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The impact of fouling on performance evaluation of multi-zone feedwater heaters

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Abstract

A numerical method for analyzing closed system feedwater heaters is presented. A general approach to determine area allocations among the desuperheating, condensing and subcooling zones under a known set of operating conditions is presented for a feedwater heater in a steam power plant. A significant amount of heat duty is handled by the condensing zone, whereas the subcooling zone handles a least amount of heat duty which essentially vanishes at low steam pressures. Fluids mass flow rates and accordingly the overall heat transfer coefficients have significant effects on the areas needed for desuperheating, condensing and subcooling in a feedwater heater. Two fouling models are considered to examine their effect on the heat exchanger performance. Insignificant changes were noticed when comparing the heat transfer rate and outlet temperature results of both the models. It is found that heat duty of the heat exchanger decreases by 2.7% in 3 years when we use the recommended fouling resistance, while the outlet shell-side fluid temperature increased by 6.3%.

Keywords: Heat exchanger; Fouling; Heat transfer area; Rating

1. Introduction

Feedwater heaters are shell-and-tube heat exchangers which perform the special function of recovering heat from turbine extraction steam by preheating the boiler feedwater. They are generally designed for high- or low-pressure operation. High-pressure feedwater heaters are located downstream of the high-pressure feedwater pump whereas low-pressure feedwater heaters are located downstream of the condensate pump. The steam that is extracted from the turbine is in most cases available at a superheated state. Heat is extracted first by desuperheating the steam, then by condensing the steam to bring it to saturated liquid state and in most cases, by further subcooling it to a temperature below the saturation temperature. In order to meet these requirements, feedwater heaters are typically designed with three zones: a desuperheating zone, followed by a condensing zone and a subcooling zone. Depending on the requirement and steam extraction point, feedwater heaters may or may not have a desuperheating or subcooling zone.

Tomczyk [1] indicated that condensers are larger then evaporators since they have the three functions: (1) desuperheating, (2) condensing and (3) subcooling. The first passes of a condenser or a feedwater heater desuperheat the steam so that they lose all of their superheat before reaching the condensing temperature at a given pressure. He has also indicated that condensation occurs in the lower "two-thirds" of the condenser. Breber [2] indicated that condensers are classified into two categories. The first category is classified as narrow-condensing-range vapors with little superheat where the heat transfer rate can be estimated accurately. In the second category wide-desuperheating range mixtures with noncondensables and significant vapor-phase heat transfer are considered, where problems are more complex and only special, idealized cases can be solved. He has also indicated that the heat transfer duty involved in desuperheating is small compared

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Nomenclature

A	heat transfer area, m^2
C^1	tube clearance, m
C_t	tube-side fluid heat capacity rate, W K^{-1}
C_s	shell-side fluid heat capacity rate, W K^{-1}
c_P	specific heat at constant pressure, kJ kg^{-1} K^{-1}
D	diameter, m
D_s	shell inner diameter, m
g	gravitational acceleration, m s^{-2}
L_b	baffle spacing, m
h	heat transfer coefficient, W m^{-2} K^{-1}
h_{fg}	change-of-phase enthalpy, kJ kg^{-1}
k	thermal conductivity, W m^{-1} K^{-1}
$\dot{M}_T$	total mass flow rate on the shell-side, kg s^{-1}
$\dot{m}$	mass flow rate, kg/s
N	number of tubes
Nu	Nusselt number
P_T	tube pitch
Pr	Prandtl Number
R	thermal resistance, K/W
S_s	cross flow area at the shell diameter ($S_s = \frac{D_s}{P_T} C^1 L_b$), m^2
T	fluid temperature, °C
ΔT	temperature difference, °C
U	overall heat transfer coefficient, W m^{-2} C
q	heat transfer rate, W
Δ	elemental
k_l	thermal conductivity of the condensing liquid, W m^{-1} K^{-1}
ρ_l	density of the condensing liquid, kg m^{-3}
ρ_v	density of the condensing vapor, kg m^{-3}
μ_l	dynamic viscosity of the condensing liquid, N s m^{-2}
μ_v	dynamic viscosity of the condensing vapor, N s m^{-2}

Subscripts

1	inlet tube-side subcooling zone or zone 1
2	outlet tube-side subcooling zone or zone 2
3	outlet tube-side condensing zone or zone 3
4	outlet tube-side desuperheating zone
5	inlet shell-side desuperheating zone
6	outlet shell-side desuperheating zone
7	outlet shell-side condensing zone
8	outlet shell-side subcooling zone
c	cold fluid or coolant
cond	condensation or condensing zone
e	equivalent
eff	effective
f	fouling
h	hot fluid
i	index or inlet
in	inlet
j	index
l	liquid
lm	log-mean
out	outlet
o	outer diameter or overall or outlet
s	shell-side
sat	saturation
sub	subcooling or subcooling zone
sup	superheating or desuperheating zone
sur	surface
t	tube-side
v	vapor

to total condensing duty. Desuperheating may occur either under dry wall or wet wall conditions. He considered an example of a tube-side-downflow condenser with desuperheating and subcooling to determine the pressure drop and the adequacy of the heat transfer surface available. In this example the area required for desuperheating was negligible compared to the total condenser area (Area of superheat = 1.03 m^2 while the condensing area = 132.2 m^2). However, the degree of superheat for the hydrocarbon mixture of his example was small compared to typical steam condensers.

Johnson et al. [3] presented a step-by-step procedure for performing a rating check of feedwater heaters using the traditional log-mean-temperature-difference (LMTD) approach. The data given in the specification sheet of a particular feedwater heater were analyzed and the method for determining the unknown temperatures was discussed. Singh [4] provided an overview of closed feedwater heaters. He discussed the occurrence of dry and wet surface desuperheating zones. A method for estimating the rate of condensation based on heat exchanger effectiveness versus Number of Transfer Units (ε – NTU) approach was presented. It is important to note that the closed Feedwater Heater Standards [5] concentrate on the feedwater heater's thermal performance and mechanical design principles, installation and maintenance. Although the importance of different zones is illustrated, no guidelines are reported about thermal design or specific desuperheating, condensing and subcooling area allocation within the heat exchanger. Recent heat exchanger design books [6–9] provide extensive information on designing different types of heat exchanger, but there is no specific procedure with respect to thermal design of feedwater heaters that have three zones.

Recently, Hussaini et al. [10] developed a detailed numerical model to quantify the areas allocated for desuperheating, condensing and subcooling of steam in a feed-