Postprint: Natural Convection Heat Transfer in a Horizontal Concentric Cylindrical Annulus

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Date: 2024-02-07T00:00:00+00:00

Abstract

Horizontal concentric cylindrical annular structures with outer wall temperature higher than inner wall temperature have been widely applied in engineering due to their excellent thermal insulation effect. The thermal insulation and cooling performance of such structures is significantly influenced by fluid flow and heat transfer within the annulus, yet research on natural convection heat transfer characteristics in horizontal concentric cylindrical annuli with outer wall temperature higher than inner wall temperature is currently lacking. Therefore, for horizontal concentric cylindrical annular structures with outer wall temperature higher than inner wall temperature, this study numerically investigates the natural convection flow patterns and heat transfer within the annulus at a Prandtl number of 0.7, with gap ratios (ratio of inner diameter to annular gap spacing, i.e., δ) ranging from 0.1 to 14 and Rayleigh numbers ranging from 10^3 to 10^7. Streamlines and isotherms are used to represent the calculated flow patterns and temperature fields, respectively, and the effects of gap ratio and Rayleigh number on the average Nusselt number of the inner cylindrical wall are examined. The findings reveal that at low Rayleigh numbers, a stable crescent-shaped flow pattern exists across the entire gap ratio range. Additionally, four distinct flow patterns are observed: two-dimensional funnel oscillating flow, three-dimensional spiral flow, two-dimensional multi-vortex flow, and two-dimensional multi-vortex oscillating flow. These four flow patterns emerge at higher Rayleigh numbers, depending on the gap ratio. Based on the distribution characteristics of the flow patterns, the entire gap ratio range can be divided into three regimes: wide gap ($\delta = 0.1$–2), moderate gap ($\delta = 2$–8), and narrow gap ($\delta = 8$–14). Correlation equations for the average Nusselt number of the inner cylindrical wall as functions of gap ratio and Rayleigh number are presented for different gap ratio ranges, with correlation coefficients (R^2) greater than 0.990 2.

Full Text

Preamble

The content of this section has been omitted due to irreparable corruption of the source text. During the document recovery process, mathematical reference markers were identified and preserved in their original sequence. However, these isolated markers cannot be meaningfully integrated into the narrative without the underlying substantive content that would normally provide context and continuity. Therefore, this section remains incomplete in the current version of the document.

Note: Figure translations are in progress. See original paper for figures.

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