White Paper:

Thermal Process Technology for Nuclear Applications-20379

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Abstract

ANSTO's Synroc technology has been developed to provide a safe, secure matrix for the immobilization and final disposal of radioactive wasted. Synroc technology will be used to manage radioactive wastes from the production of the radioisotope Molybdenum-99 (Mo-99). This paper shall outline various stages of the process development with specific reference to the thermal treatment technology of calcination. Calcination is a key step in the Synroc process [1-2]. The rotary thermal processing system includes: an advanced heating element design for increased robustness and ease of remote operation and maintenance, an enhanced modular design of components for ease of remote maintenance in a hot cell and in compliance with hot cell radioactive environment requirements for safety, reliability and maintainability.

In addition to thermal treatment of waste from nuclear medicine production, this technology provides solutions for a variety of nuclear materials processing applications including sintering UO_2 pellets for reactor fuel rods, oxidation of UO_2 pellets, swarf, and powder to U_3O_8, de-nitration of Uranyl nitrate and hydro-fluorination of UO_2 pellets. The paper will also discuss thermal processing solutions for a range of nuclear applications.

Introduction

The management of waste from the production of Molybdenum-99 nuclear medicine is a key global challenge for both regulators and producers. ANSTO's strategy is to convert all intermediate level liquid waste with alkaline chemistry from its isotope production into durable solid wasteform that meets the regulatory requirements for storage and disposal. An integral part of ANSTO's plan is to deploy technologies that maximize waste loading within a wasteform that is durable for either near surface repository or deep geological storage and disposal.

ANSTO has developed a modular process that integrates several technologies that have been proven at and industrially relevant scale [3]. Furthermore, refinement to the engineering design has been made to ensure the plant is reliable and maintainable for processing nuclear materials. Thermal process technology utilizing a rotary tube furnace is not only integral to both phase and particle formation, but also impacts on downstream Hot Isostatic Pressing (HIP) processability and ultimately the durability of the final waste product. Mixing both liquid waste and wasteform additive within the process results in the formation of a highly-homogeneous free-flowing powder (containing ~20wt.% water) that is fed to the calciner. The residual water within the powder is removed during the calcination step with some phase formation and densification also occurring.

Figure 1 below illustrates the process flowsheet for converting liquid waste into a solid durable wasteform. The first step is powder processing with mixes intermediate level waste with an additive tailored to the composition of the waste. This liquid mixture is converted into a granulated powder via a thin-film evaporator which cascades the powder into a hopper for thermal processing. The powder loaded with the radioactive waste undergoes a calcination step within the rotary tube furnace remotely configuring to contain radioactive powder. Calcined powder travels freely to a metering column where the material is dispensed reproducibly into stainless steel canister for HIP. Prior to the HIP process, the canister is evacuated and sealed. The next step in creating a durable wasteform is HIPing which occurs when heat and pressure are applied simultaneously to convert the powder into a dense inorganic compact. This step reduces the final volume of the waste package.

