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Air Heaters

Supplement to Performance Test Code
for Steam Generating Units, PTC 4.1

PERFORMANCE
TEST
CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
345 East 47th Street New York, N.Y. 10017

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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 power 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.

January, 1968

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ASME PERFORMANCE TEST CODES

Test Code for AIR HEATERS

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SECTION 0, INTRODUCTION

0.1 This Code for air heater testing shall govern the preparation for tests, the taking of data, and the calculation of test results.

0.2 The air heater is defined as a heat exchanger used to transfer heat directly from combustion gases to combustion air without the use of an intermediate heat transfer fluid.

0.3 General instructions for the conduct of tests are given in the Code on General Instructions (PTC 1) which should be studied carefully. The Code on Definitions and Values (PTC 2) and the Test Code for Steam Generating Units (PTC 4.1) should be followed where applicable. The Supplements on Instruments and Apparatus (PTC 19) shall be used as a guide to the selection and use of test equipment not specified in this Code.

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SECTION 1, OBJECT AND SCOPE

1.1 Object. The purpose of this Code is to establish procedures for conducting performance tests to determine:

1.1.1 Gas side efficiency
1.1.2 Air leakage
1.1.3 Other related operating characteristics such as:
1.1.3.1 X-Ratio
1.1.3.2 Gas and air pressure loss
1.1.3.3 Gas and air temperature
1.1.4 A determination of any or all of the performance items specified above may be necessary for:
1.1.4.1 Checking the actual performance against the manufacturer's guarantee
1.1.4.2 Comparing these items with a standard of operation
1.1.4.3 Comparing performance when firing different fuels
1.1.4.4 Determining the effect of changes to equipment
1.1.4.5 Determining corrections to air heater exit gas temperature caused by variations in inlet air temperature in an efficiency test of a steam generator.
1.1.4.6 Obtaining any other pertinent information required.

1.2 Scope. This Code applies specifically to the regenerative and tubular type air heaters. It also applies to any combustion gas-to-air heat exchangers used in conjunction with a steam generator.

1.3 For the purpose of this Code, the air heater is defined as a heat exchanger used to transfer heat from gases of combustion to combustion air without the use of an intermediate heat transfer fluid. Specifically excluded are the supplementary steam coil air heater, direct-fired air heater and low temperature economizer. However, a separate low temperature air heater would be considered part of the air heater installation.

1.4 If the installation consists of more than one air heater in parallel, all air heaters are included as a unit. However, if the air heaters are in series and have other apparatus in between, then each air heater, or each group of parallel air heaters, shall be tested individually.

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SECTION 2, DEFINITION OF TERMS, SYMBOLS AND THEIR DESCRIPTIONS

2.1 The Code on Definitions and Values (PTC 2) defines the meaning and values of basic technical terms and numerical constants, which are used throughout this Code. Definitions of terms specific to this Code are as follows:

2.1.1 Air Leakage. Weight of air passing from the air side to the gas side. It is assumed in calculations to leak directly from the air inlet to the gas outlet.

2.1.2 Exit Gas Temperature – With Leakage. The measured exit gas temperature.

2.1.3 Exit Gas Temperature – No Leakage. The temperature at which the gas would have left the air heater if there were no leakage. This temperature must be calculated by heat balance, if leakage is present. See Computations, Section 7.

2.1.4 Air Temperature Rise. Increase in the temperature of the air in passing through the air heater.

2.1.5 Gas Temperature Drop. Decrease in the temperature of the gas in passing through the air heater, based on exit gas temperature – no leakage.

2.1.6 Temperature Head. Temperature of gas entering air heater minus temperature of air entering air heater.

2.1.7 Gas Side Efficiency. Ratio of gas temperature drop, corrected for no air leakage, to temperature head.

2.1.8 X-Ratio. This is the ratio of the heat capacity of the air passing through the air heater to the heat capacity of the gas passing through the air heater. See Pars. 6.3 and 7.07.

2.2 Symbols. A list of symbols used throughout this Code follows. With numerous quantities and points of reference, it has been found impractical to restrict the Code to the use of single subscripts. Where both letter and numerical subscripts are used, a numerical one is given second for example $W_{G\,14}$. This signifies the pounds of gas per pound of "as fired" fuel at location 14, Fig. 1.

Symbols and their Descriptions

Symbol	Description	Unit
A	Air	. . . . .
A'	Dry air	. . . . .
A.F.	As fired	. . . . .
$A_{(L)}$	Air leakage	per cent
(B)	Bypass	. . . . .
C	Pounds of carbon per pound of "as fired" fuel – (laboratory analysis)	lb per lb of A.F. fuel
C_b	Pounds of carbon burned per pound of "as fired" fuel	lb per lb of A.F. fuel
CO	Per cent carbon monoxide per volume of dry flue gas. Determined by flue gas analysis	per cent
CO_2	Per cent carbon dioxide per volume of dry flue gas. Determined by flue gas analysis	per cent
$c_{pA'}$	Mean specific heat of air at constant pressure	Btu per lb F

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Symbols and their Descriptions (Cont'd)

Symbol	Description	Unit
c_{pG}	Mean specific heat of the flue gas at constant pressure	Btu per lb F
D	Standard or guarantee	. . . . .
e	Elapsed time	hr
f	Fuel	. . . . .
G	Flue gas	. . . . .
Ⓖ	Flue gas flow	lb per hr
G'	Dry flue gas	. . . . .
H	Pounds of hydrogen exclusive of that in moisture per pound of "as fired" fuel – (laboratory analysis)	lb per lb of A.F. fuel
H_2	Hydrogen content of the dry flue gas – (laboratory analysis)	cu ft per cu ft dry gas
$H_{d'p'}$	High-heat value of the dry refuse (laboratory analysis)	Btu per lb of refuse
k	Constant	. . . . .
Ⓛ	Leakage	. . . . .
m	Moisture content	per cent by weight
m_f	Moisture in fuel	lb of water per lb of A.F. fuel
N	Pounds of nitrogen per pound of "as fired" fuel – (laboratory analysis)	lb per lb of A.F. fuel
N_2	Per cent nitrogen per volume of dry flue gas. Determined by subtracting the sum of the measured quantities CO_2, O_2 and CO from 100	per cent
ⓃⓁ	No leakage	. . . . .
O	Pounds of oxygen per pound "as fired" fuel – (laboratory analysis)	lb per lb of A.F. fuel
O_2	Per cent oxygen per volume of dry flue gas. Determined by flue gas analysis	per cent
P	Pressure	in. of water (gage)
$\boxed{p}$	Ashpit	. . . . .
p'	Dry pit refuse	lb
Ⓡ	Recirculation	. . . . .
S	Pounds of sulfur per pound of "as fired" fuel – (laboratory analysis)	lb per lb of A.F. fuel
T	Temperature Rankine	R
t	Temperature Fahrenheit	F

