Electro-magnetic and Thermal Fluid Dynamics Analysis of NKK Electric Resistance Ash Melting Furnace

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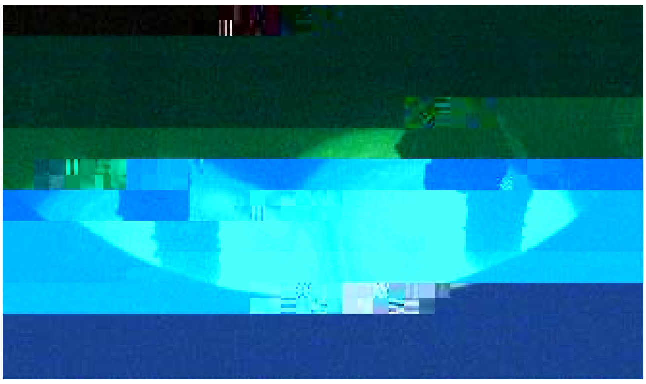
To clarify the temperature distribution and slag flow in the NKK electric resistance ash melting furnace, experiments were carried out using a small-scale furnace as well as computational analysis of the electromagnetic field and thermal fluid dynamics of the slag. The results obtained by the experiment and computational analysis were in good agreement. Ash charged into the furnace is heated by the Joule heat generated near the electrode, and heated slag rises along the electrode due to reduced density and resultant buoyancy. When the slag reaches the surface of the slag bath, it flows in the radial direction away from the electrode. The buoyancy was found to be the major driving force of the slag flow in the bath.

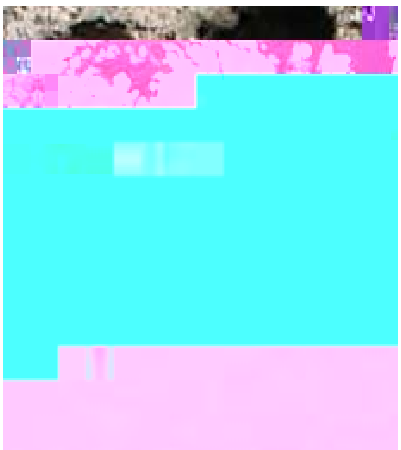
1. Introduction

Melting treatment of bottom ash and fly ash generated from waste incinerators has good potential for rendering them harmless and recyclable[1]. NKK commercialized the electric resistance furnace that melts incinerator bottom ash and fly ash using the Joule heat generated by applying an alternating electric field to slag (**Fig.1**)[2].

Fig.1

nipulated in the vertical direction. Two or three electrodes were used for applying 3-phase alternating current of up to 100 kW. For treating off gas, a post combustion chamber and spray chamber were equipped. Two types of bottom ash having the basicity (CaO/SiO_2) of 0.3 and 0.6 respectively were mainly used. Blast furnace slag was used for changing the basicity. A certain amount of ash was charged from the top of the furnace continuously. In order to allow the flow pattern of molten slag to be observed, the experiment was carried out in ambient atmosphere while purging the inside of the furnace by N_2 gas to suppress oxidation corrosion of the furnace body and electrodes. The slag temperature measured by a thermocouple was typically around 1400





3. Electro-magnetic and thermal fluid dynamics analysis

In the NKK electric resistance ash melting furnace, molten slag acts as an electrical conductor. Three electrodes supply the slag with three-phase alternating electric power and the slag is directly heated and melted by the Joule heat generated in the slag. The slag behavior in the furnace was investigated by applying electromagnetic and thermal fluid dynamics analysis with the procedure shown in **Fig.5**.

The procedure of the calculation algorithm was as follows.

(1) The electromagnetic field in the molten slag was analyzed by the A- φ (magnetic vector potential-electromagnetic potential) method using MAGNA-FIM (a general-purpose calculation code for electromagnetic analysis). As the induced electromotive force was found to be negligible as stated later, the generalized transport equation in FLUENT (a general-purpose calculation code for thermal fluid dynamics analysis) was used for calculating the distribution of electric potential for the sake of calculation efficiency.

(2) Next, the electric current density and the Joule heat were calculated from the distribution of electric potential. Using these values, thermal fluid dynamics in the molten slag were analyzed using FLUENT.

In this procedure, the values of electric conductivity and other temperature-dependent properties obtained by MAGNA/FIM or FLUENT were modified and converged based on the temperature distribution calculated by FLUENT.

3.1 Electromagnetic analysis

The electromagnetic field in the molten slag in the ash melting furnace is expressed by Equations (1) to (4) based on the Maxwell’s equations. Since the NKK ash melting furnace uses a low-frequency po

$$\mathrm{div}\,\sigma\ \ \mathrm{grad}\,\varphi = 0 \qquad \cdots\cdots (11)$$

When the value of σ does not change in accordance with the position in the slag, this equation becomes the Laplace equation.

The electric potential φ is calculated by numerical analysis using the analytical function of the generalized transport equation in FLUENT applying Equation (11) as the fundamental equation for the sake of calculation efficiency.

Electric boundary conditions were set as follows. For the electric potential on the surface of electrodes, $\varphi = \varphi_0$ was given taking into account the phase voltage of each

4. Results of electromagnetic and thermal fluid dynamics analysis and discussion

The distribution of equipotential surfaces in the cross section of the slag bath obtained by electromagnetic analysis is shown in **Fig.7**. The electric potential is high in the vicinity of the electrode, and becomes lower with increasing distance from it. The equipotential surfaces show a shell-like distribution surrounding the electrode. The gradient of the electric potential is high near the electrode, particularly near the tip of the electrode.

Fig.7 Distribution of electric potential in the slag bath

The distribution of electric current density vectors in the slag bath is shown in **Fig.8**. The electric current density vectors run in the radial direction out of the electrode. The vectors are particularly large near the tip of the electrode. Since these vectors are normal to the equi-potential surfaces, the area where the equi-potential surfaces are densely located in **Fig.7** corresponds ttie9[gs8Goss 9[ial ssd5ity b54(l)-0.6(ag b)4.-13.4T8 1 Tf8.9985 0 0