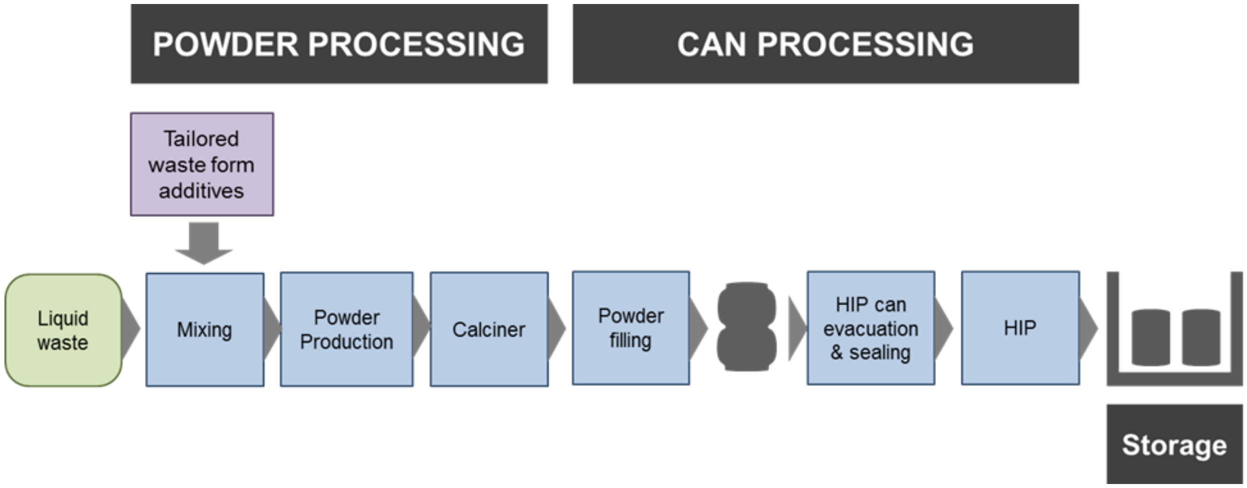

Figure 1: The Synroc Process flowsheet for intermediate liquid level waste treatment

Discussion

Following a global tender process by ANSTO, Harper International was commissioned to design, construct, and validate performance through factory acceptance testing of this key powder processing technology depicted in Figure 1. Two rotary calciners were constructed: One for the Synroc Waste Treatment Plant (SWTP) and the second for the Engineering Demonstrator at the ANSTO facility. These rotary calciners had many requirements based on the hot cell environment. A collaborative approach was adopted to review the design and development of critical features of the furnace. The success of this project was due in part to the joint cooperative effort between the teams.

The intended operation of the rotary calciner within a shielded hot cell enclosure resulted in many of the unique system requirements. High system integrity, specific requirements of materials and their construction, and remote serviceability requirements produced a complex system design challenge. The system required remote operation, service, disassembly and reassembly through access ports through a shield wall on one side of the rotary calciner system. The speed of remote disassembly and reassembly was important in limiting personal time within the service area and any potential down time of the plant. This along with the ability to substitute parts was considered essential for quick turnaround.

In addition to the specific requirements for remote serviceability, a project specific quality plan was developed consistent with a Nuclear Quality Assurance-1 (NQA-1) standard including documentary evidence. This plan was highly structured, explicit, complete and rigorously followed. Major elements of the plan included: Inspection and Test Plans (ITPs), certified materials, certified manufacturing processes such as welding, 100% dimensional inspections, certified third party NDE inspection, certified performance testing, certified COTS materials, and counterfeit inspections. All materials were handled systematically being well identified, dispositioned, and segregated with their status and availability to manufacturing clearly defined. The results of strict adherence to the quality plan enabled tight controls of the process and verified system compliance with the requirements.

Requirements for the Rotary Calciner System

The scope of the project was to design and construct rotary calciners fully compatible for the nuclear hot cell environment. This rotary calciner is integrated within the powder production system. Conceptualizing, designing, and proving a reliable system for incorporation within a hot cell was a major challenge. There were numerous space, accessibility and materials of construction limitations placed on the design. For operational and maintenance accessed gloved ports through a shield wall on one side was a key requirement of the design.

Rotary kilns are used for processing many types of free-flowing powder, granular, materials. They layout of a typical rotary system is shown in Figure 2. The system has a feeder at the front end to convey the feed material into the rotary tube. The alloy tube has an inclination typically from 0.5 to 5 degrees. This tube angle along with the tube rotation conveys the material along the length of the tube and enables control over the residence time. This provides the mechanism to deliver the material into and out of the heating section. At the tube exit the powder material enters the discharge hood where it drops down a chute to the product collection equipment. For the rotary calciner system was designed with atmosphere seals on the entrance and exit of the rotary tube to separate the room air from the process gas within the rotary system. The process gas was fed in the exit chamber and flowed through the process tube in a counter-current direction to the entrance chamber. The feeder as well as the discharge hood were designed with seals to prevent egress of kiln atmosphere or dust from exiting the system.