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Symbols and their Descriptions (Cont'd)

Symbol	Description	Unit
t_A	Temperature of air	F
t_G	Temperature of the flue gas	F
W	Weight	lb
W_A	Pounds of air supplied per pound of "as fired" fuel	lb per lb of A.F. fuel
$W_{A'}$	Pounds of dry air per pound of "as fired" fuel	lb per lb of A.F. fuel
$W_A(L)$	Pounds of air leakage per pound of "as fired" fuel	lb per lb of A.F. fuel
$W_{d'p'}$	Pounds of dry refuse per pound of "as fired" fuel	lb per lb of A.F. fuel
W_{fe}	Pounds of fuel fired (rate), either solid or liquid	lb per hr
$W_{G'}$	Pounds of dry gas leaving unit per pound of "as fired" fuel	lb per lb of A.F. fuel
$W_{mA'}$	Pounds of moisture per pound of dry air	lb per lb of dry air
(X_R)	X-Ratio	. . . . .
z	Atomizing steam	. . . . .
δ	Corrected	. . . . .
η	Efficiency	per cent
η_G	Gas side efficiency	per cent
Δ	Change	. . . . .
'(prime)	Dry	. . . . .

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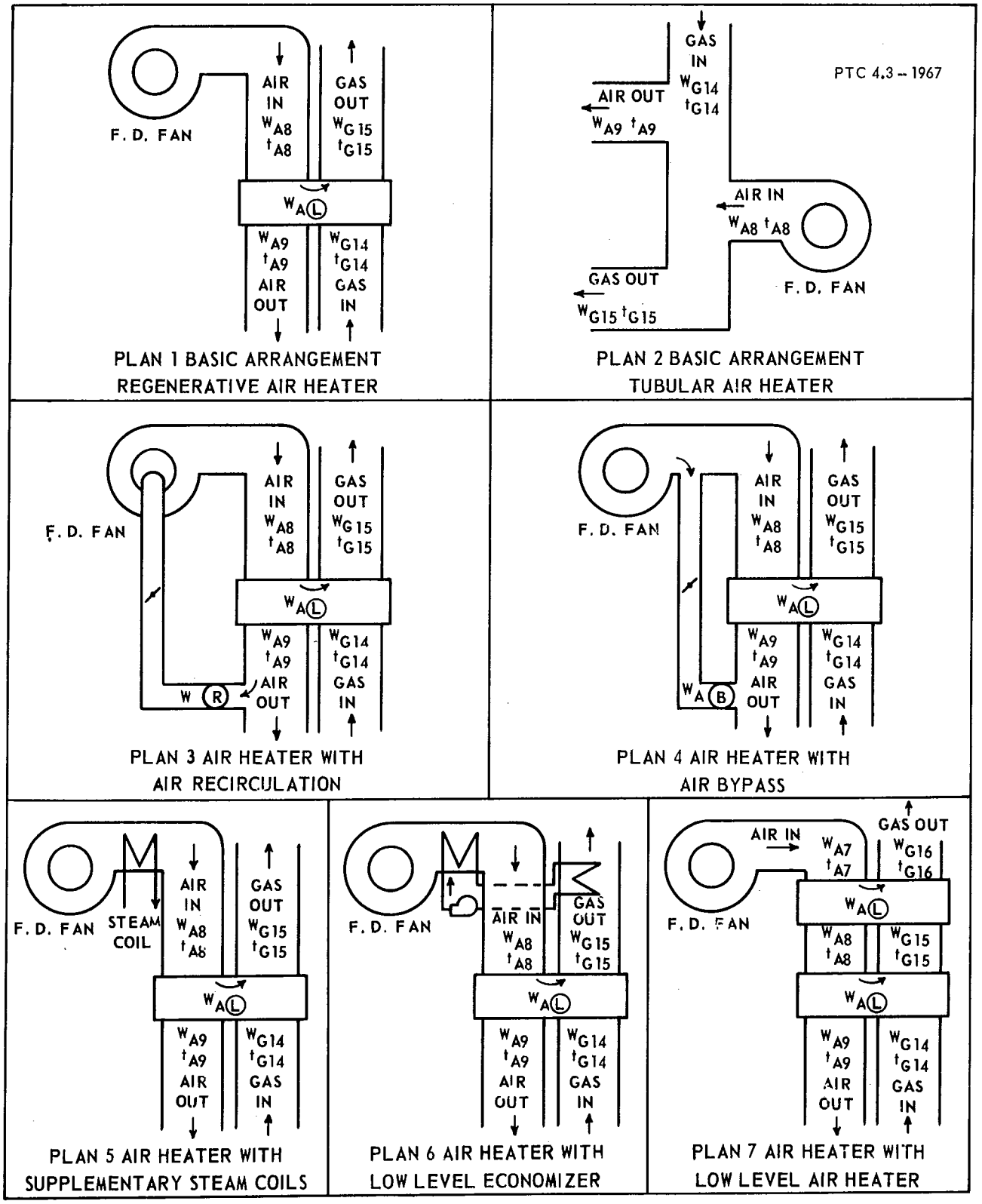

FIG. 1 AIR HEATER ARRANGEMENTS

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SECTION 3, GUIDING PRINCIPLES

3.01 Items on Which Agreement Shall be Reached Prior to Test:

3.01.01 Object of Test.

3.01.02 Permissible deviation in gas side efficiency between duplicate runs.

3.01.03 Air and gas flow quantities.

3.01.04 Allocation of responsibility for all performance and operating conditions which affect the test.

3.01.05 Selection of test personnel to conduct the test.

3.01.06 Establishment of acceptable operational conditions, number of load points, duration of runs, basis of rejection of runs and procedures to be followed during the test.

3.01.07 Cleanliness of unit initially and how this is to be maintained during the test. See Par. 3.04.2.

3.01.08 Condition of apparatus affecting air leakage.

3.01.09 The fuel to be fired, the method of obtaining fuel samples and the laboratory to make the analysis.

3.01.10 Observations and readings to be taken to comply with the object or objectives of the test.

3.01.11 Instruments to be used, calibration of instruments, methods of measurement and equipment to be used in testing the unit. The Performance Test Code Supplements on Instruments and Apparatus should be used, when applicable.

3.01.12 Tolerances and limits of error in measurement and sampling.

3.01.13 Distribution of fuel refuse quantities between various collection points and methods of sampling.

3.01.14 Corrections to be made for deviations from specified operating conditions.

3.02 Selection of Personnel. To insure obtaining reliable results, all personnel participating in the test shall be fully qualified to perform their particular function.

