

ASME PTC 4.3-2017

[Revision of ASME PTC 4.3-1968 (R1991)]

Air Heaters

Performance Test Codes

AN AMERICAN NATIONAL STANDARD



**The American Society of
Mechanical Engineers**

ASME PTC 4.3-2017

[Revision of ASME PTC 4.3-1968 (R1991)]

Air Heaters

Performance Test Codes

AN AMERICAN NATIONAL STANDARD



**The American Society of
Mechanical Engineers**

Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: March 31, 2017

This Code will be revised when the Society approves the issuance of a new edition.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this Standard. Interpretations are published on the Committee Web page and under go.asme.org/InterpsDatabase. Periodically certain actions of the ASME PTC Committee may be published as Cases. Cases are published on the ASME Web site under the PTC Committee Page at go.asme.org/PTCcommittee as they are issued.

Errata to codes and standards may be posted on the ASME Web site under the Committee Page to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in codes and standards. Such errata shall be used on the date posted.

The PTC Committee Page can be found at go.asme.org/PTCcommittee. There is an option available to automatically receive an e-mail notification when errata are posted to a particular code or standard. This option can be found on the appropriate Committee Page after selecting "Errata" in the "Publication Information" section.

ASME is the registered trademark of The American Society of Mechanical Engineers.

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment that provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable letters patent nor assumes any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations of this document issued in accordance with the established ASME procedures and policies, which precludes the issuance of interpretations by individuals.

No part of this document may be reproduced in any form,
in an electronic retrieval system or otherwise,
without the prior written permission of the publisher.

The American Society of Mechanical Engineers
Two Park Avenue, New York, NY 10016-5990

Copyright © 2017 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All rights reserved
Printed in U.S.A.

CONTENTS

Notice	xii
Foreword	xiii
Committee Roster	xiv
Correspondence With the PTC Committee	xv
Introduction	xvi
Section 1 Object and Scope	1
1-1 Object	1
1-2 Scope	1
1-3 Measurement Uncertainty	1
Section 2 Definitions of Terms and Symbols	2
2-1 General	2
2-2 Definitions	2
2-3 Calculation Acronyms	5
2-3.1 Property Symbols	6
2-3.2 Function Symbols	6
2-3.3 Equipment, Stream, and Efficiency Symbols	6
2-3.4 Location, Area, Component, and Constituent Symbols	7
2-3.5 Correction Symbols	7
2-3.6 Computational Acronyms Used In Section 5 — Computation of Results	7
2-3.7 Uncertainty Acronyms Used In Section 5 — Computation of Results	7
2-3.8 General List of Symbols Used in Section 7	7
2-4 Abbreviations	7
2-5 Abbreviations for the Boundary Figures	8
2-5.1 Property Symbols	8
2-5.2 Equipment and Stream Symbols	8
2-5.3 Location Symbols	8
2-5.4 Correction/Design Symbols	8
2-5.5 Air Heater/Preheater Boundaries	8
2-5.6 Sequence	8
Section 3 Guiding Principles	14
3-1 Introduction	14
3-2 Preparation for the Test	14
3-2.1 Pretest Agreements	15
3-2.2 Pretest Uncertainty Analysis	16
3-2.3 Selection and Training of Test Personnel	16
3-2.4 Pretest Checkout	16
3-2.5 Pretest Traverse	16
3-2.6 Preliminary Run	16
3-3 Method of Operation During Test	16
3-3.1 Stability of Test Conditions	16
3-3.2 Duration of Runs	17
3-3.3 Adjustments During Test	17
3-3.4 Rejection of Runs	17
3-3.5 Number of Runs and Repeatability Criteria	17
3-3.6 Multiple Runs	17
3-4 Comparing Results With Standard or Design Performance	18
3-5 Multiple Air Heater Configurations	18

3-5.1	Multiple Air Heaters of the Same Design/Type	18
3-5.2	Multiple Air Heaters of Different Designs/Types	18
3-6	Uncertainty	18
3-7	References to Other Codes and Standards	18
3-7.1	ASME Performance Test Codes	18
3-7.2	ASTM Standard Methods	19
3-7.3	GPA Standard	19
3-7.4	ISA Standard	19
Section 4	Instruments and Methods of Measurement.....	22
4-1	Introduction	22
4-2	Data Required	22
4-3	Grid	22
4-3.1	Measurement Location	22
4-3.2	Stratification	23
4-4	Flow Weighting	24
4-5	Temperature Measurement	25
4-5.1	Thermocouples	25
4-5.2	Liquid-in-Glass Thermometers	26
4-5.3	RTDs	26
4-5.4	Systematic Uncertainty	27
4-5.5	Air and Flue Gas Measurements	27
4-5.6	Dry Bulb (Ambient) and Wet Bulb Temperature	28
4-5.7	Ice Bath Temperature	28
4-6	Pressure Measurement	28
4-6.1	Pressure Reading Instruments	28
4-6.2	Systematic Uncertainty	28
4-6.3	Static Pressure	29
4-6.4	Velocity Pressure	29
4-6.5	Averaging of Fluctuating Pressure	30
4-6.6	Calculation of Velocity and Mass Flow From Velocity Pressure Measurements	30
4-7	Flow Measurement	33
4-7.1	General	33
4-7.2	Air and Flue Gas	33
4-7.3	Liquid Fuel	34
4-7.4	Gaseous Fuel	34
4-7.5	Solid Fuel and Sorbent Flow	34
4-7.6	Residue Spills	34
4-8	O ₂ Analysis	35
4-8.1	Electronic Analyzers	35
4-8.2	Chemical (Orsat)	35
4-8.3	Gas Sampling Techniques	35
4-8.4	Preparation Methods	36
4-9	Humidity Measurement	38
4-9.1	General	38
4-9.2	Systematic Uncertainty for Humidity Measurement	38
4-9.3	Method of Measurement	38
4-10	Fuel, Sorbent, and Residue Sampling	38
4-10.1	General	38
4-10.2	Method of Solid Fuel and Sorbent Sampling	38
4-10.3	Methods of Liquid or Gas Sampling	39
4-10.4	Residue Sampling	39
4-10.5	Systematic Uncertainty	40
4-10.6	Methods to Determine Average and Standard Deviation of the Mean	40
4-11	Fuel, Sorbent, and Residue Analysis	42
4-11.1	General	42

