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Transient thermal simulation of counterflow compact recuperator partition plates

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Design of high performance recuperators is essential for hybridized Carbonate and Solid Oxide fuel cell power plants. This work is focused on the transient thermal simulation of simplified counterflow recuperator partition plates. A finite difference scheme was written to model heat transfer in two spatial dimensions and one time. Results clearly show the effect of temperature ramping rate on transient thermal behavior. Excessive thermal stress derived from transient operation has been a crucial mode of structural degradation for conventional gas turbine recuperators. Results show that harmful temperature gradients in recuperator plates during transient operation is minimal for high temperature fuel cell ramping rates compared to conventional gas turbine ramping rates. Based on this analysis it is suggested that employing slower temperature ramping permits the use of higher performance recuperators. Stress analysis results from another study affirm this declaration, as well as suggest that plastic strain damage incurred from transient operation may be ignored when determining recuperator service life if its temperature ramping rates are consistent with hybrid fuel cell and gas turbine systems.

1. Introduction

Fuel cell technology has been identified to meet simultaneous demands for more electric power and less pollution. In particular, high temperature fuel cells can utilize existing natural gas infrastructures effectively. Carbonate and Solid Oxide fuel cells operate at high temperature and reject a significant amount of heat so that hybridized fuel cell and gas turbine (FCGT) power plants are under investigation. Ultra high fuel to electricity conversion efficiencies (>70% LHV) of such designs have been projected [1].

On the other hand, high temperature fuel cell systems have much lower power density than competing gas turbine systems, turning recuperator size into an ever more critical issue. Many hybrid FCGT system designs also require a recuperator constructed out of an expensive high temperature alloy, further necessitating optimal performance. Furthermore, to achieve an overall system efficiency of >70% low recuperator pressure drops are generally required, initiating more challenges to creating a compact design.

Compact heat exchangers offer the ability to transfer heat between large volumes of gas with minimum footprint, i.e. minimum area requirement to accommodate the heat exchanger. A gas to fluid exchanger is considered compact if it has a heat transfer area to volume ratio greater than 700 m^2/m^3 on at least one of the fluid sides, Shah [2]. Compactness is a good indication of performance, the higher the compactness generally the higher the effectiveness for a given pressure drop, Oswald [3]. High compactness is desirable for performance, although increased compactness yields increased thermal stress, which can reduce recuperator life, Voss [4]. However, it is shown by the present work that when employing temperature ramping rates consistent with high temperature fuel cells, a recuperator with higher compactness and equal pressure drop can be designed to increase recuperator performance without reducing its service life.

2. Compact heat exchanger technology

For this work, compact heat exchanger technology (CHEX) applicable to hybrid fuel cell and gas turbine technology was extensively reviewed. Comparison of (i) brazed plate-fin, (ii) fin-tube, (iii) microchannel, (iv) primary surface and (iv) spiral designs was performed by rating each exchanger type with a set of essential criteria. Based on this rating procedure two CHEX designs namely, plate-fin and microchannel, were chosen for further review for the FCGT application. Counterflow recuperator size and configuration was evaluated by assuming a CHEX core constructed with the same fin geometry for both hot and cold fluid sides. Plain, strip, louver, and wavy plate-fin surfaces as well as the semicircular (printed circuit) microchannel surface were considered in this performance evaluation. All surface candidates and their properties geometrical and thermal-hydraulic were taken from the extensive

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