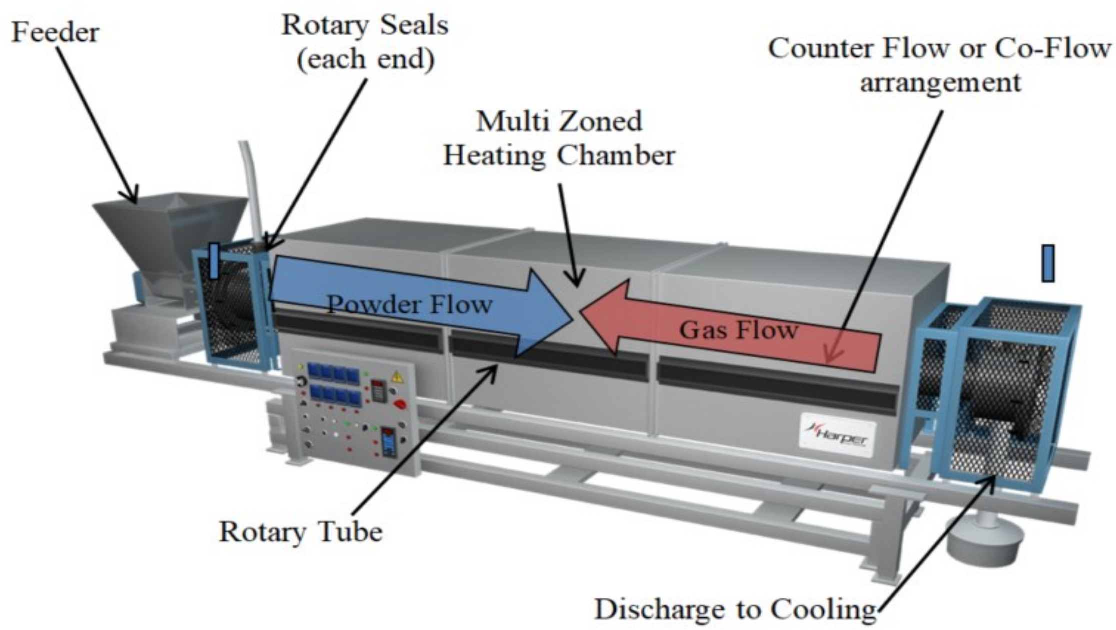

Figure 2. Typical Rotary System Major Elements

For the SWTP implementation of the rotary calciner the process is contained within a shielded hot-cell with walls of 800mm concrete to protect against gamma radiation emission from the decay of fission products. The Hot-cell in turn houses several internal enclosures in which one of them contains the calciner. ANSTO has designed a tall form powder production system where liquid waste and additive entering the enclosure cascades and converts to a free-flowing powder using gravity to feed the entry hopper into the rotary calciner. Prior to any scheduled maintenance, feedstock materials containing radioactivity will be run out minimizing the radiological inventory before servicing can take place.

Based on the restricted access of the hot cell enjoinment, the rotary calciner required remote serviceability with limited access through the shield wall. To accomplish this, the rotary system subcomponents were considered for remote removal and transport to a separate part of the facility for maintenance. The main subcomponents were the Screw Feeder, Entrance Hood and Seal, Alloy Process Tube, Entrance Trunnion and Dive Motor, Heating Elements, Exit Trunnion, and Exit Hood. Each of these subsystems were designed to be remotely removed within the Hot Cell and moved to a location where service could be performed. Figure 3 presents the major subcomponents for remote removal and replacement. These subsystems were also considered critical spare parts so substitutions of the parts could provide a means for quick service.