4-11.2	Systematic Uncertainty for Fuel, Sorbent, and Residue Analysis	42
4-11.3	Methods of Fuel, Sorbent, and Residue Analysis	42
4-12	General Measurement Requirements	42
4-13	Determination of Systematic Uncertainty Due to Measurements	43
Section 5	Computation of Results	55
5-1	Introduction	55
5-2	Measurement Data Reduction	55
5-2.1	Calibration Corrections	55
5-2.2	Outliers	55
5-2.3	Averaging Test Measurement Data	56
5-2.4	Random Uncertainty	57
5-3	Combustion and Efficiency Calculations	59
5-3.1	Fuel Properties	59
5-3.2	Sorbent and Other Additive Properties	60
5-3.3	<i>MpUbc</i> and <i>MpCb</i> — Unburned Carbon in Fuel and Carbon Burned, Percent Mass	62
5-3.4	Combustion Air Properties	63
5-3.5	Flue Gas Products	67
5-3.6	<i>QrF</i> — Fuel Input, Btu/hr (W)	70
5-4	Air and Gas Mass Flow Rates	73
5-4.1	Multiple AHs of the Same Type	74
5-4.2	Multiple AHs of Different Types (e.g., Primary and Secondary Air Heaters)	75
5-5	Flue Gas Air Heater Calculations	76
5-5.1	Performance Parameters	76
5-5.2	<i>TMnA8</i> — Composite Entering Air Temperature	76
5-5.3	<i>TMnA9</i> — Composite Leaving Air Temperature	76
5-5.4	<i>TMnFg14</i> — Composite Entering Gas Temperature, °F (°C)	77
5-5.5	<i>EFFg</i> — Gas-Side Effectiveness	77
5-5.6	<i>EFA</i> — Air-Side Effectiveness	77
5-5.7	<i>MpAl</i> — Percent Air Heater Leakage	77
5-5.8	<i>TFg15NL</i> — Gas Temperature Excluding Leakage	77
5-5.9	Test X-Ratio	78
5-6	Flue Gas Air Heater Performance Corrected to the Standard or Design Conditions	78
5-6.1	<i>TFg15NLCr</i> — Air Heater Exit Gas Temperature (Excluding Leakage) Corrected to Design Conditions	78
5-6.2	<i>TA9Cr</i> — Air Temperature Leaving the Air Heater, Corrected to Design Conditions	79
5-6.3	<i>MpAlCr</i> — Air Leakage Corrected for Deviation From Design Pressure Differential and From Design Entering Air Temperature	80
5-6.4	<i>PDiFg14Fg15Cr</i> — Gas-Side Pressure Differential Corrected for Deviation From Design Gas Mass Flow Rate and Temperature, in. wg (Pa)	80
5-6.5	<i>PDiA8A9Cr</i> — Air-Side Pressure Differential Corrected for Deviation From Design Air Mass Flow Rate and Temperature, in. wg (Pa)	81
5-7	Uncertainty	81
5-7	Sensitivity Coefficients	81
5-7.2	Random Uncertainty and Degrees of Freedom	82
5-7.3	Random Component of Uncertainty	82
5-7.4	Systematic Uncertainty	83
5-7.5	Test Uncertainty	84
5-8	Air Preheater Coils	84
5-8.1	Items to Be Measured	84
5-8.2	<i>TA8Cr</i> — Air Temperature Leaving the Air Heater, Corrected to Standard or Design Conditions	84

5-8.3	<i>PDiA7A8Cr</i> — Air-Side Pressure Differential Corrected for Deviation From Design Air Mass Flow Rate and Temperature	85
5-9	Enthalpy/Specific Heat of Air, Flue Gas, Water Vapor, and Residue	86
5-9.1	Enthalpy of Air	86
5-9.2	Enthalpy of Flue Gas	86
5-10	Acronyms and Symbols	87
5-10.1	Air Heater/Air Preheater Boundaries	87
5-10.2	Computational Acronyms Used in Section 5	87
5-10.3	Uncertainty Acronyms Used in Section 5	87
Section 6	Report of Results	95
6-1	General Requirements	95
6-2	Executive Summary	95
6-3	Introduction	95
6-4	Calculations and Results	95
6-5	Instrumentation	95
6-6	Conclusions	96
6-7	Appendices	96
Section 7	Uncertainty Analysis	97
7-1	Introduction	97
7-1.1	Random Error	97
7-1.2	Systematic Error	97
7-2	Uncertainty	97
7-2.1	Uncertainty Due to Random Error	97
7-2.2	Uncertainty Due to Systematic Error	97
7-3	Fundamental Concepts	98
7-3.1	Benefits of Uncertainty Analysis	98
7-3.2	Uncertainty Analysis Principles	98
7-3.3	Averaging	99
7-4	Procedures for Determining Random Uncertainty	99
7-4.1	Standard Deviation of Individual Parameters	99
7-4.2	Standard Deviation and Degree of Freedom of Intermediate Results	102
7-4.3	Standard Deviation and Degrees of Freedom of Test Results	102
7-5	Guidance for Determining Systematic Uncertainty	102
7-5.1	General Rules	103
7-5.2	Systematic Uncertainties Due to Instrumentation	103
7-5.3	Systematic Uncertainty in Spatially Nonuniform Parameters	103
7-5.4	Systematic Uncertainty Due to Assumed Values for Unmeasured Parameters	106
7-5.5	Degree of Freedom for Systematic Uncertainty Estimates	106
7-5.6	Systematic Uncertainty for Test Results	106
7-6	Uncertainty of Test Results	106
7-6.1	Propagation of Uncertainties	106
7-6.2	Combined Uncertainty of Calculated Result	107
7-7	General List of Symbols for Section 7	107
7-7.1	Subscripts	108
7-7.2	Superscript	108
Mandatory Appendices		
I	Air Heater Exit Gas Temperature Excluding Leakage, <i>T_{Fg15NL}</i>	111
I-1	General	111
I-2	Bi-Sector Air Heater	111
I-3	Tri-Sector Air Heater	112
II	Sampling Systems	115
II-1	Portable Probes Point-to-Point Sampling	115

