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24th Annual Conference Proceedings

Uranium-REE Conference

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PROCEEDINGS OF
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Alan Tayor has over 40 years' experience in the metallurgical, mineral and chemical processing industries in Australasia, New Zealand, North and South America, Africa, Asia and Europe. He has worked in metallurgical consulting, project development, engineering/construction, plant operations, plant start-up and technology development. Projects and studies have involved copper, gold/silver, nickel/cobalt, uranium and base metals.

Since 1985, as an independent metallurgical consultant, Alan has as undertaken feasibility studies, project assessment, project development, supervision of testwork, flowsheet development, basic engineering, supervision of detailed engineering, plant commissioning and peer reviews and audits. Clients have included a variety of major and junior mining, exploration and engineering companies throughout Australia and overseas.

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ALTA 2019 Uranium-REE Proceedings Contents

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Uranium-REE Proceedings

Opening Address

WHAT WILL FUTURE URANIUM MINING PROJECTS LOOK LIKE?

By

Dr Brett Moldovan and Dr Martin Fairclough
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Presented by

Dr Brett Moldovan
Team Leader, Uranium Resources and Production

ABSTRACT

Insights into the uranium mining projects of the future can be gained by a careful statistical analysis of past and present deposits, as well as examination of recent trends for uranium resource evaluation and primary uranium production.

The UDEPO database is an International Atomic Energy Agency collation of historic uranium deposits. It contains geoscientific information on over 3,000 deposits, spanning 15 deposit types and 50 subtypes including maximum known resource size from public sources. Statistical data indicate that historic resources have been dominated by sandstone-hosted uranium deposits in terms of the actual numbers of deposits. In contrast, the highest-grade uranium deposits are dominated by unconformity-related deposits, particularly the unconformity-contact subtype.

Total identified uranium resources are dominated by very low grade unconventional deposits such as phosphates, black shales, and importantly, polymetallic iron oxide breccia complexes such as the Olympic Dam Cu-Au-Ag-U deposit. The latter rely on polymetallic production and in a future where comprehensive extraction driven by sustainability and environmental concerns, these could become more important.

According to the joint OECD-NEA/IAEA Uranium Resources, Production and Demand (Red Book) 2018 publication, sandstone hosted uranium comprises the highest proportion of low cost resources. This share is reflected in nearly 50% of recent world uranium production being related to In Situ Recovery (ISR) of these low cost, low-grade resources. Production of high grade, but higher cost resources is dominated by unconformity-related deposits. Finally, production of very low grade, high cost resources are dominated by Olympic Dam.

Historical statistical deposit-type data and recent production data outlined above leads to the conclusion that the most financially attractive type of uranium deposit for future exploration expenditure will be higher grade sandstone hosted deposits. Structural geology, mineralogy, geochemistry and uranium grades will determine the type of mining and processing application for these deposits. In keeping with recent history, it is expected that the ISR will continue to play a major role in the development of uranium deposits of the future.

Development of high-grade unconformity-related deposits will also continue to focus on innovation and reducing production costs. Development of these deposit types are focusing on investigating new mining and processing options in order to reduce overall life cycle costs. One recent example of innovation through the application of low cost mining methods with high grade deposits is the recent announcement to investigate in-situ recovery well field testing at the Phoenix deposit; an unconformity based uranium hosted deposit.

This presentation will present on the results of the UDEPO and OECD-NEA/IAEA Uranium Resources, Production and Demand publications and provide considerations for future uranium mines based on geology, mineralogy (geochemistry) and hydrometallurgical processing.

Keywords: Uranium Resources, Uranium Production, Uranium Deposits, Uranium Mining, In Situ Recovery, ISR

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Uranium-REE Proceedings

Keynote Address

URANIUM IX – PAST, PRESENT AND FUTURE

By

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ABSTRACT

Ion exchange has played an important role in nuclear power generation. The development of resins in particular was spurred by the challenges posed by the recovery of uranium from leach liquors on the one hand and the purification of water used for reactor cooling on the other.

The application of ion exchange resins for the separation, concentration and purification of uranium leach liquors is the subject of this paper. Major developments of this technology, which has come in waves in response to the fluctuating prices and demand for uranium, are highlighted.

The first wave of uranium mining activity occurred in the nineteen fifties, underpinned by military applications and interest in nuclear power. These plants used strong base polystyrene-divinylbenzene gel resins in fixed bed systems with nitrate based elution.

The uptake and construction of new nuclear power plants in the sixties was slower than projected and a decline in uranium demand ensued. This was reversed by the oil crisis in the seventies which brought about increased uranium production and a series of innovations to the uranium hydrometallurgical flowsheet, including the coupled ion exchange/solvent extraction or Bufflex/Eluex processes, using sulfate elution, and the adoption of fluidized continuous ion exchange to treat unclarified liquors.

Two decades of sustained low uranium prices, reduced demand and draw down of military inventories, resulted in virtually no new uranium developments. Second generation plants, which commenced operation in the eighties treating higher grade ores, tended to use solvent extraction as the preferred separation technology. Ion exchange has maintained its relevance with technologies such as resin-in-pulp and in-situ recovery processes that are applied to lower grade deposits. Ion exchange has been adopted by three of the most recently built tank leaching operations, Langer Heinrich, Kayelekera and Husab, and continues to be used in all operating ISR projects in the USA, Kazakhstan and Australia.