3.03 Tolerances and Limits of Error. This Code does not include consideration of *over-all tolerances or margins on performance guarantees.* The test results shall be reported as computed from test observations, with proper corrections for calibrations.

Allowances for *errors of measurement and sampling* are permissible provided they are agreed upon in advance by the parties to the test and clearly stated in the test report.

3.04 Acceptance Test. An acceptance test shall be undertaken only when the parties to the test certify that the unit is operating to their satisfaction and is, therefore, ready for test. Especially in the case of fuel burning equipment, adjustments and changes are sometimes necessary to obtain optimum performance. The acceptance test should be started as soon as the unit is in satisfactory condition for test, provided the load and other governing factors are suitable.

3.04.1 Parties to the test may designate a person to direct the test and to serve as arbiter in the event of disputes as to the accuracy of observations, conditions or methods of operation.

3.04.2 All heat transfer surfaces, both internal and external, should be commercially clean (normal operating cleanliness) before starting the test. During the test, only the amount of cleaning shall be permitted as is necessary to maintain normal operating cleanliness.

3.04.3 After a preliminary run has been made, it may be declared an acceptance run if agreed to and provided that all the requirements of a regular run have been met.

3.04.4 At least two runs shall be made approximating the load required for acceptance. If the results exceed the previously agreed upon deviation in efficiency between runs, a third run shall be required. The test efficiency at the required load will be the average of the two runs which fall within the permissible deviation in efficiency.

3.05 Preparation for Test. Install such measuring apparatus as may be required to attain the objective of the test. It is recommended that the air heater be inspected prior to the test to note the condition of all parts which can affect the performance. In particular, the tightness and cleanliness of air heater tubes and condition and cleanliness of elements and condition of the seals of regenerative air heater should be examined and the air heater placed in proper operating condition. The bypass or recirculating dampers should be checked for tight shutoff. A preliminary check of air leakage, calculated from Orsat analysis at the gas inlet and outlet should be conducted prior to the actual test.

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3.06 A Preliminary Run shall be made for the purpose of:

3.06.1 Checking the operation of all instruments.

3.06.2 Training the observers and other test personnel.

3.06.3 Making minor adjustments, the needs for which were not evident during the preparation for the test, and establishing proper combustion conditions for the particular fuel and rate of burning to be employed.

3.07 Test Conditions. It is important that air and gas flow through the air heater remain essentially constant throughout the test. The steam generator output shall be set as close as possible to that required of the test run and shall be held stable for at least 30 minutes prior to the start of the test.

3.08 Duration. Test runs shall be of at least two-hour duration but sufficiently long to permit the taking of at least two complete sets of consistent readings.

3.09 Frequency and Consistency of Readings. Except for quantity measurements (see Pars. 5.4 and 5.5), the readings shall be taken at 15 minute intervals. If, however, there are fluctuations, the readings shall be taken at such frequency as may be necessary to determine a value that represents a true average.

3.09.1 It is suggested that, in so far as is feasible, pertinent data of the run be plotted continuously, as the run progresses, on coordinate paper of suitable scale to permit a complete review of the conduct of the run, at least hourly.

3.10 Rejection of Runs. Should inconsistencies in the observed data be detected during a run or during the computations that would cause obviously untrue results, the run shall be rejected completely, or in part if the affected part is at the beginning or at the end of the run. A run that has been rejected shall be repeated, if necessary, to attain the objectives of the test.

3.11 Records and Test Reports. All observations, measurements and instrument readings necessary for the objective of the test shall be recorded as observed. Corrections and corrected values shall be entered separately in the test record.

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SECTION 4, DATA REQUIRED, INSTRUMENTS AND APPARATUS

4.1 Data Required. The following data are needed in order to determine the performance of the air heater:

4.1.01 Temperature of air entering air heater

4.1.02 Temperature of air leaving air heater

4.1.03 Temperature of gas entering air heater

4.1.04 Temperature of gas leaving air heater

4.1.05 Quantity of air entering air heater

4.1.06 Quantity of heated air leaving air heater

4.1.07 Quantity of gas entering air heater

4.1.08 Quantity of gas leaving air heater

4.1.09 Air side inlet and outlet static pressure

4.1.10 Air side inlet and outlet velocity pressure

4.1.11 Gas side inlet and outlet static pressure

4.1.12 Gas side inlet and outlet velocity pressure

4.1.13 Humidity of inlet air

4.1.14 Gas analysis of flue gas entering and leaving air heater

4.1.15 Quantity of fuel measured or computed by steam generator output and efficiency

4.1.16 Ultimate analysis of fuel

4.1.17 Quantity of fuel oil atomizing steam if burning oil.

4.2 Instruments and Apparatus. Directions regarding the characteristics, use and calibration of the apparatus required are given in PTC 19 Supplements on Instruments and Apparatus (I & A). The instruments and apparatus required for air heater tests are as follows:

4.2.1 Determining air and gas temperatures – Calibrated thermocouples shall be used with a calibrated potentiometer. The thermocouples shall be in accordance with I & A, Temperature Measurement (PTC 19.3) and arranged so that they can be traversed across the duct.

4.2.2 Determining air humidity adjacent to air inlet – A psychrometer shall be used.

4.2.3 Measuring air and gas pressure – U-tube or inclined manometers for determining pressure shall be filled with water or a light liquid of known specific gravity. (Refer to PTC 4.1, Pars. 8.06 and 8.07.)

4.2.4 Analyzing dry flue gas – Gas analyzer shall be used to determine percentages of carbon dioxide, oxygen and carbon monoxide.

4.2.5 Measuring fuel input, if required – Calibrated coal scales, oil meters, or gas meters shall be used.

4.2.6 Sampling of fuel – Air tight containers shall be used for individual fuel samples to avoid moisture loss.

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SECTION 5, MEASUREMENT

5.1 Location of Test Sampling Points for Air and Gas Temperature and Gas Analysis. Temperature and/or gas analysis sampling points in the inlet gas and inlet air ducts shall be located as close to the air heater as practical and as consistent as possible with good velocity measurement practice. Due to the probable stratification at the gas and air outlets and air infiltration of a regenerative air heater, the traverse section should be located as far from the heater as practical and be divided into equal areas for velocity measurement and simultaneous gas sampling from the center of these areas. A weighted average can then be calculated, taking into consideration the gas temperature, Par. 5.2, as well as a velocity function. See Performance Test Code for (PTC 11). The number and arrangement of the equal areas will depend on the size and layout of the gas passage. In rectangular ducts, the areas shall be approximately square and the sampling points shall be not more than three feet apart, and a total of not less than four points shall be used. Where judgment indicates a possible severe stratification, consideration should be given to a system of closer spacings. In round ducts, test points shall be located on two traverses along axes normal to each other as described in the Performance Test Code for Fans (PTC) 11). It is recognized that there may be cases in which the gas velocity is so low that velocity measurements would be impractical. In such cases an arithmetic rather than weighted average should be employed. When the importance of the test does not warrant making velocity measurements and taking individual samples from the equal areas, an aspirator and suitable apparatus for obtaining a composite sample from several sampling points may be employed. With the exception of the area sampling instruction above, all of the procedures are to be in accordance with recommendations of I & A, Part 10 on Flue and Exhaust Gas Analyses (PTC 19.10).

