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On-line fouling monitoring model of condenser in coal-fired power plants

Jianlan Li *, Zhaoyin Zhai, Jizhou Wang, Shuhong Huang

School of Energy and Power Engineering, Huazhong University of Science & Technology, Wuhan 430074, China

HIGHLIGHTS

- A comprehensive approach to monitor the fouling of the condenser is presented.
- An all-condition mechanism model of coal-fired power plants is proposed.
- A correction of the condensation heat transfer resistance in the steam side.
- On-line fouling monitoring of the condenser is realized in the field.

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ABSTRACT

The fouling of water side surfaces decreases the thermal effectiveness of the condenser and it is always one of operational focuses in coal-fired power plants. This study presents a comprehensive approach to realize the on-line fouling monitoring for the condenser in thermal power plants. Based on the operational mechanism and the coupling property, an all-condition mechanism model (ACMM) of coal-fired power plants is proposed to simulate coupling operating characters of systems. The simulation results of a 600 MW/16.7 MPa/560 °C/560 °C supercritical coal-fired power plant indicate that the model is of sufficient accuracy for performance calculations under different off-design conditions. An on-line fouling model of the condenser is presented according to simulation results of ACMM and on-line monitoring parameters from SIS system. For the fouling model, a correction as a function of the non-condensable gas is implemented to improve the accuracy of the condensation heat transfer resistance in the steam side of the condenser. The results of the on-line fouling monitoring in the field reveal that the fouling of the condenser increased with time and the fouling growth rates kept relative stable. Furthermore, this study also provided an alarm for the leakage fault in the condenser according to the abnormal fouling resistance tend.

1. Introduction

The condenser is one of the most important elements in coal-fired power plants. The performance of the condenser has a major impact on plants' thermal performance [1,2]. In actual conditions, the condenser usually experiences a degradation of heat transfer performance due to the fouling by mineral ions, mud, impurities and biomass in the cooling water accumulate gradually on walls of exchanger tubes with time. Multiple fouling mechanisms often occur at the same time and they have an interferential effect on the fouling rate [3]. Many studies have been performed to analysis the negative influence of fouling on the effectiveness and heat transfer capability [4,5].

The most widely accepted fouling model was first proposed by Kern and Seaton [6], which pointed out that the fouling growth depended on both the rate of the fouling deposition and removal. Qureshi and Zubair [7] developed a model to demonstrate a correlation between normalized condenser performance indexes due to fouling as a function of the thickness by experimental fouling data, and studied the thermal performance under fouled conditions. It indicated that there was over 50% decrease in the effectiveness for both the evaporative cooler and the condenser. Ibrahim and Attia [8] performed a thermodynamic analysis and energy balance to study the effect of the fouling change on the thermal performance of the condenser and the thermal efficiency of a nuclear power plant. The results showed that the increase of the fouling decreased the power output and the thermal efficiency. Walker et al. [9] proposed a methodology to quantify the economic impact of the condenser fouling on the performance of thermoelectric

* Corresponding author.
E-mail address: hust_ljl@hust.edu.cn (J. Li).

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Nomenclature

Abbreviation

ACMM	all-condition mechanism model of coal-fired power plants
SIS	supervisory information system in plant level
THA	turbine heat acceptance

