Thermal Analysis of Electrorefiner for Engineering Scale Pyroprocessing Studies

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Abstract: A heat transfer analysis of the Electrorefiner cell was conducted to develop a basic tool for designing of the engineering –scale Electrorefiner. COMSOL 3.5a commercial code was used for this purpose. The simulation model was prepared, and the temperature profiles of the cover gas and the molten salt were compared with those in the Engineering scale Electrorefiner cell.

Keywords: Pyroprocessing, Electrorefiner, Heat transfer, COMSOL.

1. Introduction

Pyrochemical process based on molten salt electrorefining is ideally suited for reprocessing spent metallic fuels from Fast Breeder Reactors. This technique can be used for reprocessing short cooled, high burn-up and high plutonium containing fast reactor fuels. Other advantages of the process over the counterparts based on aqueous reprocessing methods are: higher proliferation resistance, more compact plant, less criticality problems and easier waste management. With a view of developing the Pyrochemical reprocessing method, an engineering scale demonstration facility has been set up in which studies on 1-2 kg of metal can be carried out. An electrorefiner has been incorporated in the facility. The electrorefiner comprises of a process crucible, main vessel, cover plate, three electrodes, stirrer and a heater assembly. Molten salt is used as the electrolyte in the electrorefining process to be carried out at high temperature.The electrorefiner will be maintained under inert atmosphere. The heat input into the Electrorefiner is through a resistance heater. The design requirement of the equipment is such that the molten salt temperature at all places should be above 500 °C and the structural temperature is within their design temperature. To achieve this design requirement, extensive thermal analysis of Electrorefiner was carried using COMSOL 3.5a software. Schematic drawing of Electrorefiner is shown in Figure 1.

The focus of this paper is to find out steady state temperature profiles of cover gas and molten salt, and top flange temperature of Electrorefiner.

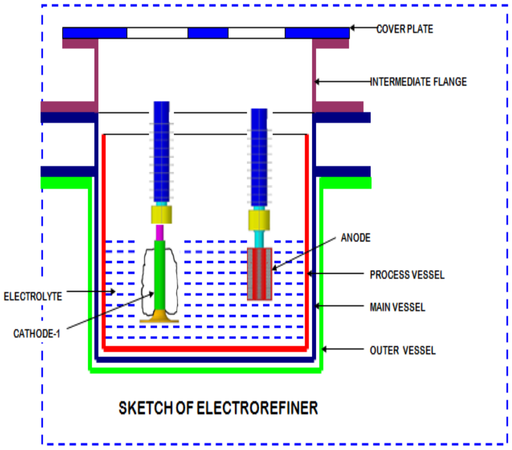

Figure.1. Schematic Electrorefiner

2. Mathematical modeling

The simulation of heat transfer from the heating zone to the inert gas phase and molten salt was carried out. Under steady state mode, temperature gradients of the inert gas and molten salt in the Electrorefiner cell were calculated. Most of the parts of Electrorefiner are axially symmetrical and so thermal analysis of Electrorefiner is done in 2-D axial symmetrical model. Fig.2 shows the axial symmetrical model of Engineering Scale Electrorefiner.

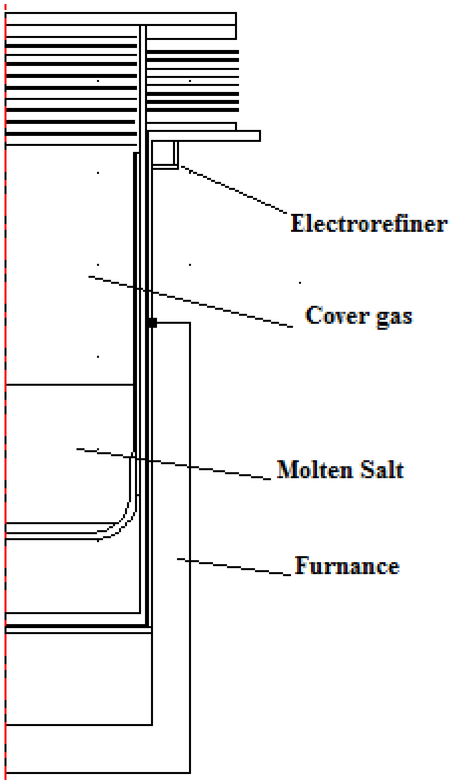

Figure.2: Axis symmetry model of Engineering Scale Electrorefiner.

