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Heat transfer and pressure drop correlations for finned plate ceramic heat exchangers

Helio Henrique Santomo Villanueva, Paulo Eduardo Batista de Mello*

Centro Universitário da FEI, Department of Mechanical Engineering, Av. Humberto de Alencar Castelo Branco, 3972, São Bernardo do Campo, SP, CEP 09850-901, Brazil

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ABSTRACT

The use of ceramic materials is a good option to build heat exchangers for high temperature applications when cost is a concern. This work presents heat transfer and pressure drop correlations for one finned plate heat exchanger evaluated using CFD (Computational fluid dynamics) simulations. One adequate turbulence model was used to include transitional Reynolds number range. The influence of geometrical parameters is included into the correlations, following the same approach commonly used for offset strip fins heat exchangers. For validation purposes, the CFD results are compared to experiments for one particular geometrical configuration. The resultant correlations for the high temperature heat exchanger could be used for optimization purposes, considering possible applications. Analysis of simulation results revealed significant heat transfer enhancement produced by a horseshoe vortex formed in the frontal part of the fins.

1. Introduction

HTHE(High temperature heat exchangers) enable performance enhancements in industrial processes and heat engines. Considering the case of heat engines, higher system efficiency can be obtained when the heat source presents higher temperature. The EFGT(externally fired gas turbine) is one thermodynamic cycle that could take advantage of the increased performance enabled by the HTHE, with the extra benefit of allowing the burn of biomass in gas turbines [1].

When it comes to temperatures higher than 800 °C, metallic heat exchangers are not a cost-effective alternative. Experiments with EFGT cycle [2,3], using metallic HTHE have demonstrated its feasibility, but with a serious limitation on the work temperature imposed to the heat exchanger. The TIT (turbine inlet temperature) was maintained lower than 750 °C in both cases. In a more recent experimental study, TIT was increased to 850 °C [4]. The influence of the TIT on the efficiency of the EFGT cycle is presented in Ref. [5], confirming that the use of one HTHE capable of supporting higher temperatures would lead to efficiency improvements. Information in literature [6,7] states that ceramic materials are the technological choice to substitute metals on HTHE due to its resistance to corrosion and temperature. Despite this, experimental data and demonstration of feasibility studies involving ceramic heat exchangers are still scarce in the literature. Some recent developments in this area may be found in Refs. [8,9] and [10].

The use of finned plate heat exchanger configuration for the construction of ceramic HTHE [1] provides the benefit of high heat transfer area per volume of the heat exchanger. The thermal performance and pressure drop for the HTHE can be predicted using the standard approach already used for compact heat exchanger [11]. Experiments gathering data for the friction and Colburn factors have been conducted under laminar regime [10], for a ceramic HTHE constructed using alumina (Al_2O_3).

CFD(Computational fluid dynamics) simulations can be used to obtain the friction and Colburn correlations numerically, as a function of Reynolds number, so that idealizations and geometry changes can be easily studied in a short time. A CFD study that used this approach, for one HTHE that could be constructed using finned plates, is presented in Ref. [12].

This paper presents a numerical study of one ceramic finned plate HTHE, as shown in Fig. 1. The objective is to gather data to evaluate the influence of geometrical parameters over the friction and Colburn factors, considering laminar and transitional regimes. The form of the correlations is similar to the one first presented in Ref. [13] for offset strip fins. The geometry of the fins is parameterized and a systematic investigation is conducted.

* Corresponding author.
E-mail addresses: heliohenriquevillanueva@gmail.com (H.H.S. Villanueva), pmello@fei.edu.br (P.E.B. de Mello).

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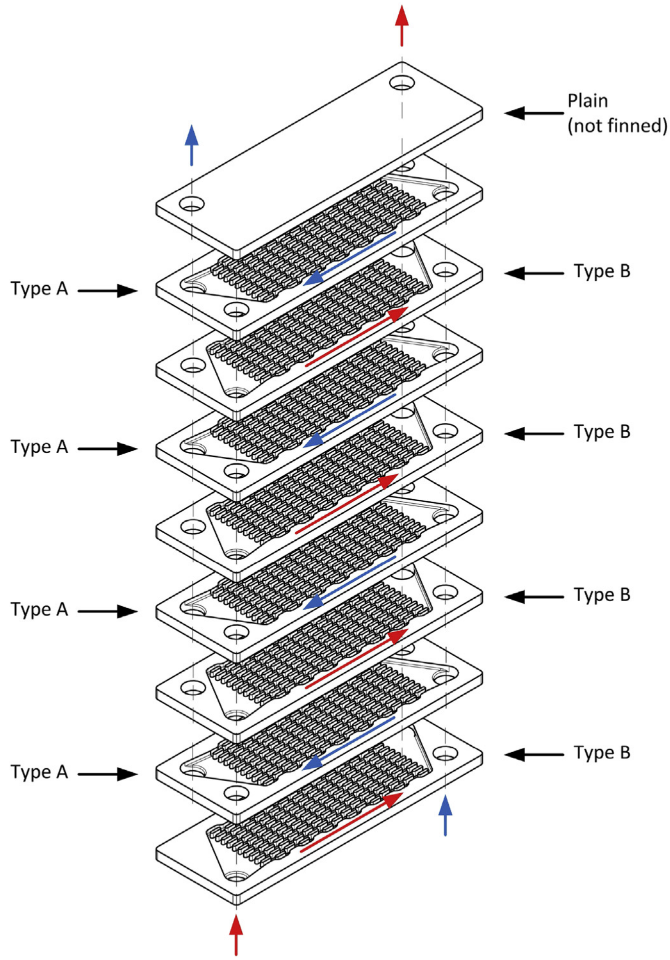

Fig. 1. High temperature heat exchanger constructed using finned ceramic plates.

