SOLSTICE	Name of the PhD candidate: **Jean-Marc AVELLANEDA** Title of the PhD thesis: **Thermodynamic optimization of Solar Receivers in presence of Turbulence** Dates : 01/10/2016 – 30/09/2019
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Context and objectives

It is critical to improve the efficiency of solar receivers in order to lower the LCOE of electricity produced by concentrated solar power plants and to promote their dissemination. This is a challenge both in technology and in physics theory, due to complex turbulent, highly non-isothermal and asymmetric flows. This thesis is part of the global optimization problem of solar receivers by combining thermodynamics, fluid dynamics and numerical simulations in order to estimate, understand and minimize entropy generation rates.

Approach

Three ways are investigated. (a) Entropy generation minimization is studied in the simpler model of the laminar boundary layer, as a sandbox allowing partly analytical calculations. This allows identifying driving parameters and their impact on the magnitude and the composition of local and total entropy production rates. This model is then enhanced step by step by varying thermal boundary conditions, taking into account thermo-dependency of fluid physical properties and turbulence. (b) The calculus of variation is used to minimize an objective functional linked with entropy production in order to find which thermal and dynamical fields lead to an optimum. This technique is applied to heat transfer and to mass diffusion phenomena and a comparative analysis is performed (c) Direct Numerical Simulations / Thermal Large Eddy Simulations will be performed in order to determine high local entropy production locations and relative contributions of averaged and fluctuation fields.

Main results

(a) The magnitude and composition of local and total entropy generation rates in a laminar boundary layer have been computed and analyzed for two main thermal boundary conditions: isothermal vs isoflux plate. In addition to local Reynolds, Prandtl and Eckert numbers, they depend on the thermal dimensionless number τ (temperature of the wall divided by the temperature gap between the wall and the free stream at a reference position). If the total thermal power transferred between the plate and the fluid is fixed, the total entropy production rate between two longitudinal positions along the plate, the starting position being fixed, lead to a critical value of τ which minimizes entropy production. The value of the optimum τ depends on the thermal boundary condition (Fig. 1). In the isoflux plate case, τ_{opt} depends on the total fixed heat power exchanged and on the starting integration point along the plate. This is not the case for an isothermal plate where τ_{opt} is invariable. In this study, the temperature gap is not neglected when compared to the wall temperature, horizontal conduction of heat is not neglected in the calculation of entropy generation rates and the behavior of the model has also been studied near the leading edge in order to know its asymptotic trend. (b) The calculus of variation has been applied to the multi-objective optimization of heat or mass transfer situations in a channel by minimizing a linear combination of the entropy generation rate by heat conduction or mass diffusion on the one hand and the viscous dissipation on the other hand. For each value of the viscous dissipation in the channel an optimized volume force is computed, which leads to optimized velocity and scalar fields (temperature or mass fraction of the minority species). The viscous dissipation constraint can be adjusted through a weighting factor C_{Φ} in the objective functional. As a general trend in the optimized solutions, lowering this weighting factor leads to lower entropy generation by heat transfer or mass transfer and to a better homogenization of the temperature or mass fraction fields (Fig. 2). At the same time, the viscous dissipation, the entropy generated by viscous friction and the maximum velocity show an increasing trend. All in all, the total entropy generation rate is reduced and the improvement factor is increased (the relative reduction of the total entropy generation rate with regard to the reference entropy generation rate when no optimization is applied). There is a critical value of the weighting factor at which a discontinuity appears, making velocity and temperature or mass fraction fields jump from profiles slightly different from the non optimized case to profiles highly perturbed. This critical value depends on boundary conditions, like inlet velocity, heat flux density or mass flow density. Mass and heat transfer optimization lead to very similar velocity and scalar fields in normalized units (by the maximum values of each field in the channel) whereas the critical value of the weighting factor may be different.

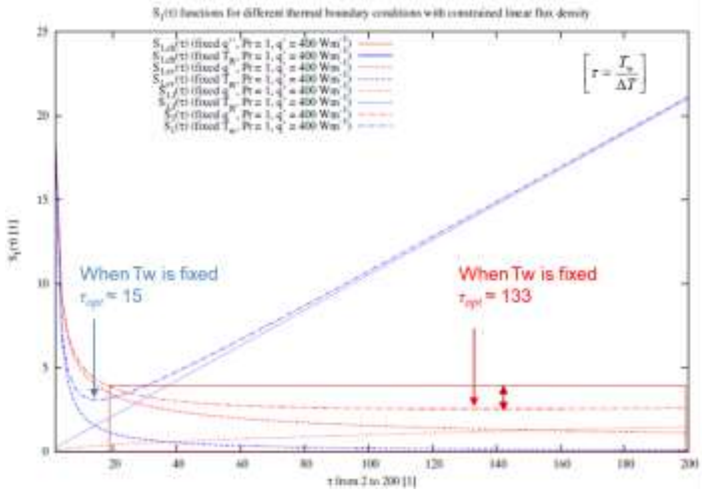

Figure 1. Dimensionless total entropy generation rates in the boundary layer over an isothermal plate (blue lines) or an isoflux plate (red lines) between two positions along the plate. The starting position is fixed (Re_a = 1000) and the total heat power exchanged between the plate and the fluid is fixed (q' = 400 W/m). Components of entropy production are also shown (ch = horizontal conduction of heat, cv = vertical conduction of heat, f = viscous friction). Pr=1.

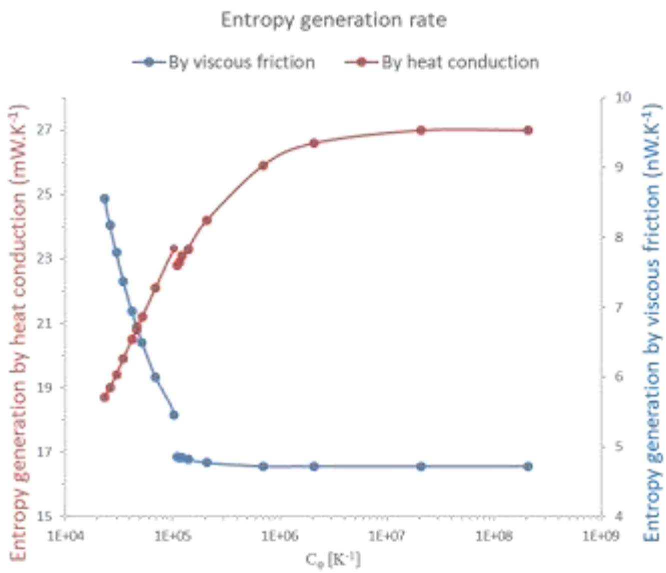

Figure 2. Entropy generation rate components in a parallel flat plane channel having its lower wall heated at a uniform heat flux density on its central third segment. C_{Φ} is the weighting factor of the viscous dissipation in the objective functional.

Publications in international conferences

J.M. Avellaneda, S. Jia, P. Neveu, F. Bataille, X. Yuan, G. Flamant, *Similarities between heat and mass transfer enhancement in convective flow, using variational optimization technique,* 16th International Heat Transfer Conference IHTC16 August 10-15, 2018, Beijing, China. Current status: accepted under corrections.