Looking to future innovations, this paper discusses the potential of ion exchange to address particular challenges and niche areas in uranium processing such as:

- The use of resins with functionalities other than conventional strong base for recovery of uranium from saline and phosphoric acid liquors;
- The use of ion exchange to facilitate reagent re-cycle;
- Improvements in elution to target more concentrated eluates; and
- Coupling ion exchange with other technologies.

Keywords: ion exchange, uranium, strong base resins

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Uranium-REE Proceedings

Heap Leaching

THE DEVELOPMENT OF A GEOMETALLURGICAL URANIUM LEACHING MODEL AS A PREDICTIVE TOOL FOR LEACH OPTIMISATION

By

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[2]BHP Planning & Technical Olympic Dam, Australia

Presenter and Corresponding Author

John Lawson

ABSTRACT

The BHP owned uranium/copper deposit at Olympic Dam has complex mineralogy. Although the uranium can be categorised into three main minerals - uraninite, coffinite and brannerite - these definitions each encompass a broad spectrum of compositions and textures. Also, these minerals are found within diverse ore-types with varying gangue mineralogy, each with different degrees of uranium mineral liberation. This diversity means that the optimum leaching conditions can be significantly different for ores from different parts of the deposit. Consequently, the Olympic Dam geometallurgical strategy involves large batch leaching programs on samples which make up the stopes scheduled for production in the near future, allowing optimisation of the leach process in terms of acid addition, oxidant addition and temperature. However, these batch leach programs are slow and costly. To overcome this, a model of the uranium leaching process has been developed which predicts the leach response to changes in pH, ORP and temperature, thus providing the required information in a fast and inexpensive manner. The model does not rely on the measurement of uranium mineral contents by quantitative SEM, but defines four forms of uranium each with different leaching behaviour. These are not specific to any uranium mineral. Their characteristics are derived from nearly two thousand data points from previous laboratory leach programs. The proportions of these forms of uranium in a new ore are determined from the ores measured response during a specially designed standard leach. This approach provides a solution to the problem which arises when a particular uranium mineral exhibits different leaching rates depending on its degree of alteration and liberation. Validation trials have shown that the predictions are sufficiently accurate for the model to be trialled as part of the production planning system at Olympic Dam.

Keywords: Uranium Leaching, Modelling, Olympic Dam, Geometallurgy

CENTRAL JORDAN URANIUM PROJECT: MONITORING THE PROJECT MATURITY VIA THE APPLICATION OF THE UNFC-2009

By

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Presenter and Corresponding Author

Hussein Allaboun

ABSTRACT

The uranium deposits in the Central Jordan Uranium Project (CJUP) are primarily hosted by the Muaqar Chalky Marl (MCM) Formation of upper Maastrichtian age, part of the Upper Cretaceous to lower Tertiary Belqa Group. Uranium exploration and resource estimation were performed over three phases in this project: phase I (2009 – 2014), phase II (2016) and phase III (2018 to current). JORC-2012 standards have been adopted and followed to carry over all exploration activities and resource estimation stages; from Inferred to the measured category.

Metallurgical testwork indicated the amenability of the ore to static leaching using alkaline lixiviants. However other metal extraction routes, including various physical beneficiation processing concepts, were investigated. Initial results, with a fourfold concentration upgrade, were encouraging but a preliminary engineering and economic trade off analysis indicated the whole of ore concept as the preferred option. Therefore, higher level process development and engineering endeavors are currently culminating into the construction of a processing pilot plant based on heap leach technology. The data generated from the pilot plant operation will provide the basis for commercial plant detailed engineering and project feasibility analysis.

This study demonstrates the advantages of using the UNFC-2009 classification system to monitor the project maturity of CJUP over different phases of exploration and technical viability. The project progressed from a “Potentially Commercial Projects/Development on Hold” project in Phase I to a more mature “Potentially Commercial Projects/Development Pending” in Phase II. Phase III is still progressing. The application of UNFC-2009 to the CJUP study in Jordan clearly demonstrates the advantage of tracking the project from a lower maturity level of assessment to a higher level. Therefore, classification and reporting of uranium project results using UNFC-2009 have clear advantages for policy makers in Jordan, as well as for internal company requirements for monitoring the progress of a project over time.

Keywords: Alkaline Uranium Extraction, Heap Leach, CJUP, UNFC, Process Development, Pilot Plant.

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THE RESEARCH OF CLADDING TECHNOLOGY FOR ACIDIC URANIUM TAILINGS AND THE CONTROL OF RADON EXHALATION

By

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Kang Jianqiao

ABSTRACT

Surface heap leaching technology is widely used to extract uranium from hard rock in natural uranium production in China. As the uranium in ore is only extracted in the heap leaching process, the parent radium that generates radon still remains in the tailings. After heap leaching tailings are used for downhole filling, radon diffuses and migrates from tailings cracks and pores to the atmosphere, which will lead to increased radiation level in the workplaces of underground uranium mines and worsen the working environment of uranium miners. It is necessary to study the cladding materials and technologies which can effectively reduce the radon exhalation from uranium tailings.

The influence of five different cladding materials on the radon exhalation of heap leaching uranium tailings was investigated through experimental methods. The above-mentioned materials included high polymer waterproof materials, finishing coat, cold-recycling emulsified asphalt, micro-surfacing emulsified asphalt and acid-resistant cement.

