CCIM-NEW ERA OF HLW MELTERS

[1]RAHUL TAYADE, [2]SHWETA PARDESHI

[1,2]Third year B.E student, Dept. of Electrical Engineering, Father Conceicao Rodrigues Institute of Technology, Mumbai, Maharashtra, India
E-mail: rahultayade244@gmail.com, 1027shweta@gmail.com

Abstract- Cold Crucible Induction Melting (CCIM) is globally emerging as an alternative technique for vitrification of high level waste. It eliminates many materials and operating constraints inherent in other available techniques of vitrication. Vitrification is reffered to the process of chemically mixing glass and radioactive waste to form a chemically inert glass matrix. Cold crucible induction melting technique involves the use of the principle of electromagnetic induction, inducing currents directly into the glass forming composition and HLW to form glass matrix. Its construction and working is designed to be efficient and innovative. CCIM posses much longer life and this crucial advantage makes it superior over other techniques. This paper provides a review of CCIM technology. Also presents system design and operation of CCIM. Included is a detailed comparison of cold crucible induction melter with other type of melters.

Keywords- Cold Crucible Induction Melter (CCIM), Electromagnetic Induction, High level waste, Vitrification.

I. INTRODUCTION:

The nuclear waste produced by the nuclear industries have different levels of radioactivity in them which are highly mobile in any medium, have a long half-life and are dangerous for our entire environment. Hence the process of vitrification is carried out which involves the mixing of these radioactive wastes with molten glass forming substances at high temperature and make them chemically inert and physically stored deep underground so that the chances of radioactive leakage can be reduced and eliminated. This process can be brought about by various heating techniques.

Different types of heating melters can be specified as follows:
1) Induction-heated metallic melter
2) Joule-heated ceramic melter
3) Cold crucible induction-heated melter

Induction-heated metallic melter was developed initially to carry out vitrification process. The induction-heated metallic melter is compact and simple system but it has low throughput on account of limited diameter and short melter life due to high temperature glass corrosion. In order to circumvent these limitations joule-heated ceramic melter was developed. It operates by passing electricity between water or air-cooled submerged electrodes in a molten pool of glass in a brick-lined chamber. Joule-heated melters are simply too limited by material considerations to allow adequate operating flexibility for cost processing of wide variety of high-activity wastes in global nuclear complex. A radically different design that has been in use in many countries for different kind of wastes is called a Cold Crucible Induction Melter (CCIM). This new technology of cold crucible melter offers several advantages like high temperature availability with long melter life, tolerance to presence of noble metals, high waste loading and high specific capacity. It is promising technology for adopting glass ceramic and synroc-based matrices for high level waste immobilization.

In 1980, a direct induction process using a water cooled metal crucible was developed in France to melt metal waste from nuclear fuel reprocessing. This experience led to development of cold crucible melter for inductively heating glass in water cooled crucible. France has more than 20 years of research and development experience in the field of CCIM. Also a full scale plant using CCIM is operational in Russia since 1999 for vitrification. In USA, prototype for vitrification is developed by Idaho National Engineering and Environmental Laboratory in collaboration with Russian scientists. In view of management of High Level Liquid Waste that will be produced by reprocessing of Fast Breeder Reactors and Advanced Heavy Water Reactors, cold crucible melting technology is being developed in India. System design and development aspects of CCIM are presented in this paper.

II. COLD CRUCIBLE INDUCTION MELTING TECHNOLOGY

A. System Design and Description of Major Components

This next generation Induction melter contains many subparts in it. The main region where the process of melting takes place is surrounded by vertically placed segmented stainless steel rods, which have a hollow construction, water flowing from inside of them for cooling purpose. The base as well as the top portion of system is also cooled by water cooling system. Each rod is separated by a thin layer of electrically insulating material. These rods will not interact with any magnetic field as they are made of stainless steel and little magnetic properties.



