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DEVELOPMENTS IN URANIUM EXTRACTION AND RECOVERY TECHNOLOGY

By

Alan Taylor

ALTA Metallurgical Services, Australia

Presenter and Corresponding Author

Alan Taylor
alantaylor@altamet.com.au

ABSTRACT

This presentation highlights a range of technologies at various stages of development and commercialisation.

Process technology for the extraction and recovery of uranium continues to develop driven by the need to reduce capital and operating costs, the move towards lower grade and more difficult ores, the need to improve the processing of saline leach solutions and the increasingly stringent environmental regulations.

Developing areas include preconcentration, solvent extraction/ion exchange and product recovery. Technologies highlighted in this presentation are Ablation, U-pgradeTM process, nonofiltration, strong acid strip SX/IX, strong acid strip/SX, basic aluminium sulphate strip, SX for high chloride solutions, alkaline SX, Wintray SX contactor, and fluid bed precipitation.

Some other developing areas, not included highlighted in this presentation include in-situ leaching, heap leaching, solid-liquid separation, IX resins and systems, and by-product uranium recovery. Process development is likely to accelerate as uranium demand increases to supply the projected expansion of nuclear power generation.

Keywords: Uranium, technology development, preconcentration, solvent extraction, ion exchange, product recovery

OUTLINE

- Introduction
- Preconcentration
- Nanofiltration
- Solvent Extraction/Ion Exchange
- Product Recovery
- Conclusions
- References

INTRODUCTION

- Drivers for developments in uranium extraction and recovery technology include the need to reduce capital and operating costs, the move towards lower grade and more difficult ores, the need to improve the processing of saline leach solutions and the increasingly stringent environmental regulations.

- This presentation highlights a range of technologies at various stages of development and commercialization.

PRECONCENTRATION

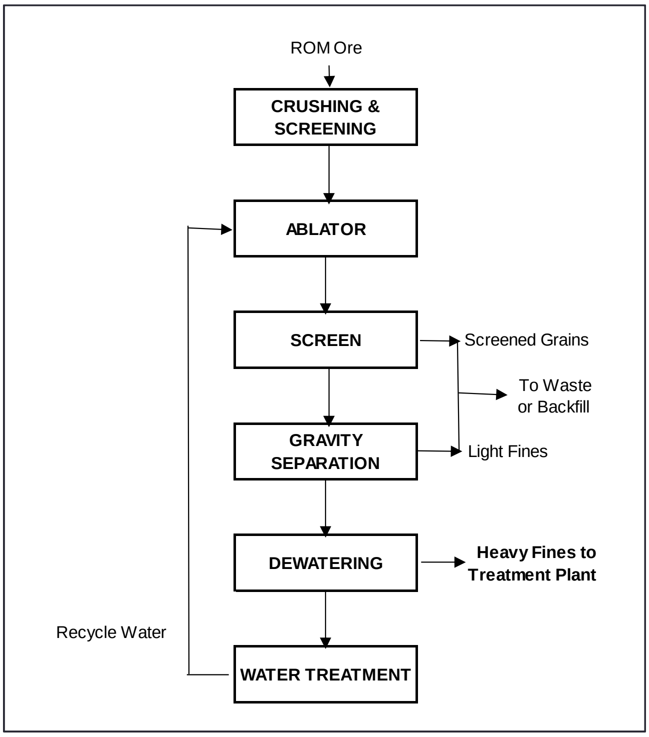
ABLATION

- Invented by Ablation Technologies, Casper, Wyoming, USA, initially for gold then patented for uranium in 2012.
- A JV, Mineral Ablation, was formed with Black Range Minerals, Australia, in 2012 to market the technology.
- Proposed for BRM's Hansen Uranium Project in Colorado, USA, along with hydraulic bore hole mining. Tested with a 5 t/h pilot ablation unit in 2013 which achieved 94.5 % uranium recovery into finest fractions.
- Black Range were taken over by Western Uranium, Toronto, Canada in 2015, who successfully tested the 5 t/h pilot plant on stockpiled ore at their Sunday Mine Complex in Colorado, and have constructed a 20 t/h commercial unit for operation in 2016.