The results showed that the micro-surfacing emulsified asphalt was more promising than other materials, whose economic and reasonable dosage range was among 10% ~ 12.5%. When the monitoring time of radon concentration was 10 hours, compared to the blank experiment without any cladding materials, the concentration of radon decreased by 45% when the dosage of micro-surfacing emulsified asphalt was 12.5%.

To further reduce the radon exhalation, a composite material (MSC) composed by micro-surfacing emulsified asphalt and powdered activated carbon with the proportion of 12.5% and 5% was made and studied.

The results demonstrated that this MSC had a remarkable effect on the reduction of radon exhalation. When the monitoring time of radon concentration was 10 hours, the concentration of radon in the experiment decreased by 71% compared that without any cladding materials.

Keywords: Uranium Tailings, Cladding Technology, Radon Exhalation Control

IAEA supported submission

Uranium-REE Proceedings

REE Projects

THE DEVELOPMENT OF THE DUBBO RARE METAL AND RARE EARTH FLOWSHEET - TOONGI NSW, AUSTRALIA

By

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Presenter and Corresponding Author

Nic Earner

ABSTRACT

The Dubbo Project (DP) is a large in-ground resource of zirconium, hafnium, niobium, (tantalum), yttrium and rare earth elements. Located at Toongi, 25 kilometres south of the large regional centre of Dubbo in central western NSW, the DP is owned by Australian Strategic Materials Limited (ASM), a wholly owned subsidiary of Alkane Resources Ltd.

The Project contains a number of unusual ore minerals hosted within a large alkaline volcanic trachyte extrusive body. There were no known commercial process to recover metals from the deposit and multiple laboratory and mini pilot plant iterations tested various flowsheets. Over the last 10 years, ASM has proved a flowsheet that is specific to the deposit and which produces a number of value added zirconium, hafnium, niobium and yttrium-rare earth products suitable for downstream applications.

The commercial process developed combines whole of ore, sulphuric acid roast, water leaching, and solvent extraction and refining to produce high purity products. While this is an innovative and complex flow sheet, many of the individual components are widely used in the mining industry. In 2008 a large scale demonstration pilot plant (DPP) was designed and constructed at ANSTO (Sydney), which has operated on a campaign basis to optimise the process and provide substantial samples for market evaluation. The DPP has also provided extensive data to inform capital and operating costs for feasibility studies, including recent FEED and Definitive Feasibility Studies.

The markets for the Project's output have continued to expand and evolve, with many new applications being developed for energy production and efficiency, super alloys, technical ceramics and catalysts.

Subject to financing, the Project is construction-ready with the surrounding land acquired and all State and Federal approvals in place.

Keywords: Large Rare Metal and Rare Earth Resource, Sulphuric Acid Roast Leach, Solvent Extraction Separation and Refining, Demonstration Pilot Plant, Definitive Feasibility Study.

THE NOLANS NdPr PROJECT – DEVELOPING A FLOWSHEET WORKING WITH ORE CHARACTERISTICS TO OPTIMSE PROJECT OUTCOMES

By

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Presenter and Corresponding Author

Stewart Watkins

ABSTRACT

Arafura Resources' flagship project and key focus is the Nolans Rare Earth Project, one of the world's largest and most intensively explored rare earth deposits, located in the Northern Territory of Australia, close to the Stuart Highway and about 130 km by road from Alice Springs. The rare earths are associated mainly with apatite (a calcium phosphate mineral), monazite (a rare earth phosphate), and allanite (a calcium and rare earth silicate mineral).

The Project has undergone extensive development over the last 15 years including multiple test work and piloting programs and numerous feasibility studies aimed at developing an efficient flowsheet for the treatment of the Nolans ore to produce rare earth oxide products. Three major flowsheet developments have been undertaken on the road to the definitive feasibility study (DFS) and Project financing.

In the first flowsheet iteration, known as hydrochloric acid pre-leach, the apatite concentrate was pre-leached with hydrochloric acid to dissolve the calcium phosphate prior to sulphation of the rare earth minerals using a sulphuric acid baking process. The "cracked" rare earths were solubilised in water, and impurities (Fe, Al, Th) removed as a solid residue prior to uranium recovery by ion exchange, and precipitation of the rare earths as a mixed carbonate precipitate. The mixed carbonate was dissolved in hydrochloric acid as feed to a solvent extraction rare earth separation process, to produce five 99% purity rare earth oxide products (Cerium oxide, Didymium oxide, a mixed heavy rare earth oxide, Lanthanum oxide and a mixed Samarium, Europium and Gadolinium oxide). The hydrochloric acid used in pre-leach was regenerated from a residual calcium chloride solution formed following phosphate precipitation from the pre-leach liquor to produce a calcium phosphate product.

Evaluation of the hydrochloric acid pre-leach flowsheet showed excellent metallurgical performance but at extremely high capital and operating costs, and therefore an alternative flowsheet was developed. The second flowsheet iteration, known sulphuric acid pre-leach with double sulphate precipitation (SAPL-DSP) carried out a pre-leach of the phosphate concentrate using recycled water leach liquor high in sulphuric acid, to dissolve the phosphate. The resulting gypsum rich pre-leach residue was then cracked with sulphuric acid and fed to water leach with the water leach liquor recycled to pre-leach. The pre-leach liquor, rich in rare earths, was fed to DSP to recover the contained rare earth elements. The resultant rare earth sulphate precipitate, rich in rare earth phosphates, required conversion to a hydroxide prior to production of a cerium product in a selective hydrochloric acid leach which also produced the rare earth chloride feed for separation. Rare earth separation then produced a 99% pure mixed heavy rare earth carbonate, a 99.9% pure NdPr oxide, and a 99% pure lanthanum oxide product using solvent extraction.