II-2	Fixed Grid Sampling Techniques	115
II-2.1	Fixed Grid — Composite Sampling	115
II-2.2	Fixed Grid — Point-to-Point (Single Pump) Sampling	116
II-2.3	Fixed Grid — Point-to-Point (Dual Pump) Sampling	116
II-2.4	Fixed Grid — Combination Sampling	117
III	Sample Calculations for Temperature Measurements	121
III-1	Thermometer (Degrees Fahrenheit)	121
III-1.1	Procedures When Not Correcting the Reading	121
III-1.2	Procedures When Correcting the Reading	121
III-2	Thermocouples and Resistance Temperature Devices (Degrees Fahrenheit)	122
III-2.1	Combining Multiple Segments With Accuracy Checks	122
III-2.2	Combining Multiple Segments With Representative Accuracy Checks	122
III-2.3	Using Accuracy Check Data	123
IV	Sample Calculations for Oxygen Measurements	146
IV-1	Introduction	146
IV-2	Method 1 — Correct Individual Readings	146
IV-2.1	Procedure	146
IV-2.2	Example	146
IV-3	Method 2 — Single Correction for All Data Collected Between Accuracy Checks	148
IV-3.1	Procedure	148
IV-3.2	Example	148
IV-4	Method 3 — Measured Values Not Corrected	150
IV-4.1	Procedure	150
IV-4.2	Example	150
V	Nondirectional and Directional Flow Probes	157
V-1	Introduction	157
V-2	Pitot-Static Tubes	157
V-3	Stauscheibe Tube	157
V-4	Three-Hole Fechheimer	157
V-5	Five-Hole Fechheimer	157
V-6	Probe Calibration	157
V-7	Yaw and Pitch	158
V-7.1	Instruments	158
V-7.2	Accuracy	158
V-7.3	Calibration	158
V-7.4	Number of Readings	159
V-7.5	Operation	159
V-8	Correction of Traverse Data	159
V-8.1	Guideline for Initial Estimation of Probe Coefficient	159
V-8.2	Correction for Probe Coefficient and Probe Blockage	160
Nonmandatory Appendices		
A	Sample Calculations	174
A-1	Introduction	174
A-2	Input Data Sheets	174
A-3	Integrated Uncertainty Input Sheets	174
A-4	Output — U.S. Units (Input and Calculation Sheet)	174
A-5	Combustion and Efficiency Calculations	174
A-6	Corrected Air Heater Performance Calculation Sheets	174
A-7	Air Heater Performance Uncertainty Worksheets	175
B	Derivation of Equation for Coefficient of Correlation	195
B-1	Average Values of Temperatures and Gas Concentrations in Ducts, and the Need for Flow Weighting	195

C	Air Heater Performance Model Based on Known Set of Conditions	198
C-1	Description	198
C-2	Inputs	198
C-3	Correction Curves for Off-Design X-Ratio and Flue Gas Mass Flow Rate	199
D	Leak-Checking Sampling Systems	205
E	Electronic Oxygen Analyzers	206
E-1	Electrochemical	206
E-1.1	Sample Condition	206
E-1.2	Calibration	206
E-1.3	External Factors Affecting Operation and Accuracy	206
E-1.4	Typical Systematic Uncertainty Values	207
E-2	Electronic — Paramagnetic	207
E-2.1	Sample Condition	207
E-2.2	Calibration	208
E-2.3	External Factors Affecting Operation and Accuracy	208
E-2.4	Instrument Systematic Uncertainty Values	208
E-3	Electronic — Zirconia	208
E-3.1	Sample and Reference Gas Condition	209
E-3.2	Calibration	209
E-3.3	External Factors Affecting Operation and Accuracy	209
E-3.4	Instrument Systematic Uncertainty Values	210
E-4	Electronic Analyzer Calibration, Instrument Systematic Uncertainty, and Raw Data Adjustment	210
E-4.1	Frequency	210
E-4.2	Calibration Gases	210
E-4.3	Calibration Gas Concentrations	210
E-4.4	Calculation Methodology	211
F	Chemical (Orsat) Flue Gas Analysis	212
F-1	Introduction	212
F-2	Sample Condition	212
F-2.1	Flow/Quantity	212
F-2.2	Moisture	212
F-2.3	Cleanliness	212
F-2.4	Temperature	212
F-2.5	Pressure	212
F-3	Orsat Preparation	212
F-4	Sampling Procedure	212
F-5	Precautions	213
F-6	Further Considerations	213
F-7	Systematic Uncertainty	213
G	Information to Be Provided in an RFP	217
H	Information to Be Provided as Part of the Contract	228
J	Routine Testing and Performance Monitoring	229
J-1	Routine Testing	229
J-1.1	Reasons for Conducting Routine Air Heater Performance Tests	229
J-1.2	Scope	229
J-1.3	Frequency of Runs	230
J-1.4	Unit Conditions	230
J-1.5	Approximate Equations for Percent Leakage	230
J-1.6	Other Simplifications for Routine Testing	232
J-2	Performance Monitoring	232
J-2.1	Leakage, Corrected to Reference Inlet Air Temperature and, if Measured, Air-to-Gas Pressure Differential	232

