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EMERGING TRENDS IN THE DEVELOPMENT AND APPLICATION OF URANIUM IX SYSTEMS

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ABSTRACT

Factors influencing uranium ore process design since the mid 2000s include the trend towards lower grade ores, the success of ISL as a low cost process with less surface environmental impact, the development of alkaline leach projects for calcrete ores, the success of heap leaching for copper and gold recovery and the extensive application of CIP and CIL in the gold industry. All of these have resulted in a resurgence of interest in the development and application of new and improved IX systems.

Uranium ion exchange was first carried out in fixed bed columns in South Africa and the USA in the early 1950s. This was followed by the introduction of the so called “moving bed” columns in Canada in which the resin is transferred to separate columns for elution. Both of these designs require clarified feed solutions, and the benefits of being able to accommodate slurries soon led to the development of the reciprocating basket (RIP) system for de-sanded slimes in 1955. A jigged bed system was piloted at Rum Jungle, Australia in 1958, but not commercialized. The reciprocating basket resin-in-pulp system was superseded by screen-mix RIP systems in the USA in the late 1950s and applied in the former USSR, Eastern Europe and Spain. Also, various fluidized bed systems for unclarified solutions were developed in the late 1960s and 1970s in the USA, Canada, and South Africa, and the Higgins loop moving bed system was applied to the recovery of uranium from copper dump leach solution and ISL solutions in the USA.

Emerging trends in development and application of IX systems in the current era include:

- Development of continuous countercurrent merry-go-round column systems for clarified solutions aimed at reducing resin requirement by increasing resin loading, optimizing product yield, concentration and purity, reducing consumption of wash water and reagents and achieving a compact layout.
- Development of new screen-mix designs for RIP and RIL applications incorporating features from the extensive application of CIP and CIL in the gold industry.
- Re-emergence of the NIMCIX and other fluidized bed systems for unclarified solutions.
- Development of new moving bed systems including the U-Tube elution system, particularly in the Kazakhstan ISL industry.
  .

INTRODUCTION

A feature of the revival in uranium ore processing since the mid 2000s has been a resurgence of interest in the application of ion exchange (IX) and the development of new and improved IX systems. Contributing factors include the trend towards lower grade ores, the success of in-situ leaching (ISL) as a low cost process with low surface environmental impact, the development of alkaline leach projects for calcrete ores, increased interest in heap leaching due to the success of heap leaching for copper and gold recovery and the extensive application of carbon-in-pulp (CIP) and carbon-in-leach (CIL) technology in the gold industry. This paper reviews some of the earlier IX system designs and identifies emerging trends in the current era.

WHY IX

IX was initially introduced as a more efficient and lower cost replacement for earlier processing methods such as precipitation, more suitable for larger scale facilities and the treatment of lower grade ores. The first commercial application was in October 1952 at the West Rand Consolidated Mine gold/uranium operation in South Africa. Numerous other applications followed in South Africa, USA, Canada, Australia, the former USSR and Eastern Europe.

IX was largely unchallenged until solvent extraction (SX) was introduced in 1956. SX rapidly became standard industry practise for sulphuric acid leach operations for medium and high grade ores based on higher selectivity, higher product purity, greater tolerance to poisons (such as cobalt cyanide in the South African gold-uranium plants), totally continuous operation, simpler controls and greater flexibility. The notable exception was in the former USSR and Eastern Europe where IX continued as the preferred option.

However, for some applications, IX has a number of advantages over SX which has ensured its survival and current resurgence. These include:

- Unlike SX it is suitable for alkaline leach solutions.
- It is generally more economic than SX for dilute solutions. (Can be coupled with a small SX facility to improve product purity if required.)
- It can be applied to unclarified solutions and pulps, thus reducing or eliminating expensive and sometimes troublesome solid/liquid separation facilities.

FIRST GENERATION SYSTEM DESIGNS

Chronology

For the purposes of this paper, first generation is defined as systems introduced during the 1950s through to the mid 1980s, after which uranium ore processing activity waned due to sustained low uranium price.

- **1952**: Fixed bed column IX for clarified solutions first applied by West Rand in South Africa.
- **1955**: Reciprocating basket resin-in-pulp (RIP) system for de-sanded slimes in the USA.
- **1957**: Porter-Arden so called “moving bed” column IX system for clarified solution applied by Denison Mines in Canada.
- **Late 1950s**: Screen-mix RIP systems introduced and used in the USA, the former USSR, Eastern Europe and Spain.
- **Late 1960s and 1970s**: Fluidized bed continuous ion exchange (CIX) systems developed for unclarified solutions in the USA, Canada, South Africa and Namibia.
- **1977**: Higgins loop moving bed system used for extracting uranium from copper dump leach solution, and later applied to ISL solutions.

