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Numerical analysis of entropy generation through non-grey gas radiation in a cylindrical annulus

K. Jarray [a,*], A. Mazgar [b], F. Ben Nejma [a]

[a] Ionized and Reactive Media Studies Research Unit, Preparatory Institute of Engineering Studies of Monastir, Monastir University, Ibn Eljazar Avenue, Monastir, 5019, Tunisia

[b] Institute of Applied Sciences and Technology of Mahdia, Monastir University, 5111, Tunisia

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ABSTRACT

This study is devoted to analyze the radiative heat transfer of non-grey gas confined in a cylindrical annulus with isothermal walls. The radiative heat transfer equation is resolved through the Ray Tracing method, which is associated to the statistical narrow bands correlated–k (SNBcK) model to compute the medium radiative properties. Special focus is given on the components of radiative entropy generation and its dependency on geometrical and thermodynamic parameters. The results show that entropy generation is greatly affected by gas and wall temperatures. Moreover, the dominance between wall radiative entropy generation and the volumetric one depends mainly on differences between gas and wall temperatures.

Introduction

The study of energy utilization and entropy generation presents an important approach in thermal design and has become the main concern in many engineering applications such as solar collectors, boiler, heat exchangers, microelectronics and nuclear reactors cooling.

Many studies dealt with fluid flow irreversibility due to heat transfer and viscous dissipation. Bejan [1] studies the entropy production due to forced convection through four fundamental flow configurations. In order to minimize irreversibility due to heat transfer, he shows the great importance when choosing the corresponding flow and geometric parameters. Since then, the entropy production minimization has become one of the initial objectives in improving the efficiency of all types of thermal systems. Ko and Ting [2] analyse the entropy generation in a curved rectangular duct externally heated in forced convection. They investigate the effects of Dean Number, external wall heat flux and cross-sectional aspect ratio on entropy generation due to frictional and heat transfer irreversibilities. Mahmud and Fraser [3] analytically investigate the first and the second laws aspect of fluid flow and transfer inside a vertical channel in the presence of transverse magnetic field. They graphically present the spatial distributions of the local and the average entropy generation rate. In order to

* Corresponding author.
E-mail addresses: jarraykhouloud89@gmail.com (K. Jarray), mazgarakram@yahoo.fr (A. Mazgar), Faycal.BenNejma@ipeim.rnu.tn (F. Ben Nejma).

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reveal the thermal performance within the cylindrical annular ducts, a large number of works are done as well as the study of Tasnim and Mahmud [4] in which they propose a new correlation for computing the optimal radius ratio, analysing the entropy production through a vertical cylindrical annulus within mixed convection. Chen et al. [5] investigate the temperature distribution and entropy production for natural convection inside a vertically concentric annular space with the aid of the Lattice Boltzmann method. They present the effect of Rayleigh number, the cylindrical annulus curvature and the Prandtl number on the flow pattern, temperature distribution and entropy generation. Poddar et al. [6] study the second law analysis for a nuclear fuel element inside a concentric annular coolant passage under forced convection flow. They present and interpret the effect of Reynolds number, diameter ratio and Biot number on overall entropy generation characteristics. Yilbas [7] develops entropy analysis of concentric annuli with rotating outer cylinder, showing that the point of minimum entropy generation in the fluid moves away from the outer cylinder wall as the Brinkman number increases. Mirzazadeh et al. [8] determine heat transfer characteristics and the resulting entropy generation in purely tangential flow of nonlinear viscoelastic fluid between concentric annulus where the inner and outer cylinders are rotating with different angular velocities. Their results show that the total entropy generation number decreases as the fluid elasticity increases and raises with increasing the Brinkman number. Mahian et al. [9] analytically analyse entropy generation due to flow and heat transfer of nanofluids confined between two rotating cylinders within isoflux thermal boundary conditions. They prove that the use of an optimum volume of nanoparticles diluted on the fluid ables to decrease the entropy production. Mahian et al. [10] examine the effect of MHD flow on the distribution of velocity, temperature and entropy generation. They prove that the increase of the Hartmann number enhances the average entropy generation. In addition, their results show that the entropy creation decreases with the decrease of the distance between the two cylinders for ratio radius <0.5 and for a ratio radius up to 0.55, the entropy production increases. Ben Nejma et al. [11,12] develop numerical analyses of entropy generation through radiative heat transfer within an emitting-absorbing and non-grey gas, respectively in cylindrical and spherical enclosures. Using the SNBcK [13] model associated to the Ray-Tracing method, they prove that the volumetric entropy generation is the most developed in heating case while wall entropy creation is the most developed in cooling configuration.

The entropy generation through thermal radiation within a participating medium has not been adequately studied, even less for a cylindrical annulus. The aim of this paper is to analyse entropy production due to non-grey gas radiation through a concentric cylindrical annulus.

General formulation

The physical model under study is considered in Fig. 1. The overheated water vapour considered as a non-grey gas, is

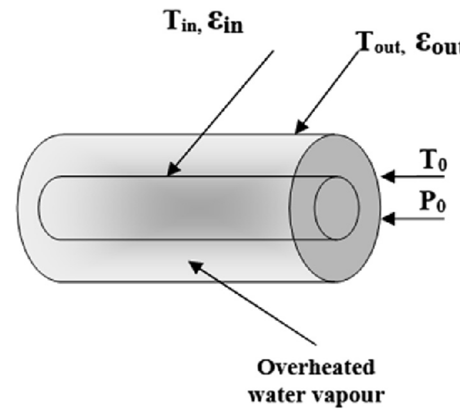

Fig. 1 – Physical domain and boundary conditions.

confined between two concentric cylinders with isothermal walls. The Ray Tracing method through T_{10} directions is associated to the SNBcK model in order to solve the radiative heat transfer and to predict spectral and radiation properties of overheated water vapour.

The SNBcK model

Goutière et al. [14] show that the application of the SNBcK model to non-grey gas radiation represents an efficient narrow-band model for radiative transfer calculation. Using the 4-points Gauss-Legendre quadrature [15], where gas radiative properties are represented by four grey-gases at each non-overlapping band. The SNBcK model helps us to extract gas absorption coefficients from gas transmissivities given by Malkmus [16] as follows:

$$\overline{\tau_{\nu(L)}} = \exp\left[-\frac{\pi B}{2}\left(\sqrt{1+\frac{4AL}{\pi B}}-1\right)\right] \quad (1)$$

Lacis and Oinas [17] present analytically the expression of the cumulative function, which is written in the following form:

$$g(\kappa) = \frac{1}{2}\left[1-erf\left(\frac{a}{\sqrt{\kappa}}-b\sqrt{\kappa}\right)\right]+\frac{1}{2}\left[1-erf\left(\frac{a}{\sqrt{\kappa}}+b\sqrt{\kappa}\right)\right]\exp^{\pi B} \quad (2)$$

where: $a\frac{1}{2}\sqrt{\pi AB}$, $b\frac{1}{2}\sqrt{\frac{\pi B}{A}}$ and erf represents the error function.

The use of the cumulative function g permits to compute the average narrow band of any radiative variable ϕ_ν expressed as follows:

$$\phi_\nu = \sum_{i=1}^{n} w^i\,\phi(g^i) \quad (3)$$

The computation of the monochromatic absorption coefficients is thus reduced to the resolution of the following equation system:

$$g(\kappa_\nu^i) = g^i \quad (4)$$

The radiative intensity is calculated through the Ray Tracing method, based on the selection of the radiative transfer directions and their associated weights:

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