J-2.2	Draft Loss (Air and/or Gas), Corrected to Reference Fan Flow and Fan Inlet Temperature	236
J-2.3	No-Leakage Exit Gas Temperature, Corrected to Reference Inlet Air Temperature and Reference Inlet Gas Temperature	238
J-2.4	Deviation From Standard or Design Gas-Side Effectiveness	239
J-2.5	X-Ratio	239
J-2.6	Temperature Drop From Air Heater Outlet to Downstream of Cold-Air Bypass Junction	240
J-2.7	Temperature Rise of Inlet Air Due to Hot-Air Recirculation	240
J-2.8	Temperature Spread Between Multiple Thermocouples in a Single Air/Gas Duct	240
J-3	Fault Tree	240
Figures		
2-3.4-1	Tubular/Plate Air Heater	9
2-3.4-2	Basic Regenerative Air Heater	10
2-3.4-3	Tri-Sector Air Heater	11
2-3.4-4	Quad-Sector Air Heater	12
2-3.4-5	Air Heater Using Intermediate Fluid	13
2-3.4-6	Fluid-to-Air Air Heater Noncondensing Heating Fluid	13
3-3.1-1	Illustration of Short-Term (Point-to-Point) Fluctuation and Long-Term Deviation	20
3-3.5-1	Number of Runs and Repeatability Criteria	21
4-3.1.1-1	Sampling Grid — Rectangular Duct	44
4-3.1.2-1	Sampling Grid — Circular Duct	45
4-5.5-1	Examples of Nonrandom Failure Patterns	46
4-10.2.1-1	Full Stream Cut Solid Sampling Process	46
4-10.2.1-2	Typical “Thief” Probe for Solids Sampling in a Solids Stream	47
7-1-1	Types of Errors in Measurements	109
7-1.1-1	Time Dependence of Errors	109
I-1-1	Ideal Air Heater — No Leakage	112
I-2-1	Air Heater With Leakage	113
I-2-2	Air/Gas Flow Schematic — Air Heater With Leakage	113
I-3-1	Tri-Sector Air Heater	114
II-2.1-1	Fixed Grid — Composite Setup	118
II-2.1-2	Boiler Test — Composite Gas Sample Flow Path	118
II-2.2-1	Fixed Grid — Point-to-Point (Single Pump) Setup	119
II-2.3-1	Fixed Grid — Point-to-Point (Dual Pump) Setup	119
II-2.4-1	Fixed Grid — Combination Setup	120
V-2-1	Pitot-Static Probe	161
V-2-2	Pitot-Static Probe Head	161
V-3-1	Pitot–Stauscheibe Tube or “S” Type Pitot	162
V-4-1	Fechheimer Probe	163
V-5-1	Five-Hole Probe Tips	164
V-5-2	Prism Probe Cutaway	165
V-6-1	Free Stream Nozzle Jet	166
V-6-2	Wind Tunnel	167
V-6-3	Free Stream	168
V-7-1	Yaw and Pitch Planes	169
V-7-2	Yaw and Pitch Convention	170
V-7-3	Five-Hole Probe	171
V-7.3-1	Pitch Angle, Φ , Versus Pitch Coefficient, C_ϕ	172
V-7.3-2	Velocity Pressure Coefficient, K_v , Versus Pitch Pressure Coefficient, C_ϕ	172
V-7.3-3	Total Pressure Coefficient, K_t , Versus Pitch Pressure Coefficient, C_ϕ	173

C-2-1	Example Visual Basic Computer Code to Calculate Air Heater Performance at Revised Boundary Conditions When Performance at a Base Set of Conditions Is Known	200
C-3-1	Example Visual Basic Computer Code to Generate Correction Curves	203
F-1-1	Standard Orsat	214
F-4-1	Dry Flue Gas Volumetric Combustion Chart	215
F-6-1	Using Compressed Air to Move the Sample	216

Tables

1-3-1	Typical Test Uncertainties	1
3-2.1-1	Operating Parameter Deviations	21
4-5.5-1	Maximum Number of Sensor Failures	47
4-6.6.23-1	Air and Flue Gas Viscosity Curve-Fit Coefficients, lbm/ft-sec	48
4-8.3.4-1	Gas Sampling Techniques	48
4-10.6.2-1	<i>F</i> Distribution	48
4-13-1	Potential Instrumentation Systematic Uncertainty	49
4-13-2	Potential Systematic Uncertainty for Coal and Residue Properties	53
4-13-3	Potential Systematic Uncertainty for Limestone Properties	53
4-13-4	Potential Systematic Uncertainty for Fuel Oil Properties	54
4-13-5	Potential Systematic Uncertainty for Natural Gas Properties	54
5-7.5-1	Two-Tailed Student's <i>t</i> Table for the 95% Confidence Level	88
5-9-1	Enthalpy Curve Fit Coefficients, Btu/lbm	88
5-10.2-1	Computational Acronyms	89
5-10.3-1	Uncertainty Acronyms	94
7-5.3.2-1	Systematic Uncertainty Coefficients Due to Numerical Integration	110
III-1.1-1	Systematic Uncertainty Worksheet — Uncorrected Reading	133
III-1.2-1	Systematic Uncertainty Worksheet — Corrected Reading	133
III-2.3.1.2-1	Representative Sensor Accuracy Check Results for Method 1	134
III-2.3.1.2-2	Electronics Pretest Accuracy Check Results for Method 1 (As-Left Calibration)	134
III-2.3.1.2.1-1	Calculation of Systematic Uncertainty From Thermocouple Calibration for Method 1 (Segment #1)	135
III-2.3.1.2.1-2	Calculation of Systematic Uncertainty From Electronics Calibration for Method 1 (Segment #2)	137
III-2.3.1.2.1-3	Calculation of Combined Corrections and Corrected Readings for Method 1 (Segment #2)	137
III-2.3.1.2.4-1	Systematic Uncertainty Worksheet for Method 1 — Air/Gas Temperature	138
III-2.3.2.2-1	Representative Sensor Accuracy Check Results for Method 2	139
III-2.3.2.2-2	Electronics Pretest Accuracy Check Results for Method 2 (As-Left Calibration)	139
III-2.3.2.2.1-1	Calculation of Systematic Uncertainty From Thermocouple Calibration for Method 2 (Segment #1)	140
III-2.3.2.2.1-2	Calculation of Systematic Uncertainty From Electronics Calibration for Method 2 (Segment #2)	141
III-2.3.2.2.1-3	Calculation of Combined Corrections and Corrected Readings for Method 2 (Segment #2)	142
III-2.3.2.2.4-1	Systematic Uncertainty Worksheet for Method 2 — Air/Gas Temperature	142
III-2.3.3.2-1	Representative Sensor Accuracy Check Results for Method 3	143
III-2.3.3.2-2	Electronics Pretest Accuracy Check Results for Method 3 (As-Left Calibration)	143
III-2.3.3.2.1-1	Calculation of Systematic Uncertainty From Thermocouple Calibration for Method 3 (Segment #1)	144
III-2.3.3.2.1-2	Calculation of Systematic Uncertainty From Electronics Calibration for Method 3 (Segment #2)	145

