



# **Design Manual for High Temperature Hot Water and Steam Systems**

---

**ROGERS E. COFIELD, JR.**

**A Wiley-Interscience Publication**

**JOHN WILEY & SONS**

**New York Chichester Brisbane Toronto Singapore**

Copyright © 1983 by John Wiley & Sons, Inc.

All rights reserved. Published simultaneously in Canada.

Reproduction or translation of any part of this work beyond that permitted by Section 107 or 108 of the 1976 United States Copyright Act without the permission of the copyright owner is unlawful. Requests for permission or further information should be addressed to the Permissions Department, John Wiley & Sons, Inc.

**Library of Congress Cataloging in Publication Data:**

Cofield, Rogers E. (Rogers Emory)

Design manual for high temperature hot water and steam systems.

"A Wiley-Interscience publication."

Includes index.

1. Heat engineering—Handbooks, manuals, etc.
  2. Water heaters—Design and construction—Handbooks, manuals, etc.
  3. Steam-boilers—Design and construction—Handbooks, manuals, etc.
- I. Title.

TJ260.C57 1983 621.402 83-1135  
ISBN 0-471-89363-3

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

# **Design Manual for High Temperature Hot Water and Steam Systems**

In tribute to the long-standing patience of my wife and daughters  
Elizabeth, Sherry, Tracy, Stacy, and Terry

# PREFACE

---

This book is written with an awareness of the transition period usually required to develop a graduate student of engineering into an economically productive professional. The material presented is intended to help accelerate an engineer's or designer's growth as a well trained practitioner. By this means, the skills and knowledge acquired in college can more promptly be applied to the benefit of industry.

To achieve this task, information has been obtained from the desks of experienced design engineers, from related technical references, and from a variety of product references used in the design and construction of HTW and steam generation plants. This reference is dedicated to the needs of the engineer responsible for immediate design decisions involving equipment design, selections, and plant construction cost estimates. The information presented covers the following points: (1) information needed to generate immediate solutions on a day to day basis and (2) current technical reference materials and manufacturer's product data coordinated to optimize project design time.

In summary, this book is meant to be used as a quick source of technical material for the engineer or designer actively involved in designing high pressure and high temperature energy generation plants.

ROGERS E. COFIELD, JR.

*Columbia, Maryland  
April 1983*

# Acknowledgments

---

In gratitude to all who have generally assisted in the preparation of this manual, I express my thanks to Director of Advertising Albert E. Scherm, Jr., Crane Company, 300 Park Avenue, New York; Marketing Communications Manager, Clean Air Division, J. C. Jorgenson, American Air Filter Company, Inc., An Allis-Chalmers Company, 215 Central Avenue, Louisville, Kentucky; technical paper titled "Interface Design Problems Between Fabric Collectors and The Boiler" by E. W. Stenby, F. A. Horney, D. M. Shattuck, and R. W. Scheck, Stearns-Roger, Inc., Denver, Colorado; Communications Manager W. C. Huckabee, Merrick Scale Manufacturing Company, 180-192 Autumn Street, Passaic, New Jersey; Advertising Manager Fred A. Paine, Worthington Group, McGraw-Edison Company, 270 Sheffield Street, Mountainside, New Jersey; Technical Library Manager S. M. Parkhill, Ingersoll-Rand Company, 253 East Washington Ave., Washington, New Jersey; Advertising Manager Peter R. James, Terry Corporation, Steam Turbine Division, P.O. Box 555, Windsor, Connecticut; Advertising Manager Elizabeth B. Osborne, Joy Industrial Equipment Company, Western Precipitation Division, 4565 Colorado Boulevard, Los Angeles, California; Marketing Services Manager, A. W. Pieper, The Permutit Company, Inc., Subsidiary of Zurn Industries, P.O. Box 355, Paramus, New Jersey; Executive Vice President, W. A. Blackwell, Midwestern Industries Incorporated, P.O. Box 810, Massillon, Ohio; Communications Department, C. E. Ostrom, C-E Power Systems, Combustion Engineering, Inc., 1000 Prospect Hill Road, Windsor, Connecticut; Advertising Manager Industrial Products, R. J. Urwin, Goulds Pumps, Inc., P.O. Box 330, Seneca Falls, New York; and other manufacturers who on request, generously provided illustrations and valuable information concerning their products.

