

# Volumetric and wall non grey gas entropy creation in a cylindrical enclosure

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*Abstract:* - We analyse a numerical computation of entropy generation by radiative heat transfer through an emitting-absorbing non-grey gas, confined in a cylindrical enclosure. The “statistical narrow band correlated-k” model is associated to the “Ray Tracing” method to deduce the radiative properties of the gas and to solve the radiative transfer equation. We present the impact of boundary conditions and cylinder dimensions on the entropy generation.

*Key-Words:* - Entropy, Emission, Absorption, Non-grey gas, Ray tracing, SNBCK model

## 1 Introduction

The assessment of energy systems is related to the use of energy, which is based on the first law of thermodynamics, reflecting the principle of energy conservation. But energy analysis has many weaknesses that can be overcome with an alternative thermodynamic analysis method. Exergy analysis, based on the second law, is a well-known tool for the evaluation and optimization of energy systems, and is used as a benchmark for energy efficiency and rational use of natural resources. Exergy analysis continues to receive considerable attention because of its importance in many practical applications like electrical generation, cogeneration, transportation, heating and cooling, and chemical and metallurgical processing. Rosen [1] affirmed that exergy analysis provides useful information, which can have direct implications on process designs and improvements. He declared also that exergy methods help in understanding and improving not only efficiency, but also environmental and economic performance as well as sustainability. Rosen [2] detailed in his study the advantages of exergy analysis over energy analysis from a combined thermodynamic and economic perspective. He [3] presented an illustration to demonstrate the importance of size considerations in applications of exergy. He concluded that an understanding of these size considerations can help guide users of exergy analysis to the most suitable manner of application for a given system.

The objective of this paper is to analyze the effect of thermal radiation on entropy generation

minimization for high-temperature systems, since radiation represents the dominant form of heat transfer in many applications such as solar collectors, boilers, furnaces and other combustion systems and represents an important source of entropy creation, contributing significantly to inefficiency [4]. Planck [5] was the first investigator who implicated radiative entropy production in his researches, which deal with irreversibility provided by interaction of light and matter. The first formulation of the transfer equation for the radiative entropy was developed by Wildt [6] in his study of thermodynamic aspects of radiative transfer processes. The irreversibility of the interaction of radiation with matter was studied by Oxenius [7] by considering a stationary isothermal gas that emits the resonance line of atoms with only two discrete energy levels. The analysis of the general form of the entropy production was developed by Kroll [8], starting from basic statistical relations. In this study, entropy production due to emission, absorption and scattering of radiation is showed to be a form bilinear in generalized thermodynamic fluxes and forces. Wright et al [9] determined the significant error that is introduced in second law analysis when the heat conduction relation is used for thermal radiation transfer. In fact, the correct evaluation of thermal radiation entropy is important when determining second-law performance of energy conversion devices. They obtained simple approximate expressions for calculating the entropy of grey radiation emission, as the exclusive use of numerical integration is laborious. Caldas and Semiao [4] approached an issue of entropy

















$s_w$  local wall entropy production ( $W.K^{-1}m^{-2}$ )  
 $T_0$  vapour temperature (K)  
 $T_w$  wall temperature (K)  
 $w$  weight parameter  
 $l$  optical path (m)

#### Greek symbols

$\kappa$  absorption coefficient ( $m^{-1}$ )  
 $\tau$  transmittivity  
 $\varepsilon$  wall emissivity  
 $\mu, \xi, \eta$  director cosines  
 $\vec{\Omega}$  ray direction  
 $d\Omega$  elementary solid angle around  $\vec{\Omega}$   
 $\Delta\nu$  spectral resolution ( $\Delta\nu = 25cm^{-1}$ )

