Thermal Analysis of Joule Heated Ceramic Melter

P. Goyal*, Vishnu Verma, R. K. Singh and K. K. Vaze

Reactor Safety Division
Bhabha Atomic Research Centre
Trombay, Mumbai-400085
pgoyal10@rediffmail.com

Abstract

High level radioactive waste (HLW) generated by nuclear fuel cycle is immobilized using glass melters. In Glass melters such as Joule Heated Ceramic Melter (JHCM) electrodes immersed in the glass generates heat by the joule heating due to electric current passing between electrodes through glass. For melter performance it is required to evlaute temperature distribution in the melter. Thermal analysis of the melter has been carried out with the help of COMSOL.

1.0 Introduction

Thermal analysis of a joule heated ceramic melter (JHCM) has been carried out at Tarapur. In the melter, concentrated high level liquid waste and glass former (in the form of granules) is fed into Joule Heated Ceramic Melter, where electrodes immersed in the glass generates heat by the joule heating due to electric current passing between electrodes through glass. Glass has the property of conducting current at a temperature above approx. 600 C because resistivity of glass decreases with increase in the temperature. The vitrified product glass melted in the furnace is withdrawn periodically by using a bottom freeze valve (central or side drain) consisting of joule heated section followed by induction heated section into the stainless steel canister.

In ceramic melter, glass is contained in a ceramic lined refractory AZS (Alumina Zirconia Silica). Bubble Alumina as backup refractory is provided to reduce molten glass migration. Standard insulation materials like insulation brick, fibre board and fibre wool were used [1] (Fig. 1). Overall dimension of JHCM is 1516 x 1466 x 1874 mm.

Thermal analysis has been carried out with the help of COMSOL [2] by taking boundary condition such as glass pool temperature of 950 °C and cold cap temperature of 150 °C as shown in Fig 2. Due to symmetry in X-Z and Y-Z plane only quarter geometry has been modeled. Steady state temperature are reported at selected locations from the overall thermal field obtained from the present analysis.

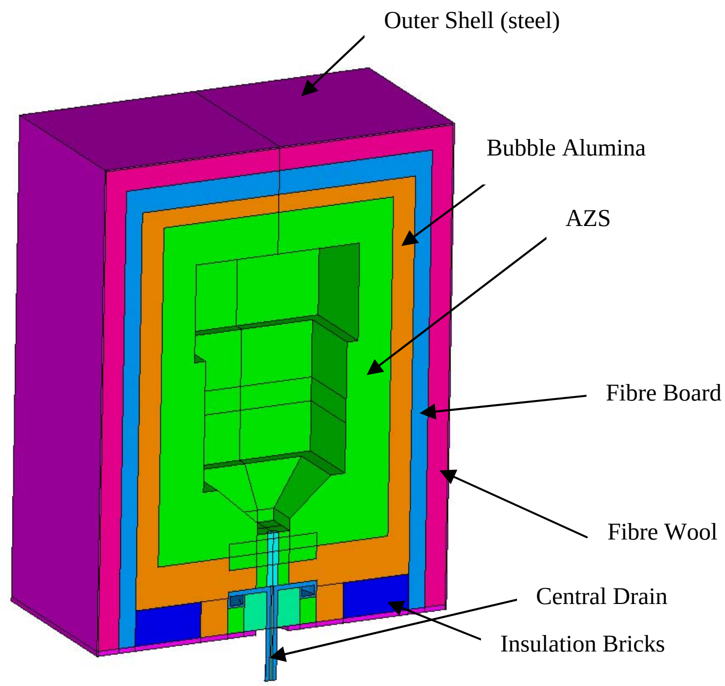

Fig. 1 Section View of JHCM

2.0 MATHEMATICAL MODEL

The temperature distribution in AVS can be obtained by solving the following 3-D conduction equation in Cartesian coordinates for all the materials.

$$\rho Cp \frac{\partial T}{\partial t} = \nabla.(k\nabla T) + Q$$
(1)

Where, T ≡ T (x, y, z, t)

In addition to conduction, radiation plays an important role in heat transfer from glass pool to AZS.