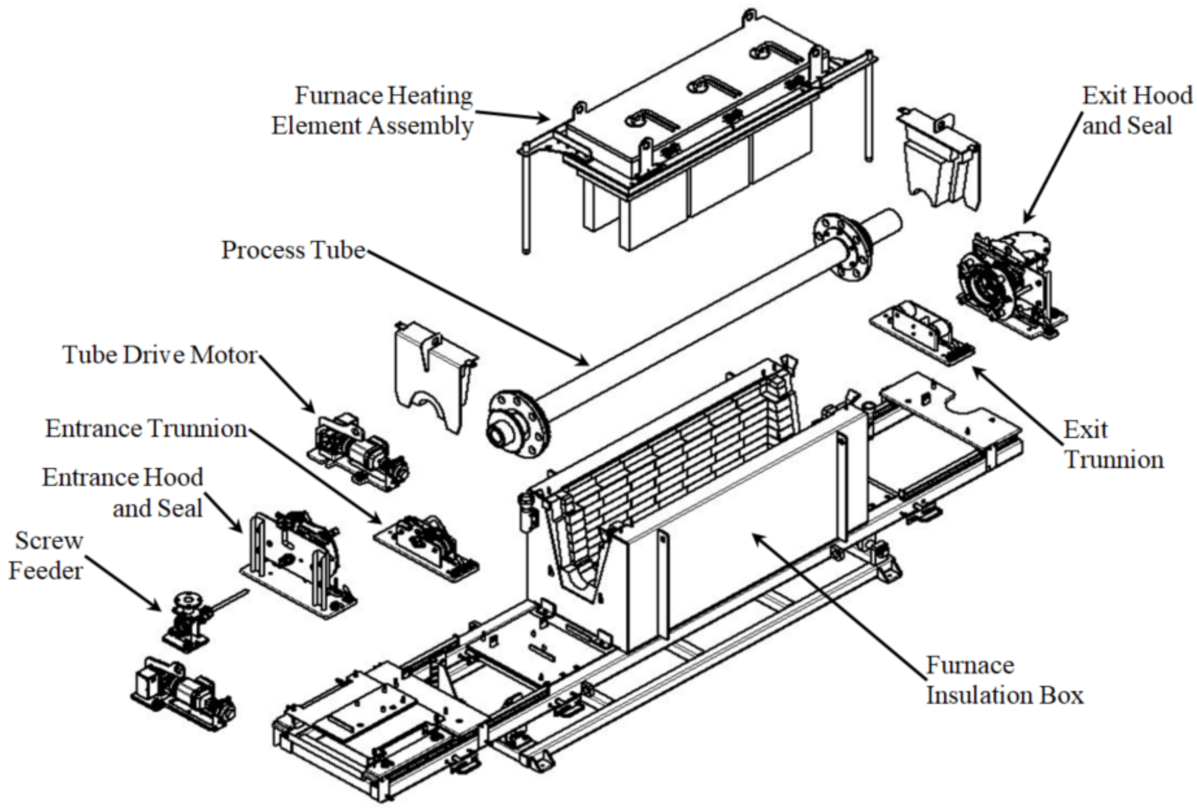

Figure 3. Rotary Calciner Remote Disassembly

Project Delivery Strategy

In order to insure compliance with the written specification as well as the overall design intent, a stepwise approach was adopted. During the engineering phase each subsystem was analyzed for compliance with the materials of construction, plan for remote disassembly, and anticipated subcomponent testing and evaluation.

A 'Quality' Foundation to Ensure a Successful Project

There were very exacting requirements as to how the system will perform and how the project will be executed due to its complexity. At the time, this was the most rigorous project Harper had ever undertaken; therefore a project specific quality plan was developed with the guidance and collaboration of ANSTO. A key element to that end were developing subassembly level inspection and test plans and then developing internal and vendor supported processes to support them will in advance of designs being release to procurement and manufacturing.

Individualized ITP's were created and adhered to, for each major sub-assembly. For example, a structural weldment would contain these main elements: fully detailed drawings with all weld and NDE call outs and including a weld map, certified weld procedures, welders, and inspectors, material certificates and dimensional inspection reports for manufactured components. For critical purchased components the ITPs would include manufacturer's certificate of conformance to specifications as well as test performance results or calibration certificates as applicable. In other cases, such as gearbox, precise scope splits and related specifications were defined, executed and verified prior to product release to the assembly step. Finally, system level function testing as the general assembly level was performed as part of that ITP and client Factory Acceptance Testing (FAT) to ultimately verify performance to requirements and gain shipping approval. As a final step, an extensive audit of all documentation was performed to ensure this discipline was universally performed throughout and recorded.

Advanced Rotary Features

A few examples of some of the challenges and solutions to the rotary calciner for hot cell environments are discussed below. This is not a full list of the advanced features, but rather a few highlights.

