Alexandria Engineering Journal (2014) 53, 1–9

Alexandria University

Alexandria Engineering Journal

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ORIGINAL ARTICLE

Second-law analysis of fluid flow over an isothermal moving wedge

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Received 22 June 2013; revised 18 November 2013; accepted 30 November 2013
Available online 28 December 2013

KEYWORDS

Boundary layer;
Moving wedge;
Thermodynamic optimization;
Entropy generation minimization;
Similarity solution

Abstract In this study, entropy generation minimization (EGM) was employed to optimize fluid flow and heat transfer over a moving wedge. Governing partial differential equations including continuity, momentum and energy are reduced to ordinary ones using similarity variables and solved numerically. The novelty of this study is to consider the effects of the moving wedge parameter λ, to find the stable system via entropy generation minimization (EGM) method. The results indicated that as the slope of the wedge increases, the absolute values of the optimum moving wedge parameter λ_o grow as well. Moreover, it was found that the minimum value of entropy generation happens for the negative values of λ_o which gets smaller as Falkner–Skan power law parameter m increases.

1. Introduction

Optimal consumption of energy depends on how to design an efficient heat transfer process from a thermodynamic point of view [1,2], but the main obstacle in this field is to determine the thermodynamically optimum size or operating regime of a certain engineering system, where by "optimum" we mean the condition in which the system losses the least power while still performing its fundamental engineering function. It turns out that, in many systems, the various mechanisms and design features that account for irreversibility compete with one another. Accordingly, the thermodynamic optimization that concerns us here is the condition of the most desirable trade-off between two or more competing irreversibilities. Design methodology, known as entropy generation minimization (EGM), is comprehensively covered by Bejan [3] specifically, in the fields of refrigeration, heat transfer, storage, solar thermal power conversion and thermal science education. The EGM is also known as second law analysis, thermodynamic optimization and thermodynamic design, or by new names such as exoirreversible, or endoreversible thermodynamics [4]. This field has experienced astounding growth during the 1980s and 1990s, in both engineering and physics. The popularity of EGM can be gauged from the researches done

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

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http://dx.doi.org/10.1016/j.aej.2013.11.011

Nomenclature

m	Falkner–Skan power law parameter
c_f	skin friction coefficient
f	dimensionless stream function
c_p	specific heat at constant pressure
k	thermal conductivity
Nu	local Nusselt number
Pr	Prandtl number
q_w	surface heat flux
Re_x	local Reynolds number
T	fluid temperature
T_w	wedge temperature
T_∞	ambient temperature
u, v	velocity components along the x- and y-directions, respectively
$u_e(x)$	free stream velocity
$u_w(x)$	moving wedge velocity
x, y	Cartesian coordinates along the surface and normal to it, respectively
S	dimensionless entropy generation
S'''_{gen}	volumetric entropy generation rate
Ec	Eckert number
Be	Bejan number
S_h	Entropy generation due to heat transfer
S_f	Entropy generation due to fluid friction

Greek symbols

α	thermal diffusivity
θ	dimensionless temperature
λ	moving wedge parameter
ν	kinematic viscosity
μ	dynamic viscosity
ρ	fluid density
τ_w	wall shear stress
ψ	stream function
η	similarity variable
ϕ	dissipation term in energy equation

Subscripts

w	condition at the surface of the wedge
∞	ambient conditions
o	optimum
c	critical

by scientists on thermodynamic optimization in convective flows that continue to appear in the heat transfer literature e.g. [5–11].

Nowadays, the classical boundary layer flow has been considered by many researchers in which the viscous forces are important and may affect the engineering process of producing. Blasius [12] studied the simplest boundary layer over a flat plate by employing a similarity transformation to reduce the partial differential boundary layer equations to a nonlinear third-order ordinary differential equation. Extension of this study has been considered by Falkner and Skan [13] on a wedge. Later on, Sakiadis [14] introduced the boundary layer flow induced by a moving plate in a quiescent ambient fluid. Tsou et al. [15] studied Thermal boundary layer flow over a moving surface analytically and experimentally. Then, Lee and Davis [16], solved numerically the general problem of the boundary layer compressible flows and temperatures induced by moving continuous plane and axisymmetric surfaces in the direction of motion numerically. Revankar [17], considered transient heat transfer from a continuous moving plot with step change in variable wall temperature. Many researchers developed this concept through the years [18–22].

Meanwhile, a more interesting problem in this field was considered by Riley and Weidman [23]. They studied the effects of moving boundary on a wedge in a viscous fluid (regular fluid) and applied a similarity transformation which led to a nonlinear third-order ordinary differential equation and solved it numerically. Recently, Ishak et al. [24] obtained a self-similar solution for a moving wedge in a micropolar fluid and solved numerically. They concluded that the micropolar fluids display a drag reduction compared to Newtonian fluids. Afterward, Ishak et al. [25] studied numerically the problem of steady two dimensional laminar fluid flow past a moving wedge in non-Newtonian fluid. Similarly, Yacob et al. [26,27] studied numerically the Falkner–Skan problem for a wedge immersed in nanofluids and flow and heat transfer over moving wedge with prescribed surface heat flux in respectively.

Recently, second-law analysis of fluid flow and heat transfer across a flat plate has been conducted by Malvandi et al. [28]. Although some increasing/decreasing trends for governing parameters were observed, they could not find any optimum case in which the entropy generation is minimized. Then, the effects of adding nanoparticles to the fluid on entropy generation were investigated analytically by Malvandi et al. [29]. Their outcomes indicated that more entropy generates in boundary layer with increasing the solid volume fraction. In another study, Malvandi et al. [30] considered the effects of velocity ratio – which represents the ratio of the wall velocity to the free stream fluid velocity – on a moving plate. Their outcomes reveal that focusing on the velocity ratio as a pivotal parameter, entropy generation can be minimized. In this paper, the authors have focused on the effects of velocity ratio in order to minimize the generated entropy over a moving wedge. Employing the appropriate similarity variables introduced by Falkner–Skan [13], a relation for entropy generation through boundary layers has been obtained. It turns out that focusing on wedge velocity; an optimum system may be reached. Hence, we set wedge velocity as a pivotal parameter and study its effects on entropy generation. In addition, the effects of Falkner–Skan power-law parameter on optimum wedge velocity was obtained and discussed in details. It is worth mentioning that the flow induced by a moving wedge have many industrial applications such as heat treatment of material traveling between a feed roll and windup roll or conveyor belts, extrusion of steel, melt spinning process in the extrusion of polymer continuous casting, glass blowing and cooling of a large metallic plate in a bath [24–27,31,32]. The current optimization technique can enhance the efficiency of the system as well as reducing the costs.