Selected First Generation System Designs

Fixed Bed Column

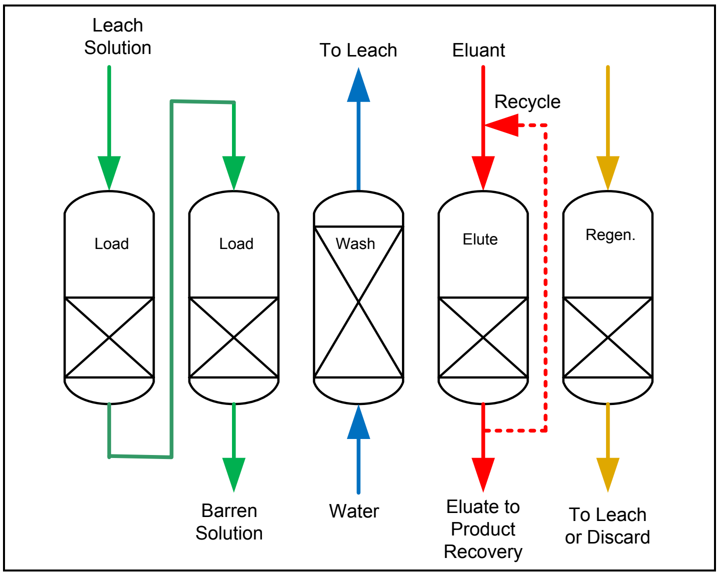

Figure 1: Five Column Fixed Bed System

The fixed bed system[1] was in common use for other applications such as water treatment prior to its adoption for uranium extraction. Like solvent extraction it requires a clarified feed solution. It is a batch operation and for uranium extraction it typically has 3 to 5 stages, including at least 2 stages always on adsorption and 1 on elution. A regeneration step may be included to remove poisons and/or condition resin before returning to adsorption duty. Operation can be downflow or upflow. Varying degrees of automation are used, and cycles can be initiated by timers or manually by the operator. Elution is carried out in the same vessel when the resin is fully loaded. Resin losses are relatively low, < 5% per annum. It typically utilizes vertical cylindrical rubber steel pressure vessels with dished ends, up to 3 m diam. Height can be up to about 5 m, depending on the application. The concentration ratio from the feed solution is typically 10-30 to 1. Split elution with recirculation of the second portion is commonly used to increase eluate concentration. A water backwashing cycle is typically included after adsorption or elution to prevent accumulation of solids. For this duty the column height usually provides for a 100% bed expansion.

Porter Arden System

Although called a “moving bed”, it is effectively a fixed bed system in which loaded resin is moved to separate columns for elution[1]. It typically utilizes 10 columns: 2 sets of 3 for adsorption, 1 set of 3 for elution, and 1 column for transfer and backwashing. Resin can fill entire the columns except for the transfer/washing column which is typically designed for a 60% bed expansion. Resin transfer is either hydraulic using water or solution pressure, or by using eductors. Containers can be used when transferring from satellite operations. Advantages over the normal fixed bed system include reduced risk of cross contamination of the various solutions, simpler controls, higher eluate concentration due to flow through a series of elution vessels, and higher resin bed depth for the same column height which can translate into lower capex. Disadvantages include greater resin attrition, about 10% per annum, due to more resin transfers, and the resin “heel” left behind after transfers which can lead to higher uranium concentration in the barren solution.

Reciprocating Basket RIP System

The reciprocating basket RIP system[1] was developed in the USA and applied to de-sanded slimes with a maximum particle size of 45 microns. Pulp density was limited to < 10% solids. Typically two parallel systems of 14 stages (or banks) were used with 6-11 stages used for adsorption at any one time. Each stage contained 2-10 baskets. A central distributor box could feed any bank, and interstage slurry transfer was by gravity or airlift. Resin make-up was relatively high due to attrition, around 15-20% per annum. Maintenance costs were also high. The baskets were typically cube shaped, with stainless steel or rubber lined frames and stainless steel or plastic screen cloth. The baskets moved up and down at 6-12 strokes/minute in rectangular tanks through which feed slurry or eluant flowed. The resin bed contracted during up strokes and expanded during down strokes. When a bank was fully loaded, it was drained, rinsed then became part of the elution circuit.

Screen-Mix RIP System

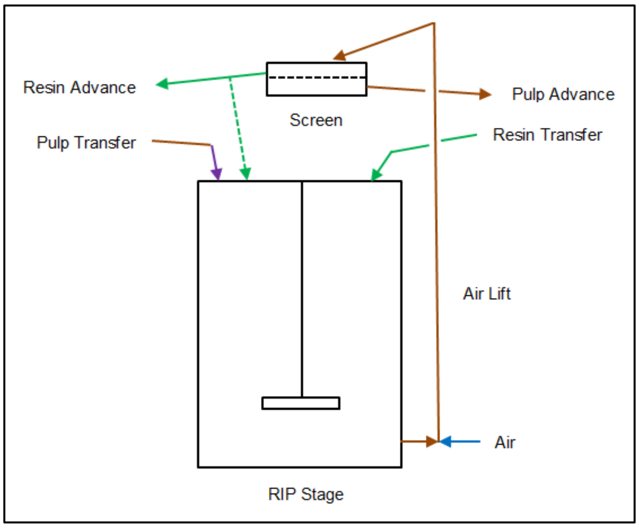

Figure 2: Typical US Screen–Mix RIP System

The screen-mix RIP system was initially applied to acid leach pulps in the USA[1] and the former USSR. It is a multi-stage countercurrent system with mechanical or air agitation. Interstage transfer of pulp and resin is via airlifts or pumps and either vibrating or stationary sloping screens. A portion of the resin transfer is recycled to control the inventory each vessel. US systems typically comprised 6-7 adsorption stages, 10-12 elution, 1-2 wash. Fixed bed elution was also used. The feed pulp was typically de-sanded to a maximum particle size of 45-75 microns and pulp density limited to 12-20% solid, though one operation reportedly achieved 30%. Operation with up to 50% solids was reported in the former USSR. Resin make-up due to attrition was 20-30% per annum. However, resin inventory was only one third to one half of that for the equivalent reciprocating basket system. Screen maintenance cost was significant. Rubber lined steel tanks were commonly used in adsorption and FRP in elution. Screen decks were in stainless steel. Concentration ratio from feed solution was in the range of 10-15 to 1. RIL was reportedly operated in the former USSR.

