INNOVATIONS AND TRENDS IN URANIUM ORE TREATMENT

By

Alan Taylor
ALTA Metallurgical Services

Presented by

Alan Taylor
alantaylor@altamet.com.au

CONTENTS

1. INTRODUCTION

During the last uranium boom in the nineteen seventies and eighties, some key innovations were introduced into the operations established during that period. Some of these were subsequently carried over into hydrometallurgical copper, gold and nickel-cobalt projects, and others have been added. Many of these are likely to be reflected in the new uranium projects sporned by the current era of increasing uranium demand and high prices.

2. OVERALL TREATMENT ROUTE

Most operations in the nineteen seventies followed the earlier trend of agitated acid or alkaline atmospheric leaching of ground ore, with the alkaline option used for ores with excessive acid consumption. New trends which began to appear included pressure leaching, heap leaching, in-situ leaching (ISL), bio-leaching and by-product uranium recovery from phosphoric acid, copper leach solutions and rare earth processing operations. These trends are likely to continue as new projects are devloped in the future, depending, of course, on the type and grade of the deposits, and the uranium price.

2.1 PRESSURE LEACHING PROCESSES

Pressure acid leaching has been adopted for a few uranium operations treating more refractory ores, especially in the presence of sulphides such as pyrite which can oxidized to form the acid and ferric iron required for the process. This trend is likely to continue for similar ores, and will now have the benefit of the extensive pressure leaching design and operation experience gained in treating zinc, gold, copper and nickel ores and concentrates. Pressure leaching is incorporated in the new SXR Uranium One Dominion project in South Africa which started up in February 2007. Pressure alkaline leaching was introduced to treat more refractory high acid consuming ores and was successfully used at a number of operations. Although there are no current operations, it will likely be considered in the future for similar ores. For example it was piloted by Western Mining for the Yeelirrie Project near Kalgoorlie in Western Australia, which is on hold because of the state government's policy of no uranium mining. The deposit is now owned by BHP Billiton. Paladin's new Langer Heinrich operation in Namibia uses atmospheric alkaline leaching.

2.2 HEAP LEACHING PROCESSES

Heap leaching initially was mainly applied as a satelite to conventional acid leaching operations, but the trend has been towards stand-alone operations and this is likely to continue for lower grade orebodies which are not suitable for ISL. Future projects will benefit from the extensive heap leaching experience gained in copper and gold heap leaching since the last uranium boom including strong acid cure, heap building techniques and operating strategies. To date the commercial operations have utilized acid leaching, though it is reported that alkaline heap leaching has been tested in China, and could be worth investigating for high acid consuming ores. Future applications are likely to include both stand-alone and satellite operations.

In the seventies a variation of heap leaching consisting of an an inovative in-ground vat leaching operation was established at Naturita, New Mexico, USA. The vat loading/unloading system which was develped for this operation went on to be widely used in copper ore heap leaching, in particular for on/off pad type systems. Apart from cost considerations, this had the advantage that the vats could be eventually used for the disposal abd burial of leach residue. The concept could be worth revisiting in the future, especially for smaller deposits.

2.3 IN-SITU LEACHING PROCESSES

ISL for uranium was developed in the nineteen sixties and seventies. Because of its low capital and operating costs, the number of operations proliferated in the nineteen eighties and nineties while conventional plants were being closed down due to the decreasing uranium price. The relatively low capital investment and absence of surface mining activities are likely to continue to be attractive in the future, especially for smaller and/or lower grade deposits.

However it can only be applied to deposits with adequate permeability and favourable configuration such as relatively shallow roll front type sandstone deposits in confined aquifers, located a safe distance from ground water used for human or animal consumption. The general trend towards alkaline systems rather than acid is likely to continue for environmental reasons. However there will be situations where it is feasible to utilize acid systems which generally exhibit faster leaching kinetics. For example the only commercial ISL project in Australia, Heathgate's Beverley operation and the upcoming Honeymoon Project have both adopted acid leaching, which is environmentally acceptable as the ground water is unsuitable for humans and animals.

