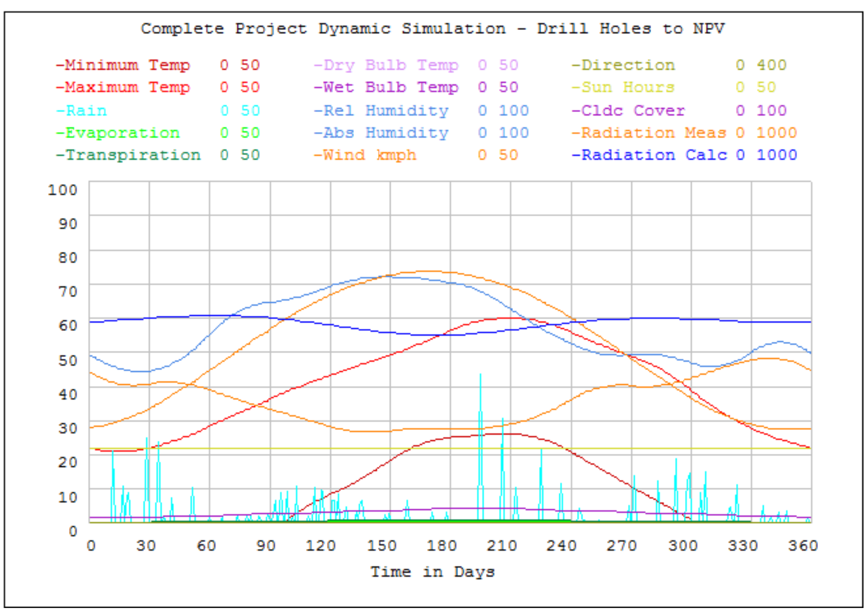


Figure 4 - Annual Meteorological Data Chart for A METSIM Model

Using minimum, average and maximum conditions METSIM can create scenarios to represent the full range of weather related effects on a given operation. If desired this can be programmed for extreme weather events to determine if overflow ponds and catchments are sufficiently sized.

Interfacing with AutoCAD DXF files allows for detailed dynamic simulation of mine, stockpile, heap leach and tailings management facilities along with the use of the METSIM Contouring module. An example of contours for a heap leach simulated in METSIM is shown in Figure 5. The ability to read DXF files into METSIM removes any restriction on design dimensions or shape as the actual shape and dimensions of the heap, stockpile, or tailings pond can be used directly. Detail is not lost due to gross approximations of non-linear objects.

