Reprocessing Technologies

Development of Head-end Equipments for High Throughput Plant

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Continuous Rotary Dissolver

Hull Rinser

ABSTRACT

India has gained sufficient experience and maturity in all aspects of spent fuel reprocessing required for closing the fuel cycle. Nuclear Recycle Group (NRG) has undertaken developmental efforts for improved equipment, which are required for a higher throughput plant in order to meet the rising demands in spent fuel reprocessing. A brief account of these developmental efforts related to head-end equipment namely Spent Fuel Chopper, Continuous Rotary Dissolver, Centrifugal Clarifier and Hull Rinser is presented in this article.

KEYWORDS: *Reprocessing, Head-end, Spent fuel, Shearing, Dissolution, Rinsing.*

Introduction

Spent fuel reprocessing is an important step in the closed fuel cycle adopted in the three-stage nuclear power programme of India. Closing the fuel cycle enables recovery of plutonium and unused uranium. The technology for reprocessing was developed and established indigenously, consisting of head-end operations, solvent extraction followed by purification and reconversion. After gaining sufficient knowhow of spent fuel reprocessing, efforts were taken up by NRG to develop improved equipment to meet the requirements of high throughput reprocessing plants. This article describes the efforts undertaken for the development of high throughput head-end equipment and the present status.

Head-end Operation

Head-end operation constitutes the first stage of spent fuel reprocessing. It involves operations such as fuel receipt and storage outside the hot-cell and fuel charging, spent fuel chopping, dissolution, feed clarification and hull management operations inside the hot-cell. The design of equipment for hot-cell operation is challenging due to highly acidic and radioactive environment. Amenability for remote handling and maintenance is also an important feature of hot-cell equipment.

Spent Fuel Chopper based on Gang Chopping

Spent Fuel Chopper (SFC) is used for shearing the fuel bundle or pins into small pieces thereby ,exposing it to leach acid for dissolution. The spent fuel chopper in PREFRE-I and KARP was based on a concept of progressive feeding, clamping and cutting of fuel with a single shear blade. Valuable experience was gained through operation and maintenance of these SFC's over the years. These experiences have helped in conceiving a novel SFC based on a new gang chopping concept[1].

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The SFC (Fig.1) comprises of fuel feed system, fuel shearing system, fuel positioning system, distribution system and hydraulics. The feed system is designed to house 10 Nos. of 220 MW PHWR fuel bundle. The fuel pushing is done with a chain pusher actuated by a hydraulic drive unit. The fuel shearing unit consists of a single shear module with a set of moving blades and fixed blades. The moving blades are mounted on carrier plates actuated by a pusher ram. The fuel positioning unit is designed to receive and position the complete fuel bundle between the cutting tools. The hydraulic unit consists of single hydraulic cylinder assembly with moving cylinder and stationary piston arrangement. The moving cylinder transmits the force to moving tool assembly via a pusher ram. The fuel distribution system controls flow of the cut pieces of fuel to dissolver-1 or dissolver-2. All the components within the hot-cell , like the shear module components, transfer system, pneumatic cylinders for distributor system, etc have been designed for remote handling using aids like in-cell crane, master slave manipulator, power manipulator etc. The hydraulic actuators and power packs, PLC and control panel are located in operating area freely accessible for maintenance. The system is provided with necessary PLC based controls with safety interlocks based on the feedback from the field sensors like reed switches and limit switches.

Fig.1: Spent Fuel Chopper Assembly.

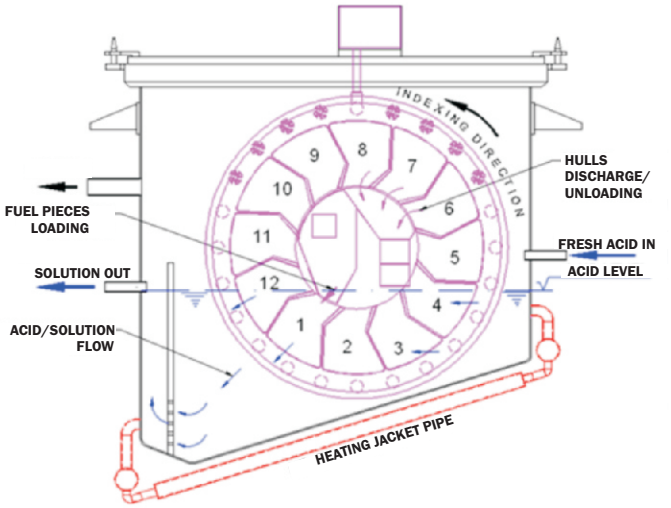

Fig.2: Schematic of Continuous Rotary Dissolver.