Again, the SAPL-DSP flowsheet provided good metallurgical performance but operating costs, particularly reagent consumption, was high and capital costs were also above the level needed to provide satisfactory Project returns.

Working with the orebody characteristics, Arafura has subsequently developed and demonstrated the viability, over the last four years, of a phosphoric acid pre-leach (PAPL) flowsheet which works with the mineralisation to minimise both capital and operating costs and provide significant improvements to Project outcomes.

This paper provides a technical overview of the PAPL process in comparison to previous flowsheets as well as an insight into the significant piloting efforts recently completed which demonstrate the technical viability of the Project. Finally, a snapshot will be provided on the results of the recently completed DFS and the planned Project activities aiming for production from the Nolans Project in the near future.

Keywords: Rare Earths, NdPr, Didymium, Phosphoric Acid, Process Development, Pilot Plant, Project Development, Feasibility Study

Uranium-REE Proceedings

By-Product Uranium

U AND REE RECOVERY FROM PHOSPHATES IN THE PHILIPPINES

By

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ABSTRACT

Phosphate-bearing rocks are an important mineral resource and are utilized as raw material in the production of phosphate-based fertilizer. Phosphate-based fertilizer is the dominant form of fertilizer produced and consumed in the Philippines. The Philippines itself has no domestic phosphate ore deposits, thus, mined phosphate-bearing rock is imported from abroad as raw material for fertilizer production. In addition to being an important phosphate source for fertilizers, phosphate-bearing rock is also known to contain naturally occurring radionuclides and rare earth elements. Chemical analysis of this material has shown that it contains 66–145 μg/g uranium, 1–20 μg/g thorium, 108–1085 μg/g rare earth elements and several other elements. Historical results have shown that during the wet phosphoric acid process for phosphate fertilizer production about 86% of the uranium reports to the phosphoric acid, while the majority of the rare earth elements and other elements report to the by-product waste phosphogypsum. Studies have shown that NPK (Nitrogen-Phosphorous-Potassium) fertilizers may have concentrations of uranium at levels as high as 228 μg/g, considerably greater than the global average concentration of uranium in soil of 0.3 – 11 μg/g. Application of uranium-bearing phosphate fertilizers to soils for agricultural purposes may result in a source term of uranium to the local biota. This is dependent on the bioavailability of the uranium in the fertilizer.

With the primary objective of recovering these elements of interest (U, REEs) to reduce potential environmental and human health risks, the Philippine Nuclear Research Institute (PNRI), in collaboration with the leading phosphate fertilizer producing company in the country, Philippine Phosphate Fertilizer Corporation (PHILPHOS), is developing technology to recover uranium from phosphoric acid (UxP) and is researching innovative approaches to recover rare earth elements from phosphogypsum. In conjunction with the technical cooperation programme of the International Atomic Energy Agency and financial assistance from local funding agencies, the Philippines Council for Industry Energy and Emerging Technology Research and Development and National Research Council of the Philippines, laboratory-scale solvent extraction technology using the D2EHPA-TOPO process was developed to extract and concentrate uranium from phosphoric acid. Batch experiments on the uranium recovery process from pretreatment of raw phosphoric acid to precipitation of uranium yellow cake provided basic understanding of the extraction process and has generated and optimized the operating parameters in each process step. In 2018, PNRI has embarked in the next step of the UxP activity cycle by developing the first scaled-up continuous uranium extraction facility in the country. Along with this, PNRI has realized the great potential for recovery and extraction of rare earths and other critical elements from the accumulated 9 Million tons (Mt) of by-product phosphogypsum at the PHILPHOS site. Further research and exploration activities will be conducted to estimate the quantity and quality of phosphogypsum with high confidence in terms of its rare earth element, as well as, its radionuclide content. This presentation will present on the results achieved to date and discuss on-going collaborative work to ultimately advance the process to full industrial scale.

Keywords: Phosphoric acid, Phosphogypsum, Solvent Extraction, Process Development

URANIUM RECOVERY FROM COPPER CONCENTRATES

By

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Presenter and Corresponding Author

Grenvil Dunn

ABSTRACT

There are numerous Iron Oxide Copper Gold Ore (IOCG) deposits that contain uranium. In some cases, uranium is present in significant concentrations which enables it to be economically recovered as a by-product of copper concentrates. However, uranium can also be present in lesser concentrations such that it is uneconomic to recover but it still may need to be removed as it could pose a health and regulatory issue in copper concentrate transportation and smelting.

Currently, there are several technologies that are either available or in development which address the removal or recovery of uranium from copper concentrates. These technologies minimize the loss of the primary value metals (e.g. copper, gold, silver etc) and assure that the overall environmental footprint is appropriately addressed. In some of these technologies, there is also the added advantage of a copper upgrade in the concentrate.

This paper discusses the hydrometallurgical technologies that have been or are employed for the removal of uranium from copper concentrates and the advantages and disadvantages of each.