Advanced Heating Element Design

The heating element design had some special requirements for the hot cell environment. The heating system required redundant and rugged heating elements capable of remote removal, and reassembly. During the design and build of the advanced heating element, attention to each of the unique requirements was addressed, and refined. The advanced heating element was designed with a remote stand for placement when removed from the rotary kiln. Locating pins are used to position the heating element into the stand and rotary kiln. The terminal connections were positioned for access from the operator access side though glove ports. The element design included a redundant feature so a single element failure would not prevent the system from operating. Robust design for element manufacture, detailed specifications, and verified repeatability ensured a predictable outcome during assembly. This advanced heating element design was successfully tested for east of remote operation and maintenance at the factory prior to shipment to the process plant facility.

Rotary Tube Drive System

The rotary tube drive system was required to provide a range of rotation speed to the rotary furnace, be remotely removable for service and adherence to material of construction limitations. For development of this system a design and refine approach was adopted. Design reviews implemented with 3D modeling for evaluation of accessibility were reviewed. Vendor feedback on the specific components and subassemblies resulted in modifications and updates to the system for improved functionality. The collaboration between Harper and ANSTO assured compatibility with the hot cell lifting system and the shield wall which was being developed in parallel with the rotary calciner.

Most subcomponents were designed to be located on pins and locked in place with a custom designed hand locking tool accessible from outside the shield wall access. In the case of the rotary tube drive, additional steps were required for engagement to the drive coupling on the entrance trunnion subassembly. The entrance trunnion system engaged a gear on the rotary tube. Proper alignment of the coupling and gear system is critical for proper functioning of the rotary drive system. For assembly of the system, the entrance trunnion system is first positioned onto the base beam. The crane lift support brackets were designed at the center of gravity, and strategically placed movement assist through the shield wall access ports. This entrance trunnion is first positioned with guiding pins, and then locked into place with the custom designed locking pins. The drive is the next subcomponent for assembly. The drive is placed using the lift support brackets designed at the center of gravity. The placement was on a slot which allowed the drive to slide forward to engage the coupling on the entrance trunnion subassembly. Once the drive system was in the correct position the locking pins were engaged. The allow tube assembly would then be placed on the trunnion system engaging the gearing.

From conceptual design to detailed design, a series of design reviews were completed along with detailed evaluation of the accessibility and ergonomics of the positioning hardware. As the detailed design progressed, 3D modeling tools were utilized to visualize the remote disassembly/assembly. Selectively designing and manufacturing precision custom alignment and locking features, and their subsequent verification, enabled a simple yet reliable multi-subassembly remote construction. Subassemblies were further demonstrated to be interchangeable between the two rotary calciners, developing confidence in future spare part purchases being assembled in this environment.

The gearbox required detailed evaluation of the materials of construction to ensure gamma radiation compatible materials of construction. The gearbox required a procedure to eliminate the non-compliant materials (grease in particular). An ITP was created for this activity to verify all non-gamma compliant materials were removed, Cleaned, and reassembled. The system was then greased with special gamma radiation resistant grease. After a thorough process of vetting capabilities and then matching those to project requirements, precise scope splits and related specifications were applied, executed and verified prior to product release to the next vendor.

An evaluation was completed for each subassembly required for remote assembly and disassembly. From that, uniquely specific ITPs were developed.

Factory System Testing

After the rotary calciner construction was complete, factory acceptance testing (FAT) was undertaken. To facilitate the unique aspects of the remote disassembly and reassembly required, a mock shield wall (Figure 5) was built with the opening planned in the SWTP. This mock shield wall was used during testing of all remote operations. Complete disassembly and reassembly was performed during the factory acceptance testing prior to shipment. Fine tuning of the features and procedure was accomplished. Figure 6 presents the assembly of the heating element. Notice the access locations are very close to the terminal connections.

Simulated assembly, operation, and maintenance were successfully demonstrated for both furnaces during the factory acceptance testing. The furnaces were completely assembled and then disassembled in well under the target time during this simulation prior to shipping. There was a less than 10% variance in timing between the two furnaces. Confidence and insights were gained with the furnace as well as the effectiveness of the mock shield wall access areas.

