International Communications in Heat and Mass Transfer 86 (2017) 81–91

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Geometric optimization of morphing fins coupled with a semicircular heat generating body: A numerical investigation on the basis of Bejan's theory

C. Biserni[a,*], F.L. Dalpiaz[b], T.M. Fagundes[b], M. Garai[a], L.A.O. Rocha[c]

[a] Dipartimento di Ingegneria Industriale, Università degli Studi di Bologna, Viale Risorgimento 2, 40136 Bologna, Italy
[b] Universidade Federal do Rio Grande do Sul, Programa de Pós-Graduação em Engenharia Mecânica, Rua Sarmento Leite, 425, 90050-170 Porto Alegre, RS, Brazil
[c] Department of Mechanical Engineering, Universidade Federal do Rio Grande do Sul, Rua Sarmento Leite, 425, Porto Alegre, RS 90.050-170, Brazil

ARTICLE INFO

Keywords:
Constructal design
Semicircular heat generating body
T-shaped morphing fins
Thermal energy removal
Convection heat transfer
Exhaustive search
Genetic algorithm

ABSTRACT

The objective of the present work is to optimize, by means of constructal design associated with exhaustive search and genetic algorithm, the geometry of morphing T-shaped fins that remove heat from a semicircular basement. The fins are bathed by a steady stream with constant ambient temperature and convective heat transfer. The semicircular body that serves as a basement for the T-shaped construct generates heat uniformly and it is perfectly insulated on the outer perimeter. It is shown numerically that the global thermal resistance can be minimized by geometric optimization subjected to constraints, namely, the basement area constraint, the T-shaped fins area fraction constraint and the auxiliary area fraction constraint, i.e. the ratio between the area that circumscribes the T-shaped fin and the basement area. The combination of the degrees of freedom values in the context of constructal design generated a search space with several "potential" local minima so that the classic technique, i.e. the exhaustive search, had to be substituted by the genetic algorithm method. In this context, the initial investigation regarding the degrees of freedom L_1/L_0 and t_1/t_0 was performed by means of the exhaustive search, while the parameters k_p, ϕ, λ and ψ have been studied by employing GA technique. First achieved results indicate that when the geometry is free to morph then the thermal performance is improved according to the constructal principle named by Bejan "optimal distribution of imperfections". Finally, a comparative analysis between T-shaped constructs coupled with rectangular, trapezoidal and semicircular geometries has been carried out in terms of effectiveness in heat removal. The performance of the T-shaped morphing fin having semicircular basement (the case here treated) proved to be considerably superior than the other tested geometries.

1. Introduction

Constructal Theory, i.e. the view of design as science, has been deeply reviewed in Refs [1–3]. It is based on the Constructal Law, that states "For a finite-size flow system to persist in time (to live), its configuration must evolve in such a way that provides greater and greater access to the currents that flow through it". This line of inquiry began accidentally in engineering, with a 1997 analytical paper on the conductive cooling of a small electronic package (a heat generating volume) by using a point-size heat sink [4]. Constructal theory [5,6] can be intended as the evolutionary design philosophy for developing flow architectures that offer greater flow access and system performance. Therefore, a great distinction has been set between the approach by fractals [7–9] and by the Constructal Theory [10]. While the former produces images with great resemblance of natural systems it does not rely on physics. The latter, on the other hand, claims that forms, patterns and configurations can be successfully determined and explained by physics [11]. Literature [12] shows that Constructal Law provides explanations for why a broader variety of designs, configurations, structures, patterns and rhythms occurred in the natural and in the anthropic realms alike. References [13,14] illustrate that the most basic features of tree and forest architecture can be put on a unifying theoretical basis given by the constructal law. Trees and forests are viewed as integral components (along with river basins, atmospheric and oceanic circulation, etc.) of the much greater global architecture that facilitates the cyclical flow of water and the flow of stresses between wind and ground. Ref. [15] highlighted the oneness of animate and inanimate designs, the origin of finite-size organs on animals and vehicles, the flow of stresses as the generator of design in solid structures (skeletons, vegetation), the universality and rigidity of hierarchy in all flow systems, and the global design of human flows. Ref. [16] illustrates a model of heat transport on the earth surface that accounts for the solar and terrestrial radiation as the heat source and heat sink and with natural convection loops as the transport mechanism. In this

* Corresponding author.
E-mail address: cesari.biserni@unibo.it (C. Biserni).

http://dx.doi.org/10.1016/j.icheatmasstransfer.2017.05.006

Nomenclature

A_b	cross section area [m^2]
h	heat transfer coefficient [W m^{-2} K^{-1}]
k_b	basement thermal conductivity [W m^{-1} K^{-1}]
k_f	fin thermal conductivity [W m^{-1} K^{-1}]
L_0	stem length [m]
L_1	half length of the tributary [m]
q'''	heat uniformly at volumetric rate [W m^{-3}]
R	radius of the semicircular basement [m]
t_0	stem thickness [m]
t_1	tributary thickness [m]
T	temperature [K]
T_∞	bulk temperature [K]
W	width [m]
x, y	coordinates [m]