5.2 Flue Gas and Air Temperatures. Flue gas temperatures must be taken at the same locations as those used for flue gas sampling, Par. 5.1, to minimize the effect of probable gas temperature stratification.

5.2.1 If a preliminary survey of flue gas flow, Par. 5.1, indicates severe stratifications, it is recommended that the temperature measurements at individual locations in the duct cross section be weighted in proportion to the gas flow at the corresponding locations, and an average of the weighted temperatures be used as representing the gas temperature at that cross section.

5.2.2 Choice of temperature measuring instruments depends upon the conditions of the individual case. The selection, design, construction, calibration, installation, and operation of temperature measuring instruments shall be in accordance with I & A, Temperature Measurement (PTC 19.3).

5.2.3 For determination of the air temperature, the same general methods and the same precautions noted in Pars. 5.2.1 and 5.2.2 shall apply for the air entering and leaving the air heater.

5.3 Gas Analysis. Gas analysis is required to calculate gas flow. Analysis to be employed is dependent upon the type of fuel burned and upon the purpose of the test. Design, construction and operation of the apparatus and preparation of the reagents shall be in accordance with I & A, Flue and Exhaust Gas Analyses (PTC 19.10).

5.3.1 An analysis should be made to verify presence or absence of gaseous combustibles. If combustibles are found and cannot be eliminated by adjustment to the fuel burning equipment, the hydrogen and hydrocarbons shall be measured and the gas flow corrected following the principles covered in Section 7 of the Test Code for Steam Generating Units, (PTC 4.1).

5.3.2 For hydrogen and hydrocarbon analyses, it is necessary to obtain representative field samples of the gases for submission to an established laboratory. Refer to I & A, Flue and Exhaust Gas Analyses (PTC 19.10).

5.3.3 Proper steps shall be taken to prevent leakage to or from gas analyzing apparatus and sampling lines, to avoid contamination and devitalization of reagents, to provide fresh reagents when needed, to keep manifolds clear of reagents, to avoid errors due to physical solubility of gases in reagents and confining liquids, to avoid injury by contact with reagents, to allow for burette error and drainage time, to avoid change of sample temperature during analysis, to keep ap-

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paratus clean, to minimize human errors by employing careful operators who are given adequate information on common sources of error, to provide operators with adequate light and reasonable comfort, to verify results by checking against theoretical, and in all other ways, to assure that recorded data are correct and their degree of precision known. Sampling should be continuous when possible. Because all gases, especially SO_2 and CO_2, are soluble to some extent in water, the water in the levelling bottle shall be saturated with sample gas before taking any readings.

5.3.4 Detailed precautions given in I & A, Part 10 on Flue and Exhaust Gas Analyses (PTC 19.10) shall be followed.

5.4 Flue Gas and Air Quantity. Flue gas quantity shall be determined by calculation from fuel analysis and flue gas composition. Calculation procedure for gas weight per heat unit of fuel shall be as given in Par. 7.04.1. Similarly, air quantities shall be calculated as per Par. 7.06.

5.5 Fuel Quantity. The quantity of fuel may be obtained by measurement in accordance with procedures given in PTC 4.1, Section 4, or by computing from test efficiency and output of the steam generator.

5.6 Power. Power requirement of the regenerative air heaters may be disregarded for performance purposes.

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SECTION 6, PERFORMANCE FACTORS

6.1 Analysis of Over-all Performance. The analysis of air heater performance is confined to the following considerations:

6.1.1 Comparison of test thermal performance with design.

6.1.2 Comparison of test air leakage with design.

6.1.3 Comparison of test air and gas side pressure loss with design.

6.2 Operating Conditions. Conditions which affect the air heater performance and which should be given special consideration are:

6.2.1 Quantity of air passing through the air heater.

6.2.2 Temperature of air entering the air heater.

6.2.3 Recirculating or bypassing of air to control cold-end temperature.

6.2.4 Tempering air and setting infiltration which did not pass through the air heater.

6.2.5 Air heater leakage – condition of seals.

6.2.6 Quantity of gas passing through the air heater.

6.2.7 Temperature of gas entering the air heater.

6.2.8 Fouled or corroded elements or tubes.

6.3 Thermal Performance. A very important factor in evaluating the thermal performance of an air heater is X-Ratio. This factor is nondimensional and is obtained during test by recording gas side in and out temperatures, air side in and out temperatures and Orsat readings at gas inlet and outlet. From the latter two readings the air leakage to the gas side is obtained in pounds per pound of wet gas and permits correction of the test temperature of gas out to temperature of gas out with zero air heater leakage. The use of the X-Ratio accounts partially for differences between test and design values of air heater exit gas temperatures. The X-Ratio is also affected by tempering air flow, sealing air flows, setting infiltration and in some arrangements by gas recirculation.

6.4 Air Heater Leakage. From the Orsat readings used to obtain X-Ratio the amount of air leakage is determined and when corrected is compared with design.

6.5 Exit Gas Temperature. Test and design exit gas temperature should not be compared until corrections to the test values have been made in accordance with Section 7, Par. 7.07 through Par. 7.11.

6.6 Pressure Loss. After corrections for temperature and flow rate, test gas side and air side pressure losses are to be compared with design values.

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SECTION 7, COMPUTATIONS

The following computation procedures are for determining air heater performance.

7.01 η_G = per cent = Gas side efficiency.

$$\eta_G = \frac{t_{G14} - t_{G15}\,(NL)}{t_{G14} - t_{A8}} \times 100$$

Where

t_{G14} = F = Measured gas temperature entering air heater.

$t_{G15}\,(NL)$ = F = Calculated gas temperature leaving air heater corrected for no air leakage as given in Par. 7.02.

t_{A8} = F = Measured air temperature entering air heater.