Notwithstanding, I offer my special appreciation to the Project Manuscript Editor and Word Processing Manager, Elizabeth Cofield, for her laborious effort to develop text presentation and text literary continuity. Finally, my thanks go to Assistant Editor, Sherry Cofield, for contributions during checking and correcting of text content in preparation for publication.

R.E.C.

# Abbreviations

---

abs.	absolute
acfm	actual cubic feet per minute
act.	actual
AGA	American Gas Association
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials
avg.	average
BFD	boiler feedwater demand
bhp	brake horsepower
Bot.	bottle
btu	British thermal unit
Bun.	bunker
cfm	cubic feet per minute
cfs	cubic feet per second
CHP	Central Heating Plant
comp.	compressor
CTR	coal tonnage requirement
db	dry bulb temperature (°F)
d.c.	mechanical dust collector
DO	ditto
eff.	Efficiency
EPA	Environmental Protection Agency
exch.	Exchanger
<i>F</i>	LTMD correction factor
FD	forced draft
FGD	flue gas desulfurization
fpm	feet per minute
fps	feet per second



**xx     ABBREVIATIONS**

ft	foot
ft <sup>2</sup>	square foot
ft <sup>3</sup>	cubic foot
fw	feedwater
gal	gallons
gen.	generator
gpm	gallons per minute
gr.	grains
gr./lb	grains per pound
HHV	high heating value
hp	Horsepower
HP <sub>B</sub>	horsepower to drive the empty belt
HP <sub>L</sub>	horsepower to move the load against friction
HP <sub>G</sub>	horsepower to overcome gravity due to raising and lowering the load
HP <sub>I</sub>	horsepower to overcome inertia in putting material into motion
HP <sub>M</sub>	horsepower to keep belt in motion under load
hr	hour
hr/min	hours per minute
ht	heat
HTE	high temperature energy
HTW	high temperature water
HVAC	heating, ventilation, and air conditioning
$h_1$	tube side heat transfer coefficient
$h_0$	shell side heat transfer coefficient
$h_s$	enthalpy of steam (btu/lb)
$h_w$	enthalpy of water (btu/lb)
icfm	inlet cubic foot per minute
ID	induced draft
I.D.	inside diameter
in.	inches
in. Hg	inches of mercury column
in. w.c.	inches of water column
IPS	iron pipe size
kW	kilowatts
kWhr	kilowatts per hour
lb	pounds
lb/hr	pounds per hour

lb/mol	pound per moles
lb/ton	pounds per ton
LMTD	logarithmic mean temperature difference
$\log_{10}$	common logarithm (base 10)
min	minute
mol	moles
(MS)	multistage
$N_2$	nitrogen
NFPA	National Fire Protection Association
No.	number
$N_{re}$	Reynolds number (dimensionless)
O.D.	outside diameter
OPEC	Organization of Petroleum Exporting Countries
OSHA	Occupational Safety and Health Act
$\Delta P$	total pressure
PPDAR	project preliminary design analysis report
ppm	parts per million
psi	pounds per square inch
psia	pounds per square inch absolute
psig	pounds per square inch gage
Remun.	remuneration
ROM	run-of-mine
rpm	revolutions per minute
$r_f$	fouling resistance heat transfer coefficient
$r_w$	tube wall resistance heat transfer coefficient
(S)	single stage
sat.	saturated steam conditions
scfm	standard cubic foot per minute
sec	second
S.F.	safety factor
sh	superheat
sp. gr.	specific gravity
sp. ht.	specific heat (btu/lb °F)
SSU	Seconds Saybolt Universal
std.	standard
stm	steam
$T_1$	hot medium (fluid) inlet temperature
$T_2$	hot medium (fluid) outlet temperature

