Vitrification Technologies

Development and Demonstration of Cold Crucible Induction Melter

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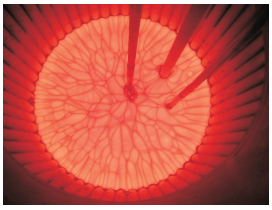
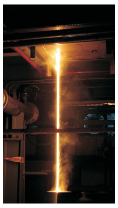


Molten glass pool inside Cold Crucible Induction Melter



Glass pouring

ABSTRACT

Indigenous development of cold crucible induction melter was taken up to address various limitations of induction-heated metallic melter and Joule-heated ceramic melter used for vitrification of high level liquid waste. Industrial scale prototype of cold crucible induction melter was developed based on the lab scale and bench scale experimental studies. Based on the operational feedbacks, a plant adaptable cold crucible induction melter was designed, fabricated and tested to demonstrate its remote operation and maintenance features for implementation in waste immobilization plant for vitrification of high level liquid waste.

KEYWORDS: *Cold crucible, Induction melter, Melter technology, Vitrification, High level waste.*

Introduction

Development of cold crucible induction melter (CCIM) technology for vitrification of radioactive liquid waste was pursued globally as it offers several advantages such as long melter life with high temperature availability and high waste loading compared to other melter technologies, *viz.*, induction-heated metallic melter (IHMM) and Joule-heated ceramic melter (JHCM)[1- 4]. In cold crucible induction melting, glass is directly heated by electromagnetic induction employing a segmented, water-cooled crucible. Internal water cooling of the segmented crucible produces a solidified glass layer, which prevents the metallic components from directly coming into contact with highly corrosive molten glass and thereby, provides long melter life. High processing temperature available with the CCIM results in high throughput per unit heat transfer area compared to IHMM and JHCM. By virtue of its structure and compactness, dismantling and decommissioning of CCIM is relatively easier compared to JHCM both in terms of remote operations involved and secondary waste generation. In view of the above mentioned advantages, indigenous development of CCIM technology was undertaken by NRG[5- 8].

Indigenous Development of CCIM Technology

Indigenous development of CCIM technology began with laboratory scale experimental studies to demonstrate the proof of concept and assess the overall thermal efficiency of the process. A segmented copper crucible with an inner diameter of 50mm and comprising 14 segments was employed for this purpose. Based on the experimental results, the overall efficiency of the cold crucible induction heating was observed to be ~17% [5]. Subsequent to the successful demonstration of the laboratory scale unit, a bench scale cold crucible induction melter of 200 mm inside diameter was developed and tested with regard to formation of solidified glass protective layer and glass pouring[5].

An industrial scale cold crucible induction melter with liquid feeding capability was developed to study its performance (Fig.1). The melter essentially has a segmented crucible formed by a circular array of 60 Nos. of SS 304 L tubes of one inch size. These stainless steel cooling tubes are arranged to hold a molten glass pool of 500mm diameter. A water-cooled mechanical plug assembly is used to drain molten glass from the melter. The plug seat protrudes into the melter in order to maintain a minimum amount of molten glass always inside the melter. The exterior of the vertical segments is provided with a 25mm thick casting of high temperature acid resistant refractory cement and a water impervious outermost layer.

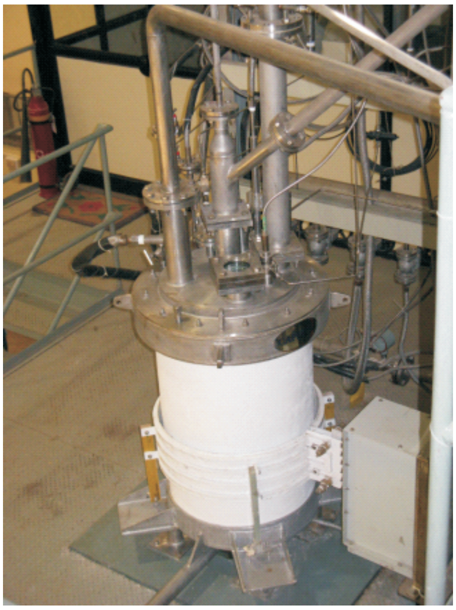


Fig.1: Industrial scale cold crucible induction melter.

