Liquid Metal Batteries as a Power Buffer in Aluminium Production Plants

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Abstract

A new type of liquid metal battery based on sodium and zinc is described. One possible use of such a battery is as a power buffer in an aluminium plant, thus enabling extreme power cycling. By locating the battery in an idled potline, existing infrastructure such as buildings, rectifiers, potshells, and busbars can be utilised. The reversible voltage of the battery is about 1.9 V, and it is suggested to place three battery stacks connected in series to 5.7 V in each potshell of the idle line. By limiting the voltage loss in the electrolyte to 0.15 V per stack at 250 kA, it was estimated that the battery capacity could be about 2.40 MAh, corresponding to 250 kA for 9.6 hours. Provided that the electrolyte height constitutes 50 percent of the total, the stack height will be less than 1.4 m, which can easily be accommodated inside a potshell.

Keywords: Liquid metal battery, aluminium cell, power cycling.

1. Introduction

Rechargeable liquid metal batteries (LMBs) are based on two liquid metals separated by a molten salt [1]. LMBs are attractive due to rapid kinetics, high electrolyte conductivity, only liquid phases (no dendrite formation), and potentially cheap and abundant materials. A new type of membrane free LMB has been suggested [2]. The concept utilises sodium and zinc, while the electrolyte is a ternary mixture of sodium chloride, zinc chloride, and calcium chloride. The battery is intended for use in stationary applications, *e.g.*, for compensation of variable electric power consumption and production in an electric grid based on other energy sources than hydropower, thereby serving to stabilise the grid.

A use case that seems well suited relates to the energy-intensive production of primary aluminium. In many regions, the spot price of electricity varies significantly with time (season, week, day, and hour). Taking Germany as an example; even strongly negative electricity prices have been observed occasionally [3]. Therefore, some aluminium plants are preparing for, experimenting with, and even practising power-cycling (power modulation), *i.e.*, operating the electrolysis cells with reduced power during hours with high energy prices, and increasing the power when the price is low. The energy balance of the electrolysis cells is very delicate however, and the energy window for safe operation is narrow, although variable cooling of the cell sides can be used as a means of increasing the window for power-cycling [4].

The use of an LMB can potentially be an extremely effective strategy for increasing the power-cycling window. The power variation would then be handled by the battery, and not by the electrolysis cells. There are no principal limitations in this type of power-cycling; the only restriction will be the installed battery capacity.

According to data compiled by Pawlek [5], 6.5 Mt/y of the World's total aluminium capacity of 79 Mt/y is idled (2016). Although this includes a number of plants that are entirely closed, it also means that many plants are operating with one or more shut down potlines. There are a few additional advantages by locating the LMB in a partly closed aluminium plant:

- The building infrastructure is already there.
- The electric bus bars are present.
- The battery can be located in vacant cell positions, perhaps inside electrolysis cell potshells, as was presumed in the present work.
- The rectifier and other electrical infrastructure is in place and may be used as-is or with modifications for charging the battery.
- The personnel in the aluminium plant are aware of and trained for the risks related to handing of liquid metals and molten salts.

3. Principle of the Liquid Metal Battery

A principle sketch of the LMB is shown in Figure 1. The battery contains zinc and sodium, separated by an electrolyte consisting of zinc chloride, sodium chloride, and calcium chloride. The electrolyte is divided in two parts by means of a diaphragm. Detailed descriptions are found below.

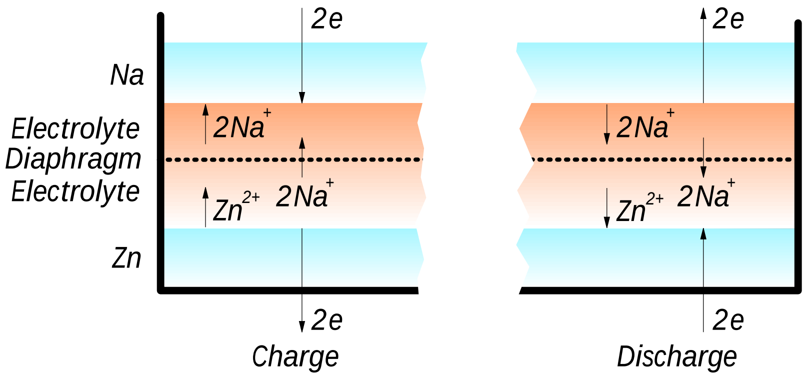

Figure 1. Principle of the liquid metal battery.

3.1. Electrode and Cell Reactions

The electrode reactions (during discharge) are as follows:

$$\text{Sodium electrode}: \quad 2\,\text{Na} + 2\,\text{Cl}^- \rightarrow 2\,\text{NaCl} + 2\,\text{e} \tag{1}$$

$$\text{Zinc electrode}: \quad \text{ZnCl}_2 + 2\,\text{e} \rightarrow \text{Zn} + 2\,\text{Cl}^- \tag{2}$$

The cell reaction is the sum of the two electrode reactions,

$$2\text{Na} + \text{ZnCl}_2 \overset{2\text{F}}{=} 2\,\text{NaCl} + \text{Zn} \tag{3}$$

The standard cell voltage for this reaction (E^0, based on Gibbs energy) and the isothermal voltage (E^{iso}, based on the enthalpy change) are +1.914 V and +2.170 V at 600 °C, respectively [6]. The reversible voltage (E^{rev}) is related to the activities of the substances in Equation 3:

$$E^{rev} = E^0 - \frac{RT}{2F} \ln\left(\frac{a_{NaCl}^2 \cdot a_{Zn}}{a_{ZnCl_2} \cdot a_{Na}^2}\right) \tag{4}$$

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7. References

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