Fig.1: An Experimental CCIM structure with induction coil

1) Induction Coil

The main induction coli, which is made of copper is placed around this assembly to provide the induction current. The purpose of the induction coil is to transform the output of the high frequency generator into a varying magnetic field. Induction coils may also require a mechanical support structure due to both the size and weight. The impedance of the coil is a function of the level of the glass in the crucible, resistivity of the charge and physical coupling available.

2) Induction Generator

The power to the coil is provided by induction generator. Its purpose is to generate high frequency alternating current to drive the induction coil. Typical frequencies for CCIM application range from 100 kHz to 2 MHz, with power levels from 20 kilowatts to several megawatts. For this frequency and power range, designs are based on either metal oxide semiconductor field effect transistor (MOS-FET) power devices or vacuum transmitting tubes. Both transmitting tubes and MOS-FET's dissipate significant power for all circuit configurations, and active cooling will be required. water has a much higher specific heat and is likely to prove superior. However, a re-circulating high-purity water system may be required because common utility water is somewhat conductive and will lower the quality factor (Q) of the induction coil.

3) Crucible

The crucible contains the melt material. In a CCIM melter the crucible consists of a tube-type heat exchanger configured such that an internal volume is created. The can be a simple right cylinder, oval, or a more complex shape such a cruciform. There are a number of crucible design issues. The crucible must be able to contain the waste feed prior to initiation of melting as well as the molten pool during processing. It must allow the varying magnetic field associated with eddy current heating to pass through in a known and predictable manner from the external induction coil to the waste matrix inside the crucible. The coil materials must be corrosion resistant to the feed material on top of the glass (liquid, slurry, paste or solids) as well as gases and condensate that contact the crucible in the plenum over the waste.

Corrosion is reduced due to the relatively cool crucible surface, but the materials of construction must withstand gases that may be highly acidic or basic, as well containing free halogens like fluoride and chloride.

4) Off Gas Control System

The off gas system for the melter helps is removing the gaseous material formed inside the crucible and to keep it under negative pressure condition for desired operation. Off gas stream composed primarily of water, NOx, SOx, and COx, with smaller amounts of HCl, HF, and trace levels of radio-nuclides and metals. The off gas temperature leaving the melter will probably be between 100ºC and 200ºC.

5) Protection for system

The system is provided with many interlocks and tripping systems in case of emergencies. The quantities temperature, pressure, liquid flow, presence and existing capacity of canister and many more parameters are remotely observed and the system is operated accordingly.

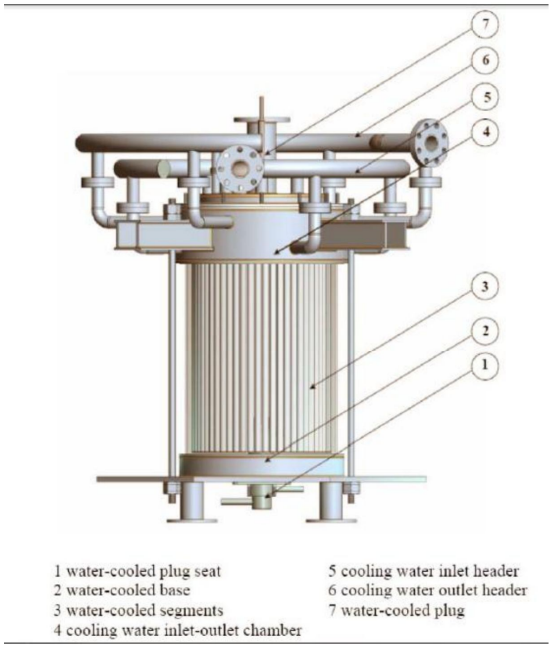


Fig.2: Design and major components of the Cold Crucible Induction Melter (CCIM) [3]

The entire working is subdivided into many portions. These can be named as:

1) Start-Up Process

2) Glass melting Process
3) Glass soaking Process
4) Glass pouring Process

The Start-up process is associated with filling of the crucible with sodium borosilicate glass compositions having SiO2, B2O3, Na2O, Fe2O3, and TiO2 in decreasing order of composition by weight%.