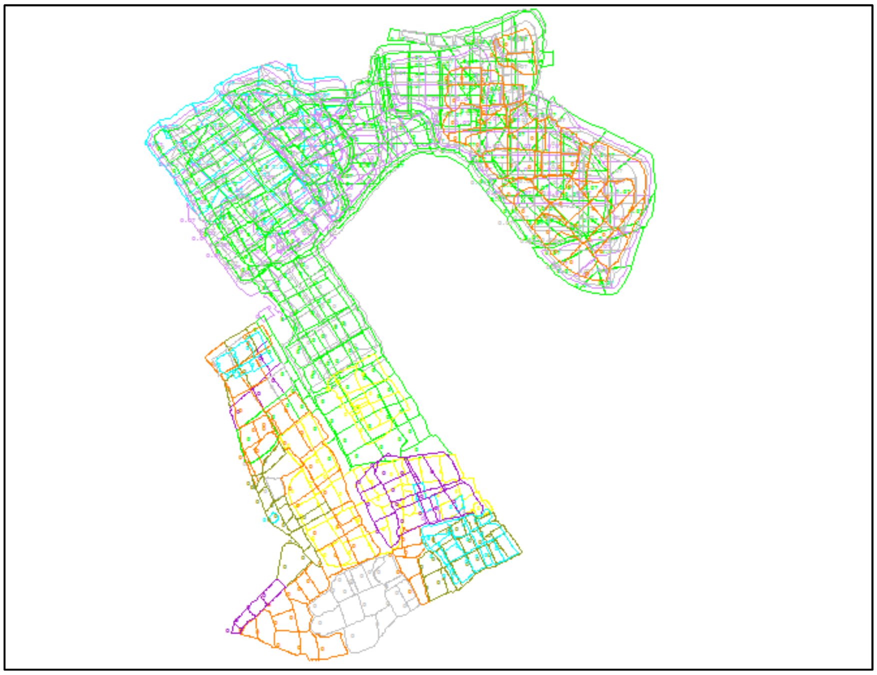


Figure 5 - Resulting Import of AutoCAD DXF file Into A METSIM Heap Leach Model

A PROGRAMMING LANGUAGE (APL)

The APL programming language, that METSIM is based on, was first developed by the Canadian Kenneth E. Iverson in the late 1950's and the early 1960's. APL was derived from the Iverson mathematical notation developed by Iverson for teaching mathematics. APL's utility for processing data in the form of scalars, vectors and matrices, very quickly and with a minimal number of coding lines make it the optimal choice for METSIM. Some of the fundamental characters and their use is shown in table 2. Within METSIM, the APL language can be used to build or modify simple calculations using the built in value functions or math functions already in METSIM, or to create user stand-alone functions which can be called in unit operations and many other locations in METSIM. If the user desires, the unit operation algorithm can be replaced entirely by a user algorithm programmed in APL and called as a function. APL is a simple language and it is well known that the code line ratio is typically 1 line of APL code to 20 lines of C++ code. This compactness provides a lot of power in a small space.

METSIM has over 600 pre-built Value Functions and Mathematical Functions already programmed and ready for use. These pre-built functions cross the full range of information users may want to see in their models or mathematical manipulations that may be required. METSIM Value Functions can provide outputs such as density and specific gravity, pressure, temperature, specific volume, mass, molar and volumetric flowrates, particle size distribution, steam, air, heat content and numerous others. The mathematical functions available for the user cover date and time, matrix manipulation and interpolation, including two-way interpolation, vector manipulation, temperature, text, trigonometry and many other more complex mathematics based manipulations of data.

Table 2 - APL Characters and Use in METSIM.

Symbol	Function Name	Keystroke	Use(s)
|	rho or reshape	Alt-r	create or determine the size of an array
…	iota or index	Alt-i	return consecutive integers from 1 to x
	left arrow or assignment	Alt-[	assign a value to a variable
/	slash or reduction	/	repeat an operation in a series of values
≠	member of	Alt-e	determine if values are present in an array
?	random	?	generate random values
·	times	Alt--	multiplication
|	divide	Alt-+	division
±	pi and trigonometry	Alt-o	pi times a value or trigonometric functions
♠	diamond	Alt-`	join two expressions on the same line
↓	minus	Alt-2	negative values
*	power or exponential	*	raise a value or e to a power
∝	logarithm	Alt-Shift-8	calculate a logarithm
	minimum or floor	Alt-d	round down or find smaller of
	maximum or ceiling	Alt-s	round up or find larger of
	upgrade	Alt-Shift-4	arrange values in ascending order
	downgrade	Alt-Shift-3	arrange values in descending order

METSIM OUTPUTS - MASS BALANCE, ENERGY BALANCE AND ENGINEERING SPECIFICATIONS

Looking again at the simple flowsheet shown in figure 1 and comparing that to figure 6, the mass balance may be seen in the table at the bottom of the diagram. The mass balance includes all components and elements in the model. Mass balance checks can be performed on the entire model or a single section of the model. Mass balances can be displayed in the model as tables either on the stream, as seen on stream 1 and 7 in figure 6, or at the bottom of the section as shown. Mass balance data can also be exported to Excel by copy and paste or via dynamic data exchange (DDE) at the end of the calculation of the model. The mass balance data can include any number of standard data items already available in METSIM or the user can create custom items to display any piece of data they need. The level of complexity in data export is again at the user’s discretion.