2.4 BIO-LEACHING PROCESSES

Bio-leaching has been applied commercially for pyritic heap leaching operations and for in-place leaching of low grade underground mine stopes broken by blasting and to old mine stopes. Since the last uranium boom there have been major advances in the application of both heap bio-leaching of ROM or crushed ore and agitated tank bioleaching of concentrates, such as the use of aeration pipes, addition of nutrients, development of more efficient agitators and the development of new ultrafine grinding equipment. This is likely to lead to a greater use of bio-leaching in future uranium projects involving sulphidic ores. Heap or in-place systems will be more suitable for lower grade ores, while tank bio-leaching will be more applicable to uranium bearing sulphidic concentrates.

2.5 BY-PRODUCT URANIUM PROCESSES

By-product uranium operarations sprang up during the last high uranium price period and will undoubtedly be once again under consideration if the present high price regime is sustained.

2.5.1 From Phosphoric Acid

The largest number of operations involved the extraction of uranium from phosphoric acid, especially in the Florida area in the USA. Extensive development work, in particlar by the Oak Ridge National Laboratory in Tennessee USA, resulted in workable, though complex, solvent extraction (SX) based processes. Further development was cut short by the drop in the uranium price, but could be resurrected in the future. However, historically the tendency has been to get into production as soon as possible while the high price lasts, rather than wait to develop superior technology. This trend is likely to be repeated, though further development work may be initiated if the current boom is sustained.

2.5.2 From Copper Leach Solutions

In the nineteen seventies and eighties, two by-product uranium extraction from copper leach solutions operated commercially in the USA, one from dump leach solution (Kennecott Bingham Canyon, Utah) and the other from atmospheric acid leach solution (Anamax Twin Buttes, Arizona). Given that copper leach solutions commonly contain trace to low levels of uranium, and that there has been a huge increase in the number of copper leaching operations, more of this type of by-product operation will likely be seen in the future. While the level of uranium in copper leach solutions is generally lower than phosphoric acid, extraction can readily be accomplished by a relatively simple eluex (IX-SX) system. The Olympic Dam deposit in South Australia has an unusually high level of uranium which can be regarded as a co-product rather than a by-product.

2.5.3 From Rare Earth Operations

A small number of commercial plants where uranium was a by-product of rare earths recovery have also been operated. This will likely be considered for future rare earth deposits with significant uranium contents, and for complex uraniferous niobium-tantalum type ores.

3. ORE PREPARATION

The main changes in uranium ore preparation in the nineteen seventies were the growing use of SAG/AG milling, the replacement of coarse ore stockpiles with ground pulp storage, and the increasing use of upgrading by radiometric ore sorting. Flotation tended to be limited to sulphidic orebodies. The future may see the adoption of high pressure rolls crushing for fine crushing in heap leaching operations, mineral sizers to instead of conventional crushing equipment for softer ores, and possibly flotation for the reduction of acid consuming carbonates.

3.1 CRUSHING AND GRINDING

3.1.1 SAG/AG Milling

SAG/AG milling was increasingly increasingly used in the nineteen seventies. As for other metaliferous ores, incentives include capital cost savings and smaller footprint which is especially important in cold climates such as Canada and the northern USA where the equipment is enclosed in buildings. With uranium ores there is the additional key benefit of wetting the ores as soon as possible, thus reducing the health issues due to dust emissions from conventional dry crushing circuits.

3.1.2 Pulp Storage in Place of Coarse Ore Storage

Some operations, especially in cold climate areas in Canada and the USA replaced coarse ore storage bins, with pulp storage in agitated tanks after SAG milling. Incentives included capital cost savings and the avoidance of problems with freezing ores in bins. Pulp storage time was essentially driven by the downtime needed for the SAG milling circuit.

3.1.3 HP Roll Crushers

Uranium ores are frequently fine grained and fine crushing may be required to achieve adequate extractions in heap leaching. Roll crushers are being increasingly considered for fine crushing of other metaliferous ores, especially those of low to moderate hardness, and this experience could be transferred to uranium ores.