NIMCIX CIX System

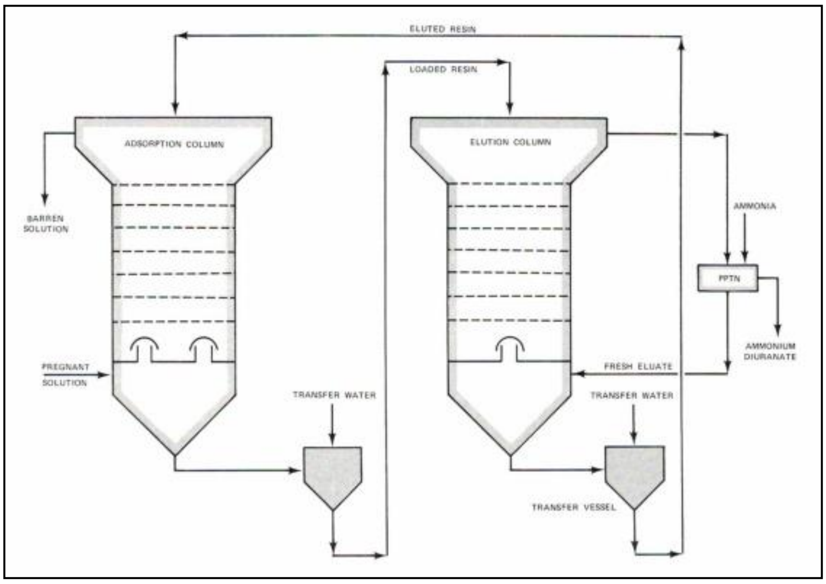

Figure 3: NIMCIX CIX System[2]

The NIMCIiX CIX system was developed for unclarified leach solutions in the late 1960s by NIM (now Mintek) in South Africa based on the Cloete-Streat concept at Imperial College, UK. Several plants were built for acid leach solutions in South Africa in 1970s and one was installed at Grants New Mexico, USA, 1980, for alkaline solution recycled from a tailings pond. It is a fluidized bed system with 10 and 14 stages separated by perforated plates. Caps are placed over holes in the bottom tray to reduce the rate of resin transfer and avoid the depletion of resin in the column. Construction material can be FRP, stainless steel or rubber lined steel depending on the solution composition. Unclarified pregnant leach solution with up to about 300 ppm of suspended solids is passed upwards through the column, fluidizing the resin in each stage. The solution flow is periodically stopped allowing resin to fall through the perforations in each tray to the stage below. Eluted resin is transferred into the top of the column, while loaded resin is withdrawn periodically from the bottom of the column during a period of backflow. Resin transfer is by hydraulic pressure via transfer bins, and is automated. Construction and operation are simple, and capital and operating costs relatively low. Operation is said to be efficient and stable over a wide range of feed rates and concentrations; efficiency of recovery is high, and resin losses are relatively low. Plant reliability and availability are claimed to be high. The first plant, at Blyvooruitzicht, South Africa[(3)], had 6 adsorption stages and 7 elution stages. The adsorption column was 2.4 m dia. X 7.8 m high, with a stage height of 1 m. The elution column was 1.2 m dia. X 7.8 m high. There were 648 12 mm dia. orifices per plate in adsorption and 112 in elution. The material was stainless steel. The specific flow rate in adsorption was 7.5 USGPM/ft^2. A number of other fluidized bed column designs were also developed and applied in the 1970s including the Himsley Column (Canada), Davy Powergas (UK), and the USBM and Utah systems (USA).

