Development of Hull Rinser for Head End Process of Spent Fuel Reprocessing

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Rinsing of hull before disposal is presently carried out as manual remote operation. Automation of head end operation of future reprocessing plant will require automated hull rinsing equipment complementing the chopping and dissolution processes. Hull rinsing technology based on vibrating helical tray carrying hulls in rinsing solution has been evolved going through the stages of conceptual design, engineering detailing, prototype manufacturing and trials with simulated hulls. The feasibility of concept, amenability for remote operation and maintenance as well as reliability ensures the availability of technology for future high throughput automated plants.

Introduction

Automation in head end process of reprocessing is one of the areas of interest for Nuclear Recycle Group and work has been underway for development of equipment to achieve the same. This will also aid in the design of large throughput plant based on continuous process as against the present batch process. The head end process (Fig. 1) consists of following operations: spent fuel chopping, dissolution, feed clarification & hull disposal. Development of Spent Fuel Chopper (SFC) [1] based on gang chopping and its deployment in present operating plant has yielded excellent results. On similar lines development of Continuous Rotary Dissolver (CRD) [2] and Centrifugal Clarifier [3] are under progress. The article presented here elaborates the effort under taken to conceptualize, design, fabricate and testing of hull rinsing equipment which forms an important part of hull disposal process.

Hull Rinsing - Present Methodology

Dissolution in present operating plants is achieved in a dissolver which is a vertical cylindrical vessel housing a perforated basket. The basket receives one batch of chopped fuel pieces from the spent fuel chopper, which is treated with nitric acid for dissolution of heavy metal. The basket retains the hulls while the solution is transferred from the dissolver for subsequent process. In order to rinse the hulls before its disposal, the dissolver is fed with 2-3 M Acid, which is agitated with air sparging. As a second stage operation, this process is repeated with water. The dissolver basket is then removed from dissolver and placed within the hull tilting equipment for transfer of hulls into a hull drum in a manual remote operation.

Automated Hull Rinsing

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

A hull rinsing equipment was conceptualized, designed, fabricated and tested to meet the above requirement, details of which are presented in this article.

Design Concept

The design is based on 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 vibratory motor. The system consists of helical trays made of structural material, a pair of vibratory motors mounted in diametrically opposite to central base cylinder, parallel but with 90° phase difference. During operation one of the motor rotates in clockwise while 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. However, the presence of liquid has tendency to damp the vibration and hence selection of
vibratory motor plays an important role in the functioning of the hull rinser. An important factor of design is also the amenability for meeting the remote operation and maintenance requirement of hot cell application.

**Design Features**

The basic objective of hull rinser, as mentioned above, is to receive the hull discharged from the dissolver, rinse, and transfer the hulls to a hull drum for disposal (Fig. 2). As equipment in series with Continuous Rotary Dissolver, which discharges the hull, it is essential that the negative atmosphere of the dissolver is not breached during the hull discharge process. Further, it is vital that all components which demand maintenance shall be amenable to remote handling.

Considering these aspects, the hull rinser is designed to have a rectangular tank filled with water, a structural support frame encasing the tank supporting the vibrator and the helical tray assembly (Fig. 3). The discharge chute of the CRD (which is the feed chute for hull rinser) will be immersed in the liquid, acting as water seal to maintain the requisite negative pressure during operation. The design of the hull rinser also facilitates remote removability of the drive assembly for maintenance purpose.

The inlet chute of hull rinser has been designed to receive one batch of hulls, which is fed to bottommost flight of helical tray (Fig. 3). The directional vibration of assembly arising due to operation of mounted vibratory motors drives the hulls upwards along the helical flights. The system is designed to have 75% of total flights immersed inside the liquid while remaining flights above the liquid level. The vibrating hulls gets rinsed in the liquid as it moves up along the spiral path. As the hulls emerges out of the liquid it is allowed to dry with provision for hot air curtain provided through spray nozzle.

**Prototype Development**

An engineering scale prototype of Hull Rinser was manufactured (Fig. 4). All the structural material of spiral elevator i.e the spiral flights, base cylinder, motor mounting frame, fasteners has been made of SS 304 L to withstand the acidic environment. The fabrication of all stainless steel structural assemblies were carried out using TIG welding process. The individual flights were formed with adequate skirting (to prevent fall of shells) and welded to each other around the central cylinder to form helical tray assembly (Fig. 5). The helical tray assembly are mounted with springs which absorbs and transfers the load on structural support. The material of construction for spring is hard chrome plated spring steel. Standard vibratory motor (Fig. 6) has been used for the application. The selection of vibratory motor has been based on the consideration of transfer of the shells in liquid medium which could damp the vibration significantly. The support frame as well as the tank has been made of structural grade carbon steel, this being an experimental prototype.