In the simulation all three mode of heat transfer Conduction, Convection and Radiation were tried to modeled. Conductive heat transfer is model by using general form of conduction equation

$$\nabla.(k\nabla T) = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

For axial symmetrical model the above equation is written as

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}(KT)\right)+\frac{\partial^2}{\partial z^2}(KT)=0 \ \ldots \ (2)$$

The heat transfer from surface of molten salt to top flange of Electrorefiner due to convection in cover gas is modeled using

$$Q = K \times \varepsilon \times A \times \frac{dT}{dx} \ \ldots\ldots\ldots\ldots\ldots \ (3)$$

Where, ε is the factor to account the natural convection heat transfer. ε is calculated using following correlation:

$$\varepsilon = 0.4 * (GrPr)^{0.2} \quad \ldots\ldots\ldots\ldots..(4)$$

$$Gr\,\mathrm{Pr} = \frac{\beta g H^3 \Delta T}{\left(\frac{\mu}{\rho}\right)^2} \times \frac{\mu C_P}{\kappa} \ \ldots\ldots\ldots..(5)$$

$$\beta = \frac{1}{T_{avg}}, \quad \ldots\ldots\ldots\ldots\ldots \ (6)$$

Where, T_{avg} is the average temperature of cover gas. All the properties of cover gas in eq.4 in evaluated at $T_{avg.}$ In this model ε value was calculated to be 16.

The radiation heat transfer is included in the model by applying radiative heat transfer on the interior and exterior boundaries of Electrorefiner.

The furnace temperature is fixed at 600°C and the ambient temperature is assumed to be around 30°C.

3. Results

The calculated temperatures in the simulation were compared with the temperature measured from the engineering scale Electrorefiner. Figure 3 shows the temperature distribution in the Electrorefiner obtained from the model using COMSOL 3.5a commercial software. Temperature in engineering scale Electrorefiner is measured in three locations i.e top-flange, cover gas and salt bath. Table 1 shows the comparison between the measured temperatures with the temperature obtained from the simulation.

Table 1: Comparison between temperatures obtained from experimental measurement and simulation.

Location	Experimental	Simulation
Top flange	70	75
Cover gas	327	331
Salt bath	405	410

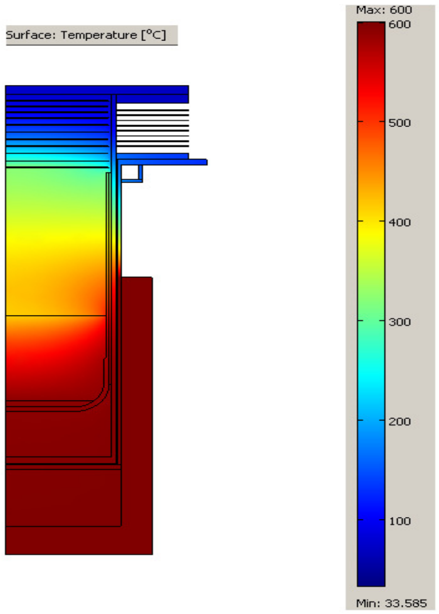

Figure .3.Steady state Temperature distribution

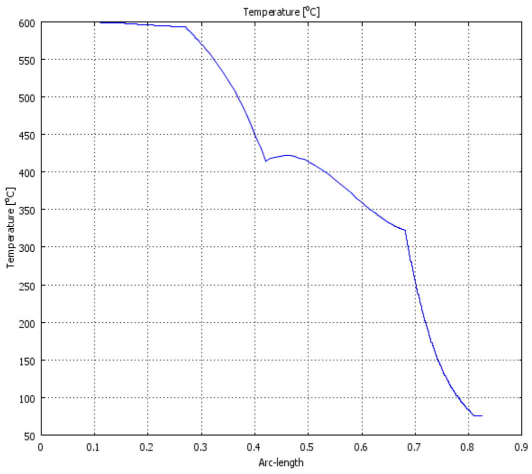

Figure.4. Temperature drops in axial direction from bottom to top.

Figure 3 shows the steady state temperature distribution of engineering scale Electrorefiner. The axial temperature drop of the Electrorefiner is shown in Fig.4.

4. Conclusions

- Thermal analysis of engineering scale Electrorefiner using COMSOL code has helped to find out the steady state temperature distribution of Electrorefiner. The temperature obtained from simulation showed good agreement with the measured temperature during experiments.

8. References

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