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A numerical study on thermal behavior of a D-type water-cooled steam boiler

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ABSTRACT

To achieve a precise assessment on thermal performance of a D-type water-cooled natural gas-fired boiler the present paper was aimed at determining temperature distribution of water and flue gas flows in its different heat exchange equipment. Using the zonal method to predict thermal radiation treatment in the boiler furnace and a numerical iterative approach, in which heat and fluid flow relations associated with different heat surfaces in the boiler convective zone were employed to estimate heat transfer characteristics, enabled this numerical study to obtain results in good agreement with experimental data measured in the utility site during steady state operation. A constant flow rate for a natural gas fuel of specified chemical composition was assumed to be mixed with a given excess ratio of air flow at a full boiler load. Significant results attributed to distribution of heat flux on different furnace walls and that of flue gas and water/steam temperature in different convective stages including superheater, evaporating risers and downcomers modules, and economizer were obtained. Besides the rate of heat absorption in every stage and other essential parameters in the boiler design too, inherent thermal characteristics like radiative and convective heat transfer coefficients as well as overall heat transfer conductance and effectiveness of convective stages considered as cross-flow heat exchangers were eventually presented for the given operating condition.

1. Introduction

In recent years, industrial natural circulation steam generating systems such as water-wall boilers have received great attention due to their benefits, like simplicity, low costs, and more particularly inherent safety [1]. D-type water-cooled steam boilers are of the most common widely used to generate steam and power. Hence, the more precise a thermal analysis is made on this type of boilers, the more efficient a design will be attained, and finally the higher and the less costly, both economical and environmental, the power or steam will be produced.

Furnace zone wherein thermal radiation is dominant heat transfer mechanism and convective zone wherein the share of thermal convection overwhelms that of radiative heat transfer, merely attributed to non-luminous flue gases, are two main parts of the D-type water-cooled steam boilers. Owing to high accuracy the zonal method has exhibited in predicting radiative behavior of gases bound to enclosures, it has growingly served as a proper method to analyze industrial furnaces. First essential steps for applying the zonal method to study radiative heat transfer phenomenon in gas-filled enclosures were taken by Hottle et al. [2,3]. Batu and Selçuk [4] made numerical analysis on a fluidized bed combustor using the zonal method. To model heat transfer in the furnace of a pulverized utility boiler, Bordbar and Hyppänen [5] also applied this method by which they presented temperature profiles within the boiler furnace as well as heat flux distribution on the furnace walls. Despite introduced as a powerful and rigorous approach for estimating radiative heat transfer in enclosures, the zonal method involves complex difficulties in calculation. In this method, the domain of interest is divided into a finite number of isothermal surface areas and volume zones. The radiative heat transfer rate is determined by the emissive power and mutual direct exchange areas (DEA) of each zone, requiring calculation of four-, five-, and six-dimensional integrals. The integrands have strong singularities when two zones are adjacent or overlap each other (self-irradiation). High accuracy numerical approximation of these multiple integrals is in turn difficult to achieve. Considerable efforts have already been made to simplify calculation of DEA. For instance, Siddall [6] developed a scheme to simplify the multiple integrals, by which the surface–volume and volume–volume DEA were reduced to a large number of single integrals. The DEA of a rectangular enclosure were numerically integrated, correlated, and graphed by Tucker [7]. Erkku [8] studied the DEA of

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