ABLATION CONCEPT

- Uses kinetic energy and water to force grains against each other using opposing nozzles to remove uranium in coatings and interstitial deposits from barren sand grains typically found in sandstone ores.
- The resulting fine material commonly contains a high percentage of the uranium and can be separated by screening into a high grade, low volume, concentrate.
- The concentrate may be further upgraded by removal of light barren fines by gravity separation.
- The final concentrate is dewatered and the water treated as required for recycling and reuse.
- Extensive testwork shows typically more than 90% of the uranium mineralisation can be recovered into about 10% of the initial mass.

ABLATION FLOWSHEET



APPLICATION

- GoviEx Uranium, Vancouver, Canada have included Ablation in the base case flowsheet for their Madaouela Project in Niger.
- The proposed flowsheet involves primary crushing, radiometric ore sorting, and secondary crushing, ahead of ablation.
- After two-stage agitated tank leaching with sulphuric acid, Cyanex 600 SX extractant is used to extract both molybdenum and uranium which are recovered separately as saleable oxides by selective stripping.

U-PGRADE PROCESS™

- Developed and patented by Marenica Energy, Australia, initially for the Marenica low grade surficial deposit in Namibia.
- Beneficiation process targeting sequential removal of the gangue minerals using commonly used unit operations.
- Bench scale tests indicate concentration of uranium into <3% of the mass, upgrading by >30 times (without the use of leaching chemicals).

U-PGRADE FLOWSHEET

- A primary beneficiation stage comprising wet scrubbing of low grade ore to separate into fine and coarse fractions (possibly with a prescreening step to minimize scrubbing of liberated carnotite).
- Fine fraction is screened to provide an undersize fraction with most of the uranium and an oversize fraction.
- The undersize fraction is separated to produce an intermediate uranium concentrate.
- The intermediate uranium concentrate may be further processed in a secondary beneficiation stage to produce a high grade uranium concentrate – possible steps include desliming, gravity separation, flotation, reflux classification and magnetic separation.

POTENTIAL BENEFITS

Potential benefits include:

- Substantial rejection of mass prior to leach.
- Rejection of carbonates prior to leach.
- Rejection of interfering minerals in the separation processes.
- Allows acid leaching of concentrate from calcrete ore types.
- Processing of high sulphate ores, usually classified as waste.
- Significant reduction in opex and capex.
- Allows option of transport of concentrate to an existing treatment plant or to a new treatment plant located at a more favourable location.