After completion of manufacturing, the hull rinser was installed at Engineering Hall of CDCFT Facility in WIP Trombay. Shells made of Aluminum were used to simulate the size and weight of Zircaloy Hulls of PHWR fuel. Rinsing trials (Fig. 7) of shells were carried out after mixing it with powder slurry to check the intended performance of the equipment. Fig. 8. and Fig. 9. represent the pictures of the simulated hull prior to rinsing and after rinsing respectively. In order to quantify the rinsing performance, the trials were carried out with 100 shells which were weighed initially. The shells were then mixed with powder slurry and further
weighed to estimated the quantity of the powder trapped on and within the shells. The shells are weighed again after the rinsing operation to determine the powder retained with the shells. 30% of shells used in the trials were pinched at the ends to simulate the crimping due to shearing operation. The crimping prevents completed dissolution and tends to retain particulates within it. To check the reliability of components, more than 1200 operational trials were carried out. Various parameters like the current & voltage of motor, feed and discharge of hulls, operational time etc were recorded. Measurement of vibration in terms of displacement, velocity and acceleration were also recorded. The reading was taken with empty tank and also tank filled with water with and without load.

Remote handling and maintenance is one of the concerns for any hot cell equipment. The components of the Hull Rinser which demands periodic maintenance, are made removable and provided with hooks at appropriate location. The hull rinser assembly has been designed for remote removal of drive assembly as well as the complete helical tray assembly. Dismantling and assembly of removable components were also satisfactorily carried out (Fig. 10).

Performance Evaluation and Observations

The trials with simulated hulls yielded desired results in terms of rinsing time and effectiveness of cleaning. It was observed that hulls weighing 7.5 kg (corresponding to hulls of 5 numbers of 220 MW PHWR Spent fuel) would be rinsed in 15 min time period. This gave sufficient time margin for next batch of rinsing as the CRD discharges hull after every one hour. Multiple number of trials were carried to maximum to verify and establish the time period.
Rinsing trials were carried out on multiple occasions. On all occasions the effectiveness of rinsing operation was found satisfactory. Results of three such trials are indicated in Table 1.

Observation of parameters during the reliability trials for 1200 operations revealed consistency in results. The vibrating mass was observed to vibrate with an acceleration of 15-18g with empty tank. The vibration however subsided to 10-12 g with filled tank. The addition of load (shells weighing 7.5 kg) didn’t have any effect on vibration as it is insignificant compared to total vibrating mass. The support structure mounted on the floor was observed to vibrate with acceleration of 3-4 g. Similar acceleration was observed on tank surface also.

One significant observation was made during switching off the motor of equipment. As its rpm lowers from operation speed to zero it encounters resonance with the support frame resulting in large amplitude vibration for few seconds.

<table>
<thead>
<tr>
<th>Trials</th>
<th>Shell weight (100 shells)</th>
<th>Shell + powder (wt)(Before Rinsing)</th>
<th>Powder (wt)</th>
<th>Shell + Powder (wt) (After rinsing)</th>
<th>% Removal</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>717.83 g</td>
<td>787.93 g</td>
<td>70.1 g</td>
<td>719.07 g</td>
<td>98.23%</td>
<td>Mixed with wet</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>powder</td>
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<tr>
<td>2</td>
<td>717.83 g</td>
<td>969.44 g</td>
<td>251.61 g</td>
<td>718.21 g</td>
<td>99.8%</td>
<td>Immersed in</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>slurry</td>
</tr>
<tr>
<td>3</td>
<td>717.83 g</td>
<td>849.44 g</td>
<td>131.61 g</td>
<td>718.08 g</td>
<td>99.9%</td>
<td>Immersed in</td>
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<td></td>
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<td>slurry and dried</td>
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Further after multiple rinsing operation it was observed that dirt particles (accumulated after multiple operation) removed from the shell also tends to move along the helical path and discharge through the same route. Hence this called for some provision to avoid the same.

The shells also drag water droplets to the point of discharge and therefore a drying provision is essential.

Finite Element Analysis

In order to estimate the life expectancy and stress level of the component, vibration measurement and FE analysis were carried out by expert team of Vibration Lab, RED. Sensitive vibration probes (tri-axial accelerometers) were mounted at different locations on the hull rinser and on supporting frame. Vibration data were acquired under various operating conditions. A finite element model was also prepared for analyzing the local stress levels and response to dynamic loading.

The stress observed at operating RPM (16.66 Hz) were well within the limits and gave infinite life for the components. The maximum stresses were however observed corresponding to the natural frequency of system (3.54Hz) encountered during coast down (i.e. stopping of Hull Rinser) at flange gusset which exceeded the endurance limit of the material. The same was resolved by increasing the gusset thickness which brought down the stress level well below endurance limit.

Conclusion

The Hull Rinser is first of a kind developmental effort which has yielded desired performance. The operation time, rinsing effectiveness and amenability to remote operation and maintenance make it suitable for automation of head end operation for a large throughput plant. Valuable feedback was obtained during manufacturing and trials of the industrial scale prototype which will aid in finalizing the design. Further, evaluation of life expectancy of components through experimental trials accompanied by theoretical modeling will aid in evolving a plant worthy equipment.

Acknowledgment

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References