Thermal Radiation towards the Sideledge in Alumina Reduction Cells

Asbjørn Solheim[1], Henrik Gudbrandsen[2]
Nils-Håvard Giskeødegård [3], Steinar Kolås [3], Eirik Manger [3] and Nancy J. Holt [4]
1. Chief Scientist
2. Research Engineer
SINTEF Materials and Chemistry, Trondheim, Norway
3. Principal Engineer
4. Manager External R&D (nancy.jorunn.holt@hydro.com)
Hydro Aluminium AS, Primary Metal Technology, Øvre Årdal, Norway
Corresponding author: asbjorn.solheim@sintef.no

Abstract

When performing energy balance calculations for aluminium electrolysis cells, it is often found that the computed superheat is higher than the measured superheat. The deviation can be explained by thermal radiation between the interior of the cell and the sideledge, effectively increasing the heat transfer coefficient. As it appeared that radiation through molten fluorides has never been directly observed, an apparatus was designed for detecting temperature variations when thermocouples were exposed to or shielded against radiation from a heating element placed in a crucible containing industrial bath. CFD calculations indicated that the recorded temperature would be little influenced by changes in the convection pattern upon shifting the radiation shield, while a temperature response in the order of 1 °C due to radiation could be expected. The estimates were confirmed by experiments. The recorded temperature responses were in the range between 0.5 °C and 2.5 °C depending on the power in the heating element. The results strongly indicate that radiation through the bath indeed takes place, but neither calculations nor experiment are accurate enough to allow for determination of emissivities or attenuation coefficients. The effect on the heat transfer coefficient may be up to 400 $Wm^{-2}K^{-1}$.

Key words: Heat transfer in aluminium electrolysis cell; radiation from bath to sideledge; heat transfer coefficient from bath to sideledge.

1. Introduction

There have been a number of studies concerning heat transfer between bath and sideledge in aluminium reduction cells. Today, it is fairly well established that the convective heat transfer coefficient (h) is 700 - 1000 $Wm^{-2}K^{-1}$ [1 - 4]. The heat transfer coefficient, the heat flux between the bath and the ledge (q), and the superheat (ΔT, difference between the bath temperature and the liquidus temperature) are related by the well-known equation

$$q = h\Delta T \tag{1}$$

The superheat is measured routinely in most aluminium companies. The heat flow can be found by measurement as well as by modelling. By calculating "backwards" from a given heat flow, it often turns out that the measured superheat is lower than the computed superheat. There is no specific reason to believe that there are systematic errors in the superheat detection, which indicates that the heat transfer coefficient must be higher than what was used in the superheat computation [5].

A possible explanation for this "superheat enigma" would be that the heat transfer coefficient is influenced by thermal radiation between the sideledge and the interior of the cell, which was earlier suggested by Gan and Thonstad [2]. On this background, it was decided to design a simple experiment for detection of radiation through molten cryolitic bath. The experimental details and the results obtained are reported in the present paper.

2. Theory

2.1. Radiation Intensity and Transparency

Infrared radiation can be defined as electromagnetic waves with wavelengths above 700 nm. The intensity of radiation from a black body is governed by Planck's law, which relates the intensity of radiation and the wavelength (or frequency) at different temperatures. A graphical representation of Planck's law is shown in Figure 1. The maximum intensity at 1000 ºC is at about 2000 nm.

Radiation between two surfaces can take place only if the intermediate medium is transparent to radiation within the actual range of wavelengths. Some data concerning the transparency range for solid compounds relevant for the aluminium electrolysis are shown in Table 1. As can be observed, most of the compounds are transparent in the entire range of wavelengths shown in Figure 1. There is no specific reason to believe that the transparency disappears upon melting; *e.g.*, it is well known that molten cryolite is "as clear as water". Therefore, the data in Table 1 strongly indicate that industrial bath will be transparent to heat radiation.

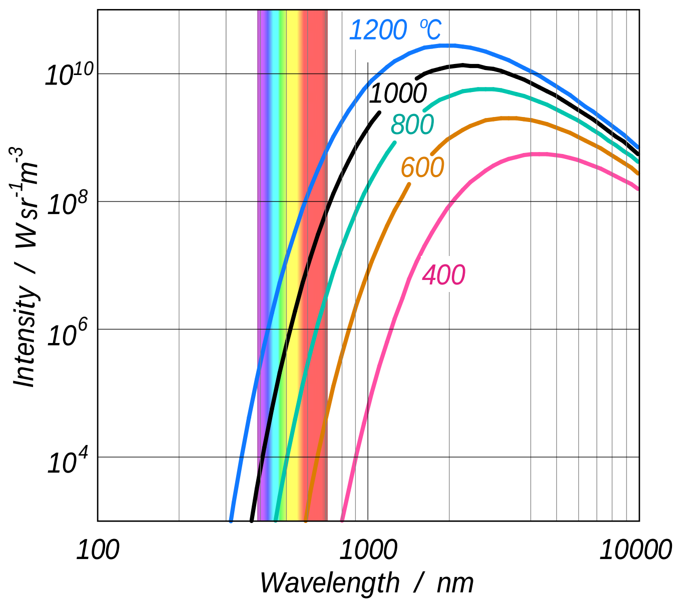

Figure 1. Radiation intensity as a function of the wavelength. Visible light is in the range of 390 - 700 nm.

Table 1. Transparency range for some relevant solid compounds. Data taken from Merck [6].

Compound	Formula	Transparency range
Alumina	Al_2O_3	200 - 5 000 nm
Aluminium fluoride	AlF_3	150 - 10 000 nm
Chiolite	$Na_5Al_3F_{14}$	200 - 14 000 nm
Cryolite	Na_3AlF_6	200 - 14 000 nm
Magnesium fluoride	MgF_2	150 - 7 000 nm

6. Acknowledgement

The present work was supported by the project "Superior Technology for Energy Efficient Aluminium Production" (STEP), financed by Hydro Aluminium and the Research Council of Norway. Permission to publish the results is gratefully acknowledged.

7. References

1. K.J. Fraser, M.P. Taylor, and A.M. Jenkin, Bath Heat Transfer and Mass Transport Processes in H-H Cells, *Light Metals* 1990, 221-226.
2. Y.R. Gan and J. Thonstad, Heat Transfer between Molten and Solid Cryolite Bath, *Light Metals* 1990, 421-427.
3. V.A. Khoklov, E.A. Filatov, A. Solheim, and J. Thonstad, Thermal Conductivity in Cryolitic Melts - New Data and Its Influence on Heat Transfer in Aluminium Cells, *Light Metals* 1998, 501-506.
4. A. Solheim, Some Aspects of Heat Transfer in Aluminium Reduction Cells, *Light Metals* 2011, 381-386.
5. Personal communication (2015), personnel at Primary Metal Technology, Hydro Aluminium.
6. Merck Evaporation Materials Product Catalog 2014, 8-9, http://cc-special.merck.de/pm/Evaporation_Materials_Product_Catalog/index.html#p=1
7. R.B. Bird, W.E. Stewart, and E.N. Lightfoot, *Transport Phenomena*, John Wiley & Sons, Inc., 1960.
8. S.W. Churchill and H.H.S. Chu, Correlating Equations for Laminar and Turbulent Free Convection from a Vertical Plate, *Int. J. of Heat and Mass Transfer* **18**(11), 1323-1329 (1975).
9. I. Martinez, Radiation View Factors, http://webserver.dmt.upm.es/~isidoro/tc3/Radiation%20View%20factors.pdf