ANALYSIS OF DIFFERENT TYPES OF DRY-WET COOLING TOWERS

by

Mow-Soung Cheng
Thomas E. Croley II
V. C. Patel

Sponsored by
Office of Water Research and Technology
Grant No. 14-31-0001-5201

IIHR Report No. 191

Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa

July 1976

ANALYSIS OF DIFFERENT TYPES OF DRY-WET COOLING TOWERS

by

Mow-Soung Cheng
Thomas E. Croley II
V. C. Patel

Sponsored by
Office of Water Research and Technology
Grant No. 14-31-0001-5201

IIHR Report No. 191

Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa

July 1976

LIST OF SYMBOLS

A	Effective surface area of the heat exchanger surface in ft^2
a	Area of water droplet interface per unit volume in ft^2/ft^3
$\bar{a}$	Dry tower constant
A_c	Area of the heat exchange surface in ft^2
B	Amount of water required for blow-downs in lb/hr
b	Dry tower constant
C	Conversion factor = 3413 Btu/kW-hr
C_B	Annual waste water treatment cost in \$/year
c_B	Unit cost of waste water treatment cost in \$/1000 gal
CC	Total capital cost in \$
C_c	Condenser cost in \$
c_c	Unit cost of condenser in \$/ft^2
C_{dt}	Capital cost of the dry section in \$
c_{dt}	Unit capital cost of the dry section in \$/ft^2
C_F	Annual fuel cost in \$/year
c_F	Unit cost of fuel in \$/kW-hr

c_L	Unit cost of energy loss in mills/kW-hr
C_L	Replacement energy cost required to make-up the operating costs in \$/year
C_ℓ	Capacity loss in MW
c_m	Unit cost of maintenance in \$/year/cell
C_{Pipe}	Capital cost of pipe system in \$
c_{pipe}	Unit cost of pipe displacement in \$/ft^3
C_{pump}	Pump system cost for a combination tower in \$
C'_{pump}	Pump cost for a wet tower in \$
C_R	Replacement capacity cost in \$
c_R	Unit cost of capacity loss in \$/MW
C_t	Cost of the turbine and all other power plant capital costs exclusive of any costs related to the cooling system in \$
C_w	Annual make-up water cost in \$/year
c_w	Unit cost of make-up water in \$/1000 gal
C_{wt}	Capital cost of the wet section in \$
c_{wt}	Unit capital cost of the wet section in \$/TU
D	Power demand in MW
E	Evaporative water loss from the cooling system in lb/hr

E_L	Annual energy loss in MW-hr/year
F	Fuel consumption rate for any set of meteorological conditions, power generation, and, system operation in kW
$f(T_{db}, T_{wb}, D)$	Probability of occurrence of given set of meteorological conditions and power demand
f (Q, P)	Specified turbine characteristics as shown in Figure 14
f (·)	Cooling tower characteristics as represented in Figure 12
FA	Required total air face area for each dry tower cell in ft^2
F_c	Annual fuel consumption in kW-hr/year
F_c'	Dimensionless crossflow correction factor for the condenser
FCR	Fixed-charge-rate
F_g	Dimensionless crossflow correction factor for dry tower
F_o	Average fogging magnitude in °F-lb/lb
F_m	Fogging magnitude at a set of meteorological conditions and power demand in °F-lb/lb
FV	Air face velocity through dry section in ft/sec
G	Air flow rate through each wet tower cell in lb/hr
g	Air flow rate loading in $lb/hr/ft^2$ face area
GC	Total gross costs in $