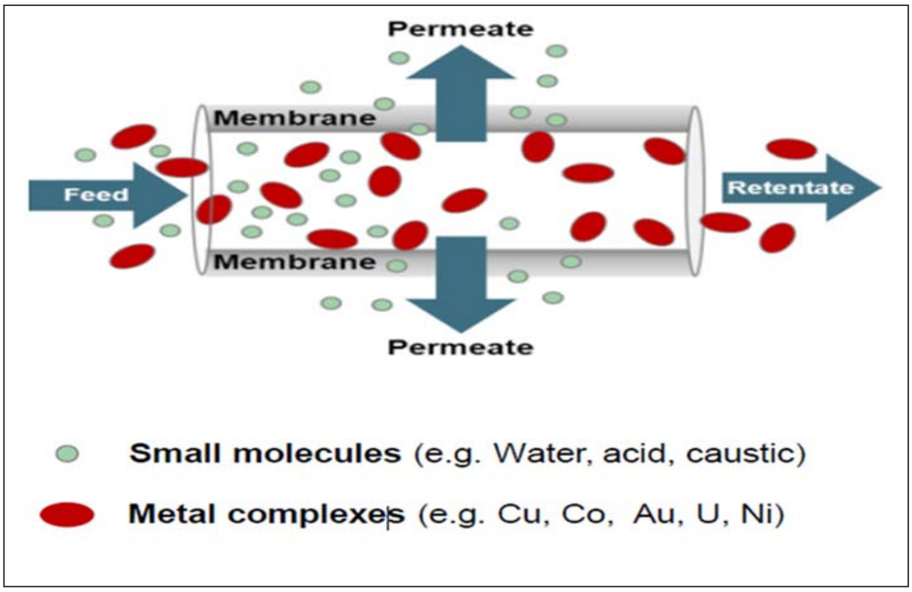
NANOFILTRATION

NANOFILTRATION

- Nanofiltration membranes have pore sizes from 1-10 Angstrom, which is smaller than for microfiltration and ultrafiltration, but just larger than for reverse osmosis.
- Used in water softening, waste water treatment, acid rock drainage, and oil & petroleum, food and phamaceutical industries.
- Small, monovalent ions pass through the membrane to the permeate, while larger ions are retained to the retentate.
- Advantages include low energy and no requirement for reagents, while disadvantages include cost and maintenance of membranes and risk of plugging or scaling.

NANOFIILTRATION CONCEPT

(Ref: AMS presentation, ALTA 2015)

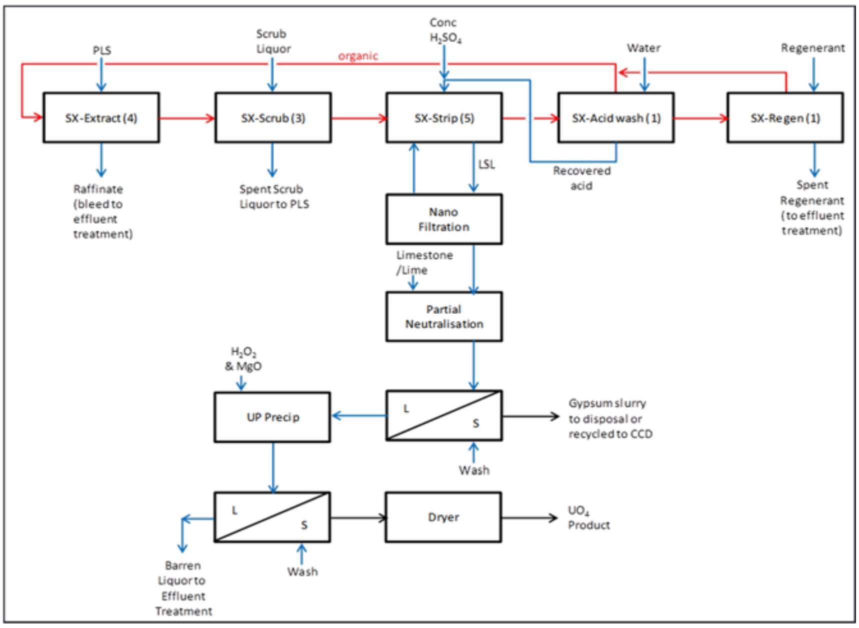


POTENTIAL APPLICATIONS

- Potential applications in uranium operations include:
  - concentration of SX strip solution or IX eluate with recovery of acid or other reagents.
  - concentration of SX or IX feed solution with recovery of acid or carbonate reagents.
  - treatment of waste or bleed streams.
  - treatment of acid rock drainage.
- Tested for a number of uranium projects including Letlhakane in Botswana for A-CAP; Michelin in Canada for Aurora Energy; Mkuju River in Tanzania for Uranium One; Kayelekera in Malawi and Langer Heinrich in Namibia for Paladin Energy (now installed at both sites).

STRONG ACID STRIP/NF FLOWSHEET

(Ref: AMEC paper, ALTA 2012)