3.1.4 Mineral Sizers

Mineral sizers have been used as a lower cost option instead of conventional crushers for softer, clayey ores with low abrasivity, and could play a similar role in future uranium operations

3.2. RADIOMETRIC ORE SORTING

The first higher tonnage sorter was developed in 1970 with Rossing in Namibia as the target. Although an installation at Rossing did not eventuate at the time, machines were installed at a number of other plants. However, the Rossing application was eventually recently revisited, and a the first module was installed and has been operating since 2005 as a pilot unit. Sorting was also incorporated into Rio Tnto's Kintyre Project feasibility study in Western Australia in the late nineteen eighties. The project was put on hold because of the low uranium price and anti-uranium government policy. Ore sorting systems have been progressively improved are likely to continue to be an option for future projects. For example, a pilot plant is to be constructed and commissioned at the Dominion Project with a view to using sorting as a means to increase capacity.

3.3 FLOTATION

Flotation was used primarily in the seventies for sulphidic gold-uranium ores in South Africa. Since then it has been applied to copper-uranium sulphide ore at Olympic Dam. This will likely be repeated for similar type ores in the future. Also, flotation may be considered to reduce the carbonate content of high acid consuming ores as an option to alkaline leaching. For example it is being tested for Summit's Mt Isa Project in QLD.

4. SOLID-LIQUID SEPARATION AND SOLUTION CLARIFICATION

Key developments in solid-liquid separation in the nineteen seventies included the introduction of the high capacity thickeners for CCD circuits and the increasing application of belt filters with counter-current washing. In future, paste thickeners could also be introduced to deal with water balance and tailings issues. There is also likely to be interest in resin-in-pulp and resin-in-leach systems to avoid solid-liquid separation all together,which will be addressed in Section 5. For solution clarification, a variety of clarifiers were used including high capacity thickener-clarifiers, hopper or cone type clarifiers as well as reactor clarifiers. In future, the more recently developed pinned bed clarifier is likely to come into contention. For polishing duty, there was a trend towards high rate down-flow multi-media fiters with mixed results. This remains a critical issue for future acid leach projects.

4.1 HIGH CAPACITY THICKENERS

High capacity thickeners were introduced into the uranium industry in the USA by Enviroclear in the seventies after being successfully used in the sugar and coal industries. Incentives included capital cost savings, suitability for locating inside a building in cold climate locations (as were the first two installations at Bear Creek Uranium in Wyoming and Bluewater in New Mexico), more rapid recovery from process upsets and easier by-passing arrangements. More recently, high capacity thickeners have been installed at the Olympic Dam Project, Dominion and Langer Heinrich. This trend is likely to continue in future projects for both acid leaching and alkaline leaching plants where CCD is the appropriate choice.

4. 2 BELT FILTERS

In the nineteen seventies, belt filters spread from gold pulps to uranium in the South African gold-uranium operations, and were beginning to make in-roads into North America when uranium project activity waned because of the decreasing uranium price. Incentives included potentially lower capital cost (for small to medium size plants), lower wash ratio which translates into a smaller higher grade flow to SX or IX, smaller footprint and the production of "dry" tailings which provide the option of truck disposal and burial instead of a conventional tailings disposal system. A number of tailings dam incidents in the USA made the "dry" tailings option increasingly attractive to regulating authorities. These potential advantages will likely lead to the consideration of belt filtration for future projects. For example, it was included in the Kintyre Project feasibility study in the late nineteen eighties. Filters have found particular application in alkaline leach plants in the past due to the critical nature of the water balance and the need to minimize reagent loss. This consideration is likely continue to apply to future alkaline leach projects where the ore is suitable for filtration

4.3 PASTE THICKENERS

Paste thickeners have been increasingly applied in the mining industry in recent years. They offer the potential for higher underflow pulp density than conventional or high capacity thickeners without having to resort to filters. Possible applications in future uranium ore processing plants include neutral thickening and final tailings thickening in order to reduce water make-up and minimize the contaminated solution released to neutralization and tailings disposal.

4.4 CLARIFIERS

The early plants in the nineteen seventies tended to adopt more traditional clarifiers such as the reactor clarifier. Later, alternative clarifiers were used such the high capacity thickener-clarifier and the hopper or cone clarifier which has no moving parts. Recently, the pinned bed clarifier, also with no moving parts, has been introduced for hydrometallurgical operations and is included in the Dominion uranium plant. Clarification is a key operation and future projects are likely to continue to seek for improved performance.