此为试读，需要完整PDF请访问：www.ertongbook.com

G_d	Air flow rate through the dry tower section in lb/hr
GR	Total gross revenues in $
H	Height of the wet tower pile in ft
h	Enthalpy of air at the wet-bulb temperature in Btu/lb dry air
h'	Enthalpy of saturated air at water temperature t in Btu/lb dry air
H_d	Enthalpy of the air exiting the dry section in Btu/lb dry air
H_{dt}	Height of the dry section in ft
H_i	Ambient air enthalpy in Btu/lb dry air
h_i	Enthalpy of the air at the wet-bulb temperature of the air entering the increment in Btu/lb dry air
h_i'	Enthalpy of the saturated air surrounding the water droplets at the temperature of water entering the increment in Btu/lb dry air
H_o	Effluent air enthalpy, in Btu/lb dry air
h_o	Enthalpy of the air leaving the increment at the wet-bulb temperature in Btu/lb dry air
h_o'	Enthalpy of the saturated air surrounding the water droplets at the temperature of water leaving the increment in Btu/lb dry air
H_p	Pumping height in ft
H_w	Enthalpy of the air exiting the wet section in Btu/lb dry air
H_{wt}	Height of the wet section in ft

I	Mode of operation (I=1 dry, I=2 wet, I=3 combination)
K	Overall mass transfer coefficient between saturated air and the main air stream in lb/hr/ft^2(lb/lb)
k	Concentration in ppm of undesirable constituents in the make-up water
K_a	Specific heat of air in Btu/lb/°F
k_m	Maximum concentration permitted in the cooling system in ppm
K_w	Specific heat of water in Btu/lb/°F
L	Water flow rate per tower cell in lb/hr
l	Water flow rate loading in lb/hr/ft^2 plan area
L_c	Capacity loss in MW
L_d	Water flow rate through the dry section in lb/hr
LMTD	Logarithmic mean temperature difference in °F
$LMTD_c$	Logarithmic mean temperature difference for the condenser in °F
L_p	Distance between the turbine and the cooling system in ft
M	Number of wet tower cells
N	Length of the operation horizon in years
n	Wet tower constant which is experimentally determined
n'	Total number of different design power loadings

O_{ij} — Resultant operating cost for stage i of year j associated with the cooling system, including penalties for encountering energy losses, in $/year

OC — Total annual operating cost in $/year

p^* — Nameplate capacity of turbine in kW

P — Vapor pressure of the air flow in units consistent with P_{atm}

P_{ij} — Turbine output which is the sum of the power output available for sale and the plant internal requirements at stage i in year j in MW

$p(Po_{ij}, D_{ij})$ — Revenue obtained when the power output available for sale is Po_{ij} and the design power output is D_{ij} at stage i in year j in $

P_{atm} — Atmospheric pressure

P — Power output at any back pressure and throttle setting, in kW

P_{cs} — Internal power requirements for the cooling system operations in MW

P_{fan} — Power required to operate the fans of the cooling system in MW

P_o — Saturation vapor pressure of the effluent air

Po_i — Variable power loading available for sale in MW

P_{pump} — Power required to operate the pumps of the cooling system in MW

P_{sa} — Saturation vapor pressure corresponding to t_o in consistent units

Q	Heat rejection rate in Btu/hr at any back pressure and throttle opening
Q^*	Heat rejection rate in Btu/hr at reference turbine back pressure
Q_a	Heat rejected from the dry tower to the air in Btu/hr
Q_c	Heat rejected from the circulating water through the dry tower in Btu/hr
Q_d	Heat rejection through a dry tower cell in Btu/hr
Q_T	Total heat rejection from the combination tower in Btu/hr
Q_w	Total heat rejection in all wet tower cells in Btu/hr
R_j	Discount factor for amortization of profit in the jth year
r	Interest rate expressed as a decimal fraction
RF	Rating factor for estimating the initial cost of the wet section
S^*	Reference turbine back pressure in in. Hg abs
S_1	Actual turbine back pressure in in. Hg abs
S_2	Turbine back pressure resulting from the operation of the cooling system in in. Hg abs
S_d	Dry section size (a vector)
S_{max}	Maximum back pressure in in. Hg abs
S_w	Wet section size (a vector)
t	Temperature of water in the pile in °F

