Applied Thermal Engineering 45-46 (2012) 42–51

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Thermodynamic optimization of a regenerator heat exchanger

L.S. Martins [a], J.C. Ordonez [a], J.V.C. Vargas [b,*], J.A.R. Parise [c]

[a] Center for Advanced Power Systems, Florida State University, Tallahassee, FL 32310-6046, USA
[b] Departamento de Engenharia Mecânica, Universidade Federal do Paraná, C. P. 19011, Curitiba, Paraná 81531-980, Brazil
[c] Departamento de Engenharia Mecânica, Pontifícia Universidade Católica, Rio de Janeiro, RJ 22453-900, Brazil

ARTICLE INFO

Article history:
Received 7 January 2012
Accepted 5 April 2012
Available online 14 April 2012

Keywords:
Constructal theory
Ejector refrigeration system
Regenerators
Volume element method

ABSTRACT

This paper introduces a general computational model for regenerators fed by a hot fluid stream on one side, whereas the other side is a fluid mixture, in which one of the components (refrigerant) undergoes a phase change. A simplified physical model, which combines fundamental and empirical correlations, and principles of classical thermodynamics, mass and heat transfer is developed and the resulting three-dimensional differential equations are discretized in space using a three-dimensional cell centered finite volume scheme. The proposed model is used to simulate numerically the behavior of the regenerator working under different operating and design conditions. Mesh refinements are conducted to ensure the convergence of the numerical results. The proposed methodology is shown to allow a coarse converged mesh for all simulations performed, therefore combining numerical accuracy with low computational time. The model was then used to determine optimal parameters for a specific geometric configuration of the regenerator, finding that the two-way maximized efficiency operating with optimal porosity and dimensionless mass flow rate of liquid ammonia, is $\eta_{max,max} = 45.5\%$ for the optimal pair $(\phi, \tilde{m}_s)_{opt} = (0.5, 0.01)$. As a result, the model is expected to be a useful tool for simulation, control, design, and optimization of regenerators for heat driven refrigerators.

1. Introduction

Utility companies worldwide acknowledge that heating, ventilation, air conditioning and refrigeration (HVAC-R) systems are responsible for roughly 30% of total energy consumption, including the domestic, commercial and industrial sectors [1], therefore unquestionably with a major impact on energy demand. Researchers in many countries have been involved in developing refrigeration systems that deal with the drawbacks of conventional systems.

Economic and environmental considerations brought a new point of view about refrigeration supplied by renewable heat sources. The international refrigeration industry has been investing considerable resources in that direction [2–13]. For example, an absorption system or ejector cooling system driven by waste heat designed adequately could supply the requirement of oil platforms or refineries in regard to refrigeration and air conditioning.

Absorption and ejector refrigeration systems can compete with compression technology in some applications. Also due to the use of cogeneration systems with turbine and gas engines in industrial sectors, interest has increased in cooling machines which use residual heat [14]. Development of these machines requires high efficiency in the heat and mass transfer processes which take place in the absorber, which in turn is the most important component in these systems [15,16].

Constructal theory originated within the field of heat transfer [17,18] and has grown into a branch of thermodynamics that deals with engineering design. System configuration is obtained from minimization of resistance (to flow, to heat transfer). In this paper the regenerator is thermodynamically optimized as a result of the balance of competing factors along the lines of other previous studies [19].

A number of papers related to thermodynamic optimization of regenerator heat exchangers can be found in the literature [20–32]. Devices studied include rotary [20–24] or periodic-flow [25,26] regenerators, moving bed heat exchangers [27], and their applications to gas turbines [28] and Stirling engines [29], as well as Stirling-cryogenic [30] and pulse tube refrigerators [31,32]. These optimization efforts involved the determination of the following optimal values and objective functions: optimum channel length and operating period for maximum second-law efficiency [20], and how the latter is affected by heat conduction in the regenerator matrix and unbalanced heat-capacity rates [21]; optimum operational conditions for maximum thermal effectiveness of an air-to-

* Corresponding author. Tel.: +55 41 3361 3307; fax: +55 41 3361 3129.
E-mail address: jvargas@demec.ufpr.br (J.V.C. Vargas).

1359-4311/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2012.04.015