7.02 $t_{G15}\,(NL)$ = F = Calculated gas temperature leaving air heater corrected for no air leakage.

$$t_{G15}\,(NL) = \frac{A_{(L)}\, c_{pA}\, (t_{G15} - t_{A8})}{100\, c_{pG}} + t_{G15}$$

Where

$A_{(L)}$ = Per cent = Air heater leakage as given in Par. 7.03

c_{pA} [(1)] $= \frac{\text{Btu}}{\text{lb} - \text{F}}$ = The mean specific heat between temperatures t_{A8} and t_{G15}

c_{pG} [(1)] $= \frac{\text{Btu}}{\text{lb} - \text{F}}$ = The mean specific heat between temperatures t_{G15} and $t_{G15}\,(NL)$

Where

t_{G15} = F = Measured gas temperature leaving air heater.

t_{A8} = F = Measured air temperature entering air heater.

7.03 $A_{(L)} = \frac{\text{lb wet air leakage}}{\text{lb wet gas entering air heater}} \times 100$ = Per cent air heater leakage, — defined as pounds of air leakage to the gas side divided by pounds gas entering the air heater.

$$A_{(L)} = \frac{W_{G15} - W_{G14}}{W_{G14}} \times 100$$

(1) For the determination of the mean specific heats use PTC 4.1, Fig. 3 for air and Fig. 7 for gas to calculate the weighted average specific heat for wet air and wet gas.

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$$W_{G\,15,14} = \frac{\text{lb wet gas leaving, entering air heater}}{\text{lb A.F. fuel}}$$

$$= W_{G'15,14} + W_{mG}\,^{(2)}$$

$W_{G'15,14} = \dfrac{\text{lb dry gas}}{\text{lb A.F. fuel}}$ = Dry gas flow leaving/entering the air heater as given in Par. 7.04

$W_{mG} = \dfrac{\text{lb moisture}}{\text{lb A.F. fuel}}$ = Total moisture in flue gas entering the air heater as given in Par. 7.05

7.03.1 While not a part of this Code, an interesting empirical approximation of percentage of leakage may be obtained by the use of the per cent volume of the CO_2 in the gas entering and leaving the heater. The approximation does not account for the moisture in the flue gas.

Thus:

$$\%\ \text{LEAKAGE} = \frac{\%\ CO_2 \text{ gas entering heater} - \%\ CO_2 \text{ gas leaving heater}}{\%\ CO_2 \text{ gas leaving heater}} \times 90$$

Experience has shown that the use of this factor, 90, will result in percentage leakage figures that are very close (plus or minus one percentage point) to leakage determined on a weight basis.

7.04

$W_{G'} = \dfrac{\text{lb dry gas}}{\text{lb A.F. fuel}}$ = Pounds of dry gas per pound of "as fired" fuel.

7.04.1

$$W_{G'14,15} = \frac{44.01\ CO_2 + 32.00\ O_2 + 28.01\ CO + 28.02\ N_2}{12.01\ (CO_2 + CO)}\left(C_b + \frac{12.01}{32.07}\ S\right)$$

The above formula is based on molecular weights accurate to four significant figures, but it is not to be implied that the dry gas weight derived has this degree of accuracy. The four digit molecular weights are used to hold errors from calculation procedure to a minimum.

CO_2, O_2, and CO = per cent by volume of dry gas.

N_2 being determined by subtracting the total of CO_2, O_2, and CO from 100 per cent.

$C_b = \dfrac{\text{lb carbon burned}}{\text{lb A.F. fuel}}$ = Pounds of carbon burned per pound of "as fired" fuel.

$$C_b = C - \left(\frac{W_{d'p'}\ H_{d'p'}}{14500}\right)$$

---

(2) In this Code, air leakage is assumed to bypass directly from the inlet air side to the outlet gas side. Therefore moisture in air leakage does not become a part of $W_{G'14} + W_{mG'}$ but does become a part of $W_{G'15} + W_{mG}$. The omission of this moisture in the latter term will not affect the accuracy of the leakage calculation since it is a very small part of the total moisture term. If it is desired to calculate this moisture term, the following procedure may be used:

1. Calculate the actual pounds of dry air leakage per pound of "as fired" fuel; $W_{G'15} - W_{G'14}$.
2. Multiply the result of (1) by the specific humidity (pounds moisture/pounds dry air) to get the pounds of moisture in leakage air per pound of "as fired" fuel.
3. Add the result of (2) to the W_{mG} term used to calculate W_{G15} and then recalculate A_L.

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Where

$C = \frac{\text{lb carbon}}{\text{lb A.F. fuel}}$ = Pounds of carbon in "as fired" fuel by laboratory analysis.

$W_{d'p'} = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of dry refuse per pound of "as fired" fuel.

$$W_{d'p'} = \frac{W_{d'p'e}}{W_{fe}}$$

Where

$W_{d'p'e} = \frac{\text{lb}}{\text{hr}}$ = Dry refuse rate

Where refuse rate at various collection points, such as ashpit, dust collector, boiler hoppers, is not actually determined, it can be estimated if all parties agree.

$W_{fe} = \frac{\text{lb}}{\text{hr}}$ = Fuel rate

If fuel rate is not measured, it shall be computed from steam generator test efficiency and output.

$H_{d'p'} = \frac{\text{Btu}}{\text{lb dry refuse}}$ = Laboratory determination of per cent combustible times 14500 Btu per lb

or

$H_{d'p'} = \frac{\text{Btu}}{\text{lb dry refuse}}$ = Laboratory determination of heating value by bomb calorimeter

$14500 = \frac{\text{Btu}}{\text{lb}}$ = Heat value of 1 lb of carbon as it occurs in refuse (see Par. 9.4 of the Test Code for Steam Generating Units, PTC 4.1)

$S = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = The "as fired" sulfur content of fuel as determined by laboratory analysis.

7.05

$W_{mG} = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of moisture in the flue gas per pound of "as fired" fuel.

$$W_{mG} = 8.936H + (W_{mA'} \times W_{A'}) + m_f + W_z + W_m \boxed{p}$$

Where

8.936 = 8.936 pounds of water produced from burning one pound of hydrogen.

$H = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of hydrogen from an "as fired" ultimate analysis.

$W_{mA'} = \frac{\text{lb}}{\text{lb dry air}}$ = Pounds of moisture per pound of dry air at boiler inlet.

$W_{A'} = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of dry air per pound of "as fired" fuel as given in Par. 7.06.

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$m_f = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of moisture per pound of "as fired" fuel.

$W_z = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of atomizing steam per pound of "as fired" fuel. The procedure for obtaining this term is given in Pars. 4.17 and 7.3.2.06 of the Test Code for Steam Generating Units, PTC 4.1.

