



Distributed parameters modeling for evaporation system in a once-through coal-fired twin-furnace boiler

Shu Zheng, Zixue Luo*, Xiangyu Zhang, Huaichun Zhou

State Key Laboratory of Coal Combustion, Huazhong University of Science and Technology, 1037, Luoyu Road, Hongshan District, Wuhan, Hubei 430074, China

ARTICLE INFO

Article history:

Received 25 December 2010

Received in revised form

19 May 2011

Accepted 19 July 2011

Available online 23 August 2011

Keywords:

Distributed parameter modeling

Evaporation system

3-D temperature distribution

Once-through boiler

ABSTRACT

In this paper, a distributed parameter model for the evaporation system of a subcritical once-through, coal-fired, twin-furnace boiler based on 3-D temperature field reconstruction is developed. The imaginary wall surface was put forward to simplify the twin-furnace problem. The mathematical model was formulated for predicting the transient distributions of parameters, such as the heat flux, the metal-surface temperature and the steam quality; while considering the non-uniform distributions of the surface heat transfer coefficient and frictional resistance coefficient. The model was based on the 3-D temperature distribution got by a flame image processing technique. The model was validated by some measurable parameters of the evaporation system at three typical loads. The results show that the heat flux and the temperature which are located at the overlapping region of the two tangential flames are higher than those in other corners. This distributed parameter model on evaporation system reflects the in-situ operating status of the power plant boiler, which may lead to the subsequent research on a supercritical boiler.

© 2011 Elsevier Masson SAS. All rights reserved.

1. Introduction

The analysis and modeling of the evaporation system of a once-through boiler are crucial for the safe operation, which is related to the combustion behavior in the furnace and the pressure of the working substance. The evaporation system of the boiler absorbs the heat from the flame in the furnace, and the study of the boiler performance and the design of an appropriate control strategy are necessary for analyzing its dynamic characteristic. The prediction of transient behavior of the evaporation system requires dynamic models.

There are two kinds of dynamic models for the evaporation system simulation. One is the fine mesh model, and the other is the lumped parameter model which focuses on the fast simulation and the control system design [1]. Considering the complexity of combustion and the heat transfer process in the furnace, many researchers are using a lumped parameter to establish a model of the evaporation system. Li H-P et al. [2] developed a lumped parameter mathematical model to analyze the helical coiled once-

Abbreviations: BMCR, boiler maximum continuous rating; DCS, distributed control systems; DNB, departure from nucleate boiling.

* Corresponding author.

E-mail address: luozixue@mail.hust.edu.cn (Z. Luo).

through steam generator. Wang et al. [3] also proposed a new lumped parameter method for modeling the evaporation zone of a once-through boiler. These lumped parameter models only considered the total heat flow rate, but neglected the non-uniform heat flux distribution. With the development of a distributed parameter model, some scholars [4,5] considered the characteristic of non-uniform heat flux distribution to build the model. Zhu and Zhang [4] put forward a real-time mathematical distributed parameter model for the heat transfer in the furnace. Pan et al. [5] calculated the thermal-hydraulic characteristics of the water wall in an ultra supercritical coal-fired boiler which adopted a mathematical distributed parameter model. However, all the models in these references are based on a reduced one-dimensional heat flux distribution model. The model for the evaporation system will become more accurate and valuable by considering a 2-D, non-uniform distribution of radiation heat flux on the water wall. Due to the lack of on-line, 3-D combustion monitoring systems, this kind of model has seldom been reported. Li Z-Q. et al. [6,7] introduced an optical pyrometer, with a measurement range from 500 to 2000 °C, to measure furnace temperature. Zhou et al. [8–10] developed a flame image processing technique on visualization of 3-D temperature distributions in pulverized-coal (pc) fired boilers. Chu et al. [11] proposed an accurate, 2-D, distributed parameter model for the evaporation system of a controlled natural circulation boiler based on the 3-D temperature distribution and the emissivity

Nomenclature

c	specific heat capacity [$\text{J kg}^{-1} \text{K}^{-1}$]
C	fitting coefficient
d	diameter [m]
D	mass flow rate [kg s^{-1}]
F	flow area [m^2]
g	acceleration of gravity [m s^{-2}]
G	mass velocity [$\text{kg m}^{-2} \text{s}^{-1}$]
h	specific enthalpy [J kg^{-1}]
H	height [m]
M	mass [kg]
Nu	Nusselt number
p	pressure [Pa]
Pr	Prandtl number
q	heat flux [W m^{-2}]
Q	heat flow rate [W]
Rd	READ number
Re	Reynolds number
S	surface area [m^2]
T	absolute temperature [K]
u	specific internal energy [J kg^{-1}]
V	volume [m^3]
x	steam quality
X_{tt}	Martinelli number

