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Research on varying condition characteristic of feedwater heater considering liquid level

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HIGHLIGHTS

- We model three-section feedwater heater based on dimensional analysis.
- Model of operating characteristic for the heater at low liquid level is proposed.
- The model is verified by comparison with the test data.
- Secure liquid level and economic liquid level of the heater are reset.

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ABSTRACT

In this paper, a mathematical model of varying condition is established for the three-section heater based on dimensional analysis, then with the combination of the derivation of heat transfer coefficient in the drain cooler section, the model of operating characteristic for the heater at low liquid level is proposed. Taking #1 high pressure feedwater heater of a 330 MW turbine as example, the terminal temperature difference at both normal liquid level and low liquid level and the change of the heat transfer condition in the drain cooler section at low liquid level can be calculated respectively by the proposed model. By comparison with the test data the accuracy of the model is verified. In addition, the influence of liquid level and load on terminal temperature difference is analyzed quantitatively, and the secure liquid level and economic liquid level are reset. The results show that the study can provide a reference for the timely adjustment of the liquid level in actual operation.

1. Introduction

The heat recovery system has become an effective method to increase the thermal efficiency in modern thermal power plant [1]. The feedwater heater is the core of heat recovery system, and the reasonable liquid level is the key point of keeping heaters operating safely and economically. If the liquid level of the heater is high, some pipes will be flooded and the effective heat transfer area will be reduced, which will make the economic of the unit decline; in severe cases the heater will split and even water intake accident of the steam turbine will be caused. Thus, the heater usually has the high liquid level alarm, for secure reasons the operating personnel also try their best to make the heater operate in the low liquid level. It is feasible for the operation of high pressure heater without the inner set drain cooler section, for the interstage water seal will be formed as long as the liquid level exists. However, for the horizontal high pressure heater with the inner set drain cooler section, if the liquid level is too low, the diving export water seal of the drain cooler section will be useless, which makes the mixed stream–water of the condensing section flows into the drain cooler section, causing the increase of terminal temperature difference and the decrease of heat economy; and the mixed fluid even scours the pipe wall of heater, causing vibration and erosion of the pipe bundle [2].

Therefore, it is necessary to ensure that the heater should be worked in a reasonable range of liquid level, i.e. the set point of the liquid level should be adjusted reasonable in daily operation. Although the shell of the heater is usually marked with the normal operation liquid level (liquid level 0) by the manufacturers, the

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Nomenclature

t_h	saturation temperature, °C
t_{od}	drain temperature, °C
t_{w1}	inlet feedwater temperature, °C
t_{1t}	outlet feedwater temperature of drain cooler section, °C
t_{2t}	outlet feedwater temperature of condensing section, °C
t_{w2}	outlet feedwater temperature of the superheated stream cooling section, °C
t_s	extraction steam temperature, °C
ε	the effectiveness of heater
NTU	the number of transfer units
C''_{pl1}	the mean specific heat at constant pressure of the water outside the pipe of the drain cooler section, J/(kg °C)
C_{pl1}	the mean specific heat at constant pressure of the water inside the pipe of the drain cooler section, J/(kg °C)
G_s	extraction mass flow, kg/s
G_w	feedwater mass flow, kg/s
K_1	the overall heat transfer coefficient of the drain cooler section, W/(m^2 °C)
F_1	the heat transfer area, m^2
c	the parameter related to the pipe location
u_i	the water flow velocity inside the pipe
ϕ_c	the clean coefficient
ϕ_m	the pipe correction coefficient
ϕ_w	the water temperature correction coefficient inside the pipe
Δt_m	the logarithmic mean temperature difference, °C
K_2	the overall heat transfer coefficient of the condensing section, W/(m^2 °C)
F_2	the heat transfer area, m^2
C_{pl2}	the mean specific heat at constant pressure of feedwater inside the pipe of the condensing section, J/(kg °C)
h_{i2}	the convective heat transfer coefficient inside the pipe of the condensing section, W/(m^2 °C)
d_{i2}	inner diameter of the pipe, m
Nu	the Nusselt number
Re	the Reynolds number
Pr	the Prandtl number
u_{i2}	the flow velocity of feedwater inside the pipe, m/s
γ_{i2}	the kinematical viscosity of fluid inside the pipe, m^2/s
μ_{i2}	the dynamic viscosity of fluid inside the pipe, Pa s
λ_{i2}	the thermal conductivity of fluid inside the pipe, W/(m °C)
c_{pi2}	the mean specific heat at constant pressure of fluid inside the pipe, kJ/(kg °C)
NP	the flow number
NT	the pipeline number
h_{02}	the convective heat transfer coefficient outside the pipe of the condensing section, W/(m^2 °C)
r_{02}	the vaporization latent heat of per unit mass of the steam, kJ/kg
g	the acceleration of gravity, m/s^2
λ_{02}	the thermal conductivity of the fluid outside the pipe, W/(m K)
ρ_{02}	the density of the fluid outside the pipe, kg/m^3
μ_{02}	the dynamic viscosity of the fluid outside the pipe, Pa s
d_{02}	the outer diameter of the pipe, m
h_s	enthalpy of the extraction steam, kJ/kg
h_h	enthalpy of the saturated steam, kJ/kg
C_{pl3}	the mean specific heat of feedwater inside the pipe of the superheated stream cooling section, J/(kg °C)
δ	terminal temperature difference, °C
θ	drain cooler approach, °C
S_d	the section area of drain section, m^2
S_l	the section area of steam section, m^2
G_l	steam leakage of drain cooler section at low liquid level, kg/s
v_w	the specific volume of saturated water, m^3/kg
v_s	the specific volume of saturated steam, m^3/kg
C'_{pl1}	the mean specific heat at constant pressure of the water outside the pipe of the drain cooler section, J/(kg °C)
h_i	heat transfer coefficient inside the pipe at low liquid level, W/(m^2 °C)
h_0	heat transfer coefficient outside the pipe, W/(m^2 °C)
d_0	the outer diameter of the pipe, m
λ_0	the thermal conductivity of the fluid outside the pipe, W/(m °C)
R_1	the fouling thermal resistance inside the pipe, (m^2 °C)/W
R_2	the fouling thermal resistance outside the pipe, (m^2 °C)/W
h_h	the enthalpy value of saturated steam, kJ/kg
h_l	the enthalpy value of saturated water, kJ/kg

Subscripts

“0”	the known working condition
“*f*”	qualitative temperatures which are steam–water mixture average temperature in the shell side
“*w*”	qualitative temperatures which are the average temperature of pipe wall

design liquid level often has some deviations with actual operation value and is not necessarily the best liquid level. So the terminal temperature difference is usually used as criterion in power plant to determine the reasonable operation liquid level through the liquid level adjustment test.

The terminal temperature difference of the heater changes with the operating condition of the turbine and the liquid level. Acquiring the relationship of these three terms is conducive to adjust liquid level in time according to the changing of unit load, which can ensure the safe and economic operation of the unit and speed up the process of the liquid level adjustment test.

At present, many scholars have studied on varying condition characteristic of the feedwater heater without considering the impact of the liquid level. Some Chinese scholars assumed that the heat transfer coefficient of the heater remains unchanged when the unit load and the inlet feedwater temperature change [3]. Although the calculation process was simplified, the result had certain errors compared with the actual situation. Ref. [4] made use of the heat transfer theory and the heat balance theory, introducing a calculation method of the optimal value of the terminal temperature difference for low pressure heater considering the influence of the inlet feedwater temperature and the unit load on the transfer