Keywords: Uranium Recovery, Copper Concentrate

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Uranium-REE Proceedings

Process Development

PREDICTING THE SPECIATION AND PROPETIES OF RARE EARTH ELEMENT DURING CHEMICAL EXTRACTION FROM MINERAL DEPOSITS

By

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ABSTRACT

This paper outlines the use of a modern electrolyte theory (chemistry model) to predict the chemical extraction of rare earth elements (REE) from mineral deposits. The aim is to aid the engineer in maximizing product yield and to predict secondary products formation resulting from the chemical extraction operation.

The paper includes a brief overview of the model and its departure from strong electrolyte models. It also discusses how experimental data for each of the sixteen REE's differ and it effect on the ability to model these elements over different compositions and ranges. We next present the prediction of REE phase stability and speciation using extractive acids. We show the impact of impurities like high chloride concentration on extraction efficiency.

The last section of the paper contains process simulation results for REE extraction from several ore sources. The simulations include the acid digestion and chemical separation sections, and present effects of different acids and complexing agents on separating these elements from impurities.

Despite the limited validation data for REE, solution/phase predictions of the ore from which the REE's are extracted (e.g., oxides, phosphates, chlorides, silicates, etc.) are well validated. This enables accurate simulation of REE extraction from the rock matrix including the corresponding composition of the leachate and the leached ore (if critical for enhanced extraction).

Keywords: Rare Earth Elements, Extraction, Process simulation, Phosphogypsum digestion, Bastnaesite ore

RARE EARTH RECOVERY AND SEPARATION USING DIGLYCOLAMIDES

By

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Eugen ANDREIADIS

ABSTRACT

Rare earth elements (REE) have become essential for our modern economy, in relation to the development of new energy and communication technologies. Depending on their technical-economic efficiency and environmental footprint, hydrometallurgical processes enabling the recovery of separated elements could be of particular interest.

Typically these processes include a first pre-treatment (crushing, milling and sieving) and an acidic leaching step (with eventual selective precipitation sub-steps), followed by a solvent extraction (SX) step aimed at the separation and purification of REE. Recently, diglycolamides (DGA) appeared as a very interesting group of extractants for the selective recovery of trivalent REE from nitric acid solutions, particularly in the presence of transition metal ions commonly found in various waste products. In this work, the TODGA extractant was successfully used for designing an efficient REE recovery process. The process integrates the mechanical and physico-chemical treatment of waste, followed by a solvent extraction step for the recovery and intra-separation of REE. Based on the experimental batch data, a phenomenological model has been elaborated taking into account the various distribution equilibria. The model has been implemented in our simulation code and used for calculation of various flowsheets, which have been tested at our pilot facility using compact continuous counter-current mixer-settlers. Experimental SX and modeling data allowing the recovery of >99.95% pure Dysprosium solution will be discussed in this paper. Preliminary technical-economic assessment and life-cycle analysis have also been conducted.

Following this first successful demonstration, several novel dissymmetrical DGA have been developed and their solvent extraction behaviour in different acid media has been studied. Indeed, most processes use symmetrical DGA such as TODGA. The present work improves upon the classic design and demonstrates that novel dissymmetrical extractants display a remarkable improvement on REE extraction efficiency compared to reference TODGA in various acid media. Furthermore, the REE separation factors towards major impurities such as Fe^{3+} are substantially enhanced.

The development of novel DGA with increased efficiency paves the way for the recovery and separation of high value REE from different streams. This opens new market opportunities since the effluent treatment has often an important impact either in the CAPEX or the OPEX of a solvent extraction plant. With some DGA extractants adapted to sulfuric acid media, the resulting effluent treatment plant could be cheaper than it would be using nitric acid media. Furthermore, their enhanced performance at low concentration should reduce the price of reagents in the OPEX.

Keywords: Rare earths, Solvent Extraction, Extractants, TODGA

HYDROMETALLURGY PROCESS ON RADIOACTIVE AND RARE EARTH ELEMENTS EXTRACTION FROM MONAZITE IN INDONESIA

By

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ABSTRACT

Monazite, one of the minerals in the tailings from tin mining activities, contains valuable and strategic elements, such as Rare Earth Elements (REEs), uranium, and thorium. BATAN has developed extraction methods for those elements. The process stages consist of milling, alkaline leaching, selective dissolution, and multistage precipitation. As required for the alkaline leaching stage, milling is aimed to obtain monazite in the fine particle size of -325 mesh. The alkaline leaching uses sodium hydroxide to dissolve phosphate, and convert monazite from phosphate compounds into hydroxides. Leaching residue is reacted with hydrochloric acid at a certain pH condition and temperature to dissolve REEs selectively. The solution obtained from the selective dissolution stage is reacted with ammonium hydroxide to precipitate REEs and U/Th based on the difference of the precipitation pH.

The products obtained are sodium tri-phosphate, REEs hydroxides, and uranium-thorium hydroxides concentrate. The process technology has already been brought to pilot scale with 50 kg monazite per batch of capacity in 2016. In 2017, the pilot plant was operated on as many as 14 batches with products averaging 15 kg of REEs hydroxide per batch, with uranium and thorium contents 8 ppm and 484 ppm, respectively. In 2018, the pilot plant operated on as many as 9 batches with product quality better than 2017, namely a thorium content in REEs hydroxide of 16.5 ppm and no uranium content. Besides REEs hydroxide, the pilot plant also produces uranium-thorium hydroxides concentrate which is ready for a purification process using solvent extraction.