Porter CIX System

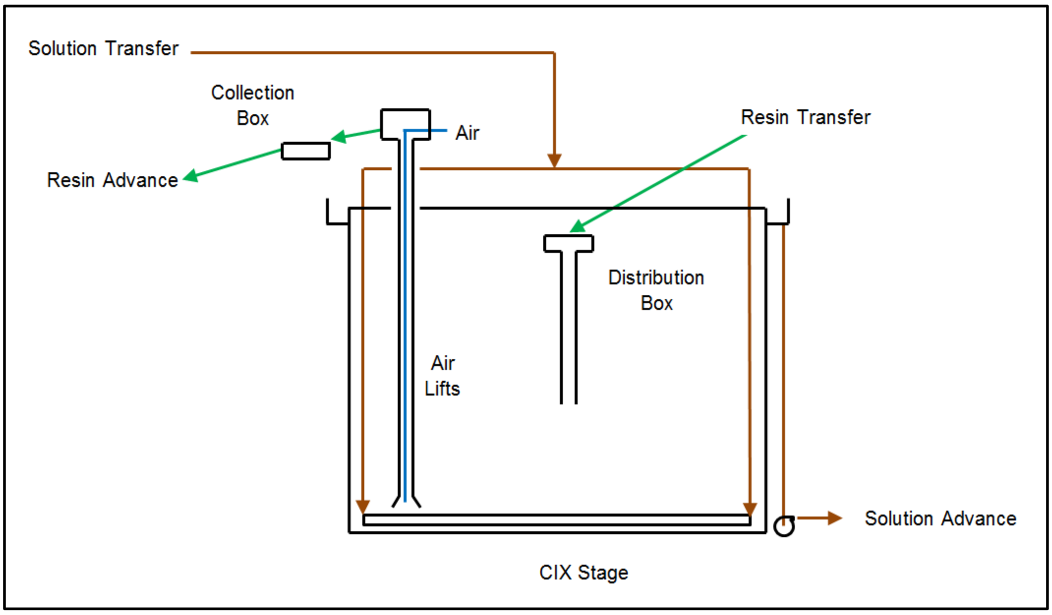

Figure 4: Porter CIX System

The system was developed by R. R. Porter, a USA based consultant, in the 1970s and was first applied to unclarified solution at Rossing, Namibia, in 1976[(4)], which is still in operation. It was also used at several ISL operations in the USA; which are no longer operating. It is a multiple tank countercurrent fluidized bed system, with typically 5 stages, The solution flows into the bottom of each stage via a distributor and up through the vessel to form a fluidized resin bed. Resin is sequentially transferred batchwise by a number of air lifts per stage from tank to tank countercurrent to the solution, then via a washing screen to elution which typically uses downflow fixed bed columns. The solution flows continuously through the CIX units by gravity, or by using interstage pumps as at Rossing. Compared to column type systems it has a higher footprint, however it has a lower profile and is therefore is more suitable for indoor locations. Resin loss is likely to be higher than single stage systems due to the number and nature of the resin movements. On the credit side, it is reported to be more tolerant to suspended solids.

Higgins Loop CIX System

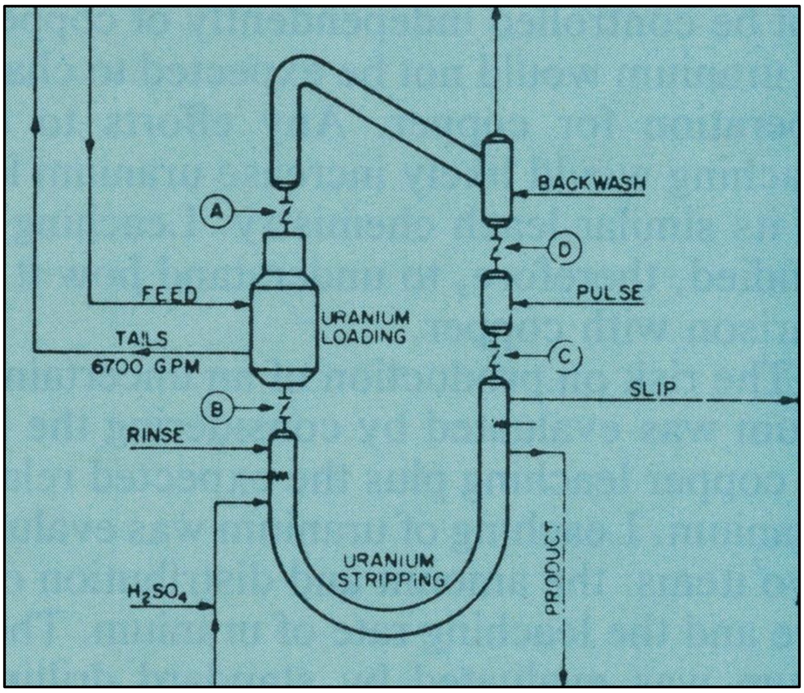

Figure 5: Higgins Loop Moving Bed CIX System

The Higgins Loop CIX system was invented in 1951 by Irwin Higgins at Oak Ridge National Laboratory in the USA, initially focused on radioactive ion separations. It was commercialized in 1995 and marketed by Chemical Separations Corp. as the Chem-Sep Contactor and applied for water treatment and in the chemical industry. In 1977 it was used in an eluex configuration by Wyoming Minerals Corp. (Westinghouse) for the recovery of uranium from copper dump leach solution at Kennecott's Bingham Canyon mine in Utah(5). It was also applied by Wyoming minerals at their Lamprecht ISL operation in Texas. It is a continuous countercurrent moving bed system consisting of a single closed loop separated by valves into sections including loading, washing, elution and regeneration as required. Resin is moved in small increments by water pressure pulse action during which solution flows are stopped. The solutions flow countercurrent to the resin in all sections. Valve movements are automatically controlled to a preset sequence. Advantages include a single vessel for all operations, low resin inventory, compact design, low footprint, high solution flow rate, relatively simple control and low capital cost. Disadvantages include relatively high resin loss, exacerbated by the valve actions, and reduced flexibility due to the movement of resin through adsorption and elution being interconnected. Suspended solids are removed during backwashing and a limited level can be accommodated. At Kennecott there were four 2.4 m diameter units.

RESURGENCE OF IX DEVELOPMENT AND EMERGING TRENDS

Resurgence of IX Development

In 2005 the U_3O_8 price surged past US$20/lb for the first time since 1983 spawning a revival of interest in uranium ore processing development. A feature of this has been a resurgence of interest in the development of new and improved IX systems. Contributing factors include the trend towards lower grade ores, the success of in-situ leaching as a low cost process with low surface environmental impact, the development of alkaline leach projects for calcrete ores, the need to combat rising capital costs, increased interest in heap leaching due to the success of heap leaching for copper and gold recovery and the extensive application of carbon-in-pulp (CIP) and carbon-in-leach (CIL) technology in the gold industry.

