Development & Demonstration of Hull Batching System for Batching of Metallic De-clad Waste of Fast Reactor Fuel Cycle Facility

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Fast Reactor Fuel Cycle Facility (FRFCF) is being constructed at Kalpakkam to close the fuel cycle of Fast Breeder Reactors (FBR). Hull compaction facility is being designed for the first time in India and also planned for the FRFCF. Large volume of hulls will be generated during fuel reprocessing of the FBR spent fuels. Hulls are highly radioactive in nature and require enormous volume for storage thereby imposing burden on the definite storage space available at the Near Surface Storage & Disposal Facility (NSSDF) and Deep Geological Repository. Hulls being hollow cut pieces they provide scope for volumetric reduction thereby minimizing the long term storage space requirements. Conditioning of hulls is planned to be carried out in three stages. In the first stage, entire hull drum containing hulls will be dried to remove the residual water content. This is followed by the second stage which involves hulls contained in a hull drum to be batched into smaller Cans to facilitate the third stage wherein the Cans filled with hulls are compacted in a Hydraulic Super compactor.

A first of its kind prototype of Batching system (1:1 scale) has been developed & demonstrated for batching of Radial subassembly (RSA) and Fuel subassembly (FSA) hulls of FBR. The system has been equipped with remote operability and maintainability features to make it suitable for operation in radioactive hot cells. Electromagnetic vibratory feeder was adopted for hull batching operation. Rigorous batching trials were conducted to generate a baseline data for further active cell operations. The paper describes design philosophy, constructional features, remote handling features & the performance of the batching system during the trials.

*Keywords: Radioactive, De-cladding, Vibratory feeder, Hulls, Batching System, Hull Can, FBR, NSSDF*

**Introduction**

The success of the three stage nuclear programme rests not only on the effectiveness of reprocessing & recycling of spent nuclear fuel generated in each stage but also on the safe management of radioactive wastes associated with it. In the chop-leach process of fuel reprocessing, the spent fuel pins are chopped into small pieces for dissolution in nitric acid. The left out empty cylindrical fuel pin cut pieces along with structural material of fuel like spacer wires, fuel end caps & cutting fines obtained after fuel dissolution are referred to as ‘Hulls’. They are associated with high level of radioactivity due to residual fission products, alpha contaminants like major & minor actinides and neutron activation products. Current practice of management of hulls is interim storage in the tile holes at NSSDF. These hulls are kept pending for subsequent conditioning before final storage & disposal in Deep Geological Repository. Hulls require enormous volume for storage thereby imposing severe burden on the definite storage space available at NSSDF and Repository. Hulls being hollow cut pieces provide scope for volumetric reduction thereby minimizing the long term storage space requirements at NSSDF & Deep Geological Repository.

Volumetric reduction of hulls is planned to be carried out in three stages. In first stage, entire hull drum containing 400-500 litres of hulls will be dried in order to completely remove the residual water content present in the hulls. The second stage involves batching of 400-500 litres of hulls present in the hull drum in to smaller Cans of 60-70 litres capacity. In the third stage, Cans filled with hulls are to be compacted in a 2000T Hydraulic super compactor [1] to form compacted pucks [2]. The compacted pucks are then loaded in stainless steel canisters and TIG welded before being sent to Alpha Storage Facility (ASF).

Hull batching system (1:1 scale) has been developed & demonstrated at Trombay for batching of RSA & FSA hulls. The system has also been tested for PHWR hulls. The system has been designed with remote operation and maintenance features, which enables the system suitable for radioactive hot cell operations. Fig.1 shows the Batching System installed at Test Facility, Kalpakkam.

![BATCHING SYSTEM INSTALLED AT TEST FACILITY, KALPAKKAM](image_url)
Development of hull batching system was carried out in several stages. In the first stage, SS hull drum of 700mm Diameter x 1400mm height (schematic shown in Fig. 2) and Hull puck canister of size 350NB x 1950 mm height was designed, developed and tested for remote handling operations (Schematic sketch shown in Fig. 3).

Second stage involved survey of feeders, mock-up trials on various feeders and selection of an appropriate feeder suiting hot cell conditions. Upon testing of various feeders, electromagnetic (EM) vibratory feeder was found most suitable for batching of hulls in the radioactive hot cell. Fig. 4 shows the photograph of mock-up trials on EM vibratory feeder.

Prototype Fast Breeder Reactor employs two types of fuel assemblies i.e. Fuel Sub-Assembly (FSA) & Radial Fuel Sub-Assembly (RSA). Table-1 gives the sizes of PFBR RSA and FSA hulls & their expected generation rate per annum.

**System description**

Detailed description of individual components of the batching system is as follows:

**Hull drum**

Development of seal tight hull drum was the first step in the design of batching system in view of alpha content of hulls. Hull drum suiting to both Fuel Reprocessing plant (FRP) as well as Waste Management plant (WMP) has been designed and tested for remote handling operations like handling of lid, empty/filled hull drum with/without lid and hull tilting operations.

