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Research Paper

Development of a model to evaluate the water level impact on drain cooling in horizontal high pressure feedwater heaters

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HIGHLIGHTS

- A model for a three-zone feedwater heater is suggested then tested.
- Model is not limited to any specified sets of operating conditions and geometry.
- Characteristics of a typical heater is analyzed.
- Performance of heater is most sensitive to level changes under full load condition.

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ABSTRACT

Feedwater heaters play an important role in improving power plant thermal efficiency. High pressure feedwater heaters are generally of shell and tube type of heat exchangers which have three shrouded zones in the shell. In present study, a mathematical model is suggested for performance evaluation of a three-zone feedwater heater. Proposed model is capable of predicting the effects of variation in liquid level and load condition. The model is verified by experimental results existing in literature. Then impact of increase or decrease of liquid level on performance characteristics are evaluated for a typical horizontal high pressure feedwater heater. The influence of water level and load on drain cooler approach is analyzed quantitatively. Results show sharp variation in drain cooler approach in low water level condition. It is also shown that at full load condition, heater is more sensitive to liquid level changes.

1. Introduction

Feedwater heaters play an important role in improvement of power plant thermal efficiency. High pressure feedwater heater admits high pressure steam in its shell and energy is transferred to feedwater flowing at tube side. Shell side of high pressure FWH generally consists of desuperheating, condensing and subcooling zones. An important parameter in performance of heater is the height of water level which is formed due to condensation of steam in condensing zone. Increasing water level leads to decrease in overall heat transfer coefficient in condensing zone while low water level height causes the two phase fluid to enter the subcooling zone, so vibration and corrosion of tube bundle happens in addition to decline in thermal efficiency. High water level may cause intense damages to heater; therefore manufacturers incorporate alarm equipment in order to avoid damages and to prolong the life of feedwater heaters as well. Thus, it is necessary to make sure that FWH is working in an appropriate range of water level. Terminal temperature difference (TTD) is another remarkable parameter which varies with variation of liquid level and load condition. In order to find the appropriate range of water level, the relationship between water level, load condition and performance parameters must be investigated.

Devising an effective and accurate method for sizing and rating of feedwater heaters has been a matter of concern for long time. Finlay [1] discussed the importance of condensation process in desuperheating zone. He use generalized heat transfer and pressure drop equations in order to find the relationship between steam velocity in desuperheater and total area of feedwater heater. He showed that there is an optimum steam velocity which leads to least heat transfer area. Singh [2] introduced two important parameters of closed feedwater heaters, namely “flash protection index” (FPI) and the “heater time constant”. He concluded that using these parameters can help designers predict some of operational heater problems. Rubin [3] discussed wet and dry desuperheating zone with reference to propane condensation in

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Nomenclature

Greek symbols

α	thermal diffusivity (m^2/s)
ϵ	effectiveness
ν	kinematic viscosity (m^2/s)
μ	dynamic viscosity (kg/(m s))

Symbols

$\dot{m}$	mass flow rate (kg/s)
$\dot{Q}$	heat transfer rate (W)
A	heat transfer area (m^2)
c_p	specific heat capacity (J/(kg K))
d	tube diameter (m)
D_e	equivalent diameter (m)
D_s	shell diameter (m)
DCA	drain cooler approach (°C)
G	mass velocity (kg/(m^2 s))
g	acceleration of gravity (m/s^2)
h	heat transfer coefficient (W/(m^2 K))
h_s	siphon port height (m)
h_w	water level (m)
i	enthalpy (J/kg)
k	conductivity (W/(m K))
N_t	number of tubes
NTU	number of transfer units
Nu	Nusselt number
Pr	Prandtl number
Ra	Rayleigh number
Re	Reynolds number
R_f	fouling resistance ((m^2 K)/W)
S_h	condensate cross section area (m^2)
S_s	steam cross section area (°C)
t	temperature (°C)
THA	turbine heat-rate acceptance
TTD	terminal temperature difference (°C)
U	overall heat transfer coefficient (W/m^2 K)
u	velocity (m/s)
U_m	mean overall heat transfer coefficient (W/m^2 K)
U_o	not-submerged overall heat transfer coefficient (W/m^2 K)
x	quality