**xxii     ABBREVIATIONS**

$t_1$	cold medium (fluid) inlet temperature
$t_2$	cold medium (fluid) outlet temperature
$\Delta T$	total temperature
TEMA	Tubular Exchangers Manufacturers Association
ton	long ton
tph	tons per hour
tpw	tons per work week
wb	wet bulb temperature (°F)
w.c.	water column
W.F.	wear safety factor
yr	year

**SYMBOLS**

$\pi$	3.1416
$\cong$	Equivalent
%	Percent
°F	degree fahrenheit
°C	degree celsius
(↑)	gaseous element or compound
$\mu$	micron
\$	U.S. dollars

# Contents

---

## ABBREVIATIONS

xix

## 1 LOAD ANALYSIS

1

- 1.1 Load Analysis 1
- 1.2 Project Preliminary Design Analysis Report 3
- 1.3 Concluding Remarks 7
- References 7

## 2 FUEL SELECTION, HANDLING, AND STORAGE

8

- 2.1 Introduction—OPEC-onomics and Petroleum Politics 8
- 2.2 Fuel (Coal) Usage 10
- 2.3 Yard Coal Handling and Coal Stockpiling 13
- 2.4 Sizing the Emergency Coal Stockpile 15
- 2.5 Plant Fuel Consumption 18
- 2.6 Coal Handling Equipment 20
  - 2.6.1 Car Pullers 22
  - 2.6.2 Carhoes 22
  - 2.6.3 Coal Hopper Car 23
  - 2.6.4 Coal Car Thawing Sheds or Pit Barriers 23
  - 2.6.5 Coal Car Unloaders 24
    - Car Shakers 24
    - Rotary Coal Car Dumpers 24
  - 2.6.6 Track Hoppers or Track Bins 24
  - 2.6.7 Coal Valves 24
  - 2.6.8 Coal Feeders 25
  - 2.6.9 Skirtboards 25
  - 2.6.10 Conveyors and Conveyor-Elevators, 25
    - Conveyors 25
    - Conveyor-Elevators 26

xi

2.6.11	Conveyor Take-Ups	26
2.6.12	Magnetic Separators	26
2.6.13	Surge Bins	27
2.6.14	Screens	27
2.6.15	Coal Chutes	28
2.6.16	Coal Crushers	28
2.6.17	Coal Scales	28
2.6.18	Conveyor Belt Travelling Trippers	28
2.6.19	Coal Distributing Spouts	29
2.6.20	Dustless Unloading Spouts	29
2.6.21	Hopper and Chute Vibrators	30
2.7	Heat Balance—Frozen Coal Hopper Car Deicing Requirements (Car Thawing)	30
2.8	Coal Transporting	35
2.9	Conveyor Belt Sizing and Belt Speed Requirements	37
2.10	Conveyor Drive Horsepower Requirements	39
2.11	In-Plant Storage and Handling of Coal	44
2.12	Coal Bunker Installation	46
2.13	Coal Segregation	46
2.14	Alternate Fuels—Gas and Oil—And Back-Up Firing Modes	47
2.15	Plant Fire Protection	51
2.15.1	Aggregate Water Supply	53
2.15.2	Yard Water Stations	53
2.15.3	Deluge/Automatic Sprinklers	53
2.15.4	Fire Alarms and Fire Detection Devices	54
2.15.5	Firefighting Foam Generation Stations	54
2.16	Dike (Cofferdam) Provisions	54
2.17	Fugitive Coal Dust Recovery and Prevention of Methane Gas Generation	55
2.17.1	History of Methane Gas Generation	56
2.17.2	Fugitive Coal Dust Control	56
2.17.3	Long-Term Bunker Storage of Coal	57
2.17.4	Brief History of Amorphous Carbons—Coal	59
2.17.5	State-of-Technology and Advanced Supervision Techniques for Continuous Bunker Ventilation	59
2.18	Alternative Fugitive Coal Dust Control and Methane Gas Prevention Options	62
2.19	Mechanical Supervision of Bunker Ventilation—Forced Air Flow Through a Packed Coal Bed	63
2.20	Static Pressure Gradients in Dilute-Phase Transport of Coal Dust (Irregular Particles) Through a Packed Coal Bed	64