COMMERCIALIZATION

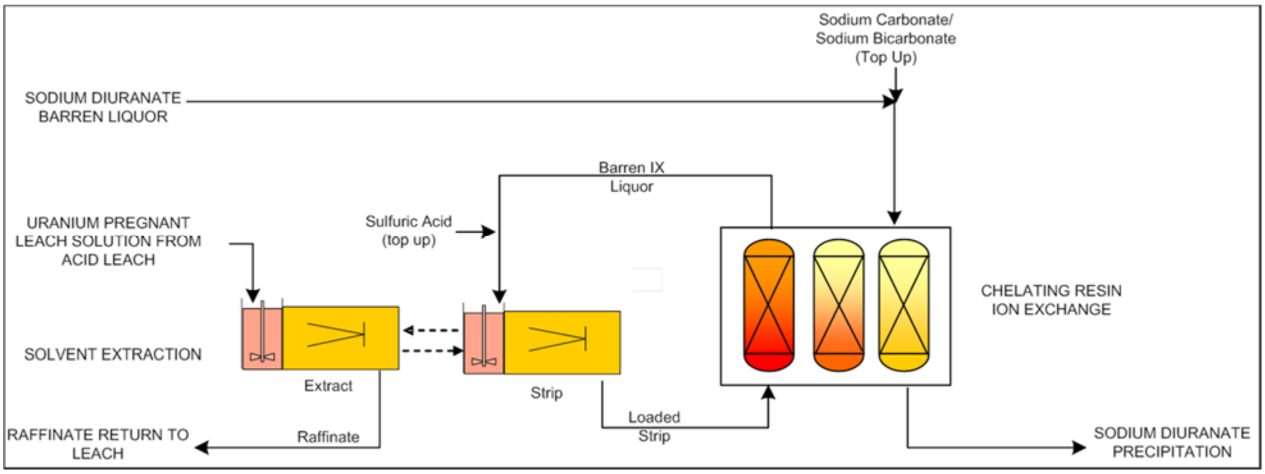
- A world first nanofiltration system for recovering acid from IX eluate prior to precipitation, designed by BMS Engineers (Perth), was installed at Paladin Energy's Kayelekera uranium operation in Malawi in 2013. An average of 56% of the acid is recovered and the consumption of neutralizing agent reduced by over 55%.
- The acid recovery technology developed has been patented by Paladin Energy, with BMS personnel as co-inventors; and BMS Engineers and Paladin Energy have agreed to jointly develop and further this technology in the uranium industry.
- BMS have also installed the world's first system for recovering bicarbonate in a uranium operation at Paladin's Langer Heinrich plant in Namibia.

SOLVENT EXTRACTION
AND
ION EXCHANGE

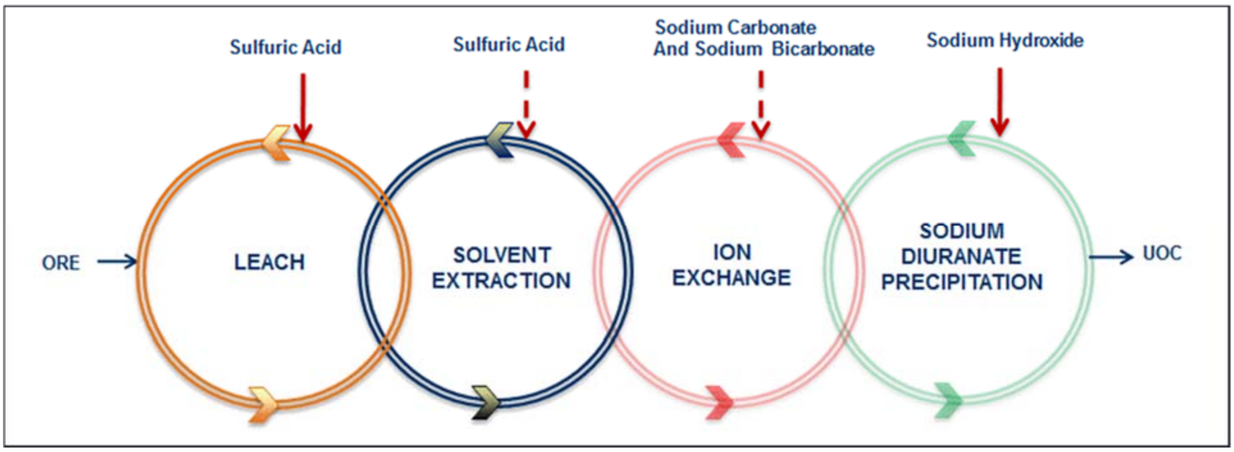
APPLICATION OF IX TO STRONG ACID STRIP OR ELUATE SOLUTIONS

- Aimed at avoiding need for partial neutralization of strong acid SX strip or IX eluate solutions ahead of uranium oxide precipitation.
- Utilizes IX with chelating resin to extract uranium and allow the acid to be recycled and reused.
- The loaded chelating resin is stripped with sodium carbonate/sodium bicarbonate solution.
- Sodium hydroxide is added to precipitate sodium diuranate which is separated and redissolved in sulphuric acid, followed by uranium oxide precipitation and drying.
- Was developed and successfully tested to treating strong acid strip solution for A-CAP Resources' Letlhakane Project, Botswana.

