191 **DA13**
Projet d'implantation d'une usine de traitement de la brasque usée à Saguenay, arrondissement de Jonquière
Saguenay **6211-19-014**

Le 3 février 2004

Madame Monique Gélinas
Secrétariat de la commission
Bureau d'audiences publiques sur l'environnement

Objet : vérification du procédé LCLL (Dynatec)

Madame,

Vous trouverez ci-joint, dans six fichiers électroniques, le sommaire de la vérification (Process Audit) du procédé LCLL effectuée par « Dynatec Corporation, Metallurgical Technologies Division, Fort Saskatchewan, Alberta, Canada » en Juin 2000.

Au terme des travaux de laboratoire et de bancs d'essais effectués à son Centre de Recherche et de Développement Arvida (CRDA), Alcan avait déjà déposé deux demandes de brevets concernant le procédé LCLL. De plus, tel que déjà souligné lors des audiences, deux sessions de pilotage ont été réalisées en 1993 et en 1998-1999.

La vérification du procédé LCLL chez Dynatec, en 2000, a été réalisée à la fin de la première étape d'ingénierie, soit l'ingénierie de concept. C'est lors de cette étape que s'est effectué le transfert technologique entre Alcan et la firme d'ingénierie retenue dans le but de finaliser le devis technologique du procédé LCLL, d'élaborer l'envergure du projet et de fournir une estimation de l'ordre de grandeur des coûts de construction.

L'étape suivante d'ingénierie préliminaire a été complétée en 2001. C'est à cette étape que sont notamment précisés avec plus d'exactitude les coûts du projet ainsi que les *équipements de longue durée de livraison. C'est également à cette période que fut* préparée l'étude d'impact.

L'ingénierie préliminaire a été réalisée en tenant compte des commentaires et recommandations exprimés par « Dynatec Corporation » et que l'on retrouve dans le sommaire de la vérification ci-joint.

Voici quelques notes explicatives supplémentaires en lien avec le sommaire de la vérification produit par Dynatec :

ITEM 1.2 Lors de l'étape de l'approvisionnement des équipements, nous procéderons aux appels d'offres en utilisant la notion de devis de performance. Ceci signifie que nous demanderons aux fournisseurs de garantir la performance des équipements proposés. Habituellement, des essais supplémentaires chez les fournisseurs d'équipement sont requis dans ces circonstances.

ITEM 1.3 Le «short term storage building for SPL» dont il est question ici est le *bâtiment qui était utilisé pour le triage et l'expédition de la brasque vers* les Etats-Unis pour traitement. Dans le projet proposé, ce lieu servira à entreposer des conteneurs de brasque en provenance des différentes sources d'approvisionnement ainsi que d'aire d'entreposage tampon pour les carbones et inertes. Quelque soit la source, la brasque sera livrée dans des conteneurs spécialement conçus à cette fin tel qu'expliqué lors des audiences.

ITEM 1.4 Des essais supplémentaires sont prévus à l'étape de l'approvisionnement et de l'ingénierie détaillée tel qu'expliqué à l'item 1.2.

ITEM 1.5 L'option UTLE a été retenue. Cette option consiste à utiliser l'Usine de Traitement des Liqueurs d'Épurateurs existante (en augmentant sa capacité) déjà en opération à l'Usine Vaudreuil. Cette usine a pour fonction de transformer les fluorures captés par les épurateurs en fluorure de calcium (CaF2) via un traitement à la chaux. Cette forme de fluorure est chimiquement très stable et se retrouve tel quel dans la nature.

ITEM 1.6 Le CaF2 qui est généré par l'UTLE sera incorporé à la boue rouge qui est acheminée au site de boue, comme cela se fait actuellement, et ce, conformément à un certificat d'autorisation existant. Cependant la valorisation du NaF généré par le procédé LCLL, soit par sa commercialisation, soit par sa transformation en d'autres produits chimiques (HF et NaOH) à l'aide de la technologie des membranes, demeurera l'option privilégiée.

Nous joignons également au rapport de vérification de Dynatec, en guise de référence, un article paru dans le Journal of Minerals (JOM) concernant les essais de pilotage.

Nous demeurons à votre disposition pour toute information supplémentaire.

Jacques Dubuc,
Coordination du projet de l'usine
de traitement de la brasque
Alcan
(514) 848-8114

Pièces jointes dans 3 messages électroniques :

1. Rapport de Dynatec Corporation (Alberta) : 6 fichiers électroniques
2. Article dans le Journal of Minerals (JOM)

Alcan International Limited

LOW CAUSTIC LEACHING AND LIMING PROCESS FOR THE TREATMENT OF SPENT POTLINING

Process Audit

by

Dynatec Corporation
Metallurgical Technologies Division
Fort Saskatchewan, Alberta, Canada

August 2000

NOTICE:

THIS DOCUMENT INCORPORATES CONFIDENTIAL INFORMATION OF DYNATEC CORPORATION. ACCORDINGLY, THIS DOCUMENT IS FURNISHED ON THE EXPRESS CONDITION THAT IT, AND THE INFORMATION CONTAINED THEREIN, WILL BE MAINTAINED IN STRICTEST CONFIDENCE BY ALCAN INTERNATIONAL LIMITED AND WILL BE USED BY ALCAN INTERNATIONAL LIMITED ONLY IN ACCORDANCE WITH THE TERMS OF THE AGREEMENT BETWEEN ALCAN INTERNATIONAL LIMITED AND DYNATEC CORPORATION – METALLURGICAL TECHNOLOGIES DIVISION DATEDDATE. ACCEPTANCE OF THE DOCUMENT WILL BE CONSTRUED AS AN ACCEPTANCE OF THE FOREGOING CONDITIONS.