In addition, the validation through comparison with experiments with a ceramic HTHE prototype is presented. Considering the technological interest in HTHE and that the ceramic heat exchanger imposes geometry significantly different from standard heat exchangers, the level of agreement between experiment and CFD predictions is considered the most relevant information presented in this paper.

2. Geometry

Correlations for the Colburn and friction factors are available in Ref. [11] for many different geometrical configurations. These geometrical configurations are not suited for ceramic heat exchangers because, ceramics require particular manufacturing processes and geometrical design. In general, small thickness plates, easily obtained with metals, would result in an excessively fragile ceramic plate. Due to this, the correlations are not available for geometries as the one shown in Fig. 1, which demonstrated its feasibility using ceramics [10]. Following the approach used in Ref. [13], geometrical parameters that define the fins have been created. As demonstrated by Ref. [12] a simulation including three rows of fins is sufficient to obtain practically identical Colburn and friction factor curves, if compared to the simulation conducted with six rows. This simplification reduces the computational costs, as the number of volumes in the mesh decreases drastically. As shown in Fig. 2, the domain is extended on the inlet and outlet regions so the flow can evolve properly and minimal effects of the idealization in

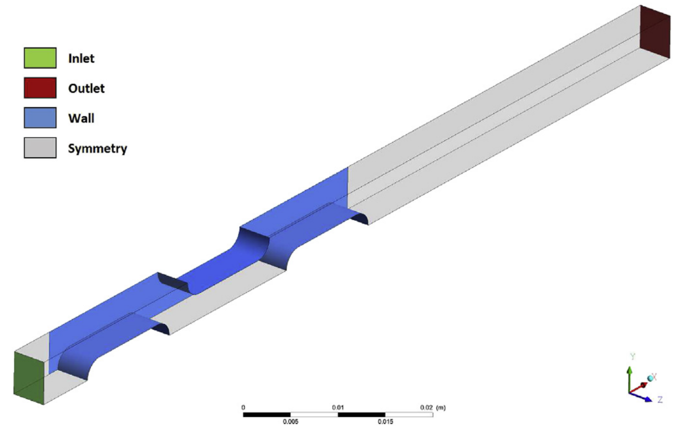

Fig. 2. : Geometry of the CFD domain with boundary conditions.

boundary conditions influence the results or cause convergence issues. Fig. 2 also shows the boundary conditions applied on the CFD domain. The inlet boundary condition sets the temperature, which the fluid enters the domain and the mass flow based on the desired Reynolds number. The outlet boundary imposes a zero gradient normal to the face and a relative pressure. The wall boundary is a no-slip wall with a fixed temperature. The other boundary faces of the computational domain are symmetry planes (adiabatic and zero gradients). Only half of the fin height is included in calculation domain due to symmetry.

2.1. Geometrical parameters

The three geometrical parameters created are λ, δ and γ. These parameters are defined by 1–3, with the fin dimensions presented in Fig. 3. The fin height is the variable H.

$$\lambda = \frac{D_1}{H} \tag{1}$$

$$\delta = \frac{D_1}{L} \tag{2}$$

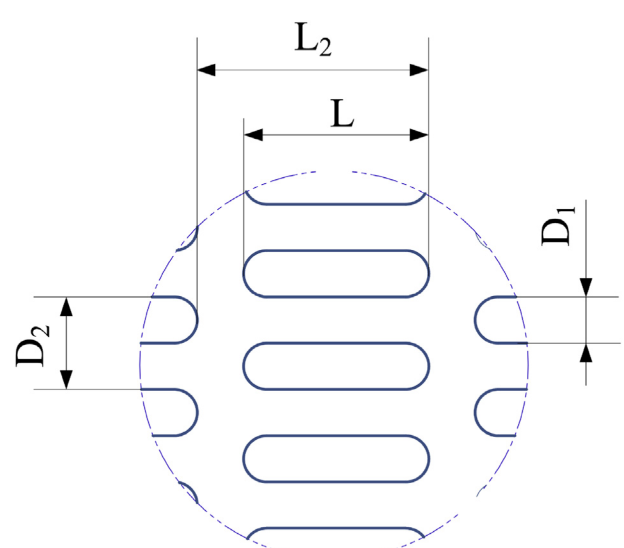

Fig. 3. : Geometrical parameters that define the fin base.