Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **12**, No. 5, pp. 1137-1165

DOI: 10.4208/aamm.OA-2019-0253
October 2020

Numerical Study of Heat Transfer from Two Cylinders in Tandem With Transverse Oscillation

W. W. Ren[1], J. Y. Shao[2,*], L. M. Yang[1] and T. Q. Li[2]

[1] *Department of Mechanical Engineering, National University of Singapore 10 Kent Ridge Crescent, Singapore 117576*
[2] *School of Transportation, Wuhan University of Technology, 1040 Heping Avenue, Wuhan, Hubei 430063, China*

Received 23 August 2019; Accepted (in revised version) 10 January 2020

Abstract. The convective heat transfer from two tandemly arranged circular cylinders, with the downstream one subjected to controlled transverse oscillation, is numerically studied in this work. At Reynolds number 100, eight oscillation frequencies varying from 0.4 to 1.7 and two oscillation amplitudes of 0.15 and 0.35 are examined at three spacing distances, which are corresponding to the Vortex Suppression, critical and the Vortex Formation regimes. Results show that in such a system, the spacing distance determines the flow regime and set the base for the flow patterns, the forcing and heat transfer characteristics. For the flow features, the locked-on phenomenon is observed in the present study, whereby the flow and thermal fields are phase-locked with the cylinder oscillation. Outside the locked-on region, an ordered and modulated near-wake can also be observed, but the variation period of the flow field is different from the oscillation period. Additionally, it is found that the parameter range to obtain a locked-on response is narrowed with an increasing spacing distance. Compared with the system with two stationary cylinder, the lift and drag force can subject to larger variations (especially for the downstream cylinder) due to the oscillatory motion. More importantly, the present study demonstrates a large room to enhance the heat transfer. It shows that in the Vortex Suppression and the Vortex Formation regimes considered here, the heat transfer rate of the downstream cylinder can be improved in most cases (with that of the upstream cylinder slightly increased or kept the same with the baseline). A maximum increase of 59.4% of the average Nusselt number can be obtained in the test matrix studied.

AMS subject classifications: 76D17, 80A20

Key words: Fluid-structure interactions, heat transfer, immersed boundary method.

*Corresponding author.
Email: jyshao@whut.edu.cn (J. Y. Shao)

1 Introduction

The fluid mechanism and thermal dynamic of system involving multiple circular cylinders is a scientific problem with rich physical phenomenon and also of practical interests in engineering applications. It serves as a fundamental model for understanding the performance of heat exchanger, cooling towers, boilers and the power cables in civil and ocean engineering applications to name a few.

In the coupled system of cylinders in a flow field, the transient interactions among the free stream, the wake and the motion of the solid bodies lead to complex flow patterns and places many challenges for this problem to be fully understand. Large separated wake with alternate shedding vortices can form behind the circular cylinders. When these cylinders are placed closely, the wakes can interact with the solid boundary, giving rise to generic flow features such as flow reattachment, vortex impingement and quasi-periodic vortices. Moreover, if the cylinder is allowed to move, the movement can further perturb the flow field and causes even more complex flow structures as well as the fluid loads. In such a system, parameters such as the number of cylinders, their arrangement (tandem, side-by-side or staggered) and the spacing distance between the cylinders can be influential. These parameters form a complex test matrix. To approach such a complex problem in detail, it is more feasible to simplify the test matrix at the first place. Thus, the present work will focus on two tandemly arranged cylinders with equal diameter, with the downstream one undergoes a controlled transverse oscillation. The fluid dynamics and the heat transfer performance of this system will be analyzed in the present work.

A closely related problem, the single transverse oscillating cylinder (oscillates across the free stream) has been extensively studied. The earliest work can be dated back to the experimental work by Bishop & Hassan [1]. They examined the hydrodynamic forces and recognized the locked-on phenomenon, in which the frequency of vortex shedding f_{vs} was synchronized with the frequency of cylinder motion f_c. They reported that the amplitude of the mean drag and lift are amplified, and the phase angle between the lift forces and the cylinder displacement is suddenly changed in the locked-on region. This phase jump, according to the analysis of Zdravkovich [2], Ongoren & Rockwell [3] and Gu et al. [4], was due to the change of timing of the shed vortices. Koopmann [5] performed a flow visualization study and discovered that the lateral spacing of the vortices decreased with increasing oscillation amplitude (A). Subsequently, the geometric alterations of the cylinder wake induced by forced transverse oscillation were investigated systematically by Griffin and his coworkers [6–8]. Williamson & Roshko [9] and also Morse & Williamson [10]. A series of vortex shedding modes have been identified from experimental works. In addition to the experimental work, Meneghini & Bearman [11] determined numerically the locked-on boundary for vortex shedding at Re=200, observed different vortex shedding modes at different oscillation amplitude. Besides the works introduced above, there are many other excellent experimental measurements and numerical simulations [12–15] that help to deepen our understanding in this problem. Apart from its influence on the flow field, transverse oscillation of cylinder is also con-