$W_m \boxed{p}^{(3)} = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of moisture evaporated in ashpit per pound of "as fired" fuel.

7.06

$W_{A'} = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of dry air per pound of "as fired" fuel.

$$W_{A'} = \frac{(W_{G'N_2} - N)}{0.7685}$$

Where

$W_{G'N_2} = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of nitrogen in dry gas per pound of "as fired" fuel.

$$W_{G'N_2} = \frac{28.02\ N_2}{12.01\ (CO_2 + CO)} \left(C_b + \frac{12.01}{32.07} S \right)$$

The preceding formula is based on molecular weights accurate to four significant figures, but it is not to be implied that the weight of dry air has this degree of accuracy. The four digit molecular weights are used to hold errors from calculation procedures to a minimum. The values used are from the National Bureau of Standards Circular 564, dated 11/1/55.

CO_2, O_2 and CO = Per cent by volume of dry flue gas. (Location 14 or 15, Fig. 1.)

N_2 being determined by subtracting the total of CO_2, O_2 and CO from 100 per cent.

$C_b = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of carbon burned per pound of "as fired" fuel.

$$C_b = C - \frac{W_{d'p'} H_{d'p'}}{14500}$$

Where

$C = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds carbon in "as fired" fuel by laboratory analysis.

$W_{d'p'} = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of dry refuse per pound of "as fired" fuel, see Par. 7.04.

$H_{d'p'} = \frac{\text{Btu}}{\text{lb dry refuse}}$ = Heat value for dry refuse from laboratory determination.

(3) This term may be ignored, by agreement, inasmuch as its magnitude is such that it affects the wet gas weight on the order of the 0.1 per cent. If it is desired, this term may be calculated as outlined in Pars. 5.23 and 7.3.2.11 of the Test Code for Steam Generating Units, PTC 4.1.

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$14500 = \frac{\text{Btu}}{\text{lb}}$ = Heat value of 1 lb of carbon as it occurs in refuse (see Par. 9.4 of the Test Code for Steam Generating Units, PTC 4.1)

$S = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds sulfur per pound of "as fired" fuel as determined by laboratory analysis.

$N = \frac{\text{lb}}{\text{lb A.F. fuel}}$ = Pounds of nitrogen per pound of "as fired" fuel.

0.7685 = Pounds of nitrogen per pound of standard air, $W_{A'}$ then becomes

$$W_{A'} = \frac{\frac{28.02\ N_2}{12.01\ (CO_2 + CO)}\left(C_b + \frac{12.01}{32.07}\ S\right) - N}{0.7685}$$

7.07 Test X-Ratio $= \frac{W_{A9}\ c_{pA}}{W_{G14}\ c_{pG}} = \frac{(t_{G14} - t_{G15}\ (NL)\ )}{(t_{A9} - t_{A8})}$ and is the ratio of the heat capacity of the air passing through the heater to the heat capacity of the gas passing through the heater.

$W_{A9} = \frac{\text{lb wet air}}{\text{lb A.F. fuel}}$ = Wet air flow leaving air heater.

$W_{G14} = \frac{\text{lb wet gas}}{\text{lb A.F. fuel}}$ = Wet gas flow entering air heater as given in Par. 7.03.

c_{pA}[4] $= \frac{\text{Btu}}{\text{lb} - \text{F}}$ = Mean specific heat of air between temperatures t_{A9} and t_{A8}.

c_{pG}[4] $= \frac{\text{Btu}}{\text{lb} - \text{F}}$ = Mean specific heat of gas between temperatures t_{G14} and $t_{G15}\ (NL)$.

t_{G14} = F = Measured gas temperature entering air heater.

$t_{G15}\ (NL)$ = F = Calculated gas temperature leaving the air heater with no leakage as given in Par. 7.02.

t_{A9} = F = Measured air temperature leaving air heater.

t_{A8} = F = Measured air temperature entering air heater.

X-Ratio is derived from heat balance taken around an air heater corrected for no air leakage. Using the basic design diagram of Fig. 1, the heat balance is as follows:

$$W_{A9}\ c_{pA}\ (t_{A9} - t_{A8}) = W_{G14}\ c_{pG}\ (t_{G14} - t_{G15}\ (NL)\ ),$$

$$\text{X-Ratio} = (X_R) = \frac{W_{A9}\ c_{pA}}{W_{G14}\ c_{pG}} = \frac{(t_{G14} - t_{G15}\ (NL)\ )}{(t_{A9} - t_{A8})}$$

[4] For the determination of the mean specific heats use PTC 4.1, Fig. 3 for air and Fig. 7 for gas to calculate the weighted average specific heat for wet air and wet gas.

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7.07.1 Design X-Ratio is obtained by using the above formula and factoring into it the design data.

7.08

$t_{G15\,\delta A}$ = F = Corrected gas temperature leaving air heater for deviation from design entering air temperature.

$$t_{G15\,\delta A} = \frac{t_{A8D}\,(t_{G14} - t_{G15}) + t_{G14}\,(t_{G15} - t_{A8})}{(t_{G14} - t_{A8})}$$

Where

t_{A8D} = F = Design air temperature entering air heater

t_{G14} = F = Measured gas temperature entering air heater

t_{G15} = F = Measured gas temperature leaving air heater

t_{A8} = F = Measured air temperature entering air heater

The above equation is based on the test gas side efficiency remaining constant with changes in inlet air temperature. It's derivation follows:

$$\frac{t_{G14} - t_{G15}\,(NL)}{t_{G14} - t_{A8}} = \frac{t_{G14} - t_{G15}\,(NL)\,\delta A}{t_{G14} - t_{A8D}}$$

The nonleakage leaving gas temperature $t_{G15}\,(NL)\,\delta A$ is the corrected variable to be solved for. This temperature is related to the leaving gas temperature with leakage as shown by Par. 7.02. The two equations for the two nonleakage leaving gas temperatures in the above equation are shown as follows:

$$t_{G15}\,(NL) = \frac{A(L)\,c_{pA}}{100\,c_{pG}}\,(t_{G15} - t_{A8}) + t_{G15}$$

$$k = \frac{A(L)\,c_{pA}}{100\,c_{pG}}$$

$$t_{G15}\,(NL) = k\,(t_{G15} - t_{A8}) + t_{G15}$$

Rewriting the above equation to correct for the deviation from design entering air temperature.

$$t_{G15}\,(NL)\,\delta A = k\,(t_{G15\,\delta A} - t_{A8D}) + t_{G15\,\delta A}$$

