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Stress analysis of internally finned bayonet tube in a high temperature heat exchanger☆

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ABSTRACT

In this paper, the thermal stress and deformation of the internally finned bayonet tube used for high temperature heat exchangers are presented. The internally finned bayonet tube is developed from the traditional bayonet tube, where the longitudinal plain fins are proposed to be welded on the inner surface of outer tube to enhance the heat transfer performance. However, significant temperature gradient is observed along both the axial and radial directions. The large stress is still generated in the joint of inner fin and inner tube, and the joint of inner fin and outer tube due to the discontinuous change of the structure, although the bayonet structure has a great potential to reduce the stress. Therefore, the inner fin and inner tube are proposed to not be welded together so that they can expand or contract freely and the expansion does not affect each other. The effect of gap between inner tube and inner fin on the stress and heat transfer performances is compared. The result indicates that the gap between them should be less than 1 mm for considered bayonet tube with 6 mm annulus height according to the coupled consideration of heat transfer and stress performances.

1. Introduction

As the energy becomes scarcer and scarcer, many highly efficient power and propulsion systems and alternative energy using the different thermodynamics cycles have been developed, such as the hydrogen production sulfur–iodine (S–I) thermochemical cycle, the very high temperature reactor (VHTR) and the externally fired combined cycle (EFCC). One of common characteristics is that they operate under extremely high temperature up to 900 °C. It brings a big challenge for high temperature heat exchangers (HTHEs), which are crucial elements to enhance the total efficiency.

For low temperature environment, the fluid flow and heat transfer as well as the fouling performances of the heat exchangers are the main concerns [1–5]. However, HTHEs are required to endure high temperature so that large thermal stress and deformation are very serious. In fact, the thermal stress and deformation of HTHE have been recognized by many researchers. Irfan and Chapman [6] compared the thermal stresses of radiant tubes in regenerative and recuperative systems. It was shown that the thermal stress of radiant tube in the recuperative system was significant due to the non-linear axial temperature gradients along the tube length, whereas that in the regenerative was small due to a comparatively linear axial temperature gradient. They [7] also investigated the effect of axial, circumferential and radial temperature distributions on the thermal stresses of radiant tubes. The results indicated that hot spots in the axial temperature gradient were a major source of thermal stress. Schulte–Fischedick et al. [8] studied thermomechanical integrity of ceramic plate-fin heat exchanger in EFCC under steady-state and emergency operation conditions. The maximum stress was found in the manifold section and could be reduced by inserting support fins. Pra et al. [9] analyzed the thermal and mechanical behavior of compact heat exchangers for modular high temperature reactor with coupled computational fluid dynamic and finite element methods. Large stress variations were observed at the interface between the fish bone section and the outer solid metals near the hot inlet. Kawashima et al. [10] discussed the high temperature strength and inelastic behavior of plate-fin heat exchanger used for high temperature gas-cooled reactors. A stress analysis method based on equivalent-homogeneous-solid concept was proposed. Tsuda et al. [11] adopted the fully implicit mathematical homogenization scheme of periodic elastic-inelastic solids to analyze the

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