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Experimental study on laminar flow over two confined isothermal cylinders in tandem during mixed convection

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ABSTRACT

An experimental investigation of laminar aiding and opposing mixed convection is carried out using particle image velocimetry (PIV) to assess the thermal effects on the wake of two isothermal cylinders of equal diameter in tandem array placed horizontally and confined inside a vertical closed-loop downward rectangular water channel. The buoyancy effect on the flow distributions are revealed for flow conditions with Reynolds number based on cylinder diameter of $Re = 100$ and 200, blockage ratio of $BR = D/H = 0.3$, aspect ratio of $AR = W/D = 5$, pitch-to-diameter ratio of $\sigma = L/D = 3$, and values of the buoyancy parameter (Richardson number) in the range $-1 \leq Ri \leq 3$. In this work, the interference effects on the complex flow features are presented in the form of mean and instantaneous contours of velocity and vorticity. In addition, separation angles, wake structure, recirculation bubble lengths, time traces of velocity fluctuation, Strouhal number and vortex shedding modes of the two-cylinder system are obtained as a function of the Richardson number. In this arrangement, the results indicate that the effects of the Reynolds number are very pronounced, and that the vortex shedding patterns exhibit a strong dependence on *Ri*. We also show the modulation effect of the channel walls on the three-dimensional flow under varying thermal buoyancy, and the results reported herein demonstrate how the flow structure, wake behavior and vortex shedding pattern are entirely different from that behind a single circular cylinder under wall confinement and thermal effects.

1. Introduction

Vortex shedding associated with the flow past two cylinders in tandem has been extensively studied because of its remarkable complex flow configurations and wide engineering applications in the design of heat exchanger tubes, electronic packages, cooling towers, cooling systems for nuclear fuel rods, offshore structures, seabed pipelines and chimney stacks. Useful reviews on how the interference effects between the cylinders affects the flow structure, wakes, shear layers and fluctuating fluid forces can be found in Refs. [1–6], and multiple investigations have provided important insight into various features of the tandem cylinder system [7–10]. In particular, for two cylinders of equal diameter, the flow structure is sensitive to the Reynolds number and the pitch ratio ($\sigma = L/D$, ratio between the center-to-center pitch and the cylinder diameter), and three basic interference flow regimes between cylinders have been identified depending on how the wake of the upstream cylinder modifies the incoming flow condition of the downstream cylinder: (i) the "extended body" regime occurs for small pitch ratios of approximately $1 < \sigma < 2$. In this regime, the two cylinders behave as a single bluff body and the shear layers that emanate from the upstream cylinder roll-up behind the downstream cylinder and form a single wake [11–15]; (ii) the "reattachment" regime occurs for intermediate pitch ratios of approximately $2 < \sigma < 5$, and two basic flow configurations have been identified depending on whether the location of the shear layer reattachment takes place at the leading surface ("fore-body", $\sigma = 3$–5) or rear ("after-body",

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