Upon substitution of the above two nonleakage leaving gas temperature equations into the equated gas side efficiency equation, the corrected leaving gas temperature with leakage $t_{G15\,\delta A}$ can be solved for. The result of this substitution is as follows:

$$\frac{t_{G14} - k(t_{G15} - t_{A8}) - t_{G15}}{t_{G14} - t_{A8}} = \frac{t_{G14} - k(t_{G15\,\delta A} - t_{A8D}) - t_{G15\,\delta A}}{t_{G14} - t_{A8D}}$$

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The above equation reduces to:

$$t_{G15\,\delta A} = \frac{t_{A8D}\,(t_{G14} - t_{G15}) + t_{G14}\,(t_{G15} - t_{A8})}{(t_{G14} - t_{A8})}$$

7.09

$t_{G15\,\delta G}$ = F = Corrected Gas Temperature Leaving Air Heater for Deviation from Design Entering Gas Temperature

$$t_{G15\,\delta G} = \frac{t_{G14D}\,(t_{G15} - t_{A8}) + t_{A8}\,(t_{G14} - t_{G15})}{(t_{G14} - t_{A8})}$$

Where

t_{G14D} = F = Design gas temperature entering air heater

t_{G15} = F = Measured gas temperature leaving air heater

t_{A8} = F = Measured air temperature entering air heater

t_{G14} = F = Measured gas temperature entering air heater

The above equation is based on the test gas side efficiency remaining constant with changes in inlet gas temperature. The derivation follows:

$$\frac{t_{G14} - t_{G15}\,(NL)}{t_{G14} - t_{A8}} = \frac{t_{G14D} - t_{G15}\,(NL)\;\delta G}{t_{G14D} - t_{A8}}$$

The nonleakage leaving gas temperature $t_{G15}\,(NL)\;\delta G$ is the corrected variable to be solved for. This temperature is related to the leaving gas temperature with leakage as shown by Par. 7.02. The two equations for the two nonleakage leaving gas temperatures in the above equation are shown below:

$$t_{G15}\,(NL) = k\,(t_{G15} - t_{A8}) + t_{G15}$$

$$t_{G15}\,(NL)\;\delta G = k\,(t_{G15\,\delta G} - t_{A8}) + t_{G15\,\delta G}$$

Where $k = \dfrac{A(L)\,c_{pA}}{100\,c_{pG}}$

Upon substitution of these nonleakage leaving gas temperature equations into the equated gas side efficiency equation, the corrected leaving gas temperature with leakage $t_{G15\,\delta G}$ can be solved for. The result of this substitution is shown below

$$\frac{t_{G14} - k(t_{G15} - t_{A8}) - t_{G15}}{t_{G14} - t_{A8}} = \frac{t_{G14D} - k(t_{G15\,\delta G} - t_{A8}) - t_{G15\,\delta G}}{t_{G14D} - t_{A8}}$$

$$t_{G15\,\delta G} = \frac{t_{G14D}\,(t_{G15} - t_{A8}) + t_{A8}\,(t_{G14} - t_{G15})}{(t_{G14} - t_{A8})}$$

7.10 $t_{G15\,\delta\,(X_R)}$ = F = Corrected Gas Temperature Leaving Air Heater for Deviation from Design X-Ratio.

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Correction to measured gas temperature leaving the air heater for deviation from design X-Ratio may be made by the use of appropriate design correction curves.[5]

7.11 $t_{G15\delta(G)} = F =$ Corrected Gas Temperature Leaving Air Heater for Deviation from Design Entering Flue Gas Flow.

Correction to measured gas temperature leaving the air heater for deviation from design flue gas flows may be made by the use of appropriate design correction curves.[5]

7.12

$t_{G15\delta_{\text{Total}}} = F =$ Totally corrected gas temperature leaving air heater

$$t_{G15\delta_{\text{Total}}} = t_{G15\delta A} + t_{G15\delta G} + t_{G15\delta(X_R)} + t_{G15\delta(G)} - 3t_{G15}$$

Where

$t_{G15\delta A} = F =$ Gas temperature leaving the air heater corrected for deviation from design entering air temperature

$t_{G15\delta G} = F =$ Gas temperature leaving the air heater corrected for deviation from design entering gas temperature

$t_{G15\delta(X_R)} = F =$ Gas temperature leaving the air heater corrected for deviation from design X-Ratio

$t_{G15\delta(G)} = F =$ Gas temperature leaving the air heater corrected for deviation from design gas flow

$t_{G15} = F =$ Measured gas temperature leaving the air heater.

7.13

$W_{A(L)\delta} = \dfrac{\text{lb}}{\text{lb of A.F. fuel}} =$ Corrected Air Leakage for Deviation from Design Pressure Differential and from Design Air Temperature

$$W_{A(L)\delta} = W_{A(L)}\left[\frac{\Delta P_{(8-15)D}}{\Delta P_{(8-15)}}\left(\frac{T_{A8}}{T_{A8D}}\right)\right]^{1/2}$$

Where

$W_{A(L)} = \dfrac{\text{lb}}{\text{lb of A.F. fuel}} =$ Air leakage

$W_{G(L)} = W_{G15} - W_{G14}$

[5] These design correction curves can be substantiated by field tests although the procedures necessary may be considered impractical.

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Where

$W_{G\,15,14}$ = lb wet gas leaving/entering air heater / lb A.F. fuel

$= W_{G'15,14} + W_{mG}$ [6]

$W_{G'15,14}$ = lb dry gas / lb A.F. fuel = Dry gas flow leaving/entering the air heater as given in Par. 7.04

W_{mG} = lb moisture / lb A.F. fuel = Total moisture in flue gas entering the air heater as given in Par. 7.05

$\Delta P_{(8-15)D}$ = Inches of water = Design static pressure difference between air inlet at the duct connection flange and gas outlet at the duct connection flange.

$\Delta P_{(8-15)}$ = Inches of water = Measured static pressure difference between air inlet at the duct connection flange and gas outlet at the duct connection flange.

T_{A8} = R = Measured average Rankine temperature of air entering air heater.

T_{A8D} = R = Design Rankine temperature of air entering air heater.

It is recognized that the above orifice correction is not a rigorous treatment of the subject but is considered sufficiently accurate for the purpose of the Code.

7.13.1 To determine the above corrections when leakage is expressed on a percentage basis, use the following procedure:

$A\,(L)\,\delta D$ = Per cent = Corrected Air Leakage for Deviation from Design Pressure Differential and from Design Air Temperature

$$A\,(L)\,\delta D = A\,(L)\,\frac{W_{G\,14}}{W_{GD\,14}}\left[\frac{\Delta P_{(8-15)D}}{\Delta P_{(8-15)}}\left(\frac{T_{A8}}{T_{A8D}}\right)\right]^{1/2}$$

Where

$A\,(L)$ = Per cent = Air heater leakage as given in Par. 7.03

$W_{G\,14}$ = lb wet gas / lb A.F. fuel = Wet gas flow entering air heater as given in Par. 7.03

$W_{GD\,14}$ = lb wet gas / lb A.F. fuel = Wet gas flow entering air heater at design conditions

$\Delta P_{(8-15)D}$ = Inches of water = Design static pressure difference between air inlet at the duct connection flange and gas outlet at the duct connection flange.