Energy balances may also be generated, displayed and exported to Excel. Energy balances include stream heat content, heat of reaction, heat of solution, energy inputs, energy losses and energy required to maintain specified output stream conditions. Heat of reaction is calculated automatically based on the thermodynamic data entered by the user for each component or from the large component database built into METSIM.

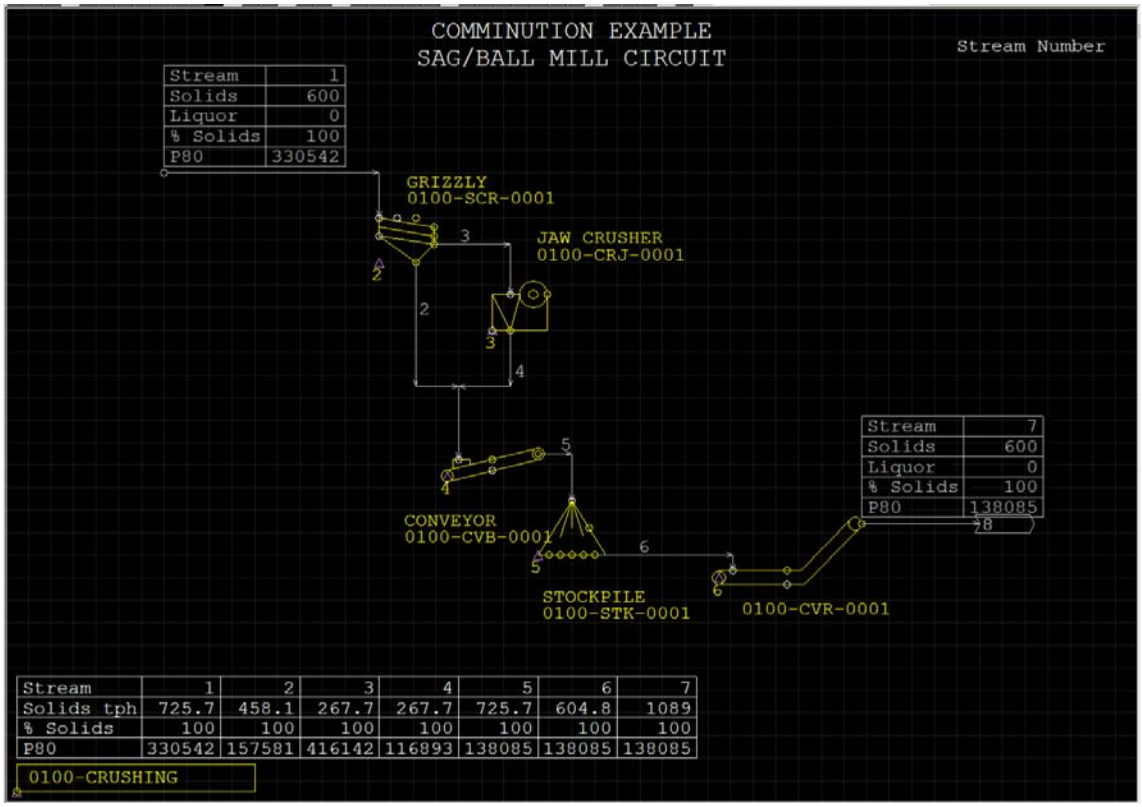


Figure 6 - Simple Crushing Circuit Mass Balance

Engineering specifications for all unit operations and streams can also be generated and exported to Excel. A sample of some of the engineering data corresponding to model shown in figure 6 is shown in table 3. Along with mass balance data for operating and design conditions, METSIM can also generate equipment tag numbers based on user specifications and engineering equipment lists containing equipment description and design parameters ready to distribute to vendors or other engineering personnel. Pipe sizing, particle size distributions, instrument lists and detailed and operating cost analysis can also be calculated and displayed in engineering documents if the user desires.