III-2.3.3.2.3-1	Systematic Uncertainty Worksheet for Method 3 — Air/Gas Temperature	145
IV-2.2-1	Data for Other Readings — O ₂ Example	152
IV-2.2-2	Estimate of Systematic Uncertainty for Method 1	155
IV-3.2-1	Estimate of Systematic Uncertainty for Method 2	156
IV-4.2-1	Estimate of Systematic Uncertainty for Method 3	156
A-2-1	Input Data Sheet 1	176
A-2-2	Input Data Sheet 2	177
A-2-3	Input Data Sheet 3	178
A-2-4	Input Data Sheet 4	179
A-3-1	Integrated Uncertainty Input Sheet 1	180
A-3-2	Integrated Uncertainty Input Sheet 2	181
A-3-3	Systematic Uncertainty Worksheet	182
A-4-1	Output — U.S. Units (Input and Calculation Sheet)	183
A-5-1	Combustion and Efficiency Calculations	184
A-6-1	Corrected Air Heater Performance Calculation Sheet	186
A-7-1	Air Heater Performance Uncertainty Worksheets: A	189
A-7-2	Air Heater Performance Uncertainty Worksheets: B	190
A-7-3	Air Heater Performance Uncertainty Worksheets: C	191
A-7-4	Air Heater Performance Uncertainty Worksheets: D	192
A-7-5	Air Heater Performance Uncertainty Worksheets: E	193
A-7-6	Air Heater Performance Uncertainty Worksheets: F	194
C-2-1	Acronyms	204
J-1.2.4-1	Required Parameters for Routine Testing of Bi-Sector Air Heaters	241
J-1.2.4-2	Required Parameters for Routine Testing of Tri-Sector Air Heaters	241
J-1.2.4-3	Parameters Required for Exit Flue Gas Temperature Evaluation	242
J-1.2.4-4	Parameters Required for Air Leakage Evaluation Based on Measured O ₂	243
J-1.2.4-5	Parameters Required for Air/Flue Gas Pressure Drop Evaluation	243
J-1.2.4-6	Parameters Required for Fuel, Air, and Flue Gas Flow Rate Evaluation	244
J-1.5.3-1	Oxygen Content, by Volume, of Wet Air Versus Humidity Ratio	244
J-3-1	Fault Tree for High Exit-Gas Temperature	245

NOTICE

All Performance Test Codes must adhere to the requirements of ASME PTC 1, General Instructions. The following information is based on that document and is included here for emphasis and for the convenience of the user of the Code. It is expected that the Code user is fully cognizant of Sections 1 and 3 of ASME PTC 1 and has read them prior to applying this Code.

ASME Performance Test Codes provide test procedures that yield results of the highest level of accuracy consistent with the best engineering knowledge and practice currently available. They were developed by balanced committees representing all concerned interests and specify procedures, instrumentation, equipment-operating requirements, calculation methods, and uncertainty analysis.

When tests are run in accordance with a Code, the test results themselves, without adjustment for uncertainty, yield the best available indication of the actual performance of the tested equipment. ASME Performance Test Codes do not specify means to compare those results to contractual guarantees. Therefore, it is recommended that the parties to a commercial test agree before starting the test and preferably before signing the contract on the method to be used for comparing the test results to the contractual guarantees. It is beyond the scope of any Code to determine or interpret how such comparisons shall be made.

FOREWORD

Performance Test Code Committee No. 4 on Stationary Steam-Generating Units was reorganized in May 1958 to rewrite and bring up to date the 1946 edition of the Test Code for Stationary Steam Generating Units.

During the formulation of the new test code, PTC 4.1-1964, the technical committee brought to the attention of the Performance Test Codes Committee that for the air heater, an auxiliary heat-absorption equipment common to all large steam generating units, there existed no performance test code. PTC Committee No. 4 recommended the development of such a test code as part of its assignment.

The Performance Test Codes Committee instructed PTC Committee No. 4 to prepare such a test code as a supplement to be known as PTC 4.3, on air heaters. This test code was developed and its format follows closely that of PTC 4.1, the Test Code for Steam Generating Units.

This test code was approved by the Performance Test Codes Committee on June 9, 1966. Final publication was delayed, however, until a number of suggestions made by the standing Committee were considered and satisfactorily resolved. It was approved and adopted by the Council as a standard practice of the Society by action of the Policy Board, Codes and Standards on November 8, 1967.

The code was subsequently approved as an American National Standard in 1974 by the American National Standards Institute (ANSI).

Work on the current revision began with the first meeting of the reorganized committee on December 16 and 17, 1999, following the publication of PTC 4, on fired steam generators.

The reasons for undertaking this revision were multifold: (a) to include test uncertainty; (b) to minimize the prescriptive guidelines and emphasize the performance-based approach; (c) to address air heater configurations with multiple flow streams; (d) to update measurement methods to include improved instrumentation currently available, and to base combustion calculations on O₂ instead of CO₂; (e) to update nomenclature; and (f) to comply with Society Policy on SI units.

This Code was approved by the PTC Standards Committee on October 12, 2016. It was then approved and adopted by the Council as a Standard practice of the Society by action of the Board on Standardization and Testing on January 5, 2017. The Performance Test Code was also approved as an American National Standard by the ANSI Board of Standards Review on February 14, 2017.

ASME PTC COMMITTEE

Performance Test Codes

(The following is roster of the Committee at the time of approval of this Code.)

STANDARDS COMMITTEE OFFICERS

P. G. Albert, *Chair*
J. W. Milton, *Vice Chair*
F. J. Constantino, *Secretary*

STANDARDS COMMITTEE PERSONNEL

P. G. Albert , General Electric Co.	T. K. Kirkpatrick , <i>Alternate</i> , McHale & Associates, Inc.
J. M. Burns , Burns Engineering Services	S. J. Korellis , Electric Power Research Institute
A. E. Butler , GE Power Systems/GE Energy Systems	M. P. McHale , McHale & Associates, Inc.
W. C. Campbell , Southern Co. Services	P. M. McHale , McHale & Associates, Inc.
F. J. Constantino , The American Society of Mechanical Engineers	J. W. Milton , RRI Energy
M. J. Dooley , Alstom Power, Inc.	S. P. Nuspl , Babcock & Wilcox
G. J. Gerber , Consultant	R. R. Priestley , General Electric
P. M. Gerhart , University of Evansville	S. A. Scavuzzo , Babcock & Wilcox
T. C. Heil , <i>Alternate</i> , Retired	J. A. Silvaggio, Jr. , Turbomachinery, Inc.
R. E. Henry , Sargent & Lundy	T. L. Toburen , T2E3
D. R. Keyser , Survice Engineering	G. E. Weber , Midwest Generation EME, LLC
	W. C. Wood , Duke Power Co.