Greek symbols

α	heat transfer coefficient [$\text{W m}^{-2} \text{K}^{-1}$]
β	frictional resistance coefficient

Δ	difference in any quantity
ε	emissivity
η	absorptance of the imaginary wall surface
κ	absorption coefficient [m^{-1}]
λ	thermal conductivity [$\text{W m}^{-1} \text{K}^{-1}$]
μ	dynamic viscosity [$\text{N m}^{-1} \text{s}^{-1}$]
ξ	resistance coefficient
ρ	density [kg m^{-3}]
σ	Stefan–Boltzmann constant [$\text{W m}^{-2} \text{K}^{-4}$]
ϕ	two-phase frictional multiplier
ω	velocity [m s^{-1}]

Subscripts

A, B	number of furnace
cr	critical point
f	flue gas
i, j	number of element
in	inner
l	liquid
max	maximum value
out	outer
w	water wall
1	inlet
2	outlet

Superscripts

'	saturated liquid state
"	saturated vapor state
–	average value

of the particle phase. However, their model can not be applied in a once-through boiler because of the large difference in the evaporation surfaces. The evaporation system is divided into subcooled region, boiling region and super heated region according to the secondary water/steam status. The boundaries of these regions are movable, and the steam-water separation takes place at the location of dryout in evaporating tubes. Swenson et al. [12] studied the effects of nucleate boiling versus film boiling on heat transfer in power boiling tubes and the experimental results show that nucleate boiling could be maintained to higher vapor qualities with rifled tubes than with smooth tubes. Pan et al. [5] proposed that not only DNB (saturated boiling zone), but dryout (film boiling range) occur in the vertical rifled tube under subcritical pressure. More refined models of the two-phase flow, such as the steam boiler evaporating tubes based on the multi-fluid models of two-phase flow are presented in the work of Delhye et al. [13], Stevanovic and Studovic [14], and Stosic and Stevanovic [15]. It is of extreme importance to determine whether heat transfer deterioration will be generated for the evaporation system, and when or where it occurs. Therefore, a dynamic, accurate, 2-D, distributed parameter model for the evaporation system of a once-through boiler is very meaningful for the development of power plant boilers.

Yao Meng power plant is a 300 MW twin-furnace subcritical once-through boiler in China, it was designed and manufactured by Shanghai Boiler Works Ltd, and a 3-D temperature field reconstruction system has been installed in this boiler. Vertical ribbed bore tubes were applied in the water wall; and rifled tubes with good heat transfer performance were adopted. The restriction orifices are mounted to meet the matching requirement between heat flux and mass flux.

In this paper, a distributed parameter model for the evaporation system based on 3-D combustion monitoring in the furnace is developed and the imaginary wall surface is put forward to simplify

the twin-furnace problem. A mathematical model was formulated for predicting the transient distributions of parameters, such as the heat flux, the metal-surface temperature and the steam quality; while considering the non-uniform distributions of the surface heat transfer coefficient and frictional resistance coefficient. Based on the 3-D temperature distribution, the heat flux, mass fraction of steam, and metal temperature distribution in the water wall at three typical loads are obtained by directly solving non-linear equations. The results show that the heat flux and temperature near the overlapping region of two tangential flames is larger than the edge. The predicted increase of the outlet steam quality and the decrease of the two-phase flow zone, caused by the load increase, are in agreement with measured data. This model strategy is helpful for fine distributed parameter research in upper-critical once-through boiler.

2. Distributed mathematical model

The evaporation system is divided into three sub-models: flue gas model, tube wall model and water/steam model. These models are connected with some coupling thermodynamic parameters, as shown in Fig. 1. In the flue gas model, the non-uniform distribution of radiation heat flux on the water walls is got from the 3-D temperature distribution of flue gas; and the average emissivity of the particle phase is obtained through the monitoring system for the 3-D combustion in the furnace. In the tube wall model, the temperatures inside/outside the water wall are taken into account. For the water/steam model, its function is to obtain the dynamics of steam quality and mass velocity.

To reduce the complexity of boiler modeling, some assumptions are made:

- (1) The furnace is assumed to be filled by a gray emitting, absorbing, and isotropically scattering medium and surrounded by gray water walls.

Download English Version:

<https://daneshyari.com/en/article/669044>

Download Persian Version:

<https://daneshyari.com/article/669044>

[Daneshyari.com](https://daneshyari.com)