1.0 SUMMARY

Alcan has, over the past decade, spent considerable efforts to develop its Low Caustic Leach and Liming (LCLL) process for the treatment of spent potlining (SPL). The process converts a hazardous waste into two non-hazardous industrial wastes, inert graphitic carbon and refractory brick materials residue and calcium fluoride, and a third stream, Bayer liquor, which is recycled to the Bayer digestion plants. The process has the potential for recovery of a high purity sodium fluoride byproduct.

Extensive laboratory process development testwork has been carried out at Alcan's Arvida Research and Development Centre in Jonquière, Quebec. Piloting testwork has been carried out in two campaigns at the COREM facilities in Quebec City: the first, in 1992, tested and demonstrated the complete process with a single sourced SPL material; the second, in 1998/1999, focused on the leaching operations and confirmed the process modifications required to treat a wide range of SPL compositions from the various reduction cell technologies.

Alcan commissioned Bechtel to carry out a Preliminary Engineering Study to estimate capital and operatings costs, and the study was updated in March 2000 (further update is still in progress).

In early 2000, Alcan decided to have an independent audit of its research and development work to confirm the adequacy of the process for commercialization. Under Proposal 7024, Dynatec performed the following work as part of the process audit:

- an in-depth review of the process fundamentals through the examination of the relevant documents, including laboratory and pilot plant test procedures and results, publications and patents;
- assess the work carried out to date by review of relevant documents and test results to verify the quality of data;
- assess the suitability of the process to treat SPL feed in a range of compositions that could be expected in a commercial plant;
- analyze the results of the entire program to assess the adequacy of data for commercial design;
- understand how the process could be integrated with existing facilities at an aluminum production plant;
- identify missing data requirements;

4

- hold meetings with Alcan personnel involved in the development of the process to review methods used to generate test results and to gauge their confidence in the data produced; and
- visit Alcan's laboratory and pilot plant as well as COREM's pilot plant facilities, to assess the equipment, facilities and procedures used for development of the process.

The following sections summarize the observations and recommendations of the Dynatec audit team. (Note: the body of the report is structured somewhat differently, and reviews the process development work and preliminary engineering design on a unit operation basis).

1.1 PROCESS FUNDAMENTALS

Overall, Alcan has invested significant effort and expenditure in developing and testing a process to solve a challenging environmental problem. The project basis is fundamentally sound, and there are no laws of chemistry or physics violated.

A good understanding of the process chemistry has been developed; this has been well utilized by Alcan personnel to diagnose the problems with variations in the SPL composition and develop a robust leaching process.

The close involvement of Alcan analytical personnel in the project development has facilitated the development of special analytical procedures and the appropriate application of standard analytical procedures. This cooperation should be continued though to the commercial plant design and operator training phases.

One area of the process chemistry that we believe requires re-examination is the aspect of free caustic concentration in cyanide destruction. Earlier Alcan testwork and the 1992 pilot plant testwork at CRM (COREM) had indicated the importance of high caustic concentration (55 to 60 g/L NaOH) in the feed solution on achieving the required extent of cyanide destruction. This concentration is significantly higher than the combined leach and wash solutions in the current design.

The configuration of the pilot plant reactor used at US Filter/Zimpro and the commercial plant reactor design should also be reviewed.

1.2 QUALITY OF DATA

A large amount of work has been carried out, at both the laboratory and continuous pilot plant scale. Overall project documentation is extensive and detailed, but appears to be fragmented and some major time investment will be required to pull everything together. A

chronological listing of all of the activities over the past decade of process development testwork and the associated reports would be a good starting point.
The quality (and quantity) of the test data was suitable for monitoring tests, interpreting results and making any required modifications, particularly in the leaching tests on the recalcitrant SPL materials.

Before any future pilot plant on leaching we suggest a review of the test data logging requirements, to develop log sheets which are more easily read.

Attention needs to be paid to the liquid-solid separation operations in the entire flowsheet. The suitability of various types of equipment for filtration and thickening can be confirmed very well in pilot plant equipment, but bench scale tests should still be done for sizing purposes. The tests on liquid-solid separation are not clearly documented.

The major process objective is that the inert residue must meet the toxicity leachate criteria. To this end, considerable effort has been directed to standardizing the test procedures and carrying out the leachate tests at both Arvida and COREM. We believe that adequate work has been done here.