STRONG ACID STRIP/IX FLOWSHEET
(Ref: Orway paper, ALTA 2015)



STRONG ACID STRIP/IX REAGENT RECYCLE
(Ref: Orway paper, ALTA 2015)



POTENTIAL BENEFITS

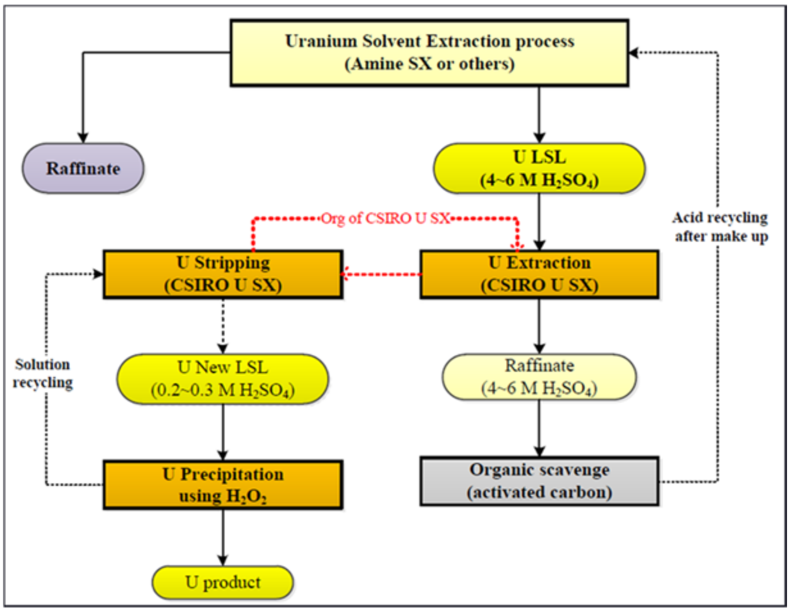
- Compared with partial neutralization method for strong acid strip application based on Letlhakane PFS testwork:
  - Saving of approx. 60% in overall recovery cost from leach PLS to UOC product due to recycle of acid and eluant.
  - Elimination of uranium loss in partial precipitation resulting in high overall uranium recovery of > 99% from leach PLS to product.
- Nano filtration was considered but there was concern over the stability of the membrane in the 4 M acid conditions and the perceived effect on the water balance (the commercial NF facility at Kayelekera operates on IX eluate at about 1 M acid strength).

APPLICATION OF CSIRO SSX SYSTEM TO STRONG ACID SX STRIP SOLUTION

- CSIRO (Perth) are developing a new synergistic SX (SSX) system to transfer uranium from strong acid (4-6 M) strip solution to a weaker acid strength (0.2–0.5 M) solution suitable for uranium precipitation with hydrogen peroxide.
- This avoids the need for partial neutralization as used at Rabbit Lake in Canada and allows the recycle and reuse of the acid.
- The SSX system is based on a blend of two stable commercially available extractants.
- Bench scale test results promising with high extraction and stripping efficiencies and fast kinetics in SSX.

CSIRO STRONG ACID STRIP/SSX FLOWSHEET

(Ref: CSIRO paper, ALTA 2015)