Table 3 – METSIM Engineering Stream Specifications

Stream Number	Nominal Solids ST/HR	Operating Time Fraction	Operating Solids ST/HR	Design Design Factor	Design Solids ST/HR	Solids %	Temp C	Density Solids t/m3
1	600.00	0.750	800.00	1.250	1000.0	100.0	33.0	2.650
2	378.72	0.750	504.96	1.250	631.2	100.0	33.0	2.650
3	221.28	0.750	295.04	1.250	368.8	100.0	33.0	2.650
4	221.28	0.750	295.04	1.250	368.8	100.0	33.0	2.650
5	600.00	0.750	800.00	1.250	1000.0	100.0	33.0	2.650
6	600.00	0.900	666.67	1.250	833.3	100.0	33.0	2.650
7	600.00	0.500	1200.00	1.250	1500.0	100.0	33.0	2.650

METSIM RECENT PROJECT – CASERONES VALLEY-FILL HEAP LEACH – COPIAPO, CHILE

Beginning in mid-2013, METSIM engineers worked alongside engineers and metallurgists from the Caserones Valley-Fill Heap Leach Project located near Copiapo, Chile. Mining and heap stacking operations there started in July 1, 2012, approximately one year before the simulation model was developed. The goal was first to accurately simulate what had occurred at the site over year 1, including solutions flows and tenors, Cu recoveries and cathode production. Following this exercise, the model would then be used to optimize future leaching operations and to serve as a production forecasting tool. Figures 7 and 8 show the heap leach and electrowinning flowsheets from the Caserones model respectively.