2.20.1	Pressure Gradients Profiles Inside a Packed Coal Bunker	64
2.21	Concluding Remarks	65
	References	65

### **3 FUEL ANALYSIS** **66**

3.1	Introduction	66
3.2	Generator Combustion Calculations	67
3.3	Combustion Air Requirements, Actual Cubic Feet per Minute	71
3.4	Flue Gas Flow Rate, Actual Cubic Feet per Minute	72
3.5	Concluding Remarks	73
	References	73

### **4 HIGH TEMPERATURE ENERGY GENERATION SYSTEM CORROSION/EROSION** **74**

4.1	Introduction	74
4.2	Prevention of High Temperature Energy Generation Equipment Corrosion	74
4.3	Water Treatment	77
4.4	Auxiliary Equipment and Systems—Introduction	81
4.5	Feedwater Deaerating—Condensate Storage Tank	81
4.6	Treated Make-up Water Pump	86
	References	88

### **5 SELECTION OF HIGH TEMPERATURE ENERGY (HTE) GENERATION SYSTEM PERFORMANCE EQUIPMENT** **89**

5.1	Introduction	89
5.2	Task List for High Temperature Energy (HTE) Generation System Component Equipment	89
5.2.1	Primary Air Heater Selection: Sizing	90
5.2.2	Secondary Air Heater Selection: Sizing	92
5.2.3	Forced Draft (FD) Fan Selection: Sizing	94
5.2.4	Generator (Furnace) Selection	97
5.2.5	Mechanical Dust Collector Selection	103
5.2.6	Bypass Damper Selection	105

5.2.7	Flue Gas Scrubber Selection	108
5.2.8	Fabric Filter (Baghouse) Selection	110
5.2.9	Induced Draft (ID) Fan Selection	116
5.2.10	Soot Blowing Air Compressor Selection	121
5.2.11	Stack Selection	123
5.2.12	Expansion Tank Selection	125
5.2.13	System Pressurization Requirement—Gas System	128
5.2.14	Degasifier and Sedimentation Tank Selection	130
5.2.15	Continuous Blowdown (CBD) or Blow-Off Tank Selection	131
5.2.16	Heat Exchanger Applications	143
5.2.17	Desuperheater Applications	152
5.2.18	Applications For Compressed Air in Power Plant Service	153
5.3	Performance of Components of the Boiler Proper	156
5.3.1	Economizer Module	156
5.3.2	Convection and/or Radiant Superheaters and Convection Reheat Superheaters	157
5.3.3	Boiler Convection Tube Module	157
5.3.4	Screen Tube Panel	157
5.4	Concluding Remarks	158
	References	158

## 6 COAL ASH AND FLUE GAS DESULFURIZATION, REMOVAL AND DISPOSAL SYSTEMS

159

6.1	Introduction	159
6.2	Estimation of Ash Generation	161
6.3	Flue Gas Desulfurization—Estimation of Sulfur Dioxide Removal	162
6.4	FGD Chemical Reagents Requirements (Usage)	164
6.5	Flue Gas Desulfurization—Estimation of Anhydrous Calcium Sulfite Salt Generation	166
6.6	Flue Gas Desulfurization—Estimation of Sludge Generation	167
6.7	Spent Anhydrous Salt/Ash Storage Silo	169
6.8	Flue Gas Desulfurization—Disposal of Spent Salts	170
6.9	Sizing the Dry Ash Transport System—Pneumatic	171
6.10	Concluding Remarks	175
	References	175

