Development of Laboratory Scale Rotary Semi Continuous Dissolver for Nuclear Spent Fuel Reprocessing Facilities

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Abstract

A continuous dissolution equipment is required to be developed to cater future higher capacity reprocessing facilities. Two-stage rotary semi-continuous dissolver was designed and developed for various lab scale dissolution studies. This paper discusses equipment development, fabrication, commission and validation of rotary semi-continuous dissolve for laboratory scale studies.

1. Introduction

Dissolution of spent nuclear fuel is one of the important head end operation of reprocessing as it converts the irradiated fuel into liquid form which is easy to extract and recycle. Normally in nuclear fuel reprocessing facilities, dissolution is performed in a geometrically safe dissolver vessel filled with boiling nitric acid (or dissolvent solution at required temperature and pressure). Batch type dissolver with two interconnected limbs is used for thermal fuel reprocessing and small capacity fast fuel reprocessing. To cater requirements of future higher capacity reprocessing plants, it is necessary to develop an equipment which is critically safe in dimension, easily automated/maintained in remote environment and can hold optimum amount of inventory at any particular instance in plant.

2. Design methodology

Design methodology and dissolver development includes following steps.

a) Selection of suitable continuous dissolver equipment.

b) Design and optimization of various parameters.

c) Fabrication of dissolver models for lab-scale studies.

d) Validation of Laboratory scale dissolver by experimental studies.

3. Selection of suitable continuous dissolver equipment

Typical continuous dissolvers like continuous pot dissolver, up-flow column dissolver and slab dissolvers are not suitable for modern processing because there is no provision of continuous removal of intern cladding material in these equipments.[1] Therefore, continuous dissolver systems where both dissolvent and fuel pins in dynamic mode are considered from available literature. Ferris wheel type French continuous dissolver was developed at Cogema reprocessing plant at La Hague, France and further commissioned at Rokassho Mura reprocessing plant.[2] This type of dissolver had problems of solid build-up on walls of unit and hence, it cannot be used for plutonium rich fuels. Spiral vibratory rotary drum type continuous dissolver developed by JAEA under collaboration with Oak Ridge National Laboratory(ORNL) was based on a screw conveyor system with additional pulsing and agitation mechanism.[3] This type of dissolver experienced repeated mechanical failures and poor heat transfer from inner cylinder to outer housing.

Similarly Pneumatically pulsed continuous dissolver developed by British Nuclear Fuel Ltd (BNFL), UK and Vibratory tray type ORNL developed continuous dissolver were utilized for pilot plant scale studies. These systems cannot be considered for fast fuel reprocessing due to its larger sizes and mechanical complex agitation mechanism.[4,5]

Compartmented rotary drum type continuous dissolver developed by ORNL for use in plant scale facilities at NFS, New York was found to be suitable for fast fuel reprocessing application as it has capability of tumbling the sheared cladded spent fuel piece during operation.[5] This type of dissolver was selected for development of spent nuclear fuel reprocessing for present studies due to its inherent design advantage which increases the dissolution rate and ensures faster complete dissolution/rinsing.

4. Working principle of Compartmented rotary drum type semi-continuous dissolver

This dissolver is basically a rotary drum having different compartments. Each compartment is having an oblique cone attached with an inclined plate/baffles. The drum rotates on roller rings/bearing. Proper arrangements are made for feeding of spent fuels pieces to the first compartment of the drum and acid/dissolver solution was pumped into the drum in counter current path to the hulls. The mixing –transfer baffles are made perforated so that dissolver solution will not spill up during rotation of drum in any direction. The total set-up is kept at designed inclination for natural transfer of process solutions from one stage to next.

Mixing mode

When dissolver is rotated in one direction the sheared fuel pieces are moving in one compartment only, and continuously get tumbled in dissolvent.

Transfer Mode

When Drum is rotated one revolution in reverse direction, all the pins are transferred to next stage through guided plate and oblique cone.

Figure 1. Working principle of rotary semi-continuous dissolver

5. optimization of design parameters

Figure 2. Equipment for angle of repose.

