Progress in Energy and Combustion Science 000 (2017) 1–62

Contents lists available at ScienceDirect

Progress in Energy and Combustion Science

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

Heatlines: Modeling, visualization, mixing and thermal management

Tanmay Basak*, Debayan Das, Pratibha Biswal

Department of Chemical Engineering, Indian Institute of Technology Madras, Chennai, 600036, India

ARTICLE INFO

Article History:
Received 11 April 2017
Accepted 31 August 2017
Available online xxx

Keywords:
Heatlines
Modeling
Nusselt number
Isotherms
Convection
Cavities
Visualization
Thermal mixing
Thermal management

ABSTRACT

The bulk motion of fluid and diffusive transport within fluid are two processes during natural or forced convection. The complexity of the convective heat flow is realized since last few decades and the analysis of the heat flow as well as thermal characteristics gradually becomes cumbersome. Although earlier researchers studied convective heat flow via velocity profiles, streamlines and isotherms, these tools were not enough for the efficient visualization of the unique features of convection heat flow. An efficient tool, termed as 'heatline' (mathematically represented as heatfunction) was first proposed by Kimura and Bejan in 1983 for the heat flow visualization during convective heat flow. The aim of this article is to review existing works on 'heatline' involving various physical systems. The mathematical implications of heatfunctions based on derivations of governing equations and boundary conditions for heatfunctions are presented in detail. The non-homogeneous boundary conditions for heatfunctions arise due to hot or cold or adiabatic walls as well as the junction between the walls and these conditions vary with the location of the reference or datum of the heatfunction. The physics on the heat flow via 'heatlines' are found to be invariant with the locations of the reference value of the heatfunction. The heat flow visualization is analyzed for various test cases from simple one dimensional boundary layer problem to convection in two dimensional complex cavities. The detailed explanations of earlier works on 'heatlines' during one dimensional flow involving forced or natural convection with various applications are discussed. Further, applications of 'heatlines' during convective heat flow within enclosed cavities involving uniform or non uniform heating of walls, discrete heating or cooling, conjugate convection and mixed convection are discussed and 'heatlines' are found to be successful to demonstrate various complex heat flow paths and multiple heat flow circulation cells. Overall, the analysis of convective heat flow from simple to complicated geometries via 'heatline' is crucial for the visualization of the thermal transport, mixing and efficient thermal management.

Contents

* Corresponding author.
E-mail address: tanmay@iitm.ac.in (T. Basak), debayan8221@gmail.com (D. Das), biswal.pratibha9@gmail.com (P. Biswal).

http://dx.doi.org/10.1016/j.pecs.2017.08.003
0360-1285/© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Convection heat transfer involves the advective transport (bulk motion of fluid) and diffusive transport (random Brownian motion of individual particles in fluid). Convection is induced via several means such as natural, forced, gravitational, thermo-magnetic etc. Heat transfer by convection plays the pivotal role in various engineering and industrial applications as evident from the review articles on domestic solar heating [1,2], electrochemical systems [3], heat exchangers [4], building and ventilation [5], food industries [6], drying of organic waste materials [7], energy storage [8] and many more. In addition, convection heat transfer also occurs in several natural phenomena such as the atmospheric air flow [9], ocean currents [10] and flow in the earth’s mantle [11]. The thermal management and efficient thermal mixing were found to be major objectives for various applications as explained by the earlier articles [12–19]. Consequently, this review projects the role of of the convection heat flow on thermal transport leading to the thermal management for convective systems.

The convection heat flow is extremely diverse and that is highly influenced by a number of parameters such as the fluid properties, geometry, nature of flow, phases etc. In general, the convection heat transfer is classified as the external or internal flow (based on the geometry), natural or forced or mixed convection (based on the driving mechanism), single or multiple phase (based on the number of phases), laminar or turbulent (based on nature of flow) etc. The field of convection has been evolved as a sequence from the simple one dimensional boundary layer problem to convection in two dimensional complex cavities. The prime focus of earlier works for the convective heat transfer analysis was to determine the velocity profiles and heat transfer coefficients. Further, the problems of convection gradually became more applied and complicated involving direct applications in a wide spectrum of industrial and engineering domains. Thus, the analysis of velocity profiles and heat transfer coefficients associated with natural convection was not enough and the efficient visualization tools were required to appreciate the unique features of convection heat flow. To start with, the tools used by researchers to understand the heat flow behaviors based on the isotherms and streamlines associated with various techniques of flow visualization are discussed below.

Significant number of recent works illustrate that, the isotherms (to visualize temperature distribution) and streamlines (to visualize fluid flow) are commonly used to study the convective heat transfer in various systems [20–26]. The importance of the visualization of the physics of energy flow in addition to the temperature distribution and fluid flow is analyzed in the previous works [20–26]. The ‘thermal management’ and ‘efficient processing’ evolved as the key factors for industrial processing and management of the heat flow in recent years. Although the fluid flow during convection can be effectively illustrated by streamlines, isotherms cannot represent the

Please cite this article as: T. Basak et al., Heatlines: Modeling, visualization, mixing and thermal management, Progress in Energy and Combustion Science (2017), http://dx.doi.org/10.1016/j.pecs.2017.08.003