Fig.3: Continuous Rotary Dissolver

The SFC based on the gang chopping concept was installed in PREFRE-2, Tarapur and KARP-2 Kalpakkam. This has significantly enhanced the throughput of the present operating plant. The modular design of internals has reduced maintenance down time considerably.

Continuous Rotary Dissolver

Reprocessing plants in India presently employ batch dissolution process. In the batch mode of operation, sheared fuel pieces are received into a perforated basket within the dissolver limb. The core of the fuel segments gets dissolved when it comes in contact with the leach acid. The dissolved solution is subsequently transferred for further processing while the basket containing the hulls is handled remotely for its interim storage. While the process is simple and reliable, there are a few disadvantages with respect to large throughput plants *viz.*, poor utilization of dissolver during heating and cooling cycles of each batch, large chunk of stagnant fuel pieces resulting in longer duration for dissolution, unsteady off gas production and design of equipment managing the off gas for maximum rate. To address these drawbacks and to meet the requirement of future high throughput plants, NRG has initiated the development of continuous dissolver[2].

The Continuous Rotary Dissolver (CRD) developed by NRG is based on periodically indexing bucket wheel assembly (containing cut fuel pieces) within a slab tank partially filled with leach acid (nitric acid). The cut pieces of fuel are fed to a perforated bucket in loading position which undergoes dissolution in the acid bath while the buckets are immersed in acid. The hulls are discharged when buckets emerge out of the acid bath and attains unloading position as the wheel indexes (Fig.2). The central portion of the wheel assembly consists of a chute, which directs the cut pieces towards the bucket in loading position and discharges the hull from the buckets in unloading position.

A prototype CRD with processing capacity of 400 T/y was designed, manufactured and installed at CDCFT, WIP. The unit (Fig.3) was designed to meet the requirements of remote operation and maintenance. The maintenance prone components are part of a removable assembly which is amenable for remote handling. The removable assembly consists of bucket wheel, top lid and central chute assembly. The fixed part of equipment consists of main vessel (slab tank) and connected process & instrumentation piping. The drive mechanism is designed to have the major components out of the cell connected with the equipment through a remote coupling.

Mechanical loading trials, thermal-hydraulic studies, mathematical modelling of dissolution in continuous mode and remote handling trials were carried out. Based on the operational feedbacks, modified roller, hybrid air lift for management of fines[3] etc. were developed. A scaled down model of CRD has been manufactured for carrying out process evaluation with depleted uranium. NRG has gained sufficient knowhow and experience to design and deploy continuous rotary dissolver in upcoming plants.

Centrifugal Clarifier

The solution resulting from dissolution of spent fuel contains Zircaloy fines (resulting from chopping), insoluble residues of fission products such as of Mo, Tc, Ru, Pd etc., and crud introduced with fuel assembly. Feed clarification practised in the present plants is by means of vacuum assisted filtration using disposable filter elements. The filter element needs to be replaced after every batch of ~1.2 T of HM and thereby, results in large amount of secondary waste for high throughput plant. Frequent replacement of filter element also increases remote handling operations. Development of centrifugal clarifier for feed clarification application was taken up by NRG[4] to address these concerns. Centrifugal separation is a mechanical means of separating the components of a two-phase system by accelerating the material in a centrifugal field. The Centrifugal Clarifier comprises of a solid cylindrical bowl rotating at high speed. Slurry of liquid and suspended solids is fed to a fixed position within the bowl, and is accelerated outward to join the pool of liquid held on the bowl wall by the centrifugal force. This same force then causes the suspended solids to settle, and accumulate at the bowl wall. The clarified liquid then flows along the bowl, to leave at one end of it, over a weir which sets the level of the liquid surface in the bowl. An engineering scale

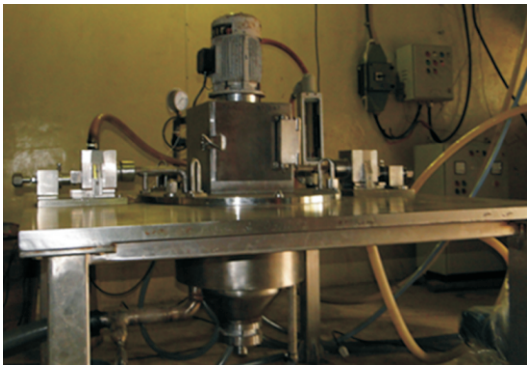

Fig.4: Centrifugal Clarifier.