1.3 IMPACT OF VARIABILITY IN SPL COMPOSITION

Variations in feed composition can play havoc with hydrometallurgical processing plants, creating upsets in leaching performance, impurities control, liquid-solid separation performance, etc. The LCLL process development work has seen various examples of the impact of feed variation, including:

- ranges in fluoride levels in the SPL affecting fluoride concentrations in the leach;
- impurities affecting the extraction of fluoride;
- old SPL affecting the cyanide leachate criteria in inert residue; and
- extraneous contaminants, e.g. clays, affecting liquid-solid separation.

Uniform blending of the feeds to a commercial SPL facility appears to be unlikely to achieve, but some attention must be made to mitigating extreme variations in the feed to the process.

The four stage leaching process appears to be capable of handling the variations in feed composition to generate inert residues meeting the fluoride and cyanide TCLP leachate criteria.

The short term storage building for SPL at the Jonquière complex provides satisfactory protection from the elements but does not appear to be adequately managed, which could result in difficulties in feed preparation for the commercial plant. In particular, there was evidence of occasional dumping of some materials which were not SPL origin.

1.4 ADEQUACY OF DATA FOR COMMERCIAL DESIGN

Feed preparation has still not been finalized. Additional testwork on feed preparation is planned or in progress, including evaluation of a roll crusher for first stage size reduction. In the examination of equipment for further size reduction to <48 mesh for the leaching operation, careful examination of the particle size distributions should be made. Excess fines (<325 mesh) could lead to difficulties in liquid-solids separation.

The leaching data appears to be adequate for commercial design. However, we recommend review of the temperature and heating requirements to prevent the possibility of excessive dilution in the system. As noted above, there does not appear to be sufficient data to size the filters for the four leaching stages, and tests should be done separately on the slurries from each leaching stage.

1.5 PROCESS INTEGRATION WITH EXISTING FACILITIES

Process streams which will be transferred to existing facilities at the Jonquière complex are as follows:

Activation leach filtrate and dissolved 4th effect sodium fluoride product to the UTLE plant for causticization and disposal;

Excess process liquids to the UTLE plant;

Bayer liquor from 4th effect evaporator and cake wash filtrate to Vaudreiul Plant.

These process streams have been characterized in sufficient detail for the process material balance. The caustic concentration in the Bayer liquor will require monitoring to ensure that the recipient plant is not receiving dilute solutions.

At one time the elimination of the causticization circuit from the LCLL process was evaluated by incorporating its requirements into the existing causticization system at the UTLE Plant (Bechtel study report). However, this "UTLE" option has not been adopted. Alcan's philosophy is to make the LCLL process plant stand alone, except for the process outputs noted above and utilities.

7

1.6 MISSING DATA REQUIREMENTS

Filtration requirements for the various leach stage stages have not been defined in sufficient detail for the next stage of engineering design. Further testwork is required.

There is an extensive amount of information on the cyanide destruction operation that needs to be pulled together and critically reviewed before the next stage of engineering design.

It was noted that the ultimate handling and disposal of the CaF_2 residue has yet to be resolved and additional work is in progress, including:

evaluation of mixing with inert residue or separate disposal;

modification of physical aspects (possibly pelletization) for disposal;

geotechnical aspects of disposal (Laval); and

evaluation of market potential.

1.7 PROCESS OVERVIEW DISCUSSIONS WITH ALCAN PERSONNEL

Confidence in the process is high within the Alcan personnel involved in the process development. Similarly, COREM personnel expressed confidence in the process meeting project objectives.

At the present time, there does not appear to be a "project champion" within the Alcan organization to lead the project and make the, at times seeming unreasonable, required demands to resolve various technical issues and push the project forward. This may be due to the nature of the project, environmental versus increased productivity or improved product quality and resultant economic benefits.

Alcan design philosophy for the commercial plant should be reviewed, in particular:

spare equipment versus capital investment;

spare equipment versus plant availability ("it's not critical if the plant stops");

equipment preferences (biases);

inert residue target, MEF or EPA;

byproduct objectives.

High purity sodium fluoride appears to be an attractive potential byproduct from the process. However, considering that a market for the material is not defined, designing and operating the circuit to produce a high purity product may be adding unnecessary complication to the

8

initial phase of commercial operation. We would recommend initial conversion of the sodium fluoride to calcium fluoride until the basic SPL treatment flowsheet is optimized.

1.8 LABORATORY AND PILOT PLANT FACILITIES

The Arvida Research and Development Centre is well equipped with R&D laboratory and pilot plant facilities. The analytical laboratory appears to be capable of developing and testing the required analytical procedures for effective process control.

We were very impressed with the facilities at COREM, and the technical and organizational capabilities of the personnel. Any future pilot plant testwork on the process would appear to be best done at COREM, given their experience with the project and the facilities. However, if a demonstration plant was to be constructed and operated, a site at the Jonquière complex would appear to be the most logical, given the requirements for large amounts of materials to be processed and eventually disposed. In this case, consideration of subcontracting COREM personnel in the operation of the demonstration plant is recommended.