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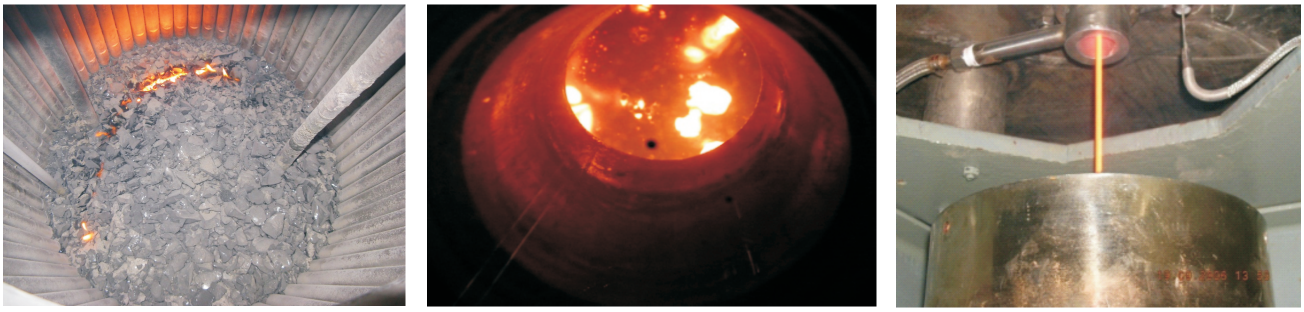


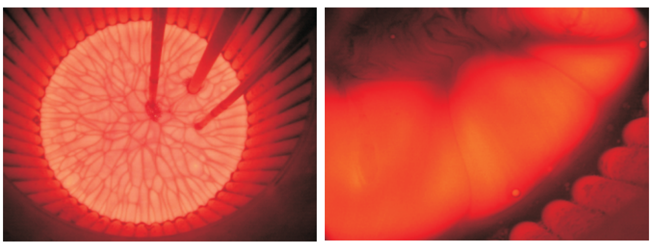
Start-up operation　　　Feeding operation　　　Pouring operation

Fig.2: Different stages of industrial scale CCIM operation.

The industrial scale CCIM was operated for more than 100 operations to assess its performance. The performance evaluation was carried out using sodium borosilicate glass having an electrical resistivity of ~5 Ohm cm at 1000°C. Industrially adaptable operating procedures for start-up, feeding and pouring operations were established (Fig.2). The overall melter efficiency, measured in terms of the ratio of thermal power output available for vitrification to electrical power input, was observed to vary with the glass level in the melter and found to be in the range of 10- 20% for the industrial scale CCIM.

A high temperature sodium borosilicate glass was used for the Cesium volatilization study. 1250 L of simulated waste as per the composition of ROP Tank-6 HLW was prepared with inactive cesium to simulate 20Ci/L activity of the waste stream. The industrial scale CCIM was operated at a temperature of 1250°C with a throughput of 25 lph. Off-gases from the melter plenum were bubbled through a cesium scrubber using a vacuum pump. Samples of cesium scrub solution were collected from the scrubber at different time intervals and analysed for Cs content. In order to compare the Cs volatilization with and without cold cap, liquid feeding was stopped at the end of ~50 hours of operation and heating was continued till melting of the cold cap was completed. The Cs scrub solution was analysed for the Cs content. Based on the experimental results, the cesium volatilization is ~5% when the CCIM was operated at 1250°C with a stable cold cap and ~ 20% without cold cap.

Industrial scale demonstration of CCIM was also demonstrated using high temperature glass containing zinc oxide, as a part of R&D efforts to establish waste form with improved radiation stability with high chemical durability. The melter was operated at 1250°C to achieve an average throughput of 25 LPH with a waste loading of 26%. Fig.3 compares the skull thickness observed for two different glasses–with and without ZnO. The skull thickness observed in the case of glass with ZnO is significantly higher than that of glass without ZnO. This effect is because of the increase in glass viscosity due to ZnO addition. The enhanced skull thickness provides better protection to the stainless steel fingers of the cold crucible.



(a)　　　**(b)**

Fig.3: Comparison of skull thickness inside CCIM: (a) glass without ZnO (b) glass with ZnO.

Plant Adaptable Cold Crucible Induction Melter

Based on the operational feedbacks, a plant adaptable CCIM with additional features for remote operation and maintenance was developed and demonstrated. The salient features of the plant adaptable CCIM are presented in this section.

Secondary Metallic Enclosure: The plant adaptable CCIM has been provided with a metallic (SS 304L) enclosure for housing the segmented crucible. This secondary enclosure ensures the confinement of the radioactive waste in case of any abnormal operation or accidents. The square enclosure has an outer dimension of 800 x 800mm with its own cooling provision (Fig.4) .

Alumina Coated Metallic Components: As the melter start - up is achieved by remotely inserting a graphite ring into the meter, there exists a rare possibility of this ring coming in contact with the metallic components of the segmented crucible, resulting in an electric arcing. This has been addressed in the plant adaptable CCIM by providing the metallic cooling tubes and pour plug with an electrically-insulating alumina coating of 300- 350 microns and qualifying the insulation characteristics by holiday test for 1 kV (Fig.5).