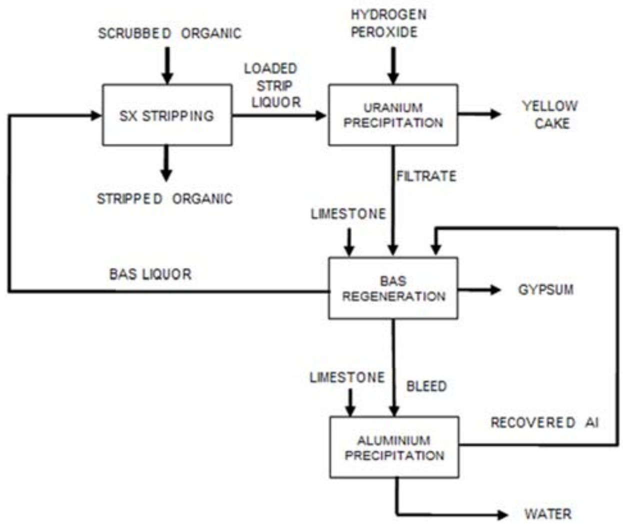


BASIC ALUMINIUM SULPHATE (BAS) STRIP PROCESS

- Strategic Metallurgy, Perth, are developing a new basic aluminium sulphate (BAS) strip process which avoids pH control and precipitation problems.
- Uses a solution containing basic aluminium sulfate (BAS) which allows uranium to be stripped from the organic via a de-protonation mechanism, and neutralizes the acid generated during uranyl peroxide precipitation with hydrogen peroxide.
- Uses inexpensive, non-hazardous reagents, aluminium sulfate (which is recoverable) and limestone (or lime).
- Testwork indicates the product contains about 0.33% Al.

BAS STRIP FLOWSHEET

(Ref: Strategic Metallurgy paper, ALTA 2014)

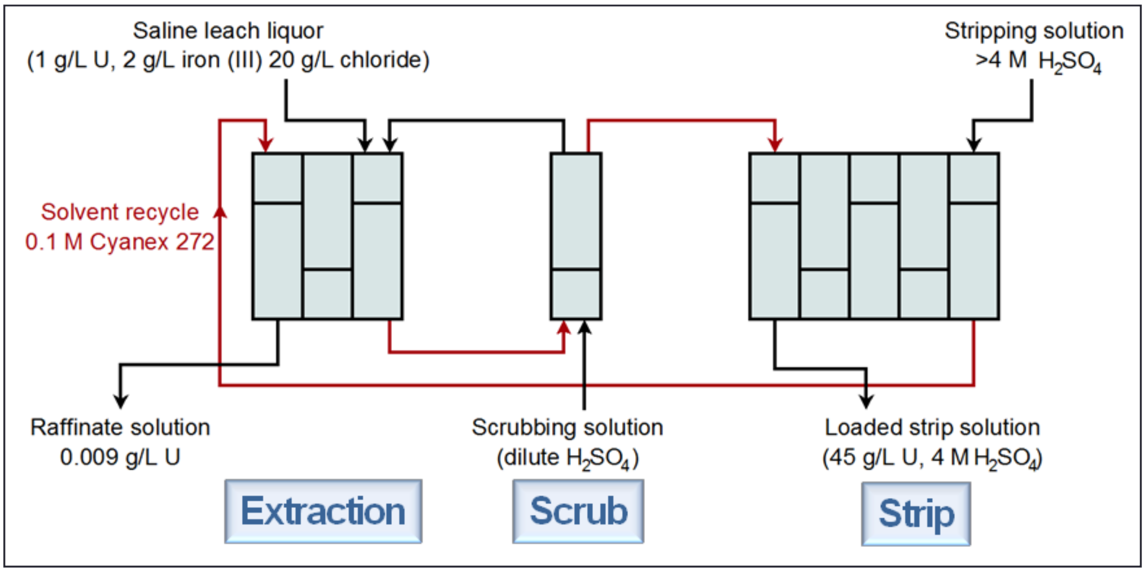


SX SYSTEMS FOR HIGH CHLORIDE SOLUTIONS

- D2EHPA / Amine synergistic mixture: improved performance, but ferric iron content must be low. Stripping with sodium carbonate. Commercially applied at Honeymoon ISL operation, South Australia. (Uranium One/PCMETS paper, ALTA 2014.)
- D2EHPA / Cyphos IL-101 (tetradecyl[trihexyl]phosphonium chloride) mixture: promising testwork results, but vanadium co-extraction is an issue. Stripping with strong sulphuric acid. (CSIRO, paper, ALTA 2014.)
- Trialkylphosphine oxides (TAPO) with or without Amine. Stripping with ammonium sulphate. (Patented by BHP Billiton Olympic Dam, 2014).
- Cyanex 272: promising testwork results. Stripping with strong sulphuric acid. (ANSTO presentation, ALTA 2015).