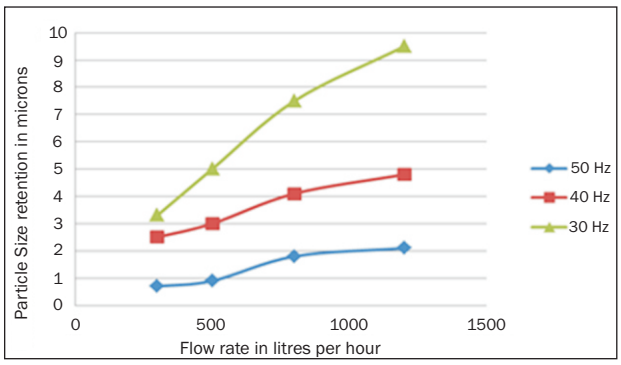

Fig.5: Particle retention characteristics.

prototype was designed, manufactured and installed at CDCFT building (Fig.4). The performance evaluation of system was carried out with simulated feed solution in a test loop. The samples of clarified solution were collected and analyzed for particulates present using DLS and SEM analysis. The results are shown in Fig.5. Remote handling trails were also carried out to check the amenability for remote maintenance.

Based on the trials carried out and experience gained, it can be concluded that system is capable of separating particulates of 2 micron at feed rate of 1200 LPH when operated at 50 Hz. At lower flow rates better clarification can be achieved. The prototype has a dirt holding capacity of 4 kg and the self-cleaning feature of the clarifier performed as intended.

Hull Rinser

Future reprocessing plants with automated head-end process will require automated hull rinsing equipment. The equipment shall receive the hulls from continuous rotary dissolver without disturbing the negative pressure atmosphere, rinse it to remove any loose particulate sticking and discharge it into drum which can be sent for disposal or interim storage. This will eliminate all the manual remote handling operation practiced in the present operating scheme.

NRG has under taken the development of Hull Rinser[5] based on the concept of movement of hulls upward along a helical path in a rinsing medium. The motive force for this upward movement is directional vibration achieved by means of a vibratory motor. The system consists of helical trays made of structural material, a pair of vibratory motors mounted diametrically opposite to central base cylinder, parallel but with 90°phase difference. During operation one of the motor rotates clockwise while the other in anti-clockwise direction. This creates a vibration which assists the movement of vibrating hulls in the desired direction. As the hulls are transferred due to vibration while immersed in rinsing liquid, the dual purpose of transfer of hulls as well as rinsing could be achieved simultaneously. An engineering scale prototype of Hull Rinser was manufactured and installed at Engineering Hall of CDCFT building (Fig.6). The performance evaluation of the system was carried out with simulated hulls and observations were recorded. Based on the performance evaluation carried out, it can be concluded that the operation time, rinsing effectiveness and amenability to remote operation and maintenance makes it suitable for automation of head-end operation for a large throughput plant. Valuable feedback was obtained during manufacturing and trials of the prototype which will aid in finalizing the design as per cell layout.

Fig.6: Hull Rinser

Conclusions

The development and deployment of Spent Fuel Chopper based on gang chopping concept is testimony to indigenous effort for improvement of system for higher throughput. The development of Continuous Rotary Dissolver, Centrifugal Clarifier and Hull rinser have been carried out with similar intension to meet the requirement of head-end operation for high throughput plant. Based on the experience gained after performance evaluation of these prototype equipment, NRG is in position to design and deploy plant adaptable units based on site requirements.

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References

[1] Shaji Karunakaran, D. A. S. Rao and K. N. S. Nair, Development of a novel Spent Fuel Chopper for PHWR Fuel, BARC Newsletter, Issue No.31, 2010.

[2] Shaji Karunakaran, G. Sugilal, K. N. S. Nair, Development of Continuous Rotary Dissolver, BARC Report(Internal) BARC/2012/I/023,2012.

[3] Shaji Karunakaran, R. Srinath, G. Sugilal, K. M. Singh, K. Agarwal, Development of Geyser Pump for lifting solid particles in a Continuous Rotary Dissolver, BARC Newsletter, 2017.

[4] Shaji Karunakaran, G. Sugilal, S. S. Khan, K. Banerjee, Development of Centrifugal Clarifier for feed clarification in reprocessing, BARC Report (Internal) BARC/2015/I/027, 2015.

[5] Shaji Karunakaran, G. Sugilal and K. Agarwal, Development of Hull Rinser for Head End Process of Spent Fuel Reprocessing, BARC Newsletter, 2017.