Review on Modelling Flow Through Porous Type Regenerators

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Abstract: The objective of this paper will be to review empirical parameters in modelling Stirling cycle regenerators using modelling tools like ANSYS Fluent. A porous media flow analysis is considered for study. The porous-media model in ANSYS Fluent is an equilibrium model, which assumes that the solid matrix and the fluid are in thermal equilibrium at each spatial location within the porous medium. Input Properties such as porosity, thermal conductivities and heat transfer coefficients of Solid and fluid, inertial coefficients are usually available and can be calculated analytically. The emphasis of this paper would be in understanding porous modelling using ANSYS as simulation to study Stirling Cycle regenerators to obtain close to actual results.

1.INTRODUCTION

Regenerators are the heart of the Cryocooler since a huge temperature drop occurs at the Regenerator. Hence formulation and modelling of regenerators are critical in optimizing overall performance. Simulation tools such as ANSYS Fluent and CFD are most widely used to study thermal performance. However study of regenerators requires microscopic flow analysis. Regenerators are usually porous i.e. mesh/wire screens arranged one above the other creating pores. The geometry of the pores in the regenerator matrix determines the pressure drop within the regenerator. Since pressure drop and heat transfer are coupled, a certain amount of pressure drop is required to achieve effective regeneration.

2.LITERATURE REVIEW

Regenerators are usually made of stacked woven wire screen or random fibers. Thus, most of the research studies conducted for the thermal and fluid characterization in the Stirling regenerator have mainly focused on empirical characterization. A number of studies have been conducted on the heat transfer between the matrix of the regenerator and the working gas from various points of view. Moreover, several experimental studies have been conducted in order to evaluate the heat transfer in different regenerator's matrices. Apart from the analytical studies, there are some numerical analyses of the heat transfer and pressure drop through wire screen matrix using different numerical discretization techniques. The finite volume method (FVM) appears to be promising as numerical investigation tool indicated by Rühlich and Quack [3], Gedeon and Wood [5], Ibrahim et al. [4], Tew [6], Cheadle et al. [7], Tao et al. [8] and others. These numerical studies suggest that the fluid flow and thermal simulations are highly required to understand the flow of interest and hence to characterize fluid flow friction behavior for such systems of regenerator applications. The work of Cheadle et al. [7] outlines the development of a design tool that is capable of deriving Nusselt number and friction factor correlations based on computational fluid dynamics (CFD) analysis of a 2-D unit-cell model that considers the microscopic interactions between the fluid and solid. One important issue in the progress to improvements of Stirling models is the geometrical shape of the matrix of the regenerator since most regenerator models don't assume a precise geometrical shape for the elements of the regenerator [9]. Dydson et al. [9] indicate that the shape of the regenerator has an important impact on the overall Stirling system design.

Ahmed Alhusseny[1] presented employing porous media analysis to rotary thermal regenerators. The geometric properties of the regenerator core were transformed into the conventional porous media parameters such as the permeability and the inertial coefficient based on empirical equations; so, the core has been dealt with as a porous medium of known features. Local thermal non-equilibrium situation was assumed between both fluid and solid phases, so heat is allowed to be exchanged between them. Overall temperature effectiveness, pressure drop, and relative output power were the results presented. The use of porous media approach was found to be sufficient to solve the problem. The data obtained by the study revealed an obvious impact of the core geometrical parameters on both the heat restored and the pressure loss; and hence, the overall efficiency of the regenerator system. The problem of turbulence was solved using standard k-ε model with a high y+ treatment at the channels walls. The core permeability K and inertial coefficient F was computed according to the semi-empirical model proposed by Jeng and Tzeng [2], where their values in the transverse directions are three orders higher than them in the axial direction to allow both streams to flow unidirectional.