ANSTO PROPOSED CYANEX 272 FLOWSHEET

(Ref: ANSTO presentation, ALTA 2015)



ANSTO CYANEX 272 SYSTEM ADVANTAGES

Indications from bench scale batch testwork:

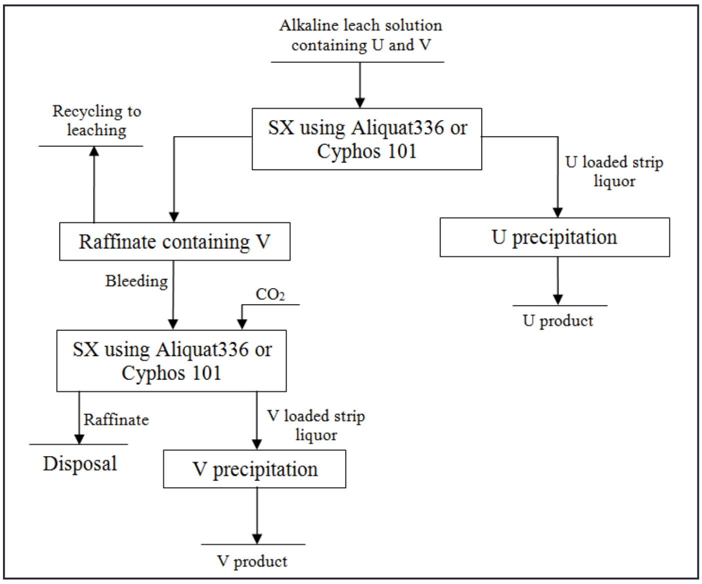
- Applicable to saline liquors 20 g/L Cl.
- High Uranium Loadings.
- Selectivity for uranium over Fe(III).
- Acceptable stripping at 4 M H_2SO_4.
- Avoids the use of ammonia.
- No requirement for phase modifier.
- Seamless integration with current conventional uranium recovery steps.

CSIRO SX SYSTEM FOR ALKALINE LEACH SOLUTIONS

- No current proven SX system for alkaline solutions.
- Cyphos 101, a tri-hexyl(tetradecyl)phosphonium salt and Aliquat 336, a quaternary amine, have been tested by CSIRO, Australia, for the recovery and separation of uranium and vanadium in alkaline leach solutions with promising results.
- Aromatic diluent or aliphatic diluent with isodecanol modifier effectively eliminate third phase formation.
- Cyphos 101 needs chloride to be < 1 and Aliquat 336 < 3.
- Uranium and vanadium can be separated at pH > 11.

PROPOSED CSIRO ALKALINE SX FLOWSHEET

(Ref: CSIRO paper, ALTA 2013)

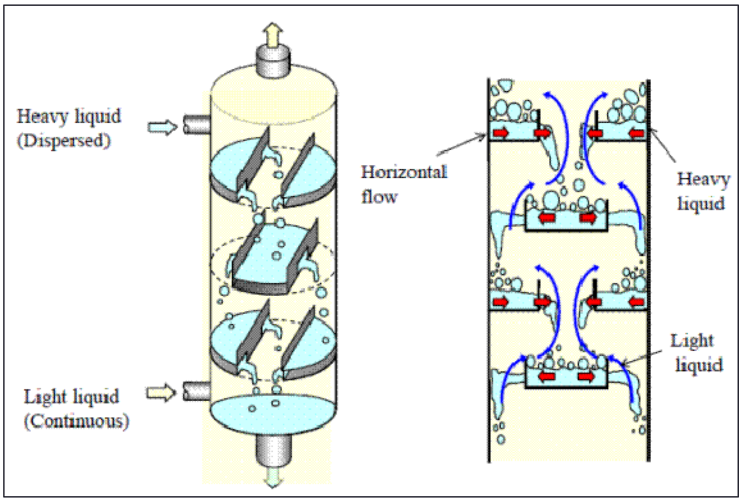


JGC WINTRAY SX COLUMN CONTACTOR

- Developed by JGC (Japan), and commercially applied in the petrochemical industry with 14 units operating in Japan and overseas by 2011, up to 2m diameter.
- Pilot scale test column program for uranium SX has been conducted at MINTEK South Africa. Also tested for cobalt SX.
- The column has multiple trays with two kinds of different shapes placed alternately, which have perpendicular plates (weir plates) with opening windows.
- Claimed advantages include large drop size, high extraction efficiency, and low plugging with crud.