Keywords: monazite, uranium, thorium, rare earth, extraction

FLUID BED PRECIPITATION WITH PARTICULAR REFERENCE TO URANIUM OXIDE CONCENTRATES

By

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ABSTRACT

The term *"Crystal Quality"* is not well understood by design and production teams yet it directly influences all downstream processes and has a significant influence on the final product. This is particularly true in the Uranium Industry where we generally use the term "*Precip Quality*" to describe how well the crystals filter and dry, with consequent impact on product recycle, product purity, and energy consumption.

The flow on effects of Precip Quality are numerous, not only reducing processing costs but also impacting transport and storage costs, as well as product purity penalty costs. The other very important outcome from improved Precip Quality is a cleaner working environment and the subsequent reduced OH&S risks associated with uranium production facilities.

This presentation looks at The Fluid Bed Precipitation process and compares both the cost and OH&S benefits of this technology with traditional precipitation processes in use in current operating plants.

DECOMPOSITION OF XENOTIME CONCENTRATE USING ALKALINE FUSION METHOD

By

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ABSTRACT

In this study, Malaysian xenotime concentrate was decomposed using sodium hydroxide (NaOH) via alkaline fusion method for the recovery of rare earth elements (REEs), thorium (Th), uranium (U) and phosphates (PO_4). Overall process consisting of digestion via alkaline fusion followed by washing and filtration was performed to remove the soluble compound with the optimum experimental conditions including alkali to concentrates (A/C) weight ratio (1:2), fusion time (3h) and heating temperature (350°C). The extraction of rare earth elements and thorium was conducted by hydrochloric acid leaching, filtration and selective precipitation using 10% oxalic acid at pH-0.2 while the extraction of uranium was performed by other selective precipitation using 6% ammonium hydroxide solution at pH-8. The phases and elemental compositions of the studied samples were analyzed using X-ray Dispersive (XRD) and Energy Dispersive X-ray Fluorescence (ED-XRF). It was found that the alkaline fusion method allowed for the production of radioactive-free trisodium phosphate (TSP) from xenotime. The final results of the study showed that about 90% of REEs and more than 95% of Th was able to precipitate as rare earths oxalate. Uranium precipitation remained nearly complete (>95%) under rare earths hydroxide. The results indicated that the selective precipitations conducted using oxalic acid and ammonium hydroxide was able to separate Th from U in two separate precipitates. This paper will be highlighting the findings from a research project that is partly supported by IAEA Technical Cooperation Project MAL2007 and Coordinated Research Project T11006.

Keywords: Xenotime, Alkaline Fusion, Radioactive-Free Trisodium Phosphate, Selective Precipitation

Uranium-REE Proceedings

Developments in IX Forum

DEVELOPMENT OF AXIONIT SELECTIVE ION EXCHANGE RESINS FOR RECOVERY OF RARE-EARTH ELEMENTS AND ACTINIDES

By

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ABSTRACT

In the recovery and separation of various elements, including REE and actinides, sorption technologies are widely used. Thus, for the recovery and refining of Pu(IV), vinylpyridine anion exchanger resins are most often used. In Russia vinylpyridine anion exchange resin VP-1Ap is used to recovery uranium and plutonium. This resin production has been stopped for a number of reasons. To meet the needs of the Russian nuclear industry, Axion has developed a method for the synthesis of the vinyl pyridine anion exchange resin AXIONIT VPA. Studies carried out at the Institute of Physical Chemistry and Electrochemistry of the Russian academy of sciences (IPCE RAS) showed that the physicochemical characteristics of this resin is an analog of VP-1Ap. Due to its sorption characteristics with respect to thorium and plutonium, as well as kinetic parameters, the AXIONIT VPA resin is superior to VP-1Ap. In 2016-2018, Axion produced and delivered a 200kg experimental batch of AXIONIT VPA to one of the enterprises of the nuclear industry in Russia.

Sorbents based on extractant N,N,N′,N′-Tetraoctyl Diglycolamide (TODGA) are widely used for the recovery of ions of radioactive REE and actinides from solutions. The sorbent is produced by impregnating the TODGA on a porous polymeric carrier. AXION has developed and industrialized the producion of a TODGA-containing sorbent produced by copolymerization of styrene, divinylbenzene and TODGA (AXIONIT MND) with an extractant content of up to 40% by weight. AXIONIT MND shows a high sorption capacity (0.3-0.4 mmol / g) for Eu^{3+}, Th^{4+} and UO_2^{2+} ions upon sorption from 1-6 mol/l nitric acid solution. The stripping of the absorbed ions is able to carried out with a 0.01 M solution of HNO_3. AXIONIT MND has better sorption and kinetic characteristics as compared to sorbents synthesized by impregnation of the finished polymer matrix.

This paper outlines the successful development and industrialization of selective ion exchange resins for effective recovery Pu(IV), most profitable middle and heavy group of REE from nitric-phosphate liquors of fertilizer production, uranium from underground leaching solution.