Symbols

A	surface area (m^2)
b	oxygen content in condensate ($mg\ L^{-1}$) oxygen content of condensate oxygen content of condensate oxygen content of condensate
D	mass flow rate ($kg\ s^{-1}$)
d	diameter (m)
F_j	fitting function of pressure ration
f_{hp_t}	function of steam temperature according to steam enthalpy and pressure
f_{ps_h}	function of steam enthalpy according to steam pressure and entropy
G_j	fitting function of efficiency and input steam flow
g	gravitational acceleration ($m\ s^{-2}$)
h	specific enthalpy ($kJ\ kg^{-1}$)
h^*	ideal enthalpy (J)
h_{lat}	latent heat of vaporization ($kJ\ kg^{-1}$)
K	mass solubility coefficient of oxygen ($mg\ L^{-1}$)
k	convective heat transfer coefficient ($W\ m^{-2}\ C^{-1}$)
k_a	overall heat transfer coefficient ($W\ m^{-2}\ C^{-1}$)
k_c	adiabatic coefficient
k_{fc}	film condensation heat transfer coefficient
k_0	condensing heat transfer coefficient ($W\ m^{-2}\ C^{-1}$)
M	molar mass of air ($g\ mol^{-1}$)
Ma	Mach number
mc_{ncg}	mass content coefficient of non-condensable gas
Nu	Nusselt number
n	number of cooling tube
np	number of cooling water pass
p	pressure (MPa)
Pr	Prandtl number
Q	overall heat load in condenser ($GJ\ h^{-1}$)
R	gas constant ($J\ mol^{-1}\ C^{-1}$)
R_{add}	additional thermal resistance ($C\ W^{-1}$)
R_a	overall heat transfer resistance of condenser (kW^{-1})
R_d	thermal conductivity resistance of cooling tube ($C\ W^{-1}$)
Re	Reynolds number
R_f	fouling conductivity resistance ($C\ W^{-1}$)
R_s	condensation heat transfer resistance in steam side ($C\ W^{-1}$)
R_w	convective heat transfer resistance in water side of cooling tube ($C\ W^{-1}$)
r	Radius (m)
s	entropy ($J\ C^{-1}$)
t	temperature (C)
t_s	saturation temperature of steam condensation (C)
u	flow rate of cooling water ($m\ s^{-1}$)
V	volume fraction of oxygen in air
v	kinematic viscosity ($m^2\ s^{-1}$)
X	dryness of turbine exhaust steam
λ	thermal conductivity ($W\ m^{-1}$)
φ_{cw}	correction coefficient of cooling water inlet temperature
φ_{ncg}	correction coefficient of condensation heat transfer caused by the non-condensable gas
φ_{np}	correction coefficient of cooling water pass number
ρ	density ($kg\ m^{-3}$)
μ	dynamic viscosity (Pa s)
ε	pressure ratio between import and export of stage
θ	terminal difference (C)
η	viscosity coefficient ($kg\ m^{-1}\ s^{-1}$)
η_s	stage efficiency

Subscripts

cd	condensate water
con	condenser
ct	cooling tube
cw	cooling water
dw	drain water into condenser
dss	dry saturated steam
ehs	turbine exhaust steam
f	fouling
is	inside
lf	liquid film
st	stream side of cooling tube
in	inlet
ets	extraction stream
cr	after correction
mg	mixed gas in condenser
ncg	non-condensable gas
o	oxygen
os	outside
ow	on water surface
q	qualitative
s	saturation
vp	vacuum pump
w	water
ws	wet steam
wt	water side of cooling tube
out	outlet
fw	feedwater

power plants. Analyses of a 550 MW coal fired power plant showed that costs arising from additional fuel requirements and production losses associated with the condenser fouling were in the range of 0.4–2.2 Million (USD 2009). Rubio et al. [10] evaluated and compared the effectiveness of different antifouling treatments in a heat exchanger.

The fouling always grows with time which contributes to the condenser's performance degradation. Prieto et al. [11] and Wang et al. [12] carried out researches on the fouling growth on the condenser water side wall and analyzed the characteristic of the fouling deposit, the effect of the working time and the cooling water's velocity. Qureshi and Zubair [7] used experimental data to develop a fouling model to predict the decrease in the heat transfer rate with the growth of the fouling. They found that the fouling of tubes reduced gains in the performance resulting from decreasing values of the air inlet wet bulb temperature, and the decrease in the effectiveness due to the fouling was about 55% and 78% for condensers. Nebot et al. [13] proposed a kinetic improvement model for the fouling evolution prediction which took into account the induction period due to the biological contribution to the fouling process. They found that the maximum asymptotic limit of the thermal resistance decreased as the velocity increased by experimental