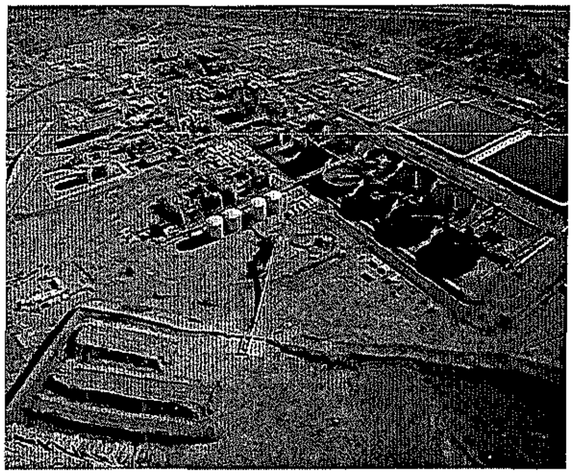
The Scale-up and Design of Pressure Hydrometallurgical Process Plants

F. Campbell, W.D. Vardill, and L. Trytten

This article reviews more than 45 years of experience in the scale-up of pressure hydrometallurgical processes, from the pioneering collaboration between Sherritt and Chemical Construction Company to current process development by their successor, Dynatec Corporation. The evolution of test work is discussed, from traditional pilot-plant operations using semicommercial equipment to small scale or minipiloting with equipment several thousand times smaller than commercial units. Nickel, uranium, zinc, and gold processes have been developed and successfully implemented in worldwide operations treating a variety of feed materials, including concentrates, ores, and mattes. Data on test work duration and the ramp-up of commercial plants are presented.

INTRODUCTION

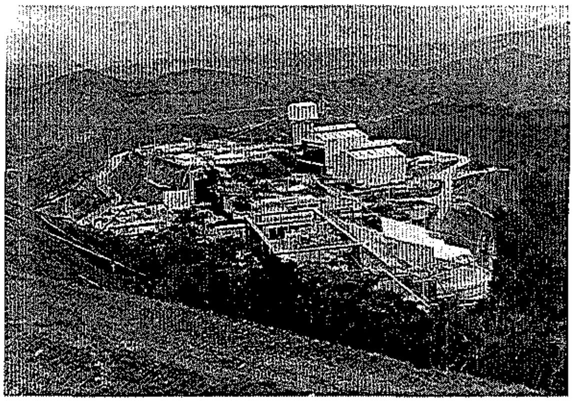
Until the early 1980s, fairly large-scale pilot plants were used to scale-up metallurgical processes; piloting at such a scale was expensive and time consuming, requiring large concentrate or ore samples. Dynatec pioneered the scale-up of pressure hydrometallurgical processes from small-scale minipilot facilities. These facilities are not purposely built to test one process, but can be adapted to test a variety of flow sheets that incorporate similar process steps. Minipilot operations can be used to demonstrate processes in a fully integrated mode; to confirm chemical behavior; to provide representative solids, solutions, and slurries; to confidently predict commercial operations; and to gather commercial design criteria.



The Murrin Murrin nickel-cobalt project, Western Australia.

THE EVOLUTION OF TEST WORK AT SHERRITT/DYNATEC

The Metallurgical Technologies Division of Dynatec Corporation is the successor to Sherritt International Consultants. The history and experience of the division is founded on a 1945 decision by Sherritt Gordon Mines Ltd. to develop their nickel ore body in Lynn Lake, Manitoba, Canada, and to refine the concentrate.



The Sao Bento plant site in Brazil.

In the early 1950s, Sherritt (in collaboration with the Chemical Construction Company) developed the process that would be used at the Fort Saskatchewan nickel refinery in Alberta, Canada, through a series of pilot plants of increasing scale.

Between 1950 and 1980, Sherritt conducted large-scale pilot-plant campaigns on four other processes: the sulfuric acid matte leaching process (which has been adopted as the process of choice by all of the PGM refineries in South Africa); the modified Caron process for treatment of low- and high-iron nickel laterites (which was commercialized at Marinduque Mining and piloted for two other clients); the S-C copper process (which was never commercialized); and the Dynatec zinc pressure leach process (which has been commercialized in four zinc refineries).

Since 1980, Sherritt and Dynatec have piloted new processes exclusively at the minipilot-plant scale. Commercial plants have been built based on the results of the minipilot-plant demonstration campaigns for zinc pressure leaching (three plants with a fourth licensee), nickel/copper matte leaching (three plants), refractory uranium ore leach and uranium recovery as yellowcake, and pressure oxidation of refractory gold ores (five plants). The investment in some projects that have been commercialized has exceeded $1 billion. Anaconda Nickel is currently constructing an $800 million plant in Western Australia for the treatment of nickel laterites based on minipilot-plant results.

The stages of process development practiced at Dynatec are as follows:

- Conduct batch scoping tests in the initial stages of a project to define the approximate conditions and to observe the performance at selected process conditions, and issue a report to the client with recommendations on process conditions and further test work.
- Conduct a conceptual engineering study to define the probable capital and operating costs of a process plant, based on the scoping tests and commercial experience.
- Conduct batch tests to define probable operating conditions and results for a process, perhaps including batch locked-cycle tests (recycle of materials in a series of batch tests) to indicate the deportment of minor elements.
- Conduct continuous test work on each step of the process independently to define operating conditions and to generate intermediate materials for recycle to facilitate a shorter integrated minipilot-plant campaign.
- Update the conceptual engineering study.
- Conduct an integrated minipilot-plant demonstration campaign to demonstrate that the process works as envisioned, with all recycles.