Keywords: selective ion exchange resins, REE recovery, actinides, Uranium recovery, vinylpyridine anion exchange resins, TODGA resin

POSITIONING OF IX IN URANIUM PROCESSING

By

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ABSTRACT

Conventional uranium processing flowsheets generally constitute comminution, acid leaching, solid/liquid separation, purification via solvent extraction and/or ion exchange with final product recovery by precipitation. Purification of the leach liquor can be achieved either by using one or a combinations of Ion Exchange (IX), solvent extraction (SX) and precipitation. IX has been embraced by many of the largest global uranium producers such as Husab in Namibia, Ranger in Australia, and Priargunski / Krasnokamensk in Russia (Kim, 2018).

In this presentation an overview of ion exchange technologies for uranium processing is given. Multiple stakeholders include resin manufacturers, suppliers and technology owners who have contributed to this technical evaluation.

In certain instances, IX offers benefits over SX and is continuously being optimised to meet specific requirements of operations. The advantages of the ion exchange processes include high selectivity for target metals, high separation capabilities, high selectivity for target metals, ability to be used for purification of both clarified and unclarified solution and flexible processing regimes (Zontov, 2006).

IX circuits consist of four process namely adsorption, washing of loaded resin, elution and washing of eluted resin. Various IX modes are available such as fixed-bed, moving beds, fluidised beds and stirred reactors. Selection of the optimal mode and resin will depend on the characteristics of the feed stream (composition and solids content) and desired process application. Fixed-bed modes require clarified solutions and is the simplest to operate in lead-lag-lag mode with relatedly low resin loss. Moving and fluidized bed can tolerate presence of some solids, thereby minimising clarification requirements. Stirred reactors are applicable for Resin-in-Pulp (RIP) applications and are generally used for difficult to filter feeds. A major advantage of RIP is that value loss via precipitation can be recovered.

Resins can be classified into two categories that is macroporous and microporous (gel-type) resins. Macroporous resins provide larger surface area but are prone to breakage whereas gel resins are stronger due to their small pores. Strong Base Anion (SBA) are the most commonly used resins for uranium recovery due to their high loading capacity. The mode of operation often dictates which resin type should be used.

A large variety of resins and IX technologies (such as fixed-bed, fluidized bed or RIP) are commercially available for different applications. In order to identify the optimal resin and IX technology to be applied it is critical that systematic testing be conducted.

Keywords: uranium, ion exchange, fixed-bed, fluidized bed, RIP

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Uranium-REE Proceedings

Included in Proceedings but not Presented

PRODUCTION OF UO_2 POWDER THROUGH YELLOW CAKE CONVERSION PROCESS USING PILOT CONVERTION PLAN FACILITIES IN CENTER FOR NUCLEAR FUEL TECHNOLOGY – BATAN

By

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ABSTRACT

The Pilot Conversion Plant (PCP) is a facility for processing yellow cake into nuclear grade uranium oxide (UO_2) powder. The PCP facility is part of the Experimental Fuel Element Installation (EFEI) located at the Nuclear Fuel Technology Center, BATAN Indonesia. The PCP facility is designed for the production of nuclear grade uranium dioxide (UO_2) powder with a capacity of 100 kg UO_2 per day, with a feed process of around 130 kg of yellow cake powder. The conversion process consists of the process of crushing and sieving YC powder, dissolving the YC into a solution of uranyl nitrate (UN), purifying the UN solution, concentrating the UN solution, the process of deposition of UN into ammonium diuranate (ADU), the process of separating and drying ADU powder, the calcination process of ADU into U_3O_8, the U_3O_8 reduction process into UO_2 powder and the passivation process of UO_2 with nitrogen gas (N_2). The PCP facility is equipped with a main control room so that all processes can be monitored and controlled from the control room. The PCP facility has been revitalized in 2010 and commissioned successfully in 2014. Currently, the PCP has been operating and can produce high purity uranium dioxide powder that meets nuclear degree requirements and used as fuel for a Pressure Heavy Water Reactor (PHWR) power reactor type. Having succeeded in producing nuclear-grade UO_2 powder, the technology of the yellow cake conversion process into UO_2 powder in the PCP has been understood, so that it can provide uranium powder requirements in the development of nuclear fuel technology in Indonesia.

Keywords: Pilot conversion plant, Revitalization, Yellowcake, Uranium dioxide powder

Included in proceedings but not presented

ALLUVIAL TIN MINING AND PROCESSING AT HEINDA MINE: A CHALLENGE FOR ENHANCING RECOVERY ALONG WITH BY-PRODUCT OF U-TH-REE IN MONAZITE

By

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ABSTRACT

The Heinda mine is the biggest alluvial tin mine in Myanmar, located at 50 km east of Dawei, Tanintharyi. This mine is a quite well-known tin mine with a long history of exploration and mining since colonial time. Heinda mine was undertaken by several operators and most recently by Myanmar Pongpipat Co., Ltd (MPC), a Thailand Company. The last a couple years, due to uncertainty of the Myanmar government's policy as well as environment constraints and poor infrastructures, the production of the mine was in the range of only 100-300 tons/year.

The Heinda concession covers an area of 8.23 sq.km. with an active mining area of 3 sq.km. approximately. The mine is characterized by hilly terrain with the highest peak at Hpolontaung. The mine is situated in an area with an 8 months annual rainy season.