Emerging Trends

- Fixed bed IX continues to be used for clarified solutions, such as for some ISL applications.
- Development of continuous countercurrent merry-go-round column systems for clarified solutions aimed at reducing resin inventory by increased resin loading, optimizing product yield, concentration and purity, reducing consumption of wash water and reagents and achieving a compact layout.
- Development of new screen-mix designs for RIP and RIL applications incorporating features from the extensive application of CIP and CIL in the gold industry.
- Re-emergence of the NIMCIX system and the development of new fluidized bed systems for unclarified solutions.
- Development of new moving bed CIX systems for both adsorption and elution, particularly in the Kazakhstan ISL industry.

System Developments

Merry-Go-Round CIX Systems

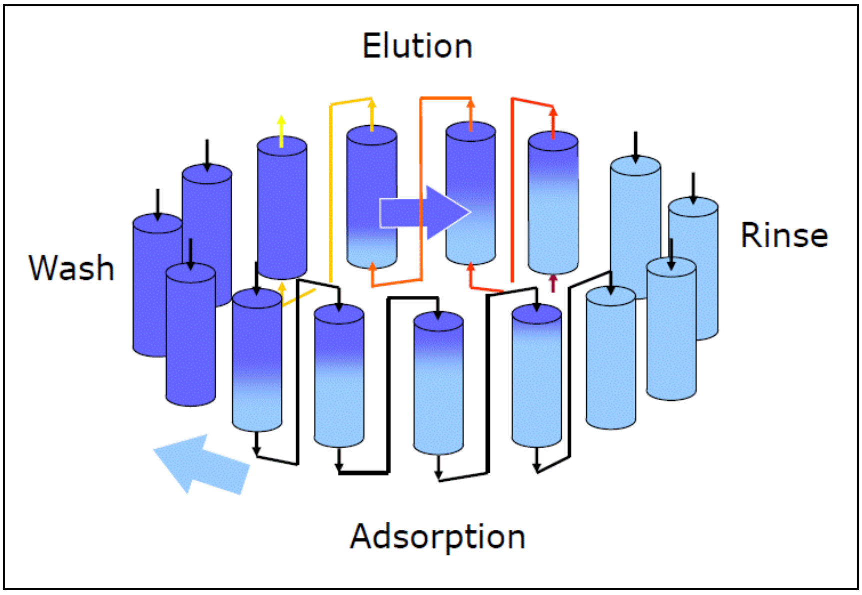

Figure 6: IONEX IXSEP-RDA CIX System[(6)]

Merry-go-round CIX systems are used in the food and chemical industries, for the separation and refining of nickel, cobalt, zinc and copper and rhenium, and have been tested at pilot plant level for uranium. Suppliers include PuriTech in Belgium, IONEX and Calgon in the USA, and SepTor now in China. The system typically consists of a series 12-30 small fixed bed columns. Continuous countercurrent operation is achieved by the operation of a rotary multiport valve connected to all the process fluids. Some systems use a simpler rotary valve with the columns mounted on a rotating carousel. Claimed advantages compared with conventional fixed bed systems include high separation efficiency, lower resin inventory, compact arrangement, reduced capital cost, higher eluate concentration with lower impurities leading to downstream benefits, reduced reagent and water consumption, lower operating cost, and reduced waste discharge. It also facilitates the use of a pre-elution stage and/or a post adsorption scrubbing stage to remove impurities. The main disadvantage is the need for clarified feed solution. To overcome this, IONEX have patented a hybrid system utilizing a solids tolerant fluid bed CIX or screen-mix RIP system for adsorption and a merry-go-round CIX system for elution.

Screen-Mix RIP Systems

Interest in screen-mix systems has been fuelled by the significant capital and operating cost benefits from the elimination of solid/liquid separation plus the extensive system design and operating experience gained in gold CIL/CIP. This has led to the development of a number of new system designs including the Kemix Pumpcell and Bateman/Mintek MetRIX™ systems in South Africa and the Clean TeQ Clean-iX® cRIP system in Australia.

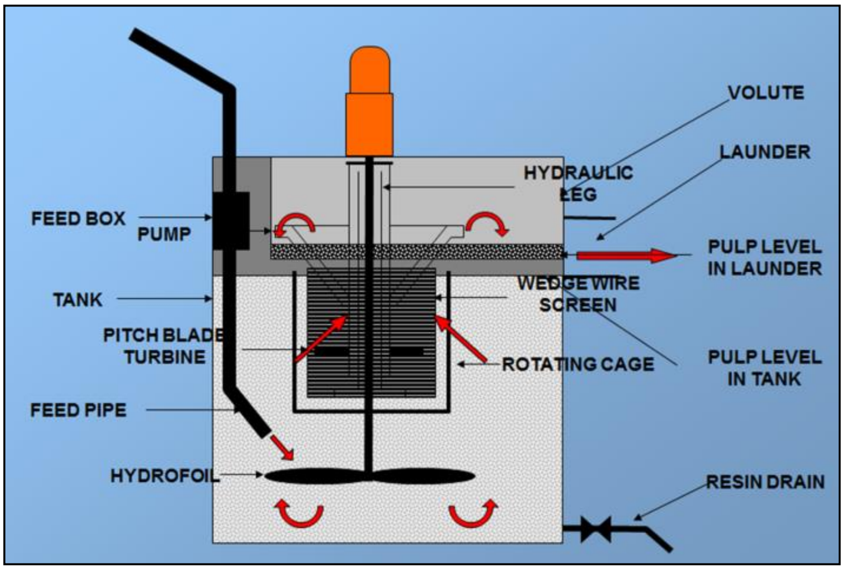

Figure 7: Kemix Pumpcell RIP System(7)