3.COMPUTATIONAL PRINCIPLES

3.1. Numerical methodology

The numerical methodology adopted in the previous work of the authors for the numerical resolution of pressure drop characteristics of Stirling flow is mainly under isothermal flow condition. However, S.C. Costa [10] has considered condition in which fluid is viscous, incompressible, unsteady and Newtonian 3-D flow with constant fluid flow properties. The flow was governed by continuity, momentum and energy equations. The governing equations are discretized and solved sequentially using a finite volume method (FVM) based numerical flow solver [11] with a second order upwind scheme for the discretization of the continuity, momentum and energy equations for the laminar flow solutions. The convergence criterion set for velocity and continuity components is set to 10^6, whereas it is set to 10^8 for the energy for all simulations. The time step value was taken as 0.01.

3.2. Computational domain and boundary conditions

The computational domain was constructed of non-uniformly distributed different hybrid mesh systems containing over 2.5 million tetrahedral and/or hexahedral volume cells for the final mesh system [10]. The boundaries were considered as velocity inlet boundary and pressure outlet boundary. No-slip wall boundary conditions together with the enhanced wall functions are assigned to interior wall boundaries between wires and fluid for turbulent simulation cases. Moreover, any thermal condition is assigned to the wall between the fluid and the solid matrix, and the two sides of the wall are coupled. Porous media flow was not considered and microscopic wire geometry was used for simulation. Results obtained demonstrated that this technique can be used to study the influence or effect of matrix geometrical parameters (volumetric porosity, hydraulic diameter, specific heat transfer area, etc.) to improve the woven wire matrix heat transfer mechanism. Therefore, further efforts are necessary, in order to derive more experimental data which may support the new correlations. It is very clear from here that microscopic analysis require some other technique.

A survey of the porous-media literature supports the need for thermal non-equilibrium porous-media models for thermal storage applications, as in Stirling regenerators. In Singh[12] it is noted that in a thermal storage system, heat transfer between the solid and fluid phases is a key phenomenon and both the phases are inherently in thermal non equilibrium. Hence the corresponding models of heat transfer will necessarily be of the 2-energy-equation type, one equation each for the fluid and solid phase temperature. Results obtained are 1- and 2-energy-equation temperature calculations (i.e. using thermal- equilibrium and non-equilibrium models) for steady-flow through porous-media with thermal fields which evolve with time; 1- and 2-energy-equation temperature profiles are compared for glass/water and metal/air porous-media systems over ranges of Reynolds number and porous-media flow lengths.

Amiri and Vafai[13] examined the validity of the thermal-equilibrium assumption via a one-dimensional study of incompressible flow through a packed bed. They noted that the transient response of the solid structure is crucial to the performance of packed beds when used for thermal storage applications, and the solid-to-fluid heat transfer coefficient is a major resistance to heat transfer at the interface between the fluid and the solid matrix. The “microscopic” governing equations were volume averaged over a representative elementary volume to arrive at the “macroscopic” transport equations, including separate fluid and solid phases; the resulting 1-D, incompressible, volume-averaged macroscopic equations used by Amiri and Vafai are a reduced form of the more general macroscopic equations given in the paper by Roy C. Tew[14]. Temperature differences between fluid and solid were calculated for a range of Reynolds No.’s and Darcy No.’s (dimensionless permeability). It was found that the ratio of fluid-to solid thermal conductivity was an important parameter in determining local temperature difference between fluid and solid, for a given set of operating conditions. This analysis was also for steady flow through the porous media (packed beds) with developing thermal fields.

A set of transient, compressible-flow, conservation equations is summarized for reference in defining the parameters whose values are needed for a macroscopic, thermal-non-equilibrium porous-media model[14]. Such a porous-media model is needed in existing commercial CFD codes (such as CFD-ACE and Fluent) in order to more accurately model the regenerator heat exchanger in Stirling engine devices (since only equilibrium porous-media models are now available in the Fluent and CFD-ACE codes).

CONCLUSION

1. Porous flow analysis in ANSYS is much effective and adequate for regenerator analysis compared with the microscopic mesh design analysis.
2. Porous flow analysis can be used for simulation of turbulent/oscillatory flows, incompressibility with great extent.
3. Results obtained demonstrated that this technique can be used to study the influence or effect of matrix geometrical parameters (volumetric porosity, hydraulic diameter, specific heat transfer area, etc.) to improve heat transfer mechanism.

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