Optimized Combined Operation of a Cooling Pond and Cooling Tower System for Condenser Cooling at a Steam Cycle Power Plant

by

Jörg Kirchhoff

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Abstract{ TC "Abstract" \l 1 }

The performance of the condenser cooling cycle of a steam cycle power plant is examined for the Columbia Generating Station of the Wisconsin Power & Light Company located near Portage, Wisconsin. The Columbia station is a coal fired power plant with a capacity of 1000 MW. A closed circuit cooling system is used for heat rejection that consists of a cooling pond and two cooling towers. Pond and towers are connected in a parallel arrangement.

To study the behavior of the cooling system, computer models of the components are developed. The cooling tower model is based on the analogy approach of a cooling tower and an heat exchanger. An effectiveness-Ntu method is employed to predict the cooling tower performance with respect to ambient and load conditions. For the calculation of cooling capacity of the cooling pond surface, a semi-empirical approach is selected that is based on the combination of free and forced convection. The water flow in the pond is approximated by a plug flow model. From the energy transfer and flow model a simulation program is developed that is capable of predicting cooling pond temperatures dependent on meteorological conditions and heat load on the pond.

The possibility of adding different cooling devices to the system is examined. A simple model of an atmospheric cooling spray is employed. A comparison between cooling tower and cooling spray performance is performed to study if the addition of a cooling spray can be an advantage for the system performance. The impact of dredging the pond to a greater depth is evaluated.

To link the cooling system to the steam cycle performance a condenser model is introduced that predicts the condenser back pressure for a given circulating water temperature and plant load. From an empirical relation the influence of condenser back pressure on the steam cycle heat rate is determined. The performance of the cooling system is then evaluated economically.

The modular system simulation program TRNSYS is used to analyze the behavior of the cooling system in combination with the power generation unit. Transient simulations are performed in hourly time steps to examine the impact of weather conditions on the whole system and to study diurnal fluctuations. A simulation program usable by the plant operators is a product of this work.

Using the simulation program the cooling system is examined under different operation modes utilizing the available equipment. Dependent on weather conditions the best plant operation mode is found. Recommendations are given for the most cost effective alteration of the cooling towers and pond.

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Figure **Description**

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Roman Symbols

a surface area of droplet

a1,..a5 curve fit coefficients for heat rate correction

A surface area

A_A, B_A curve fit coefficients for base auxiliary cooling

A_{bo}, B_{bo} curve fit coefficients for boiler efficiency

A_H, B_H, curve fit coefficients for standard heat rate

C_H

A_L, B_L curve fit coefficients for steam flow rate

A_S, B_S curve fit coefficients for subcooling

A" heat transfer surface area per unit volume

c tower coefficient, operation cost

c_p specific heat of air

c_{pw} specific heat of water

c_s derivative of enthalpy of air with respect to temperature along saturation line