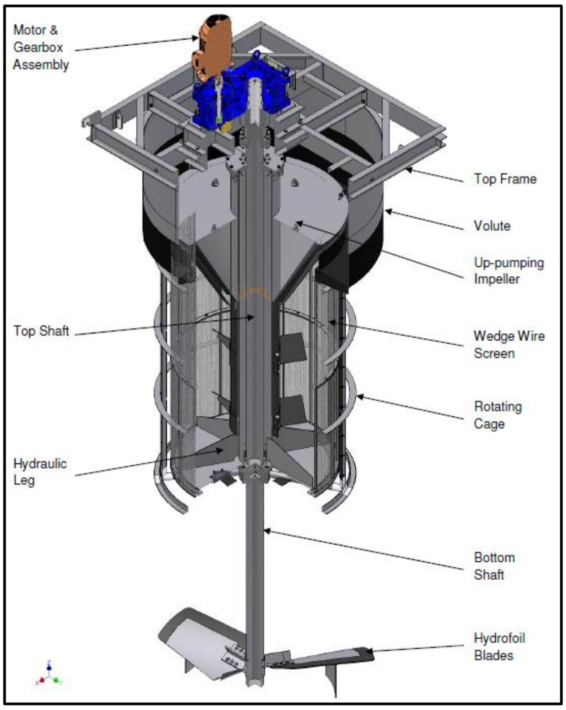

Figure 8: Kemix Pumpcell RIP Mechanism(7)

<u>The Kemix Pumpcell</u> system was installed at Kayelekera, Paladin Energy, Malawi, and Mintails, South Africa. It was originally developed by Anglo American for gold CIP/CIL with the first commercial plant in 1990. It is now available from Kemix Pty Ltd, South Africa. It combines the functions of pumping, screening, and agitation into a single drive unit operating within a modular high capacity cell with a relatively small retention time per stage. The system typically comprises a series of Pumpcells set at the same elevation operated in a carousel mode by rotating the pulp feed and discharge points to simulate countercurrent flow of resin by means of a launder system. Resin/pulp separation is by a cylindrical screen wiped by a rotating cage; pulp passes through the screen and is transferred to the next stage via an up-pumping impeller and launder. Resin is retained within the vessel and is not moved between stages, which reduces resin breakdown. Elution is carried out in a separate system.

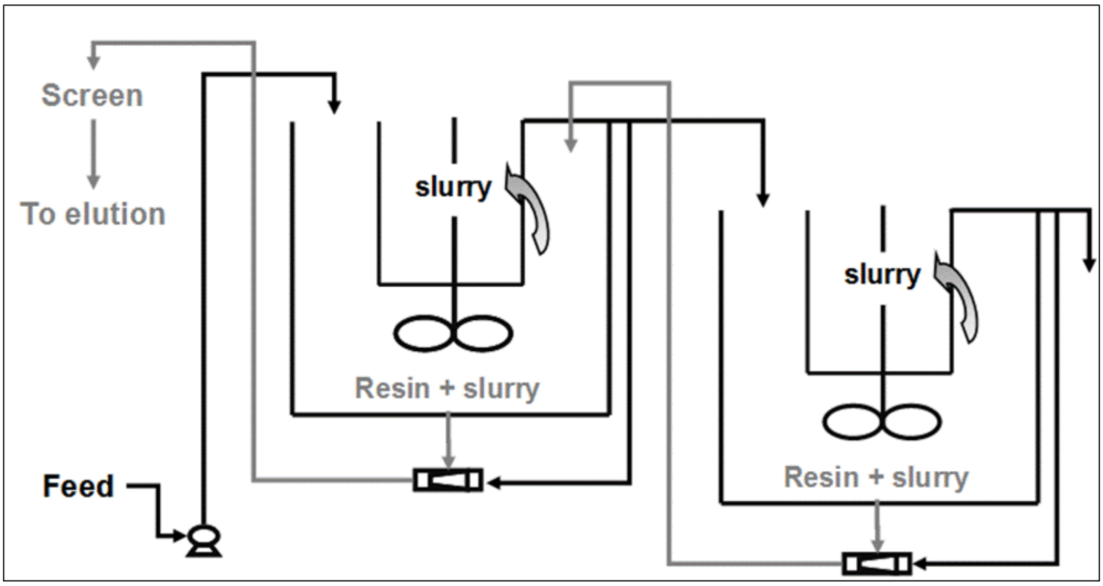

Figure 9: MetRIX RIP System[8]

The MetRIX™ System was developed by Mintek and Bateman (now Tenova) in South Africa. Following pilot plant work at Mintek, a demonstration plant was operated at Harmony Gold Mining Company, South Africa, in 2010[9] as part of the TPM Uranium Project Feasibility Study. It consists of a series of screen-mix units with countercurrent movement of pulp and resin. Pulp flows through a submerged wiped screen and by gravity to the next stage via a launder, while the resin is retained in the tank. The screen is a Bateman design proven in CIL/CIP applications. Interstage resin transfer is via an eductor using process slurry which is separated from the resin on a static sieve bend. The slurry returns to the RIP tank while the resin proceeds to the adjacent upstream RIP tank. Elution uses a batch system comprising two agitated buffer tanks and an elution column.