Subscripts

$,i$	inlet
$,o$	outlet
b	bulk
dc	drain cooler
G	saturated vapor
L	saturated liquid
m	interface
s	shell side
sat	saturation
sp	single phase
sub	submerged
t	tube side
tp	two phase
w	wall

addition to general aspects of design. Johnson et al. [4] presented a model for FWH rating using LMTD method. Le et al. [5] studied the importance of different operational variables in heat transfer area allocation in a condenser through a three zone approach. They showed that fractional area allocation is considerably under the influence of load condition. Weber and Worek [6] presented a method similar to Bell-Delaware for obtaining shell side heat transfer coefficient by tuning the correction factors for horizontal high pressure feedwater heaters. They applied the method to a typical 570 MW power plant and concluded good agreement with experimental results [7]. I.S. Husseini et al. [8] used a numerical approach to obtain area allocation in three zone feedwater heaters. They concluded that steam pressure is a significant variable in area allocation such that at pressure lower than 400 psi drain cooler disapears. They also found that heat transfer area allocation is not dependent on steam inlet temperature.

Although water level is a significant parameter for heater thermal behavior, in many researches it has been less paid attention. In an inspiring study, Xu et al. [9] measured the characteristics of a three zone 330 MW high pressure feedwater heater. Recognizing the effective variables in drain cooling zone using dimensional analysis, they suggested a mathematical model which was able to foresee the impact of low level in a typical 330 MW power plant.

With all researches have been carried out so far, still the absence of a complete geometry- independent model to explore water level impact on heater thermal performance is being felt. In present study a general and flexible model which is not limited to a certain geometry is proposed for investigation of high and low water level effects on the heater performance. The model is validated using data in literature then applied to real sets of data corresponding to a high pressure feedwater heater. The conditions in which accidental variation of water level has minimum influence on heater performance will also be discussed here. In the end, a mathematical relation for drain cooler approach based on load and liquid level is presented.

2. Heat transfer modeling

A Feedwater heater can not be evaluated without considering liquid level. This parameter is directly related to quality of fluid entering the drain cooling zone. Temperature diagram for a three zone heater discussed in this paper is indicated in Fig. 1. This thermal behavior is changed in cases the level takes values other than the designed value. If liquid level becomes lower than siphon port height, two phase fluid will enter the drain cooler. This will lead to increase in drain cooler approach as well as vibration and corrosion of tube bundle. If liquid level increases, a number of tubes may be submerged in condensate which causes effective heat transfer area to reduce. Therefore, shell side heat transfer coefficient must be evaluated considering water level or fluid condition at inlet of drain cooler. To this end, for low water level condition, one can divide drain cooling zone into two portions. First portion is under the influence of leaked steam to drain cooler while at second portion, steam is already condensed and single phase fluid is only to consider. As water level decreases, the vapor quality at entrance increases and consequently the heat transfer area which is under the influence of leaked steam increases. At this point, it is essential to express the leaked steam quantitatively. Xu et al. utilized the following relation in order to determine the quality of fluid entering drain cooler. They expressed that the ratio of steam mass flow rate to drain mass flow rate is proportional to the ratio of cross section area filled with steam to that of filled with drain [9].

$$S_h = \frac{\pi D_s^2}{8} - \left(\frac{D_s}{2} - h_w\right)\sqrt{\frac{1}{4}D_s^2 - \left(\frac{1}{2}D_s - h_w\right)^2} - \frac{1}{4}D_s^2 sin^{-1}\left(\frac{D_s - 2h_w}{D_s}\right) \quad (1)$$