2.1 Assumptions

Fixed temperature of 950 °C of glass pool has been assumed i.e. glass and AZS interface temperature also will be at 950 °C but in actual condition due to convection effect in the cavity there will be some temperature drop and glass-AZS interface temperature will be less than 950 C. By assuming same temperature of interface (950 °C) it will predict higher temperature in the melter then actual case which is conservative. Material properties of the material which is taken in the analysis is shown in Table-1.

Table-1 Material Properties

S.N.	Material	Thermal Conductivity (W/m-k)
1	AZS (Alumina Zirconia Silica)	2.88
2	Bubble Alumina	0.8
3	Fibre Board	0.17
4	Fibre Wool	0.17
5	Insulation Brick	0.28
6	Steel	15.0
7	Inconel	100 °C - 14.1 200 - 14.3 300 - 14.5 400 - 14.8 500 - 15.2 600 - 15.7 700 - 16.2 800 - 16.6 900 - 17.0 1000 - 17.4
8	Upper layer of glass and glass in drain pipe	1.5

2.2 Boundary Conditions

(i) Fixed temperature of 950 °C of glass pool up to 10 mm above top surface of main electrode has been assumed (Fig.-2).

(ii) Cold cap temperature of 150 °C with radius of 90 % of glass pool cavity radius.

(iii) Upper layer thickness of glass pool above molten glass is taken as 100 mm.

(iv) Radiation heat transfer within the cavity (emissivity 0.8).

(v) Radiation (emissivity of 0.3) and convection heat transfer from outer surface of melter to the ambient.

(vi) Outside ambient temperature of air 35 °C.

(vii) Convective cooling due to air in the channel of bottom electrode has been considered

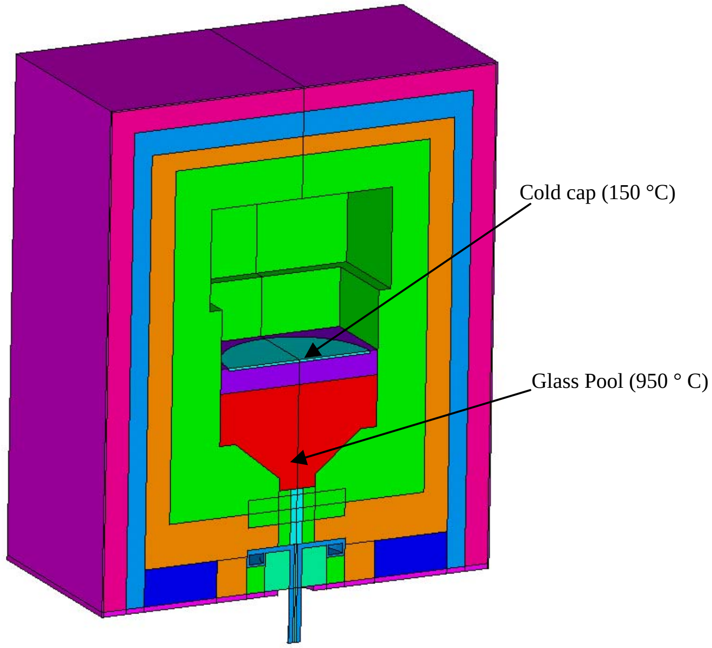

Fig. 2 Section View of JHCM with glass pool and cold cap

Result and Discussion

The computational mesh considered for the analysis is shown in Fig. 3. The mesh consists of approximately 1.7 million cells to adequately capture the temperature distribution in various components of JHCM.