The Clean-iX® cRIP System[10] was developed by Clean TeQ in Australia. A successful pilot plant program for the recovery of nickel and cobalt was carried out in 2004-2008 in collaboration with BHP Billiton, and a pilot plant for scandium recovery has been supplied to a large Japanese titanium dioxide producer. Clean TeQ are now developing a flowsheet for the recovery of scandium for the Syerston Project in NSW, Australia, which they have acquired from Ivanhoe. It has also been tested for the extraction of uranium and copper. The system uses a low shear, two-stage mechanical agitator to mix the resin and pulp, and an airlift to lift both resin and pulp to a woven wire static separation screen. An air agitated alternative is also available which has higher power consumption but lower resin attrition loss. The Clean TeQ Clean-iX® U-Tube elution system is used for elution.

Fluidized Bed CIX Systems

The NIMCIX System has re-emerged[11][12] and has been applied at a number of new projects. In South Africa it has been installed at Ezulwini, Sibanye Gold, and new columns have been installed at Vaal Reefs South, AngloGold Ashanti, which has been in operation since 1978. In Namibia it was adopted for the Trekkopje alkaline heap leach development program, the Langer Heinrich alkaline leach expansion and for the giant new Husab Project, by Swakup Uranium, scheduled to come on stream in 2016. Mintek is developing and patenting a novel countercurrent elution design[13][14], Turlajet™, that would allow continuous resin transfer, and hence a more efficient elution and a higher eluate uranium concentration. This may allow direct precipitation of uranium from the eluate, thus avoiding the extra capital and operating costs associated with a downstream solvent extraction purification stage. A pilot plant has operated in 2015.

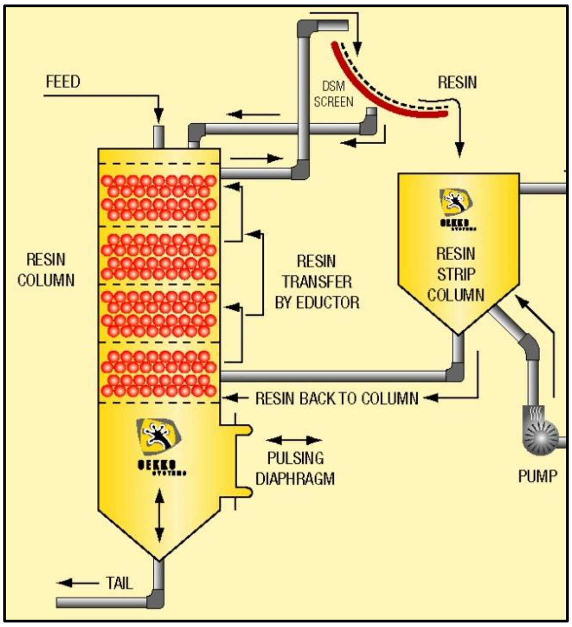

Figure 10: G-REX Fluidized Bed CIX System(15)

The G-REX System has been developed by Gekko Systems, Australia, and has been applied at commercial gold operations at Bong Mieu in Vietnam, Ballarat Goldfields in Australia; and Hoschilds in Argentina. It is potentially applicable to other IX processes including uranium extraction. It is a multistage countercurrent, pulsed, column contactor, with stages separated by internal screens. The feed solution flows down the column and the column is pulsed to fluidize the resin. Resin is transferred upwards between compartments externally using an educator, and the loaded resin is transferred to an upflow batch elution column. It is designed to minimize resin wear and is reported to handle unclarified solutions with up to 2% solids at < 200 microns.

Moving Bed Systems

New moving bed systems for both loading and elution have been developed and commercially applied for feed solutions with low suspended solids content, particularly in the Kazakhstan ISL industry. Upflow moving bed columns are generally used for adsorption and U-Tube type units for elution. Attractions include high loadings and low barren uranium tenors due to the plug flow conditions.

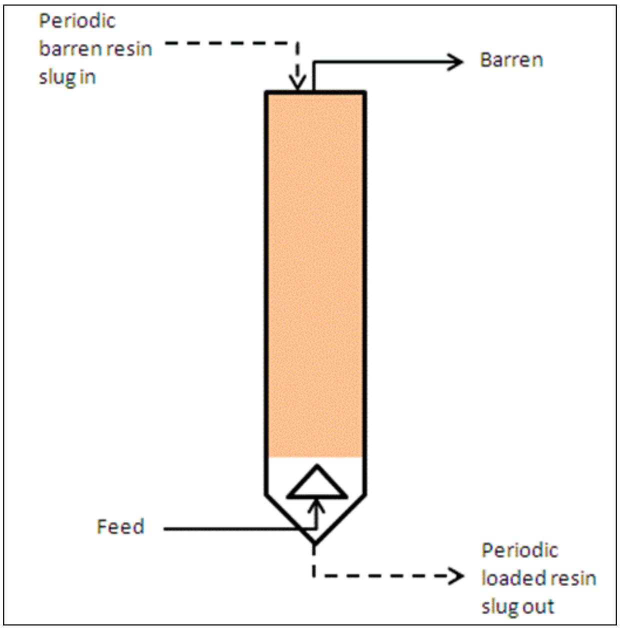

Figure 11: Upflow Moving Bed Column CIX Concept(16)