PTC 4.3 COMMITTEE — AIR HEATERS

T. C. Heil , <i>Chair</i> , Retired	P. Humphries , Powertek
D. E. Gorski , <i>Vice Chair</i> , Alstom Power, Inc.	L. W. Marshall , Ontario Power Generation
A. Amaral , <i>Secretary</i> , The American Society of Mechanical Engineers	N. Prasad , <i>Participating Member</i> , Bharat Heavy Electricals Ltd.
S. Z. Akhtar , Bechtel Power Corp.	S. A. Scavuzzo , Babcock & Wilcox
R. C. Helton , <i>Alternate</i> , Tennessee Valley Authority	S. W. Scavuzzo , <i>Alternate</i> , Babcock & Wilcox
	R. J. Tramel , Tennessee Valley Authority

CORRESPONDENCE WITH THE PTC COMMITTEE

General. ASME Codes are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Code may interact with the Committee by requesting interpretations, proposing revisions or a case, and attending Committee meetings. Correspondence should be addressed to:

Secretary, PTC Standards Committee
The American Society of Mechanical Engineers
Two Park Avenue
New York, NY 10016-5990
<http://go.asme.org/Inquiry>

Proposing Revisions. Revisions are made periodically to the Code to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Code. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Code. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Proposing a Case. Cases may be issued to provide alternative rules when justified, to permit early implementation of an approved revision when the need is urgent, or to provide rules not covered by existing provisions. Cases are effective immediately upon ASME approval and shall be posted on the ASME Committee Web page.

Requests for Cases shall provide a Statement of Need and Background Information. The request should identify the Code and the paragraph, figure, or table number(s), and be written as a Question and Reply in the same format as existing Cases. Requests for Cases should also indicate the applicable edition(s) of the Code to which the proposed Case applies.

Interpretations. Upon request, the PTC Standards Committee will render an interpretation of any requirement of the Code. Interpretations can only be rendered in response to a written request sent to the Secretary of the PTC Standards Committee.

Requests for interpretation should preferably be submitted through the online Interpretation Submittal Form. The form is accessible at <http://go.asme.org/InterpretationRequest>. Upon submittal of the form, the Inquirer will receive an automatic e-mail confirming receipt.

If the Inquirer is unable to use the online form, he/she may mail the request to the Secretary of the PTC Standards Committee at the above address. The request for an interpretation should be clear and unambiguous. It is further recommended that the Inquirer submit his/her request in the following format:

Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry in one or two words.
Edition:	Cite the applicable edition of the Code for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. Please provide a condensed and precise question, composed in such a way that a “yes” or “no” reply is acceptable.
Proposed Reply(ies):	Provide a proposed reply(ies) in the form of “Yes” or “No,” with explanation as needed. If entering replies to more than one question, please number the questions and replies.
Background Information:	Provide the Committee with any background information that will assist the Committee in understanding the inquiry. The Inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in the format described above may be rewritten in the appropriate format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not “approve,” “certify,” “rate,” or “endorse” any item, construction, proprietary device, or activity.

Attending Committee Meetings. The PTC Standards Committee regularly holds meetings and/or telephone conferences that are open to the public. Persons wishing to attend any meeting and/or telephone conference should contact the Secretary of the PTC Standards Committee. Future Committee meeting dates and locations can be found on the Committee Page at go.asme.org/PTCcommittee.

INTRODUCTION

ASME Performance Test Codes (PTCs) provide uniform rules and procedures for the planning, preparation, execution, and reporting of performance test results. These codes provide guidelines for test procedures that yield results of the highest level of accuracy based on current engineering knowledge, taking into account test costs and the value of information obtained from testing. PTCs were developed by balanced committees representing many concerned interests.

When tests are conducted in accordance with this Code, the test results themselves, without adjustment for uncertainty, yield the best available indication of actual performance of the equipment tested. ASME PTCs do not specify means to compare those results to contractual guarantees. Therefore, it is recommended that the parties to a commercial test agree, before starting the test and preferably prior to signing the contract, on the method to be used for comparing the results to the contractual guarantees. It is beyond the scope of any PTC to determine or interpret how such comparisons are made.

Test uncertainty is an estimate of the limit of error of a test result. It is the interval about a test result that contains the true value with a given probability or level of confidence. It is based on calculations utilizing statistics, instrumentation information, calculation procedure, and actual test data. Code tests are suitable for use whenever performance must be determined with minimum uncertainty. They are meant specifically for equipment operating in an industrial setting.

PTCs are generally not used in troubleshooting equipment. However, they can be used to quantify the magnitude of performance anomalies of equipment that is suspected to be performing poorly, or to confirm the need for maintenance, if simpler means are not adequate. PTCs are excellent sources or references for simpler routine or special equipment test procedures, and this Code includes a nonmandatory appendix on routine testing and performance monitoring. Conducting periodic performance tests on equipment can uncover the need for further investigation, which can lead to preventive maintenance or modification.

INTENTIONALLY LEFT BLANK

AIR HEATERS

Section 1 Object and Scope

1-1 OBJECT

(a) This Code provides procedures for conducting performance tests of air heaters to determine the following results:

- (1) exit gas temperature
- (2) air to gas leakage
- (3) fluid pressure losses
- (4) other fluid temperatures

(b) It also provides procedures to determine the heat capacity ratio (*X*-ratio) and any or all of the performance results specified above that may be necessary for

- (1) checking actual performance against standard or design performance
- (2) comparing changes in performance over time with standard or design performance
- (3) comparing performance under various operating conditions
- (4) determining the effect of changes in equipment

1-2 SCOPE

This Code applies to all air heaters used in industrial application, e.g., air heaters servicing steam generators and industrial furnaces. This specifically includes

- (a) combustion gas-to-air heat exchanger including air heaters with multisection air streams
- (b) air preheater coils utilizing noncondensing (single phase) steam, water, or other hot fluids

This Code does not cover direct-fired air heaters or gas-to-gas heat exchangers. In the latter application, this Code may be used to determine both the thermal and pressure drop performance, while alternate methods of leakage measurement should be agreed upon between the parties. This Code also does not cover heat exchangers where the heating fluid is condensed while passing through the heater.

Air heaters in parallel shall be tested individually (wherever possible) for purposes of checking actual performance.

1-3 MEASUREMENT UNCERTAINTY

This Code requires pretest and post-test uncertainty analysis in accordance with ASME PTC 19.1. The pretest uncertainty analysis is required in order to effectively plan the test. It allows corrective action to be taken prior to the test, either to decrease the uncertainty to a level consistent with the agreed-upon uncertainty, or to reduce the cost of the test while still attaining the objective. The post-test uncertainty analysis is used to determine the uncertainty intervals for the actual test. This analysis should confirm the pretest systematic and random uncertainty estimates. It serves to either validate the quality of the test results or to expose problems.