[6] In this Code, air leakage is assumed to bypass directly from the inlet air side to the outlet gas side. Therefore moisture in air leakage does not become a part of $W_{G'14} + W_{mG}$, but does become a part of $W_{G'15} + W_{mG}$. The omission of this moisture in the latter term will not affect the accuracy of the leakage calculation since it is a very small part of the total moisture term. If it is desired to calculate this moisture term, the following procedure may be used:

1. Calculate the actual pounds of dry air leakage per pound of "as fired" fuel; $W_{G'15} - W_{G'14}$.
2. Multiply the result of (1) by the specific humidity (pounds moisture/pounds dry air) to get the pounds of moisture in leakage air per pound of "as fired" fuel.
3. Add the result of (2) to the W_{mG} term used to calculate $W_{G\,15}$ and then recalculate $A\,(L)$.

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$\Delta P_{(8-15)}$ = Inches of water = Measured static pressure difference between air inlet at the duct connection flange and gas outlet at the duct connection flange.

T_{A8} = R = Measured average Rankine temperature of air entering air heater.

T_{A8D} = R = Design Rankine temperature of air entering air heater.

It is recognized that the above orifice correction is not a rigorous treatment of the subject but is considered sufficiently accurate for the purpose of the Code.

7.14

$\Delta P_{(14-15)\delta}$ = Inches of water = Gas Side Pressure Loss of the Air Heater Corrected for Deviation from Design Flow and Temperatures

$$\Delta P_{(14-15)\delta} = \Delta P_{(14-15)} \frac{W^2_{GD}\,(T_{G14D} + T_{G15D})}{W^2_{G}\,(T_{G14} + T_{G15})}$$

Where

$\Delta P_{(14-15)}$ = Inches of water = Measured pressure loss

$W_{GD} = \dfrac{\text{lb}}{\text{lb of A.F. fuel}}$ = Design gas flow

T_{G14D} = R = Design Rankine temperature of entering gas

T_{G15D} = R = Design Rankine temperature of leaving gas

$W_{G} = \dfrac{\text{lb}}{\text{lb of A.F. fuel}}$ = Test gas flow

T_{G14} = R = Measured Rankine temperature of entering gas

T_{G15} = R = Measured Rankine temperature of leaving gas

7.15

$\Delta P_{(8-9)\delta}$ = Inches of water = Air side pressure loss of the air heater corrected for deviation from design flow and temperatures.

$$\Delta P_{(8-9)\delta} = P_{(8-9)} \frac{W^2_{AD}\,(T_{A8D} + T_{A9D})}{W^2_{A}\,(T_{A8} + T_{A9})}$$

Where

$\Delta P_{(8-9)}$ = Inches of water = Measured pressure loss

$W_{AD} = \dfrac{\text{lb}}{\text{lb of A.F. fuel}}$ = Design air flow

T_{A8D} = R = Design Rankine temperature of entering air

T_{A9D} = R = Design Rankine temperature of leaving air

$W_{A} = \dfrac{\text{lb}}{\text{lb of A.F. fuel}}$ = Test air flow

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T_{A8} = R = Measured Rankine temperature of entering air

T_{A9} = R = Measured Rankine temperature of leaving air

7.16 Accuracy of Correction to Pressure Loss for Turbulent and Laminar Flow. It is recognized that the above corrections for pressure losses in Pars. 7.14 and 7.15 are not rigorous for turbulent flow but the approach is considered sufficiently accurate for the purpose of this Code. For correction to pressure losses in laminar flow air heaters coming on the market at the time of completion of this Code, the treatment is much less accurate and it is suggested the correction be made an item of agreement until such time as field testing firms up the basis of correction.

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PERFORMANCE TEST CODES

While providing for exhaustive tests, these Codes are so drawn that selected parts may be used for tests of limited scope.

A specially designed binder for holding these pamphlets is available.

A complete list of ASME publications will be furnished upon request.

PERFORMANCE TEST CODES NOW AVAILABLE

PTC 23 – Atmospheric Water Cooling Equipment	(1958)
PTC 8.2 – Centrifugal Pumps	(1965)
PTC 4.2 – Coal Pulverizers	(1944)
PTC 1 – Code on General Instructions	(1945)
PTC 2 – Code on Definitions and Values	(1945)
PTC 10 – Compressor and Exhausters	(1965)
PTC 9 – Displacement Compressors, Vacuum Pumps and Blowers	(1954)
PTC 2.1 – Displacement Pumps	(1962)
PTC 12.3 – Deaerators	(1958)
PTC 27 – Determining Dust Concentration in a Gas Stream	(1957)
PTC 28 – Determining the Properties of Fine Particulate Matter	(1965)
PTC 3.1 – Diesel and Burner Fuels	(1958)
PTC 21 – Dust Separating Apparatus	(1941)
PTC 24 – Ejectors and Boosters	(1956)
PTC 14 – Evaporating Apparatus	(1955)
PTC 12.1 – Feedwater Heaters	(1955)
PTC 16 – Gas Producers and Continuous Gas Generators	(1958)
PTC 22 – Gas Turbine Power Plants	(1966)
PTC 18 – Hydraulic Prime Movers	(1949)
PTC 17 – Internal Combustion Engines	(1957)
PTC 20.2 – Overspeed Trip Systems for Steam Turbine –Generator Units	(1965)
PTC 7 – Reciprocating Steam-Driven Displacement Pumps	(1949)
PTC 5 – Reciprocating Steam Engines	(1949)
PTC 25.2 – Safety and Relief Valves	(1966)
PTC 3.2 – Solid Fuels	(1954)
PTC 29 – Speed-Governing Systems for Hydraulic Turbine-Generator Units	(1965)
PTC 26 – Speed-Governing Systems for Internal Combustion Engine-Generator Units	(1962)
PTC 20.1 – Speed-Governing Systems for Steam Turbine-Generator Units	(1958)
PTC 12.2 – Steam Condensing Apparatus	(1955)
PTC 4.1 – Steam-Generating Units	(1964)
PTC 6 – Steam Turbines	(1964)
PTC 6A – Appendix A to Test Code for Steam Turbines	(1964)

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