4.5 POLISHING FILTERS

Early plants used pressure precoat filters (leaf, candle or rotating disc) and vacuum precoat leaf filters. In the seventies, especially when larger capacity plants came on stream, there was a trend towards high rate dual (or multi)-media high rate downflow pressure filters, which are more suitable for larger flows. Other types which have been used include high rate upflow filters and gravity sand filters. In agitated acid leach plants, filters can become blocked with chemical precipitates such as silica and gypsum. For this type of application, filters are not necessarily the best option. Future selection of equipment for solution polishing will necessarily be considered on a case by case basis.

5. URANIUM EXTRACTION

5.1 SOLUTIONS FROM AGITATED AND PRESSURE ACIDIC LEACHING

The overall trend in the nineteen seventies for acidic leach solutions was towards direct SX for higher grade solutions and IX for lower grade solutions. IX followed by SX (Eluex or Bufflex) was also adopted by a number of operations, especially in Southern Africa, for low grade solutiuons which could not yield an acceptable product purity by IX alone. Another situation which favoured IX was the treatment of ores with poor solid-liquid separation charcteristics. In such cases IX systems (CIX) were developed to treat either unclarified solution or the pulp itself (RIP). RIP and RIL (resin-in- leach) have been particularly widespread in the former Soviet block. In recent times, there has been increasing interest in RIP and RIL in order to reduce capital cost, and this is likely to lead to applications in future projects. Experience gained in gold CIP and CIL (which originally drew from uranium RIP plants) will likely be transferred back into the uranium industry.

Most IX operations have used strong based resins, which are not highly selective against iron, a common major solution impurity. As mentioned above, this led to the adoption of eluex circuits in which SX is used for final purification. However, more selective weak base resins were investigated by a number of organizations and found limited commercial application. These could be worth re-visiting for future projects.

Another development was the direct precipitation of uranium from leach solution, thus eliminating the need for SX or IX. This is favoured by high solution uranium level from high grade or upgraded ore, relatively pure leach solution, and when low capital cost needed. Magnesia was used during the first operating phase of Cluff Lake, Canada, while processing high grade ore, and peroxide was piloted for the Kintyre Project, which involved high grade solution after ore sorting. Direct precipitation is a possible low capital cost option for future acid leach projects where high grade, relatively pure, leach solution is produced.

5.2 SOLUTIONS FROM AGITATED AND PRESSURE ALKALINE LEACHING

Direct precipitation was the standard flowsheet for carbonate leach solutions in the nineteen seventies, though RIP was used for some difficult to filter ores. Since then, direct precipitation was proposed for WMC's Yeelirrie Project, while Langer Heinrich is reported to use fixed bed IX. Future alkaline leach projects will follow similar lines, with the selection based on ore characteristics, solution concentration and impurity levels.

5.3 SOLUTIONS FROM HEAP LEACHING

The overall trend has been the same as for agitated acid leach solutions with SX for stronger leach solutions and IX for more dilute. Future practise is likely to be similar.

5.4 ISL SOLUTONS

Most ISL operations, both acid and alkaline, have used IX because of the relatively dilute solution produced. The Beverley operation is a more recent example. However, the Honeymoon project is to adopt SX because the high chloride content is unsuitable for IX. (It is understood that the SX system will use a mixed D2EHPA/amine type extractant system as the choride will be too high for the standard amine extractant alone.

5.5 SX SYSTEMS

Although conventional mixer-settlers remained the work horse of uranium SX in the nineteen seventies, a number of alternative designs were introduced. The most common of these was the Krebs "double deck" design which offered a much smaller footprint area and reduced organic inventory. It found particular application for indoor plants in cold climate areas of North America. Other designs which found more limited use include the Davy combined mixer-settler, the IMI circular settler, the Lurgi plate settler and the Kenics in-line mixer. Krebs units were adopted for the initial Olympic Dam in the mid-nineties, but for the subsequent expansion Bateman columns were preferred in the extraction circuit and conventional mixer-settlers in the rest of the USX plant. Pulsed columns had previously been used in uranium operations in France in the late eighties-early nineties.

In recent years, reverse flow and Outokumpu VSF mixer-settler designs have been increasingly used for copper and nickel-cobalt SX, and will likely be considered for future uranium projects. It is also likely that pulsed columns will be comtinue to be considered as an option to mixer-settlers. For example, Bateman columns have been installed at Dominion.