This composition is in solid form and care is taken to avoid it being escaping the spaces between the segmented rods. Along with this a graphite ring with a smaller diameter than the crucible is placed inside which will serve the purpose of melting and augment the process of heating. The valve, through which waste comes, is closed during the start. When we provide supply to the induction coil, these currents produce a flux which interacts with the graphite ring. This introduces currents in the ring, and due to its heat, the ring starts melting obtaining temperature of about 700ºC.



Fig.3: Start-Up process

The Glass melting Process begins with the melting of the inside glass material attaining the same high temperature. At the same time the water flowing through the segmented rods helps the surrounding mixture to be cool and in solid form, hence forming the so called name as cold crucible. The inside glass, after attaining temperature of about 800º to 900ºC, becoming highly conductive. Since it attains conductivity, the secondary currents now are induced in this composition and heats up the glass directly without heating the outside part of crucible.

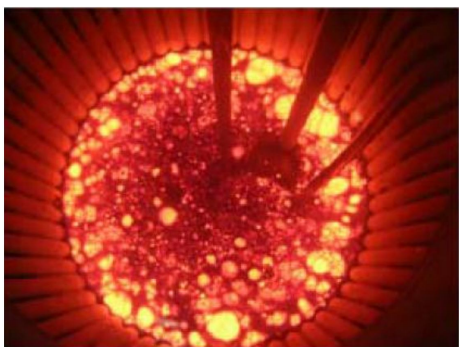


Fig.4: Glass heating Process

The inside glass when sufficiently hot, the waste fluid is introduced inside the crucible which reacts with the newly introduces glass composition, being heated by the molted material already present inside the crucible. The process of vitrification starts, which chemically bonds this waste and radioactive metals with sodium borosilicate glass, present in molten form within the crucible. This can be termed as the glass soaking process. An automated stirrer unit is provided from above of the lead which is well suspended into the mixture and ensures constant and thorough mixing process.

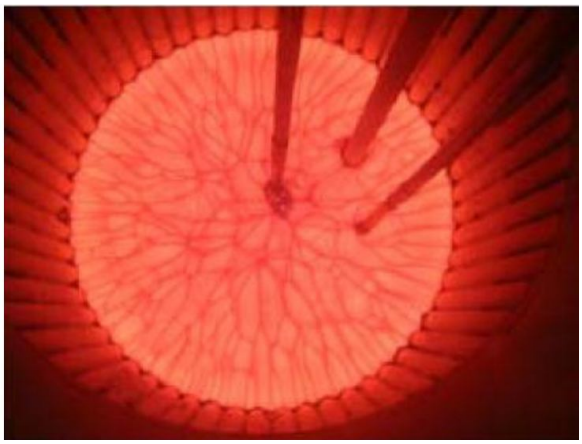


Fig.5: Glass soaking process

At the bottom of the crucible, a Freeze Valve is present, consisting of solid composition of glass. A separate heating source, resembling like a general induction heating unit is present which controls the glass pouring process. This melt is poured in the canister. After it is filled, we replace the filled one with a new one to accommodate the next pouring batch of melt. The canister is further sealed; its temperature is brought down significantly by forced and natural draft process and finally stored deep the ground or water bodies.



Fig.6: Glass pouring process

The crucible is externally connected with input pipes introducing the glass composition and radioactive waste material. There are water inlets and outlets. The Off gas coming from the crucible is passed through the condenser, then treated chemically to make it free from radioactivity and finally released in atmosphere

through stack. The assembled structure of Cold Crucible Induction Melting System can be shown as follows:



Fig.7: CCIM assembled system

III. COMPARISON WITH OTHER TYPES OF MELTERS

B. Comparison with a general Induction Melter (IM)
A metallic IM has a lot easier construction than CCIM. There are no complications with melting process and it can be controlled, stopped and started at any desired time. Whereas has more shortcomings such as elongation of the vessel/crucible with progression of process. CCIM is partially surrounded with ceramic material and cool composition, so the apparatus does not expand.