Typical values of test uncertainties for various unit configurations and performance parameters for an air heater undergoing a performance test in accordance with this Code are presented in Table 1-3-1.

Table 1-3-1 Typical Test Uncertainties

Parameters	Bi-Sector	Multi-Sector
Corrected exit gas temperature, °F (°C)	2–6 (1–3)	2–6 (1–3)
Corrected air-to-gas leakage, % leakage	1–2	1–2
Corrected fluid pressure differential, in. wg (Pa)	±0.5 (±125)	±0.5 (±125)
Corrected exit air temperature, °F (°C)	2–6 (1–3)	Not applicable
Corrected exit air temperature, weighted average, °F (°C)	Not applicable	2–6 (1–3)

Section 2

Definitions of Terms and Symbols

2-1 GENERAL

The Code on Definitions and Values (ASME PTC 2) defines the meaning and values of basic technical terms and numerical constants that are used throughout this Code.

NOTE: For the purposes of this Code, the term *flue gas* shall be used interchangeably with the term *hot fluid* to describe the hot heat transfer fluid passing through the air heater.

2-2 DEFINITIONS

absolute sensitivity (influence) coefficient: unit change in result per unit change of the measured parameter.

acceptance test: the evaluating action(s) to determine if a new or modified piece of equipment satisfactorily meets its performance criteria, permitting the purchaser to “accept” it from the supplier.

accuracy: the closeness of agreement between a measured value and the true value.

accuracy check: the process of comparing the response of an instrument to a standard over some measurement range (also see *calibration*).

additive: a substance added to a gas, liquid, or solid stream to cause a chemical or mechanical reaction.

air, corrected theoretical: the theoretical air adjusted for unburned carbon and additional oxygen required to complete the sulfation reaction.

air, excess: air supplied to burn a fuel in addition to the corrected theoretical air. Excess air is expressed as a percentage of the corrected theoretical air in this Code.

air heater: a heat exchanger that transfers heat from a high-temperature medium, e.g., hot gas, to an incoming air stream. Regenerative air heaters include bi-sector, tri-sector, and quad-sector types with fixed or rotating heating elements. Recuperative air heaters include tubular, plate, and heat pipe types.

air heater air-to-air leakage: air that leaks from a high pressure air stream to a lower pressure air stream, e.g., primary air to secondary air leakage.

air heater leakage: mass of airflow passing from all air-side streams to the heat transfer fluid. Note that this calculated value will include any ingress air that may be present between the air heater gas inlet and gas outlet test planes.

air, infiltration/ingress: air that leaks into the steam generator and/or air heater setting (same as *setting infiltration*).

air, other: combustion air other than primary air, secondary air, and infiltration air, e.g., tertiary air, that is encountered in the combustion processes covered by this Code.

air preheater coils: a heat exchanger that typically uses steam, condensate, and/or glycol to heat air entering the steam generator and is often used to control corrosion in regenerative and recuperative air heaters.

air, primary: the transport and drying air for the coal from the pulverizers to the burners in pulverized coal fired applications. The primary air is often at a temperature different from that of the secondary air as it leaves the regenerative air heaters in large steam generators, and typically represents less than 25% of the total combustion air. Oil and gas fired steam generators usually do not have primary air. Primary air is the air used for fluidizing the bed material at the base of the combustion chamber in circulating fluidized beds.

air, secondary: the balance of the combustion air not provided as primary air in pulverized and fluid bed applications. All of the combustion air leaving the air heater is usually referred to as secondary air in oil and gas fired steam generators. Secondary air may be split into over-fire air or other streams as it enters the furnace; however, it remains secondary air up to and including the wind box.

air temperature rise: the increase in temperature of the airflow passing through the air heater. For multi-sector air heaters, this parameter is defined as the composite air temperature increase of the total airflow (from all streams) passing through the air heater.

air, theoretical: amount of air required to supply the exact amount of oxygen necessary for complete combustion of a given quantity of fuel. Theoretical air and stoichiometric air are synonymous.

analysis, proximate: laboratory analysis, in accordance with the appropriate ASTM standard, of a fuel sample providing the mass percentages of fixed carbon, volatile matter, moisture, and noncombustibles (ash).

analysis, ultimate: laboratory analysis, in accordance with the appropriate ASTM standard, of a fuel sample providing the mass percentages of carbon, hydrogen (excluding hydrogen in moisture), oxygen (excluding oxygen in moisture), nitrogen, sulfur, moisture, and ash.

as-fired fuel: fuel in the condition as it enters the steam generator boundary.

ash: the noncombustible mineral-matter constituent of fuel that remains after complete burning of a fuel sample in accordance with appropriate ASTM standards.

ash, bottom: all residue removed from the combustion chamber other than that entrained in the flue gas leaving the steam generator boundary.

ash, fly: particles of residue entrained in the flue gas leaving the steam generator boundary.

ash pit: a pit or hopper located below a furnace where residue is collected and removed.

bias error: see *error, systematic*.

calcination: the endothermic chemical reaction that takes place when carbon dioxide is released from calcium carbonate to form calcium oxide, or from magnesium carbonate to form magnesium oxide.

calcium to sulfur molar ratio (Ca/S): the total moles of calcium in the sorbent feed divided by the total moles of sulfur in the fuel feed.

calcium utilization: the percent of calcium in the sorbent that reacts with sulfur dioxide (SO₂) to form calcium sulfate (CaSO₄). It is sometimes called sorbent utilization.

calibration: the process of comparing the response of an instrument to a standard over some measurement range and adjusting the instrument to match the standard if appropriate (also see *accuracy check*).

capacity: the maximum main steam mass flow rate the steam generator is capable of producing on a continuous basis with specified steam conditions and cycle configuration (including specified blowdown and auxiliary steam flow). This is frequently referred to as maximum continuous rating.

capacity, peak: the maximum main steam mass flow rate the steam generator is capable of producing with specified steam conditions and cycle configuration (including specified blowdown and auxiliary steam flow) for intermittent operation, i.e., for a specified period of time without affecting future operation of the unit.

combustion chamber: an enclosed space provided for the combustion of fuel.

