Design of Vacuum Distillation System to Remove Sodium from Irradiated Sodium Bonded Metallic Fuel Pins in Concrete Hot Cell

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1. Introduction

Sodium bonded experimental metallic fuel pins being irradiated in Fast Breeder Test Reactor will be subjected to post irradiation examination at Radio Metallurgy Laboratory (RML) concrete hot cells. For the metallographic examination of the sodium-bonded metallic fuel pins, the bond sodium including the sodium infiltrated into the pores of fuel slug have to be removed. A Vacuum Distillation System(VDS) has been designed for removing bond sodium from irradiated metallic fuel pins inside concrete hot cell. This paper discusses

2. Design consideration for Vacuum distillation System

The Vacuum Distillation System will be installed inside one of the concrete hot cells of RML. Therefore, the system has to be designed as per the standard for the design of hotcell equipments [1]. The opening size of existing inter cell transfer port between the adjacent hot cells of RML is approximately 230 mm(W) x 220 mm (H).Therefore, the system has to be compact so that it can easily pass through these openings. The maximum temperature to which the fuel pin is subjected during vacuum distillation is restricted to 400°C to avoid metallurgical changes in the irradiated fuel and structural material. The maximum temperature allowed inside the RML hot cell is 40° C to avoid degradation of PVC booting. The ambient atmosphere inside hot cell consists of circulating Nitrogen gas maintained at 25° C and pressure 25 mm of water column below operating area pressure. The material of construction of the system should be resistant to radiation damage. The height of the system should be less than 1m for proper reach of the MSM. The lifting capacity and force transmission capability of in cell material handling devices have to be considered during the design of the system. The system should be highly reliable and amenable to remote operation and maintenance using master slave manipulator (MSM).

3. Design of Vacuum distillation System

The vacuum distillation system (Fig.1) consists of three heating coils wound around a vacuum chamber, an insulation layer surrounding the heater, a temperature controller with thermocouples, a remote sealing arrangement, an intermediate chamber, a vapour trap, a vacuum pump ,a pressure gauge and a supporting stand.

VDS works on the principle that the boiling point of a liquid changes with pressure acting on its surface. Since the maximum temperature of system has been restricted to 400°C, for the evaporation of sodium, the pressure inside the vacuum chamber has to be reduced below 47 Pa (which is the vapour pressure for liquid sodium at that temperature)[2].

The vacuum chamber consists of SS304L tube whose dimensions have been arrived based on the metallic fuel pin dimensions. The vacuum chamber is designed to withstand vacuum, mechanical loads [3] and thermal loads. The vacuum chamber has an opening at the top to facilitate vertical loading of pin inside. A remote sealing arrangement (Fig.2) is used to ensure leak-proof closing of the top lid of VDS using MSM. An intermediate chamber is attached at the bottom of vacuum chamber. A pressure gauge is provided on the intermediate chamber to display the vacuum level in the system. A flexible metallic hose connects the intermediate chamber to the vapour trap. The vacuum pump is connected to the vapour trap through metallic hose and the exhaust of the vacuum pump is released inside the cell environment.