The Upflow Moving Bed System has been applied for uranium extraction at a number of ISL operations, particularly in Kazakhstan. It consists of a packed bed column where the solution flows upwards and resin is moved downwards countercurrently to optimize the mass transfer driving force. Typically, intermittent movement of the resin is achieved using air pressure. The resin is loaded to its maximum potential which reduces the resin inventory. Portions of the resin are removed intermittently and transferred to elution. Due to the plug flow, high loadings and low barren tenors are achievable. The system is suitable for clarified or low solids solutions such as heap leach or ISL solutions. An example is the Clean-iX® cLX System(10)17) available from Clean TeQ, Australia, who state that the feed solution can contain up to 100 ppm particulates which are filtered out by the resin bed and subsequently removed in a fluidized wash column prior to elution.

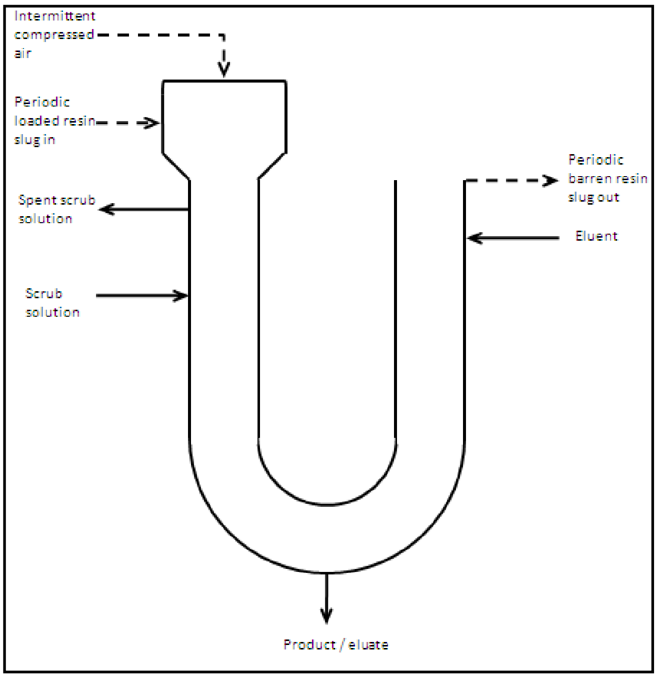

Figure 12: U-Tube Moving Bed Elution Concept(16)

The U-Tube Moving Bed Elution System(16)(17) is used in ISL operations, particularly in Kazakhstan. The loaded resin is transferred from the loading column to one leg of the U-tube and the eluant enters the opposite leg. The resin and eluant move in countercurrent plug flow, with the resin moved by some form of pulsing such as compressed air. Eluate is removed near the bottom leaving the other leg available for other steps such as scrubbing. Advantages include lower resin inventory, lower capex, higher resin stripping efficiency leading to higher extraction, and higher eluate grade increasing the possibility of direct precipitation.

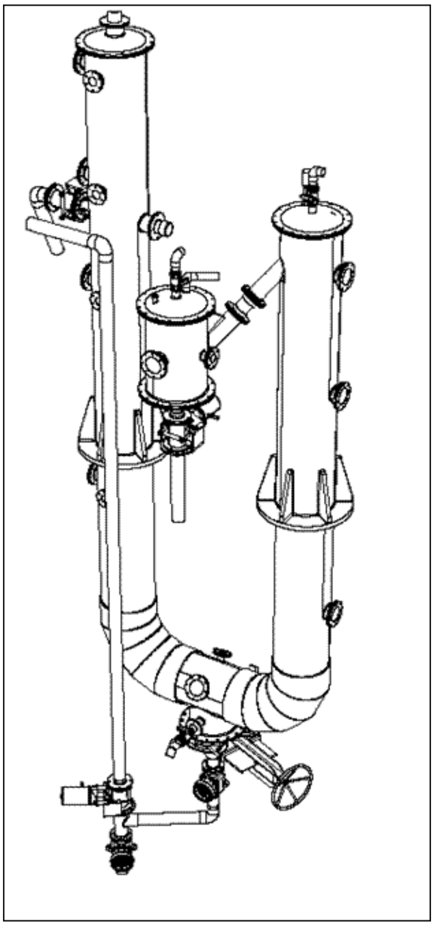

Figure 13: Clean TeQ Clean-iX® Moving Bed U-Tube Elution System(18)

CONCLUSIONS

IX has played a significant role the post 2005 revival of uranium ore processing development, and there has been a resurgence of interest in the development and application of new and improved systems.

The emerging trends for the current generation uranium plants are new screen-mix designs for resin-in-pulp operations, the resurrected MINCIX column system for unclarified solutions such as thickener overflow, and upflow moving bed adsorption columns and moving bed U-Tube elution units for clarified or low suspended solids solutions such as in ISL operations. In addition, merry-go-round fixed bed systems using a rotating carousel and/or a rotary distribution valve have been pilot tested for clarified or low suspended solids solutions.

Future trends will be influenced by the type of leaching system selected, which in turn will depend on the grade and characteristics of the ore and other factors such as environmental and social considerations. Another potentially important factor is resin development – for example increase in resistance to resin breakdown will make RIP more attractive.

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