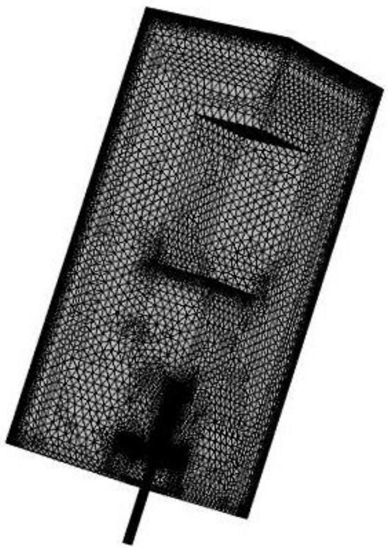

Fig. 3 : Computational Mesh for Thermal Analysis of JHCM

Temperature Contour plot and slice plot for JHCM are shown in Fig. 4. and Fig. 5 respectively

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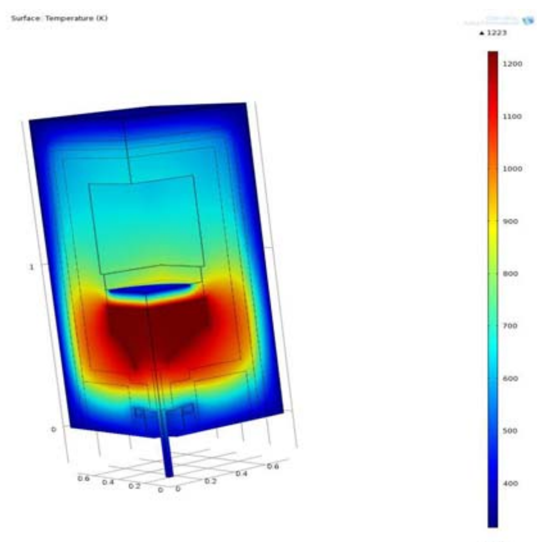

Fig.4 Temperature contour plot of JHCM (glass pool temperature of 1223 K)

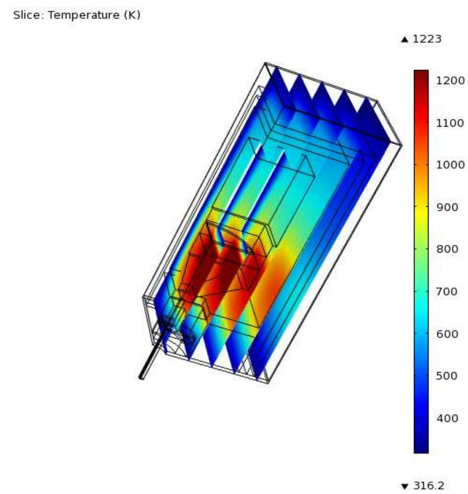

Fig. 5 Slice plot of Temperature contour plot of JHCM (glass pool temperature of 1223 K)

Steady State temperature variations at mid height location of main electrode (for no glass draining) from inside glass pool to the melter outer surface for AVS is shown in Figure 6.

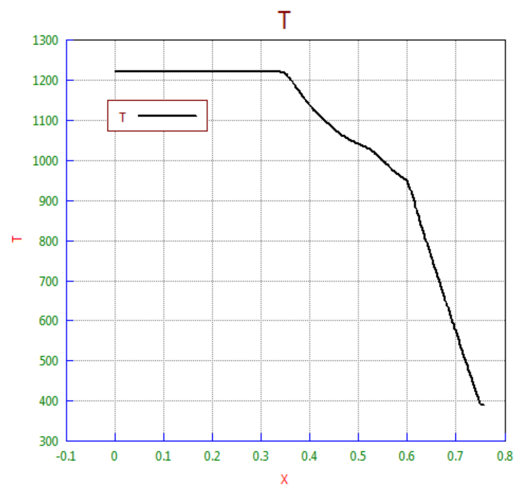

Fig.6 Temperature variation at mid height location of main electrode of JHCM

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3. Shri Umesh Dani, Shri Sangam Gupta and Shri K. Banarjee, NRG- Private communication, 2010.