

Impact case study (REF3b)

Institution: Swansea University
Unit of Assessment: 15 - General Engineering
Title of case study: Advanced Simulation Technology to Optimise the Recovery of High Value Metals Through Heap Leaching
1. Summary of the impact

This case study describes the creation and use of advanced simulation technology by international mining corporations to optimise high value metal recovery. The technology involved the development of advanced novel computational methods and software tools to model industrial scale heap leach processes for large scale industrial application at major mining operations. This focus on the development of optimised operational strategies has produced considerable economic benefits measured in the \$multi-millions to industrial sponsors, including \$58 million dollars in additional revenue for one multi-national corporation over one year following the adoption of engineered heaps based upon the advanced simulation tools from Swansea.

2. Underpinning research

During the 1990s Prof Cross as part of a large group with several professors (then at the University of Greenwich) was increasingly working on problems that involved the interactions amongst a range of physical phenomena on high performance parallel computing cluster technologies, for what became known as multi-physics modelling. A key outcome of their work on a single software framework for closely coupled problems was the PHYSICA software. This was integrated as a toolkit within the last decade and has been applied on a wide range of multi-physics problems typically (but not exclusively) within the context of manufacturing and minerals/metallurgical engineering.

In 2005 Prof Cross and his core 'multi-physics' development team (Drs Bennett, Croft, McBride, Slone and Williams) moved to the College of Engineering at Swansea University. One of their main research themes at Swansea led by Prof Cross together with Drs Bennett, Croft and McBride concerned the development of models and simulation tools for the analysis of solution and gas flow through reactive porous media in the context of industrial heap leaching processes for the recovery of high-value ores. This is particularly important when other more conventional recovery methods are no longer economic. This research was pursued collaboratively with a US-based minerals technology company, PERI, together with a range of multi-national mining concerns to develop simulation-based solutions to support the understanding and optimisation of operational procedures in major commercial mines.

Specifically, since 2005 the Swansea team have worked on the development of model components and software enhancements to novel numerical procedures within a finite volume unstructured mesh framework to capture flow through variably saturated porous media to underwrite the advanced modelling of heap leaching and enable this phenomena to be tracked in complex three dimensional geometries [R1]. Additionally, extensive developments have been pursued to enhance the basic models and develop industrial strength simulation tools specifically through the development of a non-equilibrium framework to capture increasingly complex process chemistry [R2], together with extensive studies with collaborating industrial partners on the design of a comprehensive experimental programme which led to the detailed validation and verification of the copper sulphide heap leach model [R3]. A further significant component of the programme has been on the modelling of the heap leaching of gold-silver-copper oxide complex ores. Here, a comprehensive model has been developed and carefully validated against laboratory data [R4], then a robust 'process' version of the model for modelling full commercial heaps has been developed and validated [R5] and exploited by Newmont Gold engineers in optimising their gold heap leach operation at Yanacocha in Peru [R6].

PERI was recently acquired by FLSmidth Inc, a major international supplier of minerals technology and systems into the international mining sector, where corporations such as Rio Tinto, Freeport,

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Barrick and Newmont are major clients. FLSmidth have continued this close collaboration with the Swansea team.

Main personnel involved at Swansea since January 2005:

- Academic Staff at Swansea University: Prof Mark Cross and Dr Nick Croft
- Research Staff at Swansea University: Dr Chris Bennett (until mid 2011, when he moved to a role in industry) and Dr Diane McBride

3. References to the research

The publications below represent descriptors of fundamental underpinning research, subsequent technological advances and industrial achievements. References R1, R3 and R4 are those which primarily represent the academic quality of the research contribution.

Publications:

- R1. D McBride, T N Croft, C R Bennett, M Cross** and J Gebhardt Computational modelling of variably saturated flow in porous media with complex three dimensional geometries, *International Journal of Numerical Methods in Fluids*, **50**, 1085-1117 (2006) (IF~1) – submitted in 2008 RAE in Mechanical Engineering in which all papers were rated at 2* plus.
- R2. J.E. Gebhardt, C.R. Bennett, D. McBride, and M. Cross**, Attributes of Electrochemical Potential in a Multi-Physics Heap Leach Model, *8th Symposium on Electrochemistry in Mineral and Metal Processing Proceedings*, F.M. Doyle, R. Woods, and G.H. Kelsall, Eds., The Electrochemical Society, Pennington, NJ, USA and published in *ECS Transactions*, **28(6)** 179-210 (2010) – based on an invited paper at specialist industrial research international conference of the US Electrochemical Society.
- R3. C R Bennett, D McBride, M Cross** and J E Gebhardt, A Comprehensive Model for Copper Sulphide Heap Leaching. Part 1 Basic Formulation and Validation Through Column Test Simulation, *Hydrometallurgy*, **127-128**, 150-161 (2012) (IF = 2.03) – submitted to this REF
- R4. D. McBride, M. Cross** and J E Gebhardt, A Comprehensive Gold Oxide Heap Leach Model: Development And Validation, *Hydrometallurgy*, **113-114**, (2012) Pages 98-108 (IF = 2.03) – submitted in this REF
- R5. D. McBride, M. Cross** and J E Gebhardt, Heap Leach Modelling Employing CFD Technology: A 'Process' Heap Model, *Minerals Engineering* **33**, 72-79 (2012) (IF = 1.35) – contains the details of the typical form of the model used online by the industrial collaborators
- R6. S. Garcia, C. Ramon, A. Esplin, J.E. Gebhardt, A. Hernandez, D. McBride, and M. Cross**, Gold heap leach simulation and optimization using a multi-physics model, *Minerals and Metallurgical Processing*, **27**, 196-204 (2010) (IF = 0.22) – invited contribution to a special issue of the US Society of Mining, Mineral and Exploration (SME, the professional society which licenses PEng) journal publication on gold processing after presentation at an international SME conference