TC	Total cost in mills/kW-hr
$T_{db}*$	Design dry-bulb temperature of the ambient air in °F
T_{db_d}	Dry-bulb temperature entering the dry section in °F
T_{db_d}'	Dry-bulb temperature leaving the dry section in °F
T_{db_o}	Effluent dry-bulb temperature in °F
T_{db_w}	Dry-bulb temperature entering the wet section in °F
T_{db_w}'	Dry-bulb temperature leaving the wet section in °F
$T_{HR}*$	Reference heat rate of the turbine in Btu/kW-hr
t_i	Temperature of water entering the increment in °F
t_o	Temperature of water leaving the increment in °F
T_s	Temperature of the steam entering the condenser in °F
TU	Required tower units per wet tower cell
$T_{wb}*$	Design ambient wet-bulb temperature in °F
T_{wb_o}	Effluent wet-bulb temperature in °F
T'_{wb_o}	A trial effluent wet-bulb temperature in °F
T_{wd}	Water temperature entering the dry section in °F
T'_{wd}	Water temperature leaving the dry section in °F

T_{w_w}	Water temperature entering the wet section in °F
T'_{w_w}	Water temperature leaving the wet section in °F
U	Overall coefficient of heat transfer of dry towers in Btu/hr/ft^2/°F
U_c	Overall coefficient of heat transfer for the condenser in Btu/hr/ft^2/°F
v	Allowable water velocity through the pipe system in ft/sec
W	Width of the wet tower pile in ft
W_c	Annual water consumption in acre-ft/year
W_i	Ambient air specific humidity in lb H_2O/lb dry air
W_m	Make-up water required to replace the water lost by evaporation and blowdown in lb/hr
W_o	Effluent air specific humidity in lb H_2O/lb dry air
W_o'	Wet section effluent specific humidity in lb H_2O/lb dry air
x	Coordinate of the pile, width direction
x'	Capital recovery factor (equation 91)
y	Coordinate of the pile, height direction
z	Coordinate of the pile, length direction
Z	Length of the wet tower pile in ft
Δ	Relative change in the turbine heat rate

此为试读，需要完整PDF请访问：www.ertongbook.com

Δh	Enthalpy difference in Btu/lb dry air at the wet-bulb temperature of the air entering and leaving the increment
Δt	Difference between the temperatures of water entering and leaving the increment in °F
τ_s	Throttle of the turbine
η_I	In-plant efficiency
η_p	Overall pump efficiency
γ	Specific weight of water in lb/ft^3
α	Wet tower constant, determined experimentally

ABSTRACT

A comprehensive computer code has been developed for the assessment of the economics of various types of combination dry-wet cooling towers for electric power plants. The model considers the basic thermodynamics of wet (evaporative) and dry (conductive) heat transfer, steam turbines, and condensers and the influence of different power loading patterns and changing meteorological conditions, as well as the various economic parameters. In the latter category are the capital costs associated with the equipment as well as the lost capacity at extreme meteorological conditions, and the operating costs resulting from fuel consumption, cooling water usage, maintenance of the cooling systems, internal power requirements, and under-production of energy. These factors are all described and discussed in some detail.

The computer models have been used to study the thermodynamic and economic performance of several parallel air path and series air path dry-wet cooling tower configurations. In addition to demonstrating the general usefulness of the models, the results have enabled the identification of several promising configurations which seem attractive in their economic, water conservation and fog abatement aspects. In particular, it is found that parallel air path towers are more flexible and effective than comparable series

air path configurations. Of the different type of parallel air path towers, the most favorable one is also the simplest, namely the one in which separate dry and wet units of conventional design are utilized simultaneously. Finally, it is evident that combination dry-wet cooling towers are economical in comparison with conventional wet towers when the cost of water is sufficiently high.

ACKNOWLEDGMENTS

This study was supported in part by the United States Department of the Interior, Office of Water Research and Technology, under Grant No. 14-31-0001-5201 to the University of Iowa.

TABLE OF CONTENTS

此为试读,需要完整PDF请访问: www.ertongbook.com