5.5 IX SYSTEMS

Various types of fixed bed IX and RIP systems were already in operation as far back as the nineteen fifties and sixties, and the main developments in the nineteen seventies consisted of fluidized bed and moving bed CIX systems aimed at unclarified solutions or solutions containing a small amount of slimes. These included column designs such as the USBM, Utah, NIMCIX (Mintek) and Himsley Columns, and the Higgins Loop moving bed. In addition, the Porter system, consisting of a series of fluid bed units, was installed at Rossing and several ISL operations. Meanwhile there was extensive development and application of RIP and RIL systems along with suitable resins in the former Soviet block. It would be prudent for future projects to draw on this vast amount of previous experience and avoid trying to "re-invent the wheel" when considering the application of IX. The equally extensive experience gained in gold CIP and CIL operations also forms a useful platform. Outokumpu have recently introduced a multiple fixed bed carousel type IX system (SepTor) to approach continuous operation with a reduced resin inventory. As they are fixed bed, a clarified feed is needed.

6. PRODUCT RECOVERY

6.1 SX (AMINE) BASED OPERATIONS

The main trend in the nineteen seventies was towards ammonium sulphate stripping of the loaded organic solution followed by precipitation of ammonium diuranate with ammonia, then thickening, centrifugation and calcining (to drive off ammonia). However, acidified chloride stripping was used when significant molybdenum was co-extracted. This trend was subsequently followed by operations such as Ranger in the N.T., Olympic Dam and recently at Dominion. However, in Canada in particular, the need to avoid release of ammonia to the environment led to the development of strong sulphuric acid stripping followed precipitation of uranium peroxide with hydrogen peroxide, then filtration and drying (calcining is not required). This practice will likely be considered in similar environmentally sensitive projects in the future, though precipitation of uranium trioxide with magnesia is another option which has been utilized.

6.2 IX BASED OPERATIONS

While a variety of resin elution systems were used in the seventies and eighties, the trend has been towards acidified sodium chloride for IX systems applied to acid leach solutions, and sodium chloride with sodium carbonate (or bicarbonate or caustic) for systems associated with alkaline leach operations including ISL). For acidified chloride eluates, precipitation with ammonia, hydrogen peroxide and magnesia followed by dewatering and calcining or drying have been practised, as for to SX strip solutions. For example, the Beverley ISL operation uses sodium chloride-sulphuric acid elution followed by peroxide precipitation, dewatering then drying. For alkaline chloride eluates, precipitation with sodium hydroxide, magnesium hydroxide and hydrogen peroxide has been applied, though there has been an increasing trend to peroxide.

7. CONCLUSIONS

The nineteen seventies saw numerous innovations and new trends in most aspects of uranium ore treament. Major influences included larger scale projects and the need to reduce capital and operating costs, especially for lower grade operations. These devlopments and trends have continued though to a much lesser extent because of the generally depressed nature of the uranium industry and the small number of new projects.

However, many of the innovations were transferred to hydrometallurgical processes for gold, copper and nickel-cobalt. Therefore future uranium projects will be able to benefit not only from the gains made in the seventies and early eighties but from the subsequent developments in other hydrometallurgical processes.

8. REFERENCES

1. ALTA 1997 Uranium Ore to Yellowcake Seminar**.**

2. Uranium 2000, International Symposium on Process Metallurgy of Uranium, Met. Soc. of CIM.

3. Uranium Processing: A Review of Current Methods & Technology, C.R. Edwards & A.J. Oliver, Cameco, Canada, JOM, Sept. 2000.

4. Uranium Extraction – The Key Issues for Processing, D. Lunt and A. Holden, ALTA 2006 Uranium Proceedings.

5. SepTor Technologies Continuous Counter-Current Ion Exchange, M. Weatherseed, Continuous Counter-current Ion Exchange, ALTA 2006 Uranium Proceedings.

6. Mintek's Re-Entry into Uranium Research and Development, M. H. Kotze, B. R. Green, J. W. Neale and L. Swanepoel, ALTA 2006 Uranium Proceedings.

7. Uranium Ore Treatment Short Course, A. Taylor, ALTA 2006.