Evidence of key grants and contracts:

Heap leach modelling, funded through PERI (now FLSmidth Inc, Salt Lake City), continuously from January 2005 through a rolling contract worth a total of US\$1,800,000 with Prof Cross as the PI.

4. Details of the impact

Our industrial collaborator PERI (now FLSmidth Inc) has worked in collaboration with the Swansea team for many years on a range of problem areas, although the main thrust has concerned heap leach modelling and simulation of commercial operations in the USA, Peru, Chile and Australia. The Swansea team focussed on the development and validation of the core simulation tools to capture all the significant chemical and physical behaviour: PERI provided expert knowledge on

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the physics and chemistry of the processes. PERI also led close working with our industrial partners to capture the operational process data, use it as input to the process model and then provide operational advice back to the clients. These industrial partners are all major international mining and minerals corporations and include Freeport-McMoRan, Rio Tinto, Newmont Gold and Barrick Gold; all are quoted on one of the London, New York or Australian stock exchanges.

Our conventional collaborative working practice with PERI have typically involved:

- a) The PERI industrial client/collaborator (IC) needing to develop a design for or optimise an existing operation especially in the light of changing conditions (e.g. the properties of the ore body are evolving and usually becoming more challenging);
- b) The Swansea Team developing a validated simulation tool that then embeds all the physical and chemical phenomena in the numerical model;
- c) The IC bringing facilities for engineering design, experimentation and testing;
- d) PERI managed the client interaction, developing all the user interaction supporting software, and provided high level expertise on the chemistry and engineering of heap leaching processes;
- e) Model validation proceeding as a joint effort amongst the IC, PERI and the Swansea team;
- f) Process analysis and optimisation initially as a joint effort, though eventually PERI assume responsibility for the training of IC personnel in using the simulation software so that they can embed the technology within their own organisation.

Each of the main heap leach modelling projects indicated above (delivered at Swansea) were carried out in close collaboration with PERI and its primary clients (Rio Tinto, Freeport, Newmont Gold, Barrick, etc). A particular complexity of the heap leach process, from the modelling perspective, was that the heap actually grows over time – it is constructed from layers of crushed ore (typically 10m deep covering a kilometre or more square), which are added every couple of months over an extended period of years, and so sources of the liquid solution change with time as do those of injected air (where used). Moreover, over time the initial properties of the ore body change as does the ambient climate. Capturing this complexity is vital to the process as planning engineers need to evaluate a range of potential heap development options in order to optimise production rates and ore body recovery. This means that not only does the core model have to be able to account for this complexity, but the ability to define this evolution in time has to be made accessible to its users. The PERI clients have extensive advanced laboratory facilities for column based as well as small heap experiments to provide data to parameterise and validate the computational model provided by the Swansea Team. The modelling work typically underwrote either the decision making concerning the planning of future operations or the optimisation of existing ones. These industrial operations were multi-million\$ ventures where small improvements can make huge differences to the financial outturns – for example, the principal metallurgist at FLSmidth Inc (formerly PERI) responsible for heap leach modelling, states that the engineered heap at Freeport-McMoRan which was designed using the advanced simulation tools, ‘... *demonstrated production yield improvements of roughly 25% dynamic recovery. Over a one-year period, an additional 25 million pounds of copper was produced from the Engineered Heap. At an average copper price of \$2.34 per pound in 2009, this equates to approximately \$58 million dollars in additional revenue*’. The independent evidence for this is recorded in J M Ekenes and C A Caro, Improved leaching recovery of copper from low grade chalcopyrite ores, *CD Proceedings of the Annual SME Meeting*, February 2012, Seattle, WA, paper no 12-099, where the Freeport-McMoRan engineers outline the development of their Engineered Heap operational strategy which yielded significantly improved recoveries on a full-scale industrial heap in Arizona. These economic impacts have been achieved since the late 2000s, and this quote relates to just one industrial project.

5. Sources to corroborate the impact

1. Letter of key support for the above project has been supplied by the Principal Metallurgist of PERI, Salt Lake City, USA (recently acquired by FLSmidth, Salt Lake City) who coordinates their heap leaching simulation activities
2. A copy of a USA based international conference paper presented by our industrial collaborators on the performance of the engineered heap designed through the simulation tools reported here:
J M Ekenes and C A Caro, Improved leaching recovery of copper from low grade chalcopyrite ores, *CD Proceedings of the Annual SME Meeting*, February 2012, Seattle, WA, paper no 12-099