- Conduct a feasibility study on the process plant.

This approach streamlines process development by identifying problems and their solutions as early as possible, thus reducing the length and cost of the minipilot-plant campaign. Ideally, most process problems are solved before the minipilot-plant run; the run serves to collect commercial design data and representative process materials for equipment sizing and to demonstrate the integrity of the process and the quality of the process products to the client and financial institutions. In reality, a continuous minipilot-plant run usually generates some unexpected results that the project team must be prepared to solve quickly. In the presence of recycles, the steady-state concentration of some elements may stabilize at levels not anticipated from batch tests. The characteristics of residues and chemical precipitates that affect pipe or heat exchanger fouling, liquid-solid separation, corrosion, and slurry viscosity often differ from those observed under batch conditions as a consequence of a different sequence of chemical reactions under steady-state continuous conditions. The analysis of observed changes in results during a continuous run often shows a need for flow sheet modifications to develop a process that is robust in accommodating subtle variations in plant feeds.

PLANT COMMERCIALIZATION

Dynatec has carried out the process development for more than 20 commercial pressure hydrometallurgical operations, with processes for the recovery of gold, zinc, nickel, copper, cobalt, and uranium. Feed materials include ores, concentrates, mattes, residues, and intermediate products. These commercial process plants had scale-up ratios ranging from 60:1 to 84,000:1. The scale-up per autoclave train has ranged from 60:1 to 21,000:1, with the largest scale-up being for the Murrin Murrin nickel laterite project in Western Australia. A partial list of Dynatec's commercial plant scale-up work is provided in Table I.

Sherritt Fort Saskatchewan

Sherritt developed and piloted its ammonia/ammonium sulfate leach for the treatment of nickel sulfide concentrates from 1946 to 1952. The first pilot plant was built in 1949 to treat 272 kg/d of nickel concentrate. The flow sheet and pilot plant were revised for a second campaign, which was conducted in 1950. Various unit operations were subsequently tested on a semicommercial scale. A third pilot plant was built in 1951, and the data collected from about five weeks of operations formed the basis for the refinery design. In 1952, a fourth pilot plant was built to identify any likely problems for start-up and to train the key operators. The commercial refinery was designed to operate at a feed rate of 184 times the feed rate of the third pilot plant.

The refinery was designed and constructed from 1952 to 1954 and was commissioned in May 1954. The refinery reached 90 percent of design capacity within six months and achieved the annual design production in 1955.[1,2]

Impala Platinum

The first commercial plant piloted at Fort Saskatchewan was licensed to Impala Platinum for a refinery at Springs, South Africa. The platinum-rich nickel-copper matte leaching plant was designed and constructed in 1968–1969.

Sherritt had conducted a continuous pilot-plant campaign on the acid pressure leaching of matte in a small commercial autoclave at the Sherritt nickel refinery in 1963. The initial design of the Impala refinery was based on this experience, while a concurrent laboratory pilot-plant campaign provided confirmatory data. As no actual matte was available from Impala Platinum, test work was conducted on a synthetic matte that was prepared at Fort Saskatchewan. The batch laboratory program was conducted in autoclaves of up to 100 liter capacity.[3,4]

Matte was fed to the Impala refinery within 18 months of the start of construction, and the design rate was achieved within six months. The plant was expanded in 1975, achieving design rates within two months.

DECIDING ON PILOT-PLANT CAPACITY AND SIZE

Large-scale pilot-plant testing is expensive (possibly on the order of $50 million) and time consuming (often 1–2 years). It requires large amounts of representative samples of feed materials, which can be very difficult and expensive to obtain. If conducted properly, large-scale pilot testing can provide a great deal of information about the process and what will work on a commercial scale.

Minipilot plant testing is relatively inexpensive ($0.5–2 million) and quick (4–8 weeks). It requires only a small amount of representative feed material, which can usually be generated from blending of drill core samples. Miniplant testing provides representative samples of solids and solutions for thickening and filtration test work and equipment sizing and provides other information that can be used for sizing continuous reactors and other equipment.

Hydrometallurgical processes tend to lend themselves to minipilot-plant testing due to the relatively homogeneous nature of slurries. Pyrometallurgical processes, with their reliance on heterogeneous gas-solid processing, tend to require large-scale pilot-plant testing to generate the engineering data required for successful scale-up.

A hydrometallurgical process that is already commercially established is a good candidate for minipilot-plant testing and commercial implementation. If the process is a rearrangement of known unit operations (perhaps on a new feed material), it is also a good candidate for minipiloting.

