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Experimental investigation on heat transfer and frictional characteristics of vertical upward rifled tube in supercritical CFB boiler

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ABSTRACT

Water wall design is a key issue for supercritical Circulating Fluidized Bed (CFB) boiler. On account of the good heat transfer performance, rifled tube is applied in the water wall design of a 600 MW supercritical CFB boiler in China. In order to investigate the heat transfer and frictional characteristics of the rifled tube with vertical upward flow, an in-depth experiment was conducted in the range of pressure from 12 to 30 MPa, mass flux from 230 to 1200 kg/(m^2 s), and inner wall heat flux from 130 to 720 kW/m^2. The wall temperature distribution and pressure drop in the rifled tube were obtained in the experiment. The normal, enhanced and deteriorated heat transfer characteristics were also captured. In this paper, the effects of pressure, inner wall heat flux and mass flux on heat transfer characteristics are analyzed, the heat transfer mechanism and the frictional resistance performance are discussed, and the corresponding empirical correlations are presented. The experimental results show that the rifled tube can effectively prevent the occurrence of Departure from Nucleate Boiling (DNB) and keep the tube wall temperature in a permissible range under the operating condition of supercritical CFB boiler.
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1. Introduction

In the 1980s, CFB combustion technology began to be developed in the world. On account of the good performances including good fuel flexibility, high combustion efficiency and efficient pollution control, CFB boiler is successfully commercialized for coal-fired power generation. As a clean coal technology with bright prospect, supercritical CFB boiler technology can further improve the boiler efficiency and reduce the pollution emission [1], so it becomes a very important development trend for coal-fired power plants in China [2]. At present, a 460 MWe supercritical CFB boiler at Lagisza power plant in Poland, which is the first supercritical CFB boiler and the largest CFB boiler in the world, has been put into operation at March, 2009 [3]. Foster Wheeler and Alstom Power all present different conceptual designs of supercritical CFB boiler with larger scale and higher parameter now.

With the aim to meet the operating requirement of high efficiency, low pollution emission and variable load, high operating parameters, low mass flux and sliding pressure mode are often applied in the design of supercritical CFB boiler. Additionally, breeches-legs structure and additional evaporating heating surface may be adopted in supercritical CFB boiler. So the water wall structure and the boiler operating condition is very complex. Therefore, it is a key technology in the water wall design to ensure all water wall tubes can be cooled effectively and to keep the tube wall temperature in a permissible range [4]. Due to the good heat transfer performance, rifled tube is often applied in boiler water wall to enhance turbulization and to prevent the burnout of tubes walls.

Many scholars experimentally investigated the heat transfer characteristics of rifled tubes at subcritical pressure. Swenson et al. [5] studied the effects of nucleate boiling versus film boiling on heat transfer in power boiling tubes and the experimental results shows that nucleate boiling could be maintained to higher vapor qualities with rifled tube than with smooth tube. Watson et al. [6] found that the rotational flow in ribbed tube can greatly raise CHF and critical vapor quality. Nishikawa et al. [7] found that rifled tubes with different geometrical structures have different heat transfer enhancement performances. Iwabuchi et al. [8] detected that in near-critical pressure region the heat transfer enhanced by rotational flow in rifled tube disappeared and heat transfer deterioration even occurs in subcooling region. Kolher and Kastner [9] experimentally ascertained that rifled tube can effectively delay heat transfer deterioration and improve heat transfer in post-dryout region.

Due to the special thermophysical properties, great importance was attached to the heat transfer characteristics of supercritical water. Shitsman [10] studied the heat transfer deterioration near pseudo-critical point. Swenson et al. [11] detected that pressure and heat flux has important influence on the heat transfer of supercritical water. Virkrev et al. [12] discovered two kinds of heat transfer deterioration. One occurs in the inlet region at high heat

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