WINTRAY COLUMN CONCEPT

(Ref: JGC paper, ALTA 2012)



The above is for organic continuous operation.
The plates would be inverted for aqueous continuous.

PRODUCT RECOVERY

AREVA FLUID BED PRECIPITATION PROCESS

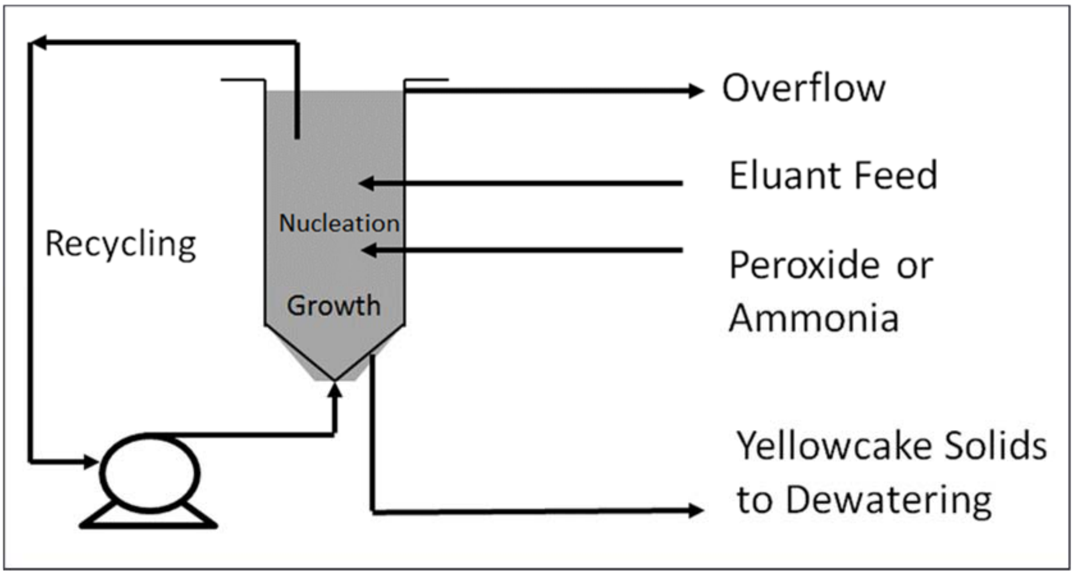
- Patented process developed and commercialized by Areva.
- Available from Adelaide Control Engineering (ACE), South Australia.
- Claimed advantages (by ACE):
  - Lower cost of production and maintenance.
  - Increased recovery of uranium.
  - Increased uranium content of calcined product.
  - Larger particle size.
  - Reduced fines, less dust and lower risks to operators.

AREVA FLUID BED PRECIPITATION PROCESS

- Improved dewatering reduces calcining costs or allows increased throughput.
- Increased calcined product bulk density - lower transport cost.
- Facilitates drying or calcining with horizontal kiln – previously, too much product was lost in off-gas and stuck inside the tube.
- Flexibility for peroxide or ammonia precipitation.
- Modular construction, smaller site footprint.

AREVA FLUID BED FLOWSHEET

(Ref: ACE presentation, ALTA 2013)



CONCLUSIONS

- Process technology for the extraction and recovery of uranium continues to develop driven by cost reduction, available resources, technical challenges and environmental issues.
- Developing areas include preconcentration, solvent extraction/ion exchange and product recovery.
- Some other areas not highlighted in this presentation include in-situ leaching, heap leaching, solid-liquid separation, IX resins and systems, and by-product uranium recovery.
- Process development is likely to accelerate as uranium demand increases to supply the projected expansion of nuclear power generation.

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