A wise plant owner will insist that miniplant planning and operation and development of plant-design criteria will be conducted by a team with a strong track record in successful commercial hydrometallurgical plant design, as well as a strong track record in the interpretation of minipilot-plant data. Scale-up must be based on a comprehensive understanding of the process being developed and knowledge and background of other commercial processes and plants.

Marinduque Mining Nickel Refinery

The modified Caron process, which was installed at the Marinduque Mining nickel refinery on Nonoc Island, Philippines, was piloted at Fort Saskatchewan in 1969 and 1970 at a rate of 23 t/d of ore. The pilot plant, which operated for more than ten months, was used to define the operating parameters for the commercial refinery, test materials of construction, train key operating personnel, and demonstrate product quality. The commercial plant was designed with an overall feed rate of 10,800 t/d, 472 times the feed rate of the pilot plant. The commercial plant featured 14 roaster trains, resulting in a scale-up factor of 34 for each roaster.

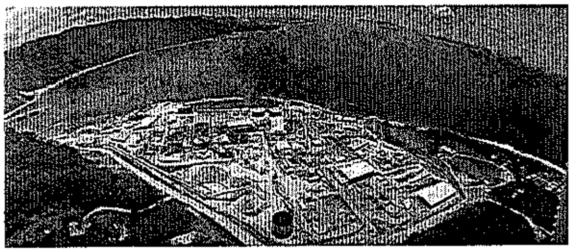
The refinery was commissioned in 1974, with the first ore being fed to the primary crusher in early August, the first feed to the roasters in late October, and production of the first nickel briquettes on December 30, 1974. Upon start-up, the refinery experienced significant problems with materials handling and the roaster operations. The refinery was never able to sustain production rates above 80% of design.

The roasters met metallurgical expectations, and the hydrometallurgical section of the plant performed well, with two leach trains operating at a scale-up of 236 times the pilot rate. The main production restrictions were caused by mechanical problems with roaster ancillaries that had not been tested in a similar configuration at the pilot scale. The scale-up of dry materials handling equipment and furnace and combustion equipment has been a frequent problem for pyrometallurgical operations.

Overall, the plant did not sustain production rates above 80% of design, even though individual roasters, when online, met expectations. This project demonstrated that even relatively small scale-up increments do not assure success for novel mechanical systems, whereas metallurgical performance in hydrometallurgical processes can be extrapolated over a greater range.

Key Lake Uranium Mill

Test work for the Key Lake uranium mill in Saskatchewan, Canada, was conducted at Fort Saskatchewan in 1978 and 1979 on a refractory uranium ore. The leaching test work was conducted batchwise, in vessels of up to 60 liters capacity. Uranium recovery by solvent



The Lihir plant site, Papua New Guinea.

extraction was tested continuously at rates of 3–6 liters per hour for more than one month.[5]

The project was approved in 1981, and construction on the 710 t/d ore plant was completed in 1983. The plant started up in October 1983 and achieved design rates within nine months of commissioning. The Key Lake operation sustained an annual production at 100% of the design rates three years after start-up, and reached 120% the following year. Piloting of that process required some unusual precautions as the ore contained in excess of 2.5% U_3O_8. The commercial plant is the largest in the western world, and currently produces more than 6,000 t/y of U_3O_8.

Hudson Bay Mining and Smelting Zinc Refinery

The Hudson Bay Mining and Smelting two-stage zinc pressure leach plant, which uses Dynatec's technology, was piloted at Fort Saskatchewan in 1984. The minipilot-plant campaign ran at a concentrate feed rate of 5 kg/h for 171 hours. The commercial plant replaced an aging conventional roast/leach plant, eliminating sulfur-dioxide emissions to the atmosphere. The commercial plant was designed to produce 100,000 t/y of zinc to match the design capacity of the zinc purification and electrowinning circuits. The pressure leach plant was designed at a scale-up factor of more than 4,000.

The refinery was commissioned in mid-August 1993, and full design rate of the pressure leach plant was achieved in mid-September 1993.[6] Since then, the plant has run very close to design rates.

Lihir Refractory Gold Refinery

The pressure-oxidation process for gold liberation from sulfidic minerals was developed at Fort Saskatchewan for Homestake Mining and saw first application at their McLaughlin mine in Northern California in 1985 at a rate of 3,000 t/d. The process has since been adopted by a number of mines both inside and outside of the United States.

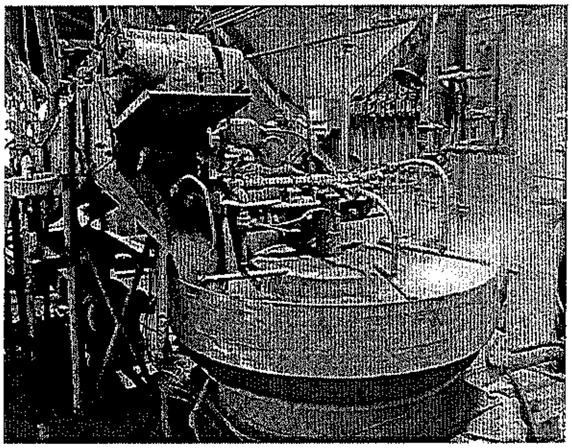
The Lihir refractory gold pressure oxidation plant was piloted at Fort Saskatchewan in 1988 at a rate of 7–15 kg/h. The autoclave circuit in the minipilot-plant was operated for almost 400 hours on three different feed blends; continuous cyanide leach and carbon-in-pulp circuits were operated for 240 hours.