#### Subscript

$v$  spectral  
 $V$  volumetric  
 $W$  wall  
 $t$  global

#### Superscript

$b$  black body  
 $i$  grey gas associated

#### References:

- [1] M.A. Rosen, Exergy as a Tool for Sustainability, 3<sup>rd</sup> IASME/WSEAS Int. Conf. on Energy & Environment, 2008, pp 90-98.
- [2] M.A. Rosen, A Concise Review of Exergy-Based Economic Methods, 3<sup>rd</sup> IASME/WSEAS Int. Conf. on Energy & Environment, 2008, pp 136-144.
- [3] M.A. Rosen, Thermodynamic Analysis Based on the Second Law Using Exergy: Illustrative Applications of a Size-Based Assessment Hierarchy, Proceedings of the 2nd WSEAS International Conference on Engineering Mechanics Structure and Engineering Geology, 2009, pp 47-55.
- [4] M. Caldas and V. Semiao, Entropy generation through radiative transfer in participating media: analysis and numerical computation, JQSRT, Vol. 96, 2005, pp. 423-437.
- [5] M. Planck, The theory of heat radiation, New York: Dover 1959
- [6] R. Wildt, Radiative transfer and thermodynamics, Astrophys J, Vol. 123, 1956, pp. 107-16.
- [7] J. Oxenius, Radiative temperature irreversibility, JQSRT, Vol. 6, 1966, pp. 65-91.
- [8] W. Kroll, Properties of the entropy production due to radiative transfer, JQSRT, Vol. 7, 1967, pp. 715-723.
- [9] S.E. Wright, D.S. Scott, J.B. Haddow and M.A. Rosen, On the entropy of radiative heat transfer in engineering thermodynamics, Int J Eng Sci, Vol. 39, 2001, pp. 691-706.
- [10] L.H. Liu and S.X. Chu, On the entropy generation formula of radiation heat transfer processes, J Heat Transfer, Vol. 128, 2006, pp. 504-506.
- [11] L.H. Liu and S.X. Chu, Verification of numerical simulation method for entropy generation of radiative heat transfer in semitransparent medium, JQSRT, Vol. 103, 2007, pp. 43-56.
- [12] F. Ben Nejma, A. Mazgar, N. Abdallah and K. Charrada, Entropy Generation through combined non-grey gas radiation and forced convection between two parallel plates, ENERGY, Vol. 33, 2008, pp. 1169-1178.
- [13] A. Mazgar, F. Ben Nejma and K. Charrada, Numerical analysis of coupled radiation and laminar forced convection in the entrance region of a circular duct for non-grey media: entropy generation, WSEAS Transactions on Heat and Mass Transfer, Vol. 3, 2008, pp. 165-176.
- [14] A. Mazgar, F. Ben Nejma and K. Charrada, Entropy generation through combined non-grey gas radiation and natural convection in vertical pipe, Progress in Computational Fluid Dynamics, Vol. 9, 2009, pp. 495-506.
- [15] S.X. Chu and L.H. Liu, Entropy generation analysis of two-dimensional high-temperature confined jet, Int. J. Thermal Sciences, Vol. 48, 2009, pp. 998-1006.
- [16] O.D. Makinde, Hermite-Padé approach to thermal radiation effect on inherent irreversibility in a variable viscosity channel flow, Computers and Mathematics with Applications. vol. 58, 2009, pp. 2330-2338.
- [17] S.X. Chu and L.H. Liu, Analysis of terrestrial solar exergy, Solar Energy, vol. 4, 2010, pp. 326-332.
- [18] A. Agudelo and C. Cortés, Thermal radiation and the second law, Energy, vol. 35, 2010, pp. 679-691.
- [19] D. Makhanlall and L. Liu, Entropy production analysis of swirling diffusion combustion processes, Frontiers of Energy and power Engineering in China., vol. 4, 2010, pp. 326-332.
- [20] D. Makhanlall and L.H. Liu, entropy generation of coupled natural convection and radiation in two dimensional rectangular enclosure and its evolution with time, AIP Proceedings, vol. 1207, 2010, pp. 410-415.
- [21] D. Makhanlall and L.H. Liu, Second law analysis of coupled conduction-radiation heat transfer with phase change, Int J Thermal Sciences., vol. 49, 2010, pp. 1829-1836.
- [22] D. Makhanlall, L.H. Liu and H.C. Zhang, Determination of loss coefficients for high-temperature flow devices: An entropy-based approach, Int J Thermal Sciences, vol. 49, 2010, pp. 1848-1855.
- [23] E.M.A. Mokheimer, Parametric analysis of entropy generation due to laminar developing mixed convection between differentially heated isothermal vertical parallel plates, Int J Numerical Methods for Heat and Fluid Flow, vol. 20, no. 8, 2010, pp. 941-971.

- [24] D. Makhanlall, L.H. Liu and H.C. Zhang, SLA (Second-law analysis) of transient radiative transfer processes, *Energy*, vol. 35, 2010, pp. 5151-5160.
- [25] L.H. Liu and S.X. Chu, Radiative exergy transfer equation, *J Thermophysics Heat Transfer*, vol. 21, no. 4, 2007, pp. 819-822.
- [26] F. Liu, G.J. Smallwood and Ö.L.Gülder, Application of the statistical narrow-band correlated-k method to low-resolution spectral intensity and radiative heat transfer calculations - effects of the quadrature scheme, *Int. J. Heat and Mass Transfer*, vol. 43, 2000, pp. 3119-3135.
- [27] Z. Chen, X. Qin, B. Xu, Y. Ju and F. Liu. Studies of radiation absorption on flame speed and flammability limit of CO<sub>2</sub> diluted methane flames at elevated pressures. *Proceedings of the Combustion Institute*. vol 31, 2007, pp. 2693-2700.