combustion efficiency: a measure of the completeness of oxidation of all fuel compounds. It is usually quantified as the ratio of actual heat released by combustion to the maximum heat of combustion available.

combustion split: the portion of energy released in the dense bed region of a fluidized bed, expressed as a percentage of the total energy released.

composite air temperature: the mass weighted average temperature of all the air streams either entering or leaving a multi-sector air heater.

coverage: the percentage of observations (measurements) of a parameter that can be expected to differ from the true value of the parameter by no more than the uncertainty.

credits: energy entering the steam generator envelope other than the chemical energy in the as-fired fuel. These credits include sensible heat (a function of specific heat and temperature) in the fuel, entering air, and atomizing steam; energy from power conversion in the pulverizers, circulating pumps, primary air fans, and gas recirculation fans; and chemical reactions, e.g., sulfation. Credits can be negative, e.g., when the air temperature is below the reference temperature.

dehydration: the endothermic chemical reaction that takes place when water is released from calcium hydroxide to form calcium oxide, or from magnesium hydroxide to form magnesium oxide.

design conditions: see *specified conditions*.

dilute phase: the portion of the bed in a circulating fluidized bed combustion chamber above the secondary air inlet ducts (made up primarily of the circulating particulate material).

efficiency, fuel: the ratio of the output to the input as chemical energy of fuel.

efficiency, gross: the ratio of the output to the total energy entering the steam generator envelope.

energy-balance method: Formerly the "heat loss method." A method of determining steam generator efficiency by a detailed accounting of all energy entering and leaving the steam generator envelope.

error, random: sometimes called precision error, random error is a statistical quantity and is expected to be normally distributed. Random error results from the fact that repeated measurements of the same quantity by the same measuring system, operated by the same personnel, do not yield identical values.

error, systematic: sometimes called bias error; the difference between the average of the total population and the true value. The true systematic or fixed error that characterizes every member of any set of measurements from the population.

error, total: combination of systematic error and random error.

exit gas temperature: the average temperature of the flue gas leaving the steam generator boundary. This temperature may or may not be adjusted for air heater leakage.

fixed carbon: the carbonaceous residue less the ash remaining in the test container after moisture and the volatile matter has been driven off in making the proximate analysis of a solid fuel in accordance with the appropriate ASTM standard. Also see *volatile matter*.

flue gas: the gaseous products of combustion including excess air.

flue gas (hot fluid) exit temperature — excluding leakage: the temperature at which the flue gas would have exited the air heater if there were no leakage. If leakage is present, this parameter is calculated by energy balance. For the purposes of the energy-balance calculations, the temperature of the leakage flow, including any ingress air, is assumed to be the same as the entering air stream(s).

flue gas (hot fluid) exit temperature — including leakage: the measured temperature of the flue gas exiting the air heater.

flue gas (hot fluid) side effectiveness: the ratio of the flue gas temperature drop, excluding leakage, to the temperature head.

flue gas (hot fluid) temperature drop — excluding leakage: the decrease in the temperature of the flue gas passing through the air heater, based on the fluid exit temperature excluding leakage.

fluidized bed: a bed of suitably sized combustible and noncombustible particles through which a fluid (air in fluidized bed steam generators) is caused to flow upward at a sufficient velocity to suspend the particles and to impart to them a fluid-like motion.

fluidized bed, bubbling: a fluidized bed in which the fluidizing air velocity is less than the terminal velocity of most of the individual particles. Part of the gas passes through the bed as bubbles. This results in a distinct bed region because an insignificant amount of the bed is carried away by the fluidizing air.

fluidized bed, circulating: a fluidized bed in which the fluidizing air velocity exceeds the terminal velocity of most of the individual particles, so that they are carried from the combustion chamber and later reinjected.

furnace: an enclosed space provided for the combustion of fuel.

heat capacity ratio (X-ratio): the ratio of the mean heat capacity of the air passing through the air heater to the mean heat capacity of the flue gas passing through the air heater. For a multi-sector air heater, the air-side component is based on the composite air-side temperatures. See para. 5-5.9.

heating value, higher: the total energy liberated per unit mass of fuel upon complete combustion as determined by appropriate ASTM standards. The higher heating value includes the latent heat of the water vapor. When the heating value is measured at constant volume, it must be converted to a constant pressure value for use in this Code.

heating value, lower: the total heat liberated per unit mass of fuel minus the latent heat of the water vapor in the products of combustion as determined by appropriate ASTM standards (not used in this Code).

humidity ratio: mass of water vapor in a gas per pound of dry gas (also see *specific humidity*).

influence coefficient: see *absolute* and/or *relative sensitivity (influence) coefficient*.

input from fuel: the total chemical energy available from the fuel. Input is based on the higher heating value.

input–output method: a method of determining steam generator efficiency by direct measurement of output and input (I/O method).

instrument: any tool or device used in the measurement of the present value of a physical, electrical, or chemical variable. These variables can include pressure, temperature, fluid flow, voltage, electric current, chemical composition, density, viscosity, size, and power. This includes sensors and any ancillary equipment used to transmit, display, and record these variables.

losses: the energy that exits the steam generator envelope other than the energy in the output stream(s).

loss on ignition: commonly referred to as LOI. The loss in mass of a dried dust sample, expressed as a percentage of the initial mass, that occurs when the sample is heated in the presence of oxygen. Typically used to approximate unburned carbon in residue.

maximum continuous rating: see *capacity*.

measurement error: the true (unknown) difference between the measured value and the true value.

moisture: water in fuel or sorbent as determined by the appropriate ASTM standard(s), or water in the liquid or vapor phase, present in other streams.

outliers: a data point judged to be spurious or erroneous.

output: energy absorbed by the working fluid that is not recovered within the steam generator envelope.

parties to a test: those persons and companies participating in the test.

precision error: see *error, random*.

primary variables: those used in calculations of test results. They are further classified as shown below.

Class 1: those that have a relative sensitivity (influence) coefficient of 0.2 or greater

Class 2: those that have a relative sensitivity (influence) coefficient of less than 0.2 [Refer to ASME PTC 19.1 for the determination of relative sensitivity (influence) coefficients.]

purge: to introduce air into the furnace or the boiler flue passages in such volume and manner as to completely replace the air or gas–air mixture contained within.

recycle rate: the mass flow rate of material being reinjected into a furnace or combustion chamber.

recycle ratio: the recycle rate divided by the fuel mass flow rate.