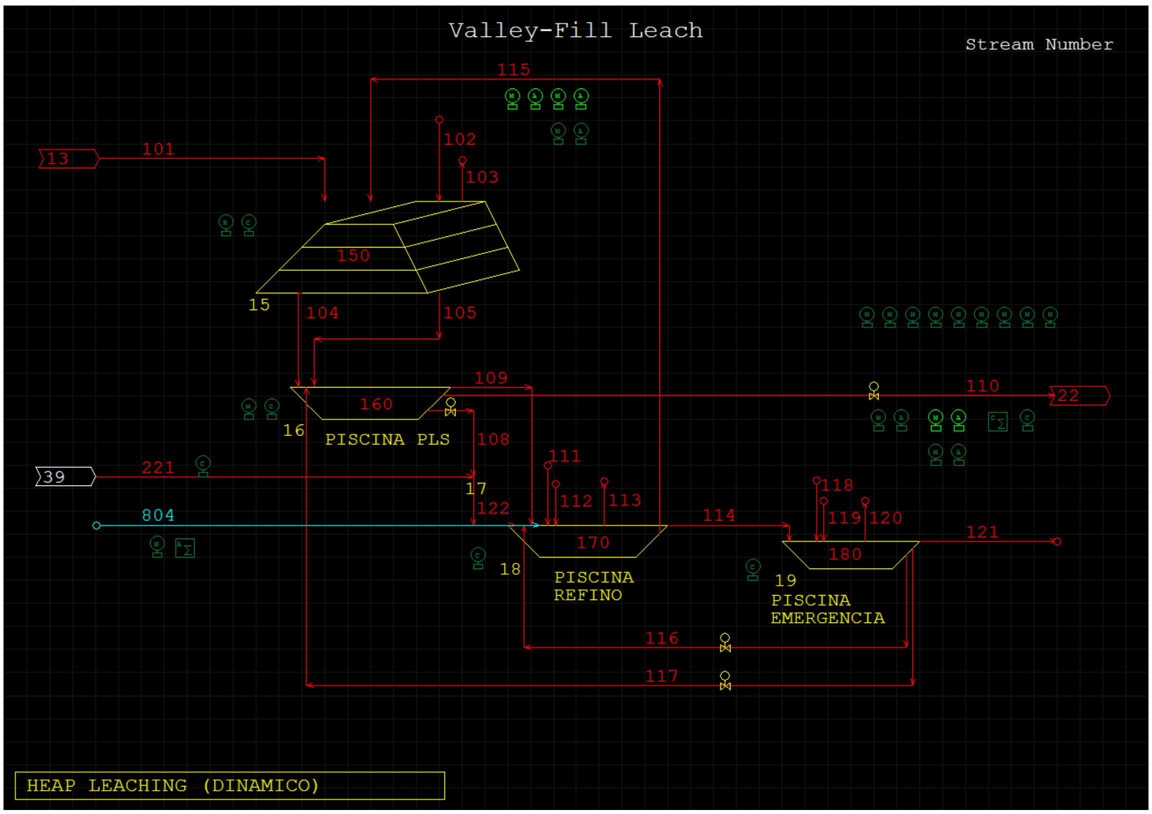


Figure 7 – Caserones Heap Leach Model – Heap Leach Section

Daily historical data for ore tons and grade along with heap construction contours were organized in METSIM to accurately simulate daily heap inventories over time. Leach cycles per lift were included to generate simulated raffinate and pregnant leach solution (PLS) flows to and from the heap (including initial solution stacking during the first 6 months of operation). Furthermore, each copper bearing mineral corresponded to column recovery data which was curve-fit in METSIM to generate reaction rates. These rates were then used to determine the reaction chemistry taking place inside the heap. Combining these key parameters, along with historical weather data, simulated solution tenors for copper were generated by the model. The actual operating solution tenors and those generated by the METSIM model are shown in figure 9 and 10, respectively, for comparison.