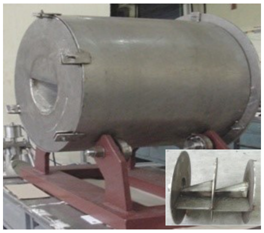

Figure 3. (a). 540mm ID Two-stage dissolver model.

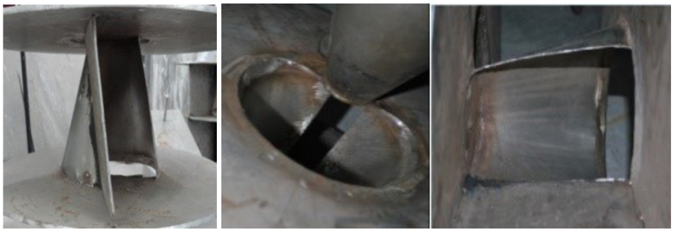

Figure 3. (b) Compartment refill with different cone and plate openings

For design and developmental studies, following parameters affecting the performance of rotary semi-continuous dissolver was identified.

· Optimum angle required for total transfer of fuel pins : SS Simulated fuel pins of 6mm diameter and 22mm length was used to find out angle of repose using equipment shown in Fig. 2 (a).

· Two stage 540mm ID rotary drum was fabricated with different compartmental refills as shown in Fig3(a) and 3(b). This compartmented refills were having different cone openings, different disc (compartment plate) openings and different plate (guiding baffles) angles. Simulated SS fuel pins bits were used to conduct experiments to establish this parameter to avoid any backflow, retention or forward flow of pins during transfer/mixing operation.

6. Design basis

Lab scale rotary dissolver was designed to carry out various lab-scale experiments and to validate various design parameters and ability to remote operation and maintenance. The size and other parameters was designed in such way that final plant scale prototypes can be scaled up just by increasing number of stages.

Hence, diameter of inner drum is fixed at 150mm while capacity of each stage is optimized based on actual FBTR fuel pin cut-bits in existing reprocessing facilities.

7. Fabrication of lab-scale dissolvers :

Based on design experience of various 2-stage dissolvers, a 5-stage 150mm ID Perspex dissolver (Fig.4) was fabricated. This model was supported directly on roller bearings and was rotated by belt driven stepper motor drive. Experiments were conducted in this dissolver without dissolvent solution to validate various design parameters and capacity.

Figure 4. Five stage 150mm ID Perspex made rotary continuous dissolver.

Figure 5. Two stage 150mm ID SS rotary continuous dissolver inside Fume-hood.

It was observed that available designs in literature has inherent mechanical complexity and is difficult to provide heating arrangement in continuously rotating drum. To address this problem , an modified design was proposed where extended oblique cone is provided and drum body is made perforated , hence each drum compartment can work as individual dissolver segment and hulls can be separated after complete dissolution. This type of design provides effective control over heating/cooling of dissolvent, temperature monitoring and sample collection.

To validate this concept, a two stage 150mm ID rotary dissolver was fabricated for studies in lab studies (Fig.5). The 2-stage segmented drum was accommodated in enclosed outer drum. ID of perforated SS inner drum was 150mm while outer drum Id was 180mm. Rotating drum is supported directly on roller bearings. Low speed stepper motor drive was coupled with rotating drum. Motor is located out-side the drum to avoid electric part failure due to acidic vapors. Material of construction was SS-304 L.

8. Lab-scale design validation studies :

This dissolver was commissioned inside standard laboratory fume-hood. Dry runs were carried out with simulated SS pin bits of 6mm diameter and 22mm length. To validate operation of dissolver, unirradiated UO_2 pellets with SS cladding were dissolved in boiling nitric acid of 8M concentration at 90°C. Samples were collected at pre-defined time intervals and complete dissolution of pellet was observed in a reasonable time.

9. Results and Conclusion :

Two stage 150mm ID SS rotary semi-continuous dissolver was used for complete dissolution of unirradiated UO_2 pellets in 8M boiling nitric acid at various speeds, without any mechanical failure. Same equipment was used for comparative dissolution studies of UO_2 pellet in batch and rotary dissolver and it was observed that rate of dissolution was much faster in dynamic condition than static batch condition. [6]

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