Hull drum has been developed along with impact wrench fixture (as shown in Fig. 5) for remote locking and unlocking of drum lid.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>FSA</th>
<th>RSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Stainless</td>
<td>Stainless</td>
</tr>
<tr>
<td></td>
<td>Steel D-9</td>
<td>Steel D-9</td>
</tr>
<tr>
<td>Outside Diameter</td>
<td>6.6mm</td>
<td>14.3mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>450 μm</td>
<td>900 μm</td>
</tr>
<tr>
<td>Length</td>
<td>30–40mm</td>
<td>30–40mm</td>
</tr>
<tr>
<td>Hull drum volume (containing 4 batches of fuel reprocessing)</td>
<td>360 litres</td>
<td>400 litres</td>
</tr>
<tr>
<td>Annual generation rate (drums/annum)</td>
<td>25 nos.</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 5: Hull Drum with impact wrench**
Tilting flask

It is a cylindrical flask designed to accommodate the hull drum and has provision to tilt the hull drum to 135° from vertical position for complete draining of hulls into the Hopper. It has also been provided with an arrester at the top flange to prevent the hull drum from toppling during tilting operation.

Hopper & Hopper Door

Hopper plays a vital role in the optimum performance of the feeder. Parameters governing the hopper design are size of hopper, front wall slope, rear wall slope, throat opening dimensions and gap between hopper & feeder trough. The parameters were arrived at based on the standard practice followed in the industry and repeated trials. The hopper is provided with a motorized fork-type gate (as shown in Fig.6) to control the flow rate of hulls and to reduce the load of hulls on the feeder trough.

![Hopper Gate](image)

**Fig. 6: Internal view of fork-type gate HULL DRUM IMPACT WRECH FIXTURE of hull hopper**

Electromagnetic Vibratory Feeder (EMV Feeder)

Among various types of feeders available in the industry for conveying bulk solids: Screw conveyors, unbalanced mass motors feeders & EMV feeders were studied and tested. Screw conveyer being susceptible to jamming between conveyer and feeder body owing to the presence of fines & spacer wires along with the hulls was found to be unsuitable for the current application. Unbalanced mass motors type vibratory feeder was also found not suitable due to imprecise control over material flow and higher amplitude of vibrations.

EMV feeder owing to compact construction, amenability for remote operation and maintenance, precise control of flow rate, low amplitude of vibrations, and ability to instantaneous start/stop with an accuracy of one hull and ease in decontamination was found to be suitable for batching operations in hot cell conditions [3]. Specifications of the present EMV feeder are:

- Size of feeder trough: 500 mm width (with tapered discharge) X 1600 mm length X 200 mm height with outlet diameter of 150 mm.
- Conveying Capacity and Power Consumption: 2 Te/Hr, 0.5 kW
- Vibration Frequency & Maximum amplitude of vibration is 3000 VPM & 1.5mm
- Inclination of trough: 0°
- Mounting of feeder trough: Base mounting with spring damper
- Class of electrical insulation: Class H

Vibratory feeder trough is provided with a pneumatic cylinder operated gate at its outlet to prevent any unintentional material flow during feeding of hulls into the hopper and also during changeover of hull Can after completion of one batch of operation.

Trolley

Trolley is required for positioning of hull Can and hull drum below the outlet of feeder trough. It is also provided with a load cell (300 Kg capacity, ± 50 g accuracy) to measure the weight of hulls filled in the Hull Can. Hull Can (300mm diameter x 1mm thickness x 1000 mm height) was used to collect the hulls from the feeder outlet. It was filled up to height of 900 mm keeping 100mm free board volume to contain the formation of heap. During emergency operation hull drum is positioned below the feeder outlet to collect the residual inventory of hulls.

Control Panel

Control panel controls the operation of vibratory feeder, hopper door, pneumatic operated feeder outlet gate and load cell. Feeder and load cell are equipped with safety interlocks. The feeder operation can be carried out in automatic and as well as manual mode. A selector switch has been provided on the panel to select the type of hull pieces i.e. RSA or FSA to be batched. Set point of load cell was fixed as 80kg for FSA hulls and 78kg for RSA hulls.