Greek symbols

ϕ	area fraction
θ	dimensionless temperature
λ	dimensionless parameter
ψ	auxiliary area fraction

Subscripts

b	basement
aux	auxiliary
m	once minimized
2m	twice minimized
max	maximum
o	optimized
2o	twice optimized

Superscripts

$(\tilde{})$	dimensionless variables

paper we consider the constructal theory in its original engineering focus, i.e. the geometric optimization of shapes in heat transfer. In this context, Bejan's Constructal theory has been widely adopted in heat transfer optimization. Ref. [17] illustrates the constructal optimizations of H- and X-shaped heat exchangers by taking the maximum thermal efficiency (the ratio of the dimensionless heat transfer rate to the dimensionless total pumping power) as optimization objective. The advantage of constructal law in the engineering field is that the flow architecture is not assumed in advance, but it is the consequence of allowing the structure to morph [18–21]. Several applications of constructal theory have been reviewed by Feng et al. in Ref. [22].

In this paper our focus is on the geometric study of T-shaped fins cooling a semicircular solid body with internal heat generation. The objective is to minimize, by means of the numerical investigation, the maximal excess of temperature between the solid body and the ambient. The fins are bathed by a steady stream with constant ambient temperature and convective heat transfer. The outer surfaces of the heat generating body are perfectly insulated.

2. Mathematical model

Consider the domain shown in Fig. 1. There is an adiabatic semicircular body (basement) with internal constant heat generation per unit volume q''' and constant thermal conductivity k_b. Attached to the body is a T-shaped fin. The configuration is two-dimensional, with the third dimension (W) sufficiently long in comparison with the body radius R. The heat transfer coefficient h is uniform over all the exposed surfaces of the T-shaped fins and the temperature of the fluid (T_∞) is known. The maximum temperature (T_{max}) occurs into the basement and varies with the geometry of the T-shaped construct.

The objective of the analysis is to determine the optimal geometry (L_1/L_0, t_1/t_0), that is characterized by the maximal excess of temperature $(T_{max} - T_\infty) / (q'''A_b / k_b)$. According to constructal design, this search can be subjected to constraints, namely, the cross section area, A_b, of the rectangular body constraint,

$$A_b = \frac{1}{2}\pi R^2 \quad (1)$$

where R is the radius of the semicircular basement. The T-shaped fin-material area constraint,

$$A_f = t_0 L_0 + 2\, t_1 L_1 \quad (2)$$

The area that circumscribes one T-shaped fins is given by

$$A_{aux} = 2L_0L_1. \quad (3)$$

Eqs. (2) and (3) can be expressed respectively as the T-shaped fins area fraction

$$\varphi = \frac{A_f}{A_b} \quad (4)$$

and area fraction constraint given by the ratio between the area that circumscribes the T-shaped fins and the basement area:

$$\psi = \frac{A_{\rm aux}}{A_b} \quad (5)$$

The analysis that delivers the maximal excess of temperature as a function of the T-shaped geometry consists to solve numerically the heat conduction equation along the entire domain. The basement body

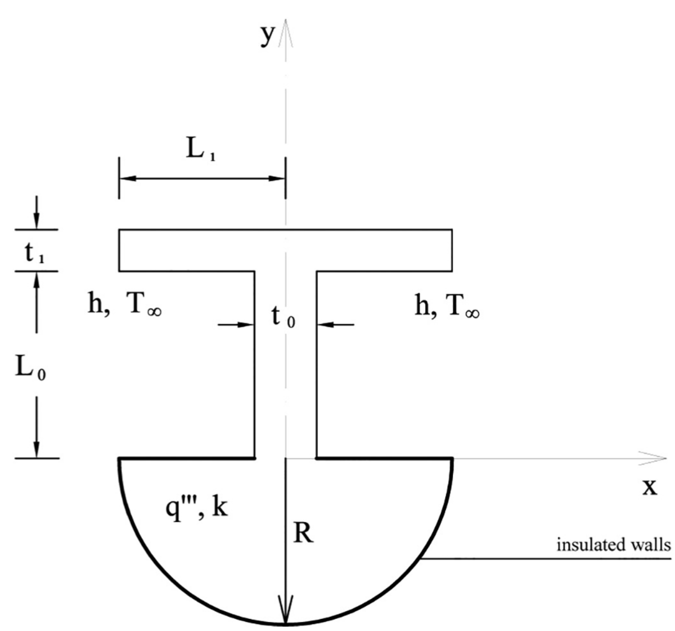

Fig. 1. Semicircular heat generating basement coupled with a morphing convective T-shaped fin.