However it has a complicated construction. IM has very less efficiency, its life is smaller and throughput is very less (less than 6-10 LPH). On the other hand CCIM is known to have the highest efficiency amongst all the melting techniques and gives high output.

C. Comparison with Joule Heated Induction Melting (JHIM)
The JHIM was designed for getting huge amount of output glass matrix and having more efficiency than IM but less than CCIM. The actual contact of the melting material with the ceramic wall can make the entire vessel contaminated and hence reduces the life of the melter to 2-3 years.

Whereas in CCIM there is no contact of this melt with any vessel or metallic part. So contaminated nuclei are well isolated. No plenum heaters are required for CCIM and its life is more than a JHIM.

IV. ADVANTAGES AND DISADVANTAGES

Most of the advantages and disadvantages were observed in the comparison section. In an overall view it vitrifies a wider range of products and ultimately to reduce the volume of final waste. The cold crucible is 'multi-glass', i.e. it allows for vitrification of various types of waste, due to its use at a higher temperature and its cold structure that is not sensitive to corrosion [5]

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Apart from its advantages, there are issues related to the crucible and coil design.

1) The electrical losses are to be kept as minimum as possible.
2) The coil should maintain its temperature so as not to reach its melting point.
3) The crucible should have a sustained cooling system and it must remove head at a rapid rate so as to maintain the solid glass layer, successfully for the operation.
4) It is extremely important to maintain negative pressure inside the crucible, otherwise can cause the bursting of entire assembly.
5) Also, Caesium and Strontium retention has been an issue because of the potential high temperatures in the CCIM, and increases volatility of system.

These issues are still needed to be evaluated for future testing. Further research can help us overcome these shortcomings and make the entire system more reliable.

CONCLUSION

After going through all theoretical and practical concepts of Induction Melting Processes and There comparisons with other types, we find that the CCIM is the next generation and best found efficient melting technology of time. Unlike other methods, CCIM's concept of direct induction heating to glass composition material present inside the crucible provides better electrical efficiency of 80-90% and 20-25% of thermal efficiency. The cold crucible is known to be the only production tool in the world to increase frequency of vitrification and provide a solution for conditioning of a wider range of waste types. Though its construction is complicated, it provides high reliability of performance for a longer span of time and more output. This melter has been proved viably successful in vitrification process, providing complete isolation of radioactive waste and contamination from the outside world, providing high reliability. The entire process is compact in both experimental and industrial based models. This provides great aid for the industries in nuclear field. With further experimenting on all the shortcomings of this method, this technology can be made innovative, more usable, and more viable for the world.

REFERENCES

[1]. Gombert, D., "Vitrification of Mixed Wastes, the Good, the Bad, and the Ugly," Idaho National Engineering Laboratory, Waste Management '99 Technical Proceedings, Tucson, AZ.

[2]. D. Gombert, J.R. Richardson, "Cold Crucible Induction Melter Design and development", Nuclear Technology 141(2003) pp. 301-308.

[3]. G. Sughilal, P.K. Wattal, "Development of Cold Crucible Induction Melting Technology for vitrification of High level Liquid Waste", Kalpakkam, India (2003).

[4]. C.C. Herman, et.al., "Vitrification Demonstration of DOE High Alkaline Surrogate in the Radon 200 mm Crucible", WSRC-RP-2002-00319, Westinghouse Savannah River Company, Aiken, South Carolina (2002).

[5]. www.areva.com/EN/operations-3400/the-cold-crucible-a-world-first-for-highlevel-waste.html#tab=tab4

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