Geologically, it consists of mainly of alluvial tin deposits with some intercalations of eluvial mineralization, indicated by a significant proportion of gravels in the formations. Several episodes of deposition are separated into different distinct layers, namely overburden, A1, A2, B1, and B2 in descending order. In-situ tin resource is estimated at more than 50,000 tons at 0.3 kg/m^3 cutoff grade. However, a mineable reserve has not yet been completely determined.

Mining method is by regular open-cut style. Excavation and haulage are undertaken by a simple fleet of backhoes and trucks. Run-of-mine (ROM) ore are transported to on-site processing plants. Overburden and oversized waste from processing plants are conveyed to dumping area.

Processing steps to produce tin concentrate can be divided into 2 operations, namely the crude (primary) concentration operation and the tin shed operation. The primary concentration operation commences with dumping ROM material into the hopper, where it is loosened and washed by high pressure water jet from 2 nozzles (so-called the monitors). A 4-inch bar grizzly is used to remove oversized stones and two trommels (2.5 and ¾ inches) are used to further remove oversized gravels. Then the material is sent to a series of palongs (sluicing boxes). Concentrates from riffles of palongs are passed to primary and secondary jigs and finally to a series of shaking tables. At this point the concentrate is around 30-40%Sn. In the tin shed operation, crude concentrates from the previous operation are treated by simple but laborious processes, performed manually. A "Willoughby Washer" is used as the hydraulic classifier, in conjunction with a short sluice known as the "Lanchute". After that the concentrates are passed through a drying process and finally with magnetic separation. The product is a marketable grade at more than 72%Sn. Currently the efficiency and recovery ratio are uncertain but are unlikely to be high.

Monazite is one of major by-products of the mine. However, the mine has not yet established the exact strategy for the monazite. They are currently secured and stored on site in a secure place. From analysis of a few samples, the monazite contains some REE (mainly Ce) but the contents of Th and U are quite low. low and intermittent flow rates for 6 months are required in order to obtain sufficient data for further process commercialization.

Keywords: Tin, Uranium, Thorium, Rare Earth Element, Myanmar

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Included in proceedings but not presented

A SELECTIVE REMOVAL OF THORIUM BY ION IMPRINTED POLY(BIS[2-METHACRYLOYLOXY)ETHYL]PHOSPHATE)-GRAFTED NON-WOVEN FABRICS

By

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ABSTRACT

This paper is focused on the preparation of a selective adsorbent towards thorium by associating radiation grafting and crosslinking processes for the sustainability ion imprint polymerization technique. PE/PP nonwoven fabrics (NWF) were grafted with (bis [2-(methacryloyloxy)ethyl] phosphate) (P2M) via a radiation induced grafting technique which subsequently followed mutual radiation crosslinking with divinylbenzene (DVB). P2M was used as a functional monomer which is responsible for the adsorption of thorium. The P2M-grafted NWF consequently cross-linked with divinylbenzene (DVB) for template formation using electron beam radiation. Prior to crosslinking with DVB, complexation of P2M and thorium was carried out onto ion imprinted polymer (IIP). On the other hand, complexation for non-imprinted polymer (NIP) was carried out in the same condition with only P2M in the absence of thorium. The chemical and physical properties of the adsorbent were intact as single step grafting and crosslink using radiation was capable to produce IIP with high selectivity. The NWF, P2M-grafted NWF, IIP and NIP were characterized with Scanning Electron Microscopy- Energy Dispersive X-ray (SEM-EDX), Fourier Transformed Infrared Spectroscopy (ATR-FTIR), Thermogravimetric Analyzer (TGA), and water uptake capacity. The binding performances of both IIP samples were assessed at different grafting extent and crosslinking percentage via X-ray fluorescence (XRF). Finally, the selectivity performance of both IIP and NIP was tested using mixed ions system (binary elements) in batch mode.

Keywords: Pre-radiation grafting; crosslinking; ion imprinted polymer; non-ion imprinted polymer.

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URANIUM MINE DEVELOPMENT IN MONGOLIA

By

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ABSTRACT

Most of the known uranium deposits in Mongolia are related to volcano-tectonic structure of Late Mesozoic and permeable sandstone aquifers of terrigenous sedimentary rocks in Late Mesozoic-Cenozoic basin. A young surficial uranium deposit was recently discovered in Quaternary alluvial sediments.

Uranium deposits were classified according to the IAEA classification scheme. Besides supergene and hydrothermal uranium discoveries, uranium mineralization is also found in Lower Cretaceous lignite seams, in the Mesozoic alkaline intrusive related REE, Th-, U and in metasomatic rocks, migmatites, pegmatites localized in Precambrian metamorphic rocks.

Currently, no uranium is being produced in Mongolia though the pilot testing has been done. Pilot testing was carried out for the Khairhan and Kharaat deposits in Mongolia and these have been shown to be amenable to acid leach (sulphuric acid) with the addition of an oxidizing agent. These tests confirmed that hydraulic control can be maintained and that the uranium solubilization and mobilization can be controlled. The results of the test were encouraging, with the well production rate, uranium concentration in produced solutions, chemical usage, and estimated uranium recovery all within ranges expected for normal commercial operations.

However, a number of deposits are in the stage of mine development. The Government of Mongolia has approved the Agreement for mine development of the Zuuvch ovoo and Dulaan uul deposits. Pilot testing on these deposits are underway and uranium will be soon be extracted by in-situ leaching.

Keywords: Uranium deposits and in situ leaching.