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Review Article

Molten carbonates for advanced and sustainable energy applications: Part II. Review of recent literature

S. Frangini [a,*], A. Masi [a,b]

[a] DTE-PCU-SPCT, ENEA CR Casaccia, 00123 Rome, Italy
[b] DAFNE, University of Tuscia, Via San Camillo de Lellis snc, 01100 Viterbo, Italy

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ABSTRACT

Unprecedented interest for clean and sustainable energy innovation has recently stimulated a return of attention on molten alkali carbonate salts not only for traditional use as electrolyte and high temperature reaction media but also as innovative energetic material for advanced applications in hybrid fuel cell systems and high-temperature CO_2 gas separation processes. The main focus of this literature review is on examining novel and emerging molten carbonate applications in energy sectors beyond the well-assessed and mature domain of the Molten Carbonate Fuel Cells. In general, a number of advanced processes and highly functional materials are currently under investigation involving molten carbonates in a key role, suggesting a high potential of these salt systems for the future development of sustainable energy technologies. Current research activities can be grouped into three main energy research areas related to generation/conversion/storage of energy, materials and manufacturing processes, hot gas processing and gasification technologies. As already analyzed in Part I of this work, notable features of molten carbonates include their chemical stability, safety and optimal performance under a wide range of moderate (500–600 °C) and moderate-to-high temperature (600–800 °C) conditions. Thanks to these peculiar aspects, molten carbonate processes can be ideally integrated with solar energy sources for maximum sustainable level of use and with broad development prospects in the storage of solar energy and solar-to-chemical conversion systems. This view is confirmed, for example, by a series of extensive studies that has recently investigated novel solar-to-chemical energy conversion strategies based on a molten carbonate electrolysis process for solar production of fuels and other important chemical products, including iron and cement. In the last part of this work, several directions and opportunities for future research and studies on molten carbonates are suggested.

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* *Corresponding author*. Fax: +39 06 30486357.
E-mail address: stefano.frangini@enea.it (S. Frangini).

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Contents

Introduction

Application of Molten Alkali Carbonate (MAC) salts in various key sectors of sustainable energy development is a research area of growing interest, although still relatively overlooked. In the last years, interest for MAC salt research is slowly expanding beyond the traditional area of Molten Carbonate Fuel Cells (MCFCs) [1] to embrace many important and advanced areas of modern energy research, including the broad and complex area of sustainable energy as witnessed by a stream of journal articles and book chapters (see, for instance [2–4]) that have been published on the theme over the past few years. The recent launch of a new series of biennial international workshops (IWMC, International Workshop of Molten Carbonates and Related Topics) is a further sign on the growing attention for molten carbonates in the emerging arena of sustainable and advanced energetic technologies.

Thus, by way of example, the unique ability of MAC salts to naturally absorb CO_2 makes them very interesting systems for capture and chemical conversion of CO_2 via molten carbonate electrolysis as suggested by Cassir and co-workers [5]. As a further example, the possibility of using MAC salts as efficient electrolytes for converting, storing and harvesting the renewable energy produced by high temperature solar power sources such as Concentrating Solar Power (CSP) plants is another field of research with a tremendous potential growth. For example, according to a series of recent studies conducted at The George Washington University [6–10], solar-integrated molten carbonate electrolysis processes seem to have a much future promise for a really sustainable production of fuels, chemicals and commodity products, including strategic commodities like iron and cement.

Thus, as a contribution to move beyond the traditional view that molten salts belong to a general class of complex, reactive or corrosive chemical systems, Part I of this study [11] has in detail analyzed the most relevant MAC salt properties, notably from a sustainability point of view and shown to be largely superior with respect to other common molten salts in providing an efficient, benign and stable high temperature liquid chemical system. Our analysis supports the view of molten carbonate salts as a good choice for implementing a potentially sustainable molten salt technology with high application versatility and functionality under a wide range of moderate-to-high temperatures. MAC salts are being primarily investigated as electrolyte, reaction and synthesis media, although other emerging application areas include their uses as solar thermal storage material or as highly functional material for advanced composite high-ionic conductors in gas separation membranes or hybrid fuel cell systems. The current body of literature dealing with novel energy uses of molten carbonates is not vast and it is also dispersed on many different energy-related areas of current or potential future interest. Review studies covering all the current research activities are not available in literature. Therefore, it is purpose of Part II of this study to fill this gap offering a broad coverage across all the ongoing research activities, in which MAC salts are involved, with exclusion of MCFC research, which is nowadays a well mature field of activity.

Molten alkali carbonates for sustainable energy applications

Fig. 1 presents a summary of recent research activities involving sustainable use of molten carbonates that, for sake

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