Figure 5. Mock Shield Wall for Rotary Calciner Testing


Figure 6. Assembly of the heating element into the rotary kiln

Testing of Rotary Calciner at the Engineering Demonstrator Facility

In order to increase the technical maturity of the Synroc technology, a second custom designed rotary calciner with the equivalent modular design was installed into its inactive engineering demonstrator to develop, test and validate the operational process parameters for powder production (Figure 7) [4] . The rotary calciner has been successfully commissioned into the plant, producing powder that meets the requirements for downstream processing. Figure 8 shows simulant of powder flowing within the rotary tube. Feed rates of 3.5kg/hr have been achieved which are within the technical specification for processing. A second unit with equivalent design and construction shall be commissioned within the final waste treatment plant after completion of the building.

Figure 7. Harper Rotary Calciner within the ANSTO Synroc Demonstration Plant

Figure 8. Calcined powder with waste stimulant from the unit integrated within Synroc's inactive engineering demonstrator

Calciner installation, integration and commissioning into final plant

Construction of the final waste treatment plant is advancing with handover of the building anticipated in the 2nd half of 2020. Plant layout and equipment configuration for the powder production step, which includes the second rotary calciner, has been designed and configured within the shielded enclosure based on the inactive engineering demonstrator. After building handover, fit out of the plant and equipment for the waste treatment facility shall take place followed by commissioning phases.

Technology Solutions for Nuclear Materials Processing Applications

The rotary calciner design for shielded hot cell enclosures described in some detail within provides an elegant example of how supplier and client can work collectively to implement technical solutions for waste management projects. Further to treating liquid and solid wastes from radioisotope production, this thermal process technology is applicable for a broad range of legacy nuclear wastes where expertise can solve complex processing requirements through custom rotary calciner design concepts.

Rotary calciners can also provide a versatile test tool for numerous government and university lab based research projects. Other uses for rotary calciners include De-Nitration of Uranyl Nitrate, Hydro-Fluorination of UO_2, processing where dust or toxicity containment are key requirements. Another common application for this thermal technology occurs at nuclear fuel fabrication plants that recycle damaged off spec fuel pellets, swarf and powder, which is then processed under oxidative conditions to convert the waste UO_2 back to U_3O_8 in limited access or housed within hot cell & hot room environments. This material is subsequently reprocessed back to green UO_2 pellets for feed into the Sintering step of the fuel fabrication cycle. This thermal technology is also applicable in nuclear fuel fabrication where hydrogen reduction atmosphere pusher tunnel furnaces and kilns for the sintering of the green UO_2 pellets that are subsequently used in reactor fuel rods.

Conclusion

Harper's rotary calciner for hot cell environment provides an effective technical solution for the calcination step in order to treat liquid waste streams from radioisotope production. The rotary calciner has been designed to fully integrate into Synroc's modular process technology. The success of this project was founded on many considerations. The mutual collaborative approach between Harper International and ANSTO throughout the design, build, and system testing to address the written specifications as well as the overall design intent brought focus to the technical challenges of confinement of waste product and serviceability of the equipment within the hot cell environment. In addition to the design challenges, strict adherence to the high quality standards as well as the various material of construction limitations resulted in a project that met and exceeded the applicable quality standards that applied to the project. During the

Factory acceptance testing, the remote operation, serviceability, as well as remote disassembly/reassembly of the rotary calciner was demonstrated successfully with the access restrictions expected within the SWTP. The attention to the detail of the service environment, and practical physical limitations resulted in a system that was quickly manageable for these operational and maintenance functions.

This rotary calciner designed for hot cell applications has been commissioned within the Engineering Demonstrator at the ANSTO facility. This demonstrator facility has run inactive material through the calciner, validating the design and establishing process conditions for its final implementation. The implementation of the rotary calincer to process radioactive material within ANSTO's SWTP is planned for 2021. While there is expected to be ample process capability within the designed calciner, the size and design of these modular thermal processing units provides an option for capacity expansion. This capacity scale-up is achievable with multiple parallel lines. This approach results in low risk scale-up while minimizing the amount of process material within the service area.

Acronyms

NDE Non-Destructive testing

ITP Inspection and Test Plans

NQA-1 Nuclear Quality Assurance-1

COTS Commercial Off-the-Shelf

FAT Factory Acceptance Testing

SWTP Synroc Waste Treatment Plant

HIP Hot Isostatic Pressing

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