<b>7</b>	<b>HIGH TEMPERATURE WATER (HTW) AND STEAM GENERATION PRIMARY COOLING WATER AND WATER OR STEAM DISTRIBUTION PIPING SYSTEMS</b>	<b>176</b>
7.1	Introduction	176
7.2	Primary Circulation Cooling Water Pump	178
7.3	Generator Circulation Water Main (Transmission Header Pipe)	181
7.4	Main Distribution Water Pump	184
7.5	Forced-Flow Steam Service Pipe Leaders and Header Piping	186
7.6	Concluding Remarks	189
	References	189
<b>8</b>	<b>PLANT HEATING, VENTILATION, AND COLD AIR CONDITIONING GENERATION</b>	<b>190</b>
8.1	Introduction	190
8.2	Predicting Plant Ventilation Air Requirements	191
8.3	Plant Heating Requirements	194
8.4	Plant Cold Air Conditioning Generation	196
8.5	Cold Air Generators	197
8.6	Sizing The Cold Air Conditioning Generator Cooling Water Coil	198
8.7	The Cold Air Conditioning Generator Refrigerant Gas Compressor	199
	References	201
<b>9</b>	<b>THE EMERGENCY POWER—ELECTRIC DIESEL GENERATION SYSTEM</b>	<b>202</b>
9.1	Introduction	202
9.2	Generator Design Criteria	205
9.3	Fuel Oil Storage Tank	205
9.4	The Diesel Fuel Oil Day Tank	209
9.5	The Fuel Oil Transfer Pump	210
<b>Appendix 1</b>	<b>Material Coefficient</b>	<b>214</b>
<b>Appendix 2</b>	<b>Table of Coal Rank</b>	<b>215</b>
<b>Appendix 3</b>	<b>Flight Conveyor Data</b>	<b>216</b>



<b>Appendix 4</b>	<b>Flue Gas Density Chart at 30 in. Hg Barometric Pressure</b>	<b>217</b>
<b>Appendix 5</b>	<b>Selected Thermal Properties of Water and Steam</b>	<b>218</b>
<b>Appendix 6</b>	<b>Thermodynamic Properties of Steam</b>	<b>220</b>
<b>Appendix 7</b>	<b>Properties of Water at Various Temperatures</b>	<b>266</b>
<b>Appendix 8</b>	<b>Flue Gas Enthalpy above 80°F at 30 in. Hg (btu/lb)*</b>	<b>270</b>
<b>Appendix 9</b>	<b>Absolute Viscosity Gas and Liquids</b>	<b>274</b>
<b>Appendix 10</b>	<b>Absolute Viscosity of Steam</b>	<b>277</b>
<b>Appendix 11</b>	<b>C<sub>2</sub> Values</b>	<b>278</b>
<b>Appendix 12</b>	<b>Reasonable Velocities for the Flow of Water through Pipe</b>	<b>280</b>
<b>Appendix 13</b>	<b>High Temperature Water System Losses</b>	<b>281</b>
<b>Appendix 14</b>	<b>Properties of Circular Segments</b>	<b>282</b>
<b>Appendix 15</b>	<b>Pipe Friction Losses</b>	<b>283</b>
<b>Appendix 16</b>	<b>Conversion Tables</b>	<b>286</b>
<b>Appendix 17</b>	<b>Shape Factors for Non-spherical Particles</b>	<b>295</b>
<b>Appendix 18</b>	<b>Logarithmic Mean Temperature Difference Correction Factor Chart</b>	<b>296</b>
<b>Appendix 19</b>	<b>Flow of Air Through Schedule 40 Steel Pipe</b>	<b>298</b>
<b>Appendix 20</b>	<b>Formulas and Nomograph for Velocity of Liquids in Pipe</b>	<b>300</b>
<b>Appendix 21</b>	<b>Duct Friction Losses Chart</b>	<b>302</b>
<b>Appendix 22</b>	<b>Estimating Turbine Efficiency</b>	<b>303</b>
<b>Appendix 23</b>	<b>Resistance Coefficient (k), Equivalent Length L/D, and Flow Coefficient C<sub>v</sub></b>	<b>305</b>
<b>Appendix 24</b>	<b>Tables of Measurement</b>	<b>317</b>
<b>Appendix 25</b>	<b>Net Positive Suction and Cavitation</b>	<b>318</b>
<b>Appendix 26</b>	<b>Basic Formulas and Symbols for Pumps</b>	<b>320</b>
<b>Appendix 27</b>	<b>Properties of the U.S. Standard Atmosphere (English Units)</b>	<b>321</b>
<b>Appendix 28</b>	<b>Temperature Conversion Chart</b>	<b>322</b>