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The effects of chaotic advection on mixing and heat transfer in coiled tube heat exchangers

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Abstract

The propose of this work is to analyze the feasibility of using chaotic mixing as a mean of enhancing the in-tube convective heat transfer in a coiled tube heat exchanger and point out that is possible to increase the heat transfer by suitably designing the coils to alter the secondary pattern and induce chaotic mixing. In order to assess the enhancement of heat transfer by chaotic advection, we compared two different shell-and-tube heat exchangers having the same heat-transfer area and the same tube length, but different configurations: one is a convectional helical coil with a fixed axis which produces regular mixing, while the other one is a new configuration in which there is a periodic change in helical coils paths.

Velocity vectors and temperature field are computed. Furthermore, the Liaapounov exponents are used to identify the presence of chaos in particle path lines. By means of Lagrangian tracing of fluid particles in the flow field and fluid elements stretching calculations, it is shown that mixing and heat transfer is increased significantly due to change advection mechanism to chaotic advection.

Furthermore, a higher Nusselt number indicates an enhanced heat transfer and a more uniform temperature distribution for the fluid flow in the chaotic coil.

Keywords: Chaotic advection, Helical coiled Tube, Heat exchanger, Heat transfer

1. Introduction

Heat exchangers are used in a wide variety of applications, e.g. refrigeration and air-conditioning systems, power engineering and other thermal processing plants.

Besides the performance of the heat exchanger being improved, the heat transfer enhancement enables the size of the heat exchanger to be considerably decreased. In general, the enhancement techniques can be divided into two groups: active and passive techniques. The active techniques require external forces, e.g. electric field, acoustic, surface vibration. The passive techniques require special surface geometries or fluid additives. Both techniques have been used for improving heat transfer in heat exchangers. Due to their compact structure and high heat transfer coefficient, curved tubes have been introduced as one of the passive heat transfer enhancement techniques and are widely used in various industrial applications [1].

Helically coiled tubes, classified as passive techniques, are a simple and effective means of augmenting heat transfer in a wide variety of industrial applications such as, heat recovery processes, air conditioning and refrigeration systems, chemical reactors, food and dairy processes [2]. The modification of the flow is due to the centrifugal forces caused by the curvature of the tube, which produce a secondary flow field with a circulatory motion pushing the fluid particles toward the core region of the tube. Because of the stabilizing effects of this secondary flow, laminar flow persists in much higher Reynolds numbers in helical coils than in straight tubes. Consequently, the differences in heat-transfer performance between coils and straight tubes are particularly distinct in the laminar flow region, and it is this region that has received the most research attention [3].

Under certain conditions, however, natural convection can become important in the heat-transfer process. At low Reynolds numbers, the natural convection effect is often predominant, depending upon the physical properties and the difference between the wall and the bulk temperatures. The higher heat-transfer coefficients obtained for flow in a helical coil are thus not only due to the presence of the superimposed secondary flow caused by the centrifugal action, but also due to natural convection [4].

Chaotic advection, which is the production of chaotic particle paths in the laminar regime, is a novel passive technique for increasing heat transfer. The increase in mixing and heat transfer [5] in the chaotic advection regime compared to the regular flow has already been established. Chaotic advection, or in more precise terms Lagrangian chaos, is a flow regime in which chaos is generated in the physical space. From the Eulerian point of view the flow can be laminar and time-independent, however, the fluid particles follow irregular trajectories different from the Eulerian streamlines, and therefore overcome the virtual barriers which constitute the streamlines for mixing [4].

Mixing in chaotic regimes is more efficient than others. In chaotic advection, fluid particles trajectories diverge exponentially. These especial divergences give rise to increasing and stretching interaction surfaces of fluid elements and make mixing more efficient [6].

Yang et al [7] presented a numerical model to study the fully developed laminar convective heat transfer in a helicoidal pipe having a finite pitch. The effects of the