Redundant Pouring Units: The plant adaptable CCIM has been provided with two pour ports for pouring (Fig.6). A monolith AZS block is provided to fill the dead volume between the base and two pour ports. One of the pour ports is raised by 50 mm as compared to other and is meant for regular pouring operation. This helps to maintain a pool of molten glass available for next batch of operation. The lower pour port is meant for completely emptying the melter at the end of its service life. However, the lower pour port can be used for normal pouring in case of non-availability of regular pour port.

Remotely Operable and Maintainable Pouring Mechanism: The pouring in industrial scale CCIM was achieved through actuation of mechanical pour plug using pneumatic actuator.

Fig.4: Secondary metallic enclosure.

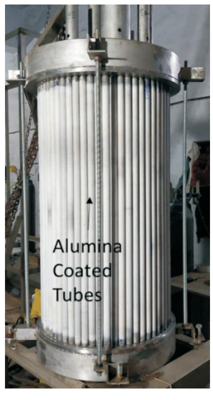


Fig.5: Alumina cooling tubes.

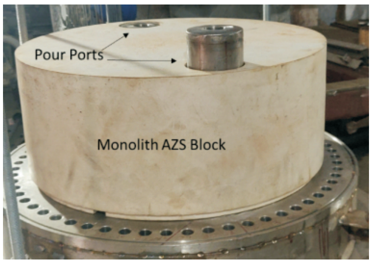


Fig.6: Redundant pour ports.

Fig.7: Pour plug actuator.

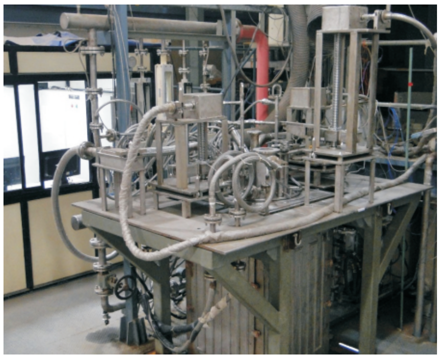


Fig.10: Plant adaptable CCIM.

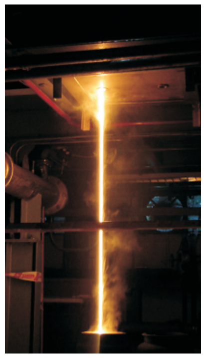


Fig.11: Glass pouring.

The pouring mechanism of the plant adaptable CCIM has now been modified by employing a ball screw actuated mechanism with power transmission through flexible shaft driven by remotely placed motor (Fig.7). The mechanism has enough flexibility for remote manual intervention and maintenance in case of failure of any component. Similar mechanism has been adopted for actuation of retractable thermocouple employed for temperature and level measurement.

Remote Connector for 50 NB Water Cooling Lines: A combination of customized three-jaw connector and block connector with an interconnecting flexible pipe spool has been used in the inlet and outlet of the main cooling water circuit connection to the plant adaptable CCIM (Fig.8). This has been employed considering the optimum utilization of in-cell space and remote operability and maintainability. The leak-tightness of these joints has been qualified through hydro-testing .

Quick Coupling for Smaller Water and Air Lines: Remotely operable stainless steel quick couplings (Fig.9) have been used for various smaller water and air lines connected to the plant adaptable CCIM. These coupling are amenable for actuation through master-slave manipulator employed in the hot-cell.

The plant adaptable CCIM has been installed in the engineering hall of CDCFT building at Trombay (Fig.10). It has been integrated with the existing high frequency (200 kHz) induction heating power supply system and operated to check the efficacy of all newly added features. Satisfactory commissioning of the system was carried out confirming high temperature operation (1250°C) and smooth pouring (Fig.11). Thus, the plant adaptable CCIM with all the remote operation and maintenance features is amenable for implementation in hot-cell for vitrification of high level liquid waste.

Conclusions

Cold crucible induction melter offers several advantages such as high temperature availability and high waste loading with long melter life. Other salient features such as compactness and ease of melter replacement with less secondary waste generation makes CCIM as a promising candidate for vitrification of high level liquid waste. Development and demonstration of plant adaptable CCIM with remote operation and maintenance features pave the viable route for its implementation in Indian Waste Immobilization Plant for HLW vitrification.

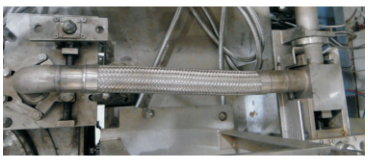


Fig.8: Three-Jaw connector & Block connector.

Fig.9: Quick couplings.

Acknowledgements

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