Special Design Features

- Since, the batching system has to be operated in a radioactive hot cell, the system was designed to facilitate remote removability of components that may demand maintenance. Components such as hopper, EM vibratory feeder, pneumatic cylinder feeder outlet gate and load cell have been equipped with the remote removability features. Figs. 7, 8, 9 & 10 respectively illustrate the demonstration of remote removability of aforesaid components.
- Electrical insulation of EMV feeder coils are selected as Class H insulation to have radiation resistance in hot cells.
- Emergency Conditions: In case of failure of EMV feeder, entire hulls residing on the feeder trough and in the hopper can be evacuated by tilting the structure up to 30° using hydraulic cylinders. This is possible because of feeder trough & hopper being assembled on a common structural frame, which is in turn hinged to the base structure of batching system. Fig. 11 illustrates the batching system tilted for draining of hulls into the hull drum in the event of emergency.
Batching trials results and discussions

Batching system was rigorously tested to investigate its performance for RSA and FSA hulls (as shown in Fig. 12,13 respectively) under different amplitudes of vibration and to estimate the time taken for batching of hulls from a single hull drum. The base line data generated during the trials would serve as reference for active plant scale operations. Feasibility study for batching of PHWR hulls with 19 pin end plugs was carried out as illustrated in Fig. 14.

Table 2 & Table 3 respectively show variation in time taken for batching of FSA & RSA hulls for different amplitude of vibration and maximum time taken for complete batching of a hull drum. Fig. 15 and Fig. 16 illustrate the influence of amplitude of vibration on the mass flow rate of hulls and the current drawn for FSA and RSA respectively.

Table 2: Variation in Mass Flow rate of FSA Hulls with Vibration Amplitude

<table>
<thead>
<tr>
<th>Vibration amplitude (µm)</th>
<th>Qty.</th>
<th>Time taken (minutes)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in Kg</td>
<td>in Litres</td>
<td></td>
</tr>
<tr>
<td>375</td>
<td>80</td>
<td>64</td>
<td>7.41</td>
</tr>
<tr>
<td>750</td>
<td>80</td>
<td>64</td>
<td>3.43</td>
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<td>1125</td>
<td>80</td>
<td>64</td>
<td>2.25</td>
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<tr>
<td>1500</td>
<td>80</td>
<td>64</td>
<td>1.38</td>
</tr>
<tr>
<td>375</td>
<td>450</td>
<td>360</td>
<td>43</td>
</tr>
</tbody>
</table>

Table 3: Variation in Mass Flow rate of RSA Hulls with Vibration Amplitude

<table>
<thead>
<tr>
<th>Vibration amplitude (µm)</th>
<th>Qty.</th>
<th>Time taken (minutes)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in Kg</td>
<td>in Litres</td>
<td></td>
</tr>
<tr>
<td>375</td>
<td>78</td>
<td>64</td>
<td>5.17</td>
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<tr>
<td>750</td>
<td>78</td>
<td>64</td>
<td>3.40</td>
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<tr>
<td>1125</td>
<td>78</td>
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<td>2.08</td>
</tr>
<tr>
<td>1500</td>
<td>78</td>
<td>64</td>
<td>1.39</td>
</tr>
<tr>
<td>375</td>
<td>488</td>
<td>400</td>
<td>33</td>
</tr>
</tbody>
</table>

Fig. 12: Batching of RSA Hulls

Fig. 13: Batching of FSA Hulls

Fig. 14: Batching of PHWR Hulls with End plugs

Fig. 15 Variation of Mass Flow rate & Current with amplitude of vibration for FSA hulls

Fig. 16: Variation of Mass Flow rate & Current with amplitude of vibration for RSA hulls
It was observed that the mass flow rate of hulls increased with an increase in the vibration amplitude. Total time taken for complete batching of a hull drum was determined to be 43 minutes and 33 minutes for FSA and RSA hulls respectively. Low mass flow rate of FSA hulls is attributed to higher flow resistance (interlocking) of FSA hulls due to their smaller size compared to RSA hulls.

The hull tilting operation ensured complete draining of hulls from hull drum in to the hopper. The EMV feeder control during instantaneous start/stop condition was to the extent of control of one hull thereby rendering precise control over the flow rate of hulls. Remote removability of individual components such as hopper, feeder, feeder outlet door and load cell was demonstrated. Tilting of hopper and feeder assembly by means of hydraulic cylinders to completely drain out the residual hulls under emergency conditions, was also demonstrated.

Summary

The batching trials and demonstration of remote removability features establish the suitability of the batching system for active plant operations. The optimum operating parameter for batching of FSA hulls shall be 80kg/Can with a cycle time of 7.41 minutes for a vibration amplitude of 375µm, and for RSA hulls it shall be 78kg/Can & cycle time of 5.17 minutes for 375µm vibration amplitude. The current batching system with certain modifications can be directly adopted for active plant scale operations. Modifications include: housing the system in an enclosure maintained at a negative pressure to prevent any contamination spread, the tilting flask housing

hull drum can be motorized with provision for tilting by means of in-cell crane in the event of emergency and the trolley meant for positioning of hull Can and hull drum for the receipt of hulls, can be motorized with a manual override feature. The current batching system can also be employed for batching of PHWR hulls with 19 pin end plugs by eliminating the hopper door.

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