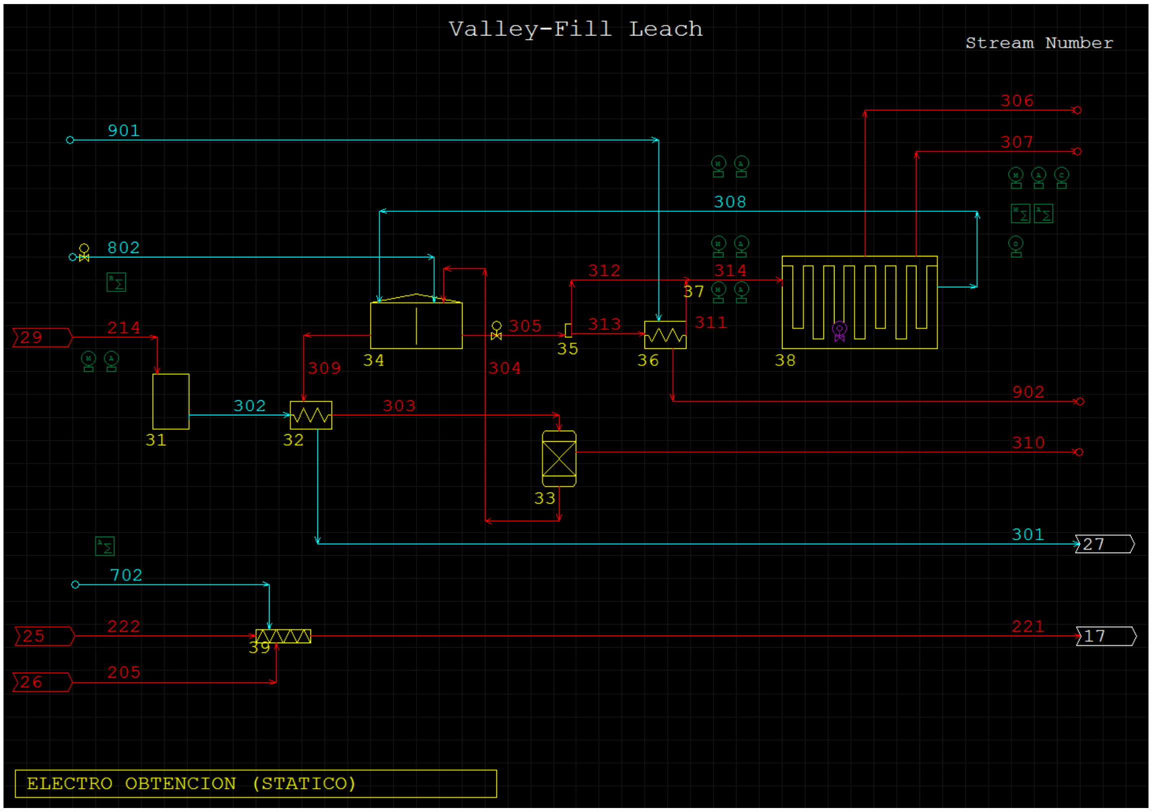


Figure 8 – Caserones Heap Leach Model – Electrowinning Section

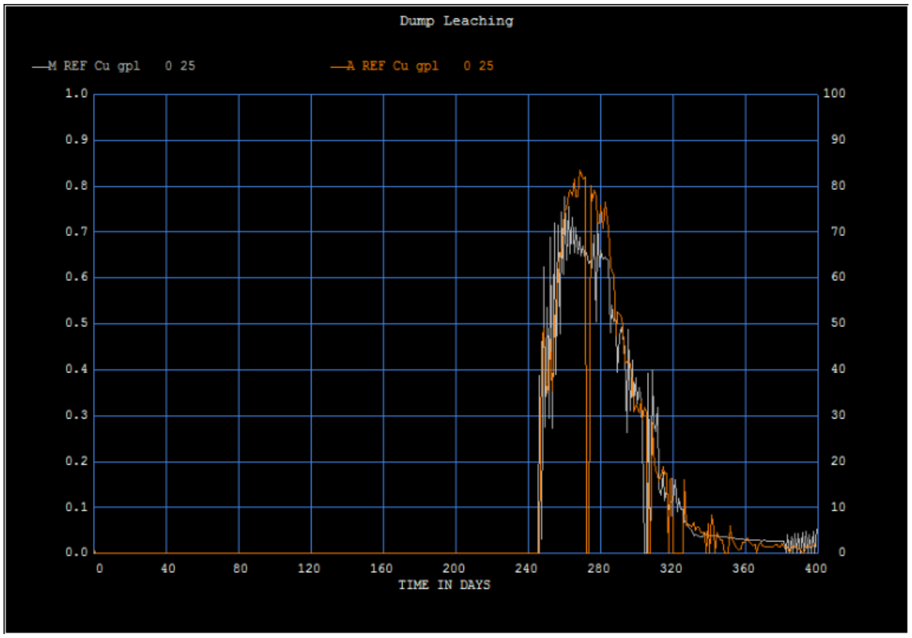


Figure 9 – Comparisons Of Simulated Cu Solution Tenors Versus Actual Cu Solution Tenors For Raffinate.