The overall plant was designed at a scale-up factor of more than 26,000:1; the scale-up factor per autoclave train was 8,900:1. The Lihir commercial pressure oxidation plant is designed to treat 2.8 million tonnes of sulfide ore per year. The plant was commissioned in Papua New Guinea in August 1997 and reached the design sulfur oxidation rate in less than six months.

DIFFICULTIES IN COMMERCIALIZATION

The history of metallurgical plant start-ups have not been without failures and serious design problems that have resulted in plants falling short of projected design rates. Many of these problems have occurred in the scale-up of pyrometallurgical operations.

As noted, the Marinduque Mining nickel refinery never ran at more than 80% of design rate. The problems at Marinduque were primarily related to the materials handling and mechanical ancillaries of the reduction roasters. When individual roaster trains were fully operational, the design throughput and metallurgical results were met, but overall plant throughput was limited by equipment availability. Relatively few major problems were encountered in the

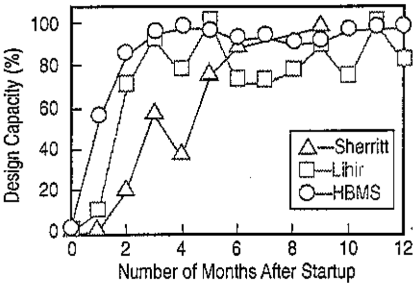


A pan filter.

Table I. The Scale-Up of Hydrometallurgical Process Plants

Plant	Prototype Process	Client	Location	Original Feed	Year Piloted	Overall Scale-up	No. of Trains	Scale-up per Train
Sherritt	Yes	Sherritt	Canada	Nickel concentrate	1951	180	2	90
Moa Bay*	Yes	Freeport	Cuba	Nickel laterite	1955	550	4	138
Nonoc	No	MMIC	Philippines	Nickel laterite	1969	470	14	34
Trail	Yes	Cominco	Canada	Zinc concentrate	1977	60	1	60
Key Lake	Yes	Uranerz (now Key Lake Mining)	Canada	Uranium ore	1979	batch pilot program	2	—
Kidd Creek	No	Kidd Creek Mines (now Falconbridge)	Canada	Zinc concentrate	1980	batch pilot program	1	—
McLaughlin	Yes	Homestake	United States	Gold ore	1981	42,000	3	14,000
Western Platinum	No	Western Platinum	South Africa	Nickel-copper matte	1983	500	1	500
Flin Flon	Yes	HBMS	Canada	Zinc concentrate	1984	4,150	1	4,150
Sao Bento	No	Gencor (now Eldorado Gold)	Brazil	Gold concentrate	1984	4,150	2	2,100
Porgera	No	Placer Dome	Papua New Guinea	Gold concentrate	1987	37,500	6	6,250
Lihir	No	BP Minerals (now Lihir Gold Company)	Papua New Guinea	Gold ore	1988	26,700	3	8,900
Ruhr-Zink	No	Ruhr-Zink	Germany	Zinc concentrate	1989	3,600	1	3,600
Campbell Red Lake	No	Placer Dome	Canada	Gold concentrate	1989	1,300	1	1,300
Murrin Murrin**	No	Anaconda	Australia	Laterite	1996	84,000	4	21,000

* Piloted by Freeport.
** Plant currently being commissioned.



Examples of start-up profiles.

hydrometallurgical process steps.

Hydrometallurgical plants have not been trouble-free. Notable problems that have occured have been related to prototype unit operations or to equipment that is commercially unproven. In one case, a unit operation that separated an aqueous slurry phase from molten sulfur failed to operate reliably at the commercial scale. Fortunately, an alternative flow sheet that had been tested in the pilot plant could be introduced without excessive delay.

Some autoclave installations have experienced significant problems in acid-resistant brick linings when the bricks failed to withstand the severe conditions associated with rapid start-ups and shutdowns. Corrosion, often associated with the presence of chlorides, is a constant concern for hydrometallurgical processes using aggressive acidic conditions, and careful piloting does not necessarily ensure that problems will be avoided in the commercial plant.

Problems with associated facilities may prevent a plant from achieving design capacity. Mining difficulties at a platinum mine in Zimbabwe have exacerbated overall commissioning difficulties. Similar problems at a platinum mine in South Africa have prevented that plant from achieving design capacity.

There have been relatively few large-scale failures in the hydrometallurgical industry compared to the pyrometallurgical industry. This can be attributed to the greater ease of scaling-up unit operations that deal with slurries and solutions compared with those that deal with gas-solid mixtures and molten materials at high temperatures. Hydrometallurgical pilot plants are easier to build and operate, and the analysis of the test results is usually less complex.