C infrared cloud amount

C1..C4 correction coefficients for condenser heat transfer calculation

C_D drag coefficient

C_R dimensionless convection ratio

dHR_{pb} heat rate correction due to back pressure

D droplet diameter

D_{AB} binary diffusion coefficient

D_C distance between clusters in one row

D_R distance between spray rows

D_S rectangular length of spray cluster

ΔT_{sub} subcooling temperature difference

ΔT_m logarythmic mean temperature difference

ΔT_w cooling water temperature rise in condenser

D_{vs} Sauter mean diameter

$\dot{E}_w$ evaporaive energy flux

$\dot{E}_e''$ evaporative energy flux per unit volume

f_v wind function

f fuel cost

g gravitation constan

GHR gross station heat rate

GTHR gross turbine heat rate

GSTH gross turbine standard heat rate

h_a enthalpy of air

h_c heat transfer coefficient

h_{cl} cloud base height

h_{con} condensate enthalpy

h_0 reference height for cloud emissivity calculation

h_{ex} exhaust steam enthalpy

h_{fg} latent heat of vaporization

h_m mass transfer coefficient $\frac{ft}{s}$

$h_{s,eff}$ effective surface enthalpy

h_w enthalpy at saruration at water surface temperature

I solar radiation on horizontal surface

K mass transfer coefficient $\frac{lb}{ft^2 \cdot s}$

L characteristic length

L_C length of cluste leg

L_R length of spray row

Le	Lewis number
m	exponent for relation of Nusselt numbers
$\dot{m}_a$	mass flow rate of air
m_d	droplet mass
$\dot{m}_e$	mass flow associated with evaporation
$\dot{m}_e''$	mass evaporative mass flux per unit surface area
$\dot{m}_e'''$	evaporative mass flux per unit volume
$\dot{m}_{ex}$	exhaust steam flow
$\dot{m}_{th}$	main throttle steam flow rate
$\dot{m}_w$	water mass flow rate
$\dot{m}_{w,c}$	cooling wate flow rate in condenser
m^*	capacitance rate
m'_w	water flow rate per unit length of spray canal
n	tower coefficient
$n_{lh,av}$	average number of low head cycle pumps
$n_{lh,sum}$	sum of operation hours of low head pumps
$n_{lh,sum}$	number of hours in month
NHR	net staion heat rate
NHR_c	net heat rate without auxiliary power
NHR_{st}	net heat rate at standard condition
NTHR	net turbine heat rate
Ntu	number of transver units
NU_d	Nusselt number for a droplet
p	partial water vapor pressure

p_{atm} atmospheric pressure

p_b back pressure

p_s saturation water pressure at surface temperatur

p_a water vapor pressure in ambient air

P perimeter

P_{net} net station power

P_{gr} gross turbine power

$P_{aux,b}$ base auxiliary power

$P_{aux,c}$ auxiliary power due to cooling

Pr Prandtl number

P_{st} load at standard conditions

q energy transfer per unit surface area

$\dot{Q}_{cyc}$ rate of heat added to steam cycle

$\dot{Q}_{st}$ rate of heat added to steam generator

$\dot{Q}$ energy tansfer rate

Q' heat transfer per unit length of spray field

r_c fraction of sky covered with clouds

r_m mass flow ratio of exhaust steam to cooling water

r_{st} fraction of main steam that enters condenser

r_T ratio of wate temperature rise over logarythmic mean temperature difference

Ra Rayleigh number

R_B Bowen ratio

Re Reynolds number

R_S radius of spray pattern

Sc Schmidt number

Sh Sherwood number

t_f flying time

T temperature

T_a local air temperature

T_c temperature at which heat is rejected in power plant

T_h temperature at which heat is added to steam cycle

T_{db} drybulb temperature

T_{shell} condenser shell temperature

T_V virtual temperature

T_{wb} wetbulb temperature

T_w water temperature

u relative velocity between droplet and air

U heat transfer coefficient for pond equilibrium temperature

UA overall heat transfer coefficient

U_i internal energy

v_1, v_2 wind velocity at different heights

v_{av} average wind velocity over spray height

v_d horizontal droplet velocity

v_{inf} wind speed, measured at weather station

v_{wat} water velocity in condenser tubes

V_d volume of water droplet

V volume

w humidity ratio of local air

w_a humidity ratio of ambient air

w_d vertical droplet velocity

$w_{s,eff}$ effective saturation humidity ratio

w_w humidity ratio at saturation at water surface temperature

W	width of spray field
X_{cal}	calibraion constant
z_1, z_2	measurement heights of wind speed
Z_u, Z_s	droplet flying heights
Z_r	reference height for wind velocity measurement

Greek Symbols

α	thermal diffusivity
β	expansion coefficient
ε	effectiveness, emissivity
ε_{boi}	boiler efficiency
ε_0	clear sky emmissivity
ε_h	diurnal correction factor for sky emissivity
ε_e	elevation correction for emissivity
ε_{cl}	corrected clear sky emissivity
ε_{sky}	overall sky emissivity
ε_c	cloud emissivity
ε_w	water surface emissivity
Γ	factor for cloud base height
η_c	Carnot efficiency
κ	power law exponent
ρ_w	density of water
$\rho_{w,s}$	density of water vapor at saturaion at water temperature
$\rho_{w,inf}$	density of water vapor in ambient air
σ	Stefan Boltzmann constant, $\sigma = 1.729 \cdot 10^{-9} \frac{\mathrm{Btu}}{\mathrm{ft}^2 \cdot \mathrm{hr} \cdot {}^\circ\mathrm{R}}$
τ	time

μ	dynamic viscosity
ν	kinematic viscosity
Ψ	angle of approach of wind velocity to spray field

Additional Subscripts

c	characteristic
C	cold
com	combined
conv	convection
con	condenser
D	droplet
E	equilibrium
el	element
ev	evaporation
for	forced
free	free
ground	ground
H	hot
in	inlet
L	lake
mu	make up
out	outlet
s	saturation at water surface temperature
spray	spray
sol	solar
rad,sky	radiation from sky
rad,w	radiation from water surface

w	water