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Thermal resistance of solar volumetric absorbers made of mullite, brown alumina and ceria foams under concentrated solar radiation

F.A.C. Oliveira[a,*], J.C. Fernandes[b], J. Galindo[c], J. Rodríguez[c], I. Canãdas[c], L.G. Rosa[b]

[a] LNEG – Laboratório Nacional de Energia e Geologia I.P., LEN, Laboratório de Energia, UER – Unidade de Energias Renováveis e Integração de Sistemas de Energia, Estrada do Paço do Lumiar, 22, 1649-038 Lisboa, Portugal

[b] UL – Universidade de Lisboa, IST – Instituto Superior Técnico, DEM – Departamento de Engenharia Mecânica, IDMEC – Instituto de Engenharia Mecânica, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

[c] PSA - Plataforma Solar de Almería, CIEMAT - Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Apartado 22, E-04200 Tabernas (Almería), Spain

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ABSTRACT

Three semi-closed open cell ceramic foams, namely mullite, brown alumina and ceria-based materials, were subjected to thermal cycles by direct concentrated solar irradiation to study their thermal resistance in view of their potential application as photothermal devices, such as volumetric solar absorbers. After cycling, the extent of the damage in the samples was determined by measuring the retained crushing (compressive) strength. The extent of the damage was found to depend on the composition, the applied surface temperature difference (ΔT) of thermal cycling and the temperature gradient across the foams. It was found that the retained crushing strength gradually decreased with an increase in ΔT and was independent of the number of thermal cycles in the range investigated. The ceria foams displayed the poorest thermal shock resistance. Experimental data fit the Gibson-Ashby model for the thermal shock resistance of ceramic foams, for a constant C = 0.65.

1. Introduction

Solar radiation is a clean, renewable energy resource which can be converted into process heat and chemical fuels. The conversion of solar radiation into usable energy is quite an engineering challenge, as the maximum direct incident radiative flux is merely of 1 kW m^{-2} [1]. The systematic development of four types of solar concentrating systems, namely parabolic trough, power tower, parabolic dish and double concentration, has led to their increasing efficiency in converting concentrated solar thermal energy into process heat, chemical fuels and electricity in a conventional steam turbine [2,3]. This typically requires increasing operating temperatures as well as new materials and designs resistant to high thermal stresses [4]. Providing solar heat at increasingly higher temperatures (up to 1000 °C) faces significant challenges, such as refractory materials for high temperatures, optics for high concentration and optimization of radiative and convective heat transfer in the solar receiver and/or reactor in order to minimize heat losses [5,6]. A key component in the solar thermal conversion process is, therefore, the radiation absorber media also known as receiver. Solar receivers are classified into three groups: (a) surface receivers (external, tubular, cavity), (b) porous receivers (wire mesh, honeycombs, metallic or ceramic foam structures) and (c) particle receivers (entrained particles, falling curtain). Several materials have been investigated for such purpose since the 80s [7]. The most promising ones are porous materials whose application in solar energy systems has been recently reviewed [8]. Reticulated porous ceramic (RPC) or ceramic sponges (i.e. open-celled foams) belong to the class of the cellular materials. The term “foam” stands for cellular materials obtained by foaming of liquids. However, when the solid phase of the open-cell network structure is present only in their struts, these foams are termed reticulated materials, i.e. a class of high-porosity (70–95%) materials. In some cases, the cells are not fully opened. These materials are known as semi-closed open cell ceramic foams. Typically, however, they are known simply as ceramic foams.

The potential application of ceramic foams is not only governed by their chemical composition, but also by the porosity characteristics, such as pore size and its distribution, specific surface area and tortuosity [9,10]. While surface area – provided by micro- (< 2 nm) and meso- (2–50 nm) pores – is essential for catalysis, macroporosity (50 nm to several mm) improves mass and heat transfer [11]. The key characteristics of ceramic foams are low pressure drop of fluids through them and higher radial heat transfer when compared to packed beds. This makes such highly porous materials suitable for solar energy systems as absorbing, heat transfer, storage, insulation and phase change

* Corresponding author.
E-mail address: fernando.oliveira@lneg.pt (F.A.C. Oliveira).

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