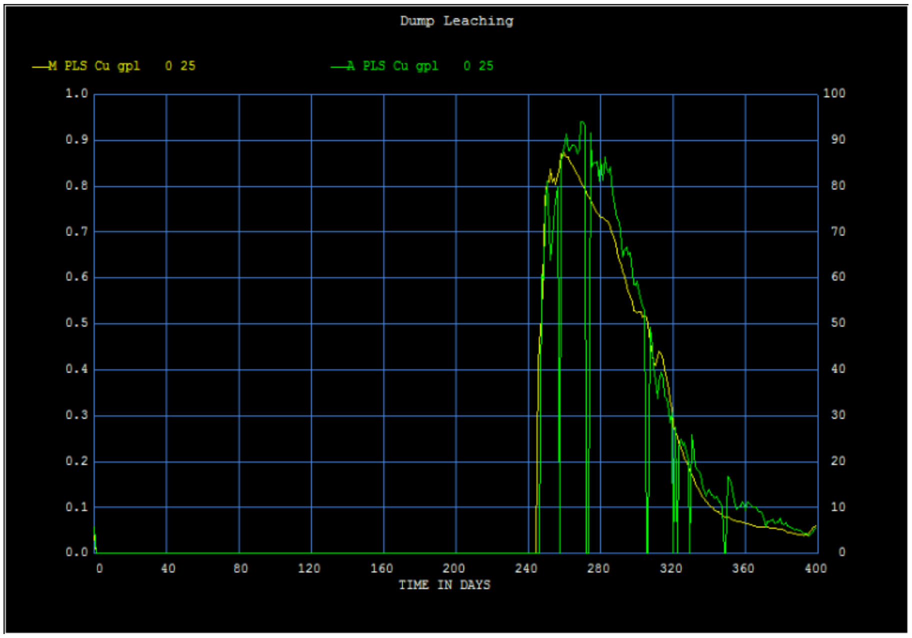


Figure 10 – Comparisons Of Simulated Cu Solution Tenors Versus Actual Cu Solution Tenors For PLS.

Also included in this model was the solvent extraction (SX) and electrowinning (EW) plant for the production of copper cathode. Isotherms for both extraction and stripping (re-extraction) were used to simulate extraction of copper through the SX plant while actual EW cell parameters such as current efficiency and working amperage simulated the weight of total cathode produced daily. A comparison of the cumulative actual cathode plated versus the METSIM simulated cathode production is seen in figure 11.

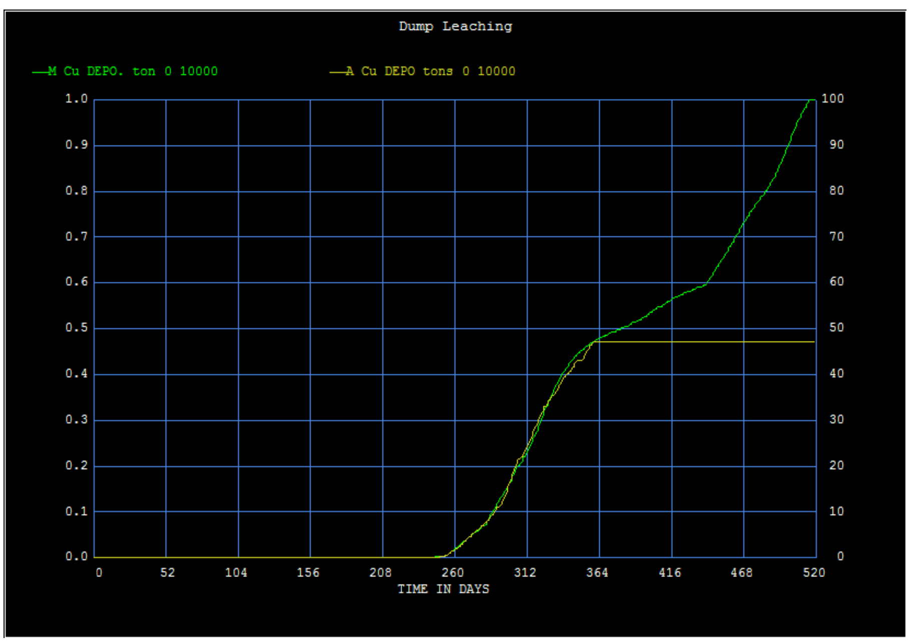


Figure 11 – Comparison Of Actual Cu Cathode Production (yellow) Versus METSIM Simulated Cu Cathode Production (green). Actual Data Stops At Day 360. METSIM Production Prediction Continues Through Day 520.

Given the success of the heap leach simulation model, Caserones has since contracted METSIM to dynamically simulate their copper concentrator, which is yet to start production, with further interest in simulating the entire site dynamically including the mine block model and detailed contoured tailings management facility.

CONCLUSION

METSIM is currently being used by over 600 companies including 2000 individuals worldwide to model or simulate a wide variety of processes in an even wider range of industries. METSIM is able to simulate mining operations from the ground to the tailings facilities dynamically from ground breaking to closure in a single model. Various modules within METSIM allow the user to choose what they need for their specific process. The level of detail in any model is dictated by the user and can be as simple as a flowsheet and mass balance or as complex as the day to day dynamic operation of an entire mine, mill, and tailings facility. With the use of APL there is no limit to what can be accomplished in METSIM.

ACKNOWLEDGMENTS

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