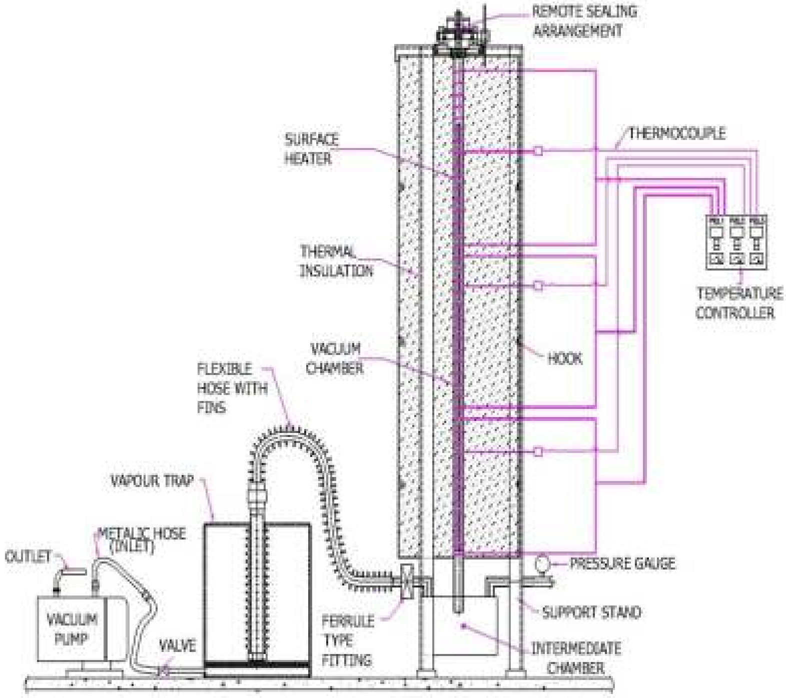

Figure 1 : Vacuum Distillation System

The remote sealing arrangement consists of a seating flange connected to the vacuum chamber, an annealed copper gasket, a plunger, a threaded top lid,a torque transmission coupling and a hand wheel. The copper gasket, plunger ,top lid and coupling are placed in sequence on the seating flange using MSM .When the hand wheel is rotated, the coupling rotates the top lid. This causes the top lid to move downwards and pushes the plunger .The gasket gets compressed between the plunger and seating flange to achieve leak tightness. Heat and mass transfer calculations have been carried out to determine the optimum heater power, insulation layer thickness and vacuum pump capacity. The selected insulation material and thickness ensures that the VDS size is within inter-cell port dimensions and the outside surface temperature of VDS is maintained below 40 °C .

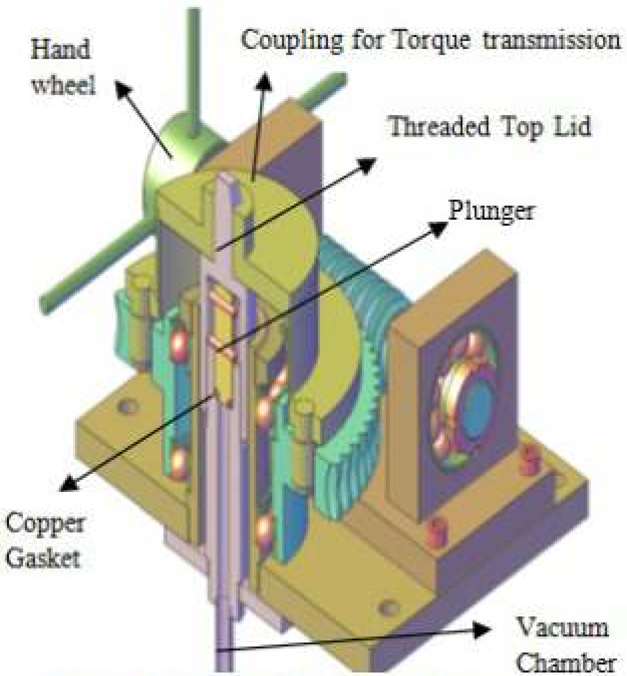

Figure 2. Remote Sealing Arrangement

The vacuum chamber is divided into three heating zones to maintain uniform temperature (400°C) throughout the length of the chamber. Thermocouples are provided in each heating zone for continuous monitoring and control of temperature. The feedback from thermocouple is send to the temperature controller which maintains the temperature of various zone within ± 1°C of the set limit. Hooks are attached at the periphery of VDS system for tilting to enable unloading of fuel pin from the system using in-cell crane.

During VDS operation, the fuel pin with two punctured holes is placed inside the vacuum chamber using MSM and the top lid is closed using remote sealing arrangement .When the temperature and vacuum level inside the vacuum chamber reaches the specified level, the bond sodium inside fuel pin evaporates .The sodium vapour condenses in the Intermediate chamber. Any uncondensed vapour is collected in the vapour trap.

4. Conclusion

A Vacuum Distillation System has been designed to remove bond sodium from irradiated metallic fuel pin. The system satisfies the design requirements for hot cell operation. The system will be fabricated and tested extensively prior to installation inside concrete hot cell.

References

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3. ASME, Boiler and Pressure Vessel Code , Section VIII, Divison I,2010 Edition