It is important that hydrometallurgical processes be piloted using the same quality water and reagents that will be used in the commercial plant. For example, the reactivity of limestone might have a major impact on retention time requirements in a neutralization step and product recovery will suffer if substantial quantities of unreacted lime are rejected in solids residues. High chloride water can have a devastating effect on the corrosion rates of some stainless steels. In one case, test work to develop an acid-leach process to recover copper from lead smelter dross used reagent-grade sulfuric acid during test work instead of the black acid that was available at the smelter site. As a result, high-quality acid had to be purchased at a high freight cost until problems associated with the use of black acid were resolved. During minipiloting for the Lihir project, seawater was transported from Vancouver and added to feed ore to simulate the ingress of seawater into the volcanic caldera which now forms the Lihir mine.

McNulty[7] has suggested several reasons for the failure of plants to achieve design expectations, including

- Pilot testing was limited and did not address the whole flow sheet.
- Pilot testing was not conducted to confirm process parameters.
- The plant was designed to fit within the available budget.
- Process flow sheets were very complex.
- Prototype equipment was used in two or more unit operations.
- Process chemistry was not understood.
- Design and construction of the plant was started before the process was understood.
- There was inadequate technical support during commissioning.
- Training of the workforce and operating manuals were inferior.

McNulty's conclusions reinforce the need for continuous pilot testing of the entire process, skilled interpretation of the data from pilot testing, a sound understanding of the process chemistry, full recognition of the pilot-plant test results in the plant design, and technical support from the research and process design team throughout the design and commissioning phases of the project. McNulty's comment on the budget for test work raises an interesting comparison with the large expenditures that are required for drilling programs to define a deposit to a sufficient level of detail for project feasibility studies. Relatively small expenditures are generally made in defining the optimum process for treating the well defined orebody. Expenditures made to refine a flow sheet generally result in faster plant startups and lower operating costs.

CONCLUSIONS

It is the objective of test work to demonstrate that a process works as proposed, in a fully integrated manner, producing quality products. Most new hydrometallurgical processes employ known unit operations, even though there are variations in the chemistry. Departure from proven commercialized unit operations requires a great deal of care, as this is where pitfalls lie.

The scale-up of hydrometallurgical processes is more reliable than the scale-up of pyrometallurgical processes, as slurries tend to be more homogeneous than gas-solid mixtures. Scale-up by a factor of 5,000 or more is acceptable for hydrometallurgical processes, as long as the following conditions apply.

Management can be confident of scale-up from minipilot-plant data if

- The process was piloted on representative feed material with all recycle streams incorporated into the pilot-plant flow sheet.
- There are no radical innovations in technology.
- The research and engineering teams work in close collaboration to ensure that all pertinent questions are answered.
- The scale-up is carried out by an experienced design team.
- Reagents and water that will be used in the commercial operation are tested in the minipilot plant.

Caution should be taken when innovative unit operations are introduced; new construction materials are proposed; the feed was not representative of actual planned operations; or the scale-up to commercial design is made without the knowledge of the relationships between proven commercial equipment and the pilot-plant equipment, or the design team lacks the complementary blend of research, design, and operating experience to be aware of what can be scaled-up in practice.

When dealing with novel process technology, owners are advised to insure that the experience and pilot-plant results of the process developer are applied to the final design. There is danger if initiatives to minimize capital cost, particularly in the context of lump-sum turnkey contracts, ignore this experience in the final design.

References

1. D.G.E. Kerfoot, "The Development of the Sherritt Ammonia Pressure Leach Process," *CIM Bulletin*, 82 (926) (1989), pp. 136–141.
2. S. Nashner, "The Sherritt Gordon Lynn Lake Project, Refining at Fort Saskatchewan," *CIM Transactions*, LVIII (1955), pp. 212–226.
3. R.P. Plasket and S. Romanchuk, "Recovery of Nickel and Copper from High-Grade Matte at Impala Platinum by the Sherritt Process," *Hydrometallurgy*, 3 (1978), pp. 135–151.
4. R.P. Plasket and C.M.G. Wortley, "Equipment Selection, Plant Design and Personnel Training at the Impala Nickel-Copper Refinery"(Paper presented at the 7th Annual Hydrometallurgical Meeting of the Metallurgical Society of CIM, Vancouver, Canada, August 1977.)
5. P.J. Clarke et al., "The Key Lake Uranium Process" (Paper presented at the 19th Annual Conference of Metallurgists of the CIM, Halifax, Canada, 1980).
6. M.J. Collins et al., "Operation of the Sherritt Zinc Pressure Leach Process at the HBMS Refinery: The First Fifteen Months" (Paper presented at Zinc and Lead '95, Sendai, Japan, 1995).
7. T. McNulty, "Developing Innovative Technology," *Mining Engineering* (October 1998), pp. 50–55.

F. Campbell, W.D. Vardill, and L. Trytten are with Dynatec Corporation.

For more information, contact B. Vardill, Dynatec Corporation, Metallurgical Technologies Division, 8301-113 Street, Fort Sas-katchewan, Alberta T8L 4K7, Canada; (780) 992-8190; fax (780) 992-8100; e-mail wvardill@mettech.dynatec.ca.