BSR/ASHRAE/AHRI Standard 155P

Public Review Draft

Method of Testing for Rating Commercial Space Heating Boiler Systems

Second Public Review (August 2019)
(Draft Shows Proposed Independent Substantive Changes to Previous Public Review Draft)

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed standard, go to the ASHRAE website at www.ashrae.org/standards-research--technology/public-review-drafts and access the online comment database. The draft is subject to modification until it is approved for publication by the Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE website) remains in effect. The current edition of any standard may be purchased from the ASHRAE Online Store at www.ashrae.org/bookstore or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

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This is a review of Independent Substantive Changes that were made since the last (First) Public Review. Text that was removed from the previous Public Review is provided for reference but is shown in ~~strikeout~~, and text that has been added is shown with underlines.

Only these changes are open to comment at this time. All other material is provided for context only and is not open for Public Review comment except as it relates to the proposed changes.

(This foreword is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

FOREWORD

This proposed standard provides a method of test for rating commercial space heating boiler systems. The ultimate objective is to provide a means to determine the seasonal efficiency of individual, modular and multiple boiler systems having various means of staging boilers to meet the building load, various boiler outlet ("supply") or boiler inlet ("return") water control strategies, and various pumping strategies, when applied to meet the load of a particular building or prototype building in a particular climate. This version of the standard provides test procedures together with calculation procedures that allow a full performance map to be created for an individual boiler from the test results. It is anticipated that the project committee will remain constituted to extend the standard to provide procedures to compute the application seasonal efficiency for diverse boiler systems as well as prototypical hourly load profiles for various types of buildings in various climate zones. Much work on these future elements of the standard has already been completed.

Development of this standard was initiated in 1993-1994 by ASHRAE Technical Committee 6.1, Hydronic and Steam Equipment and Systems. At that time, ASHRAE Standing Standard Project Committee 90.1, Energy Standard for Buildings except Low-Rise Residential Buildings was independently pushing for a more meaningful standard for rating of commercial boilers. Among the needs identified by these committees were procedures that would: result in ratings based on thermal efficiency rather than combustion efficiency for all boilers; test boilers at entering and leaving temperatures typical of space heating applications; allow performance to be determined at part load and idling conditions as well as at full load conditions; and include energy used by integral electrical equipment. No other standard available at that time or developed since has addressed these needs.

In developing this standard, the project committee gave substantial consideration to the testing burden, since many commercial boiler models are sold in small quantities. The resulting standard requires only steady state tests and idling tests; no part load tests under cyclic operation (i.e., while cycling on and off below the lowest steady state input to meet a load below the lowest steady-state output) are required. At the same time, the project committee sought to avoid the single load profile and oversizing ratio implicit in the Standard 103 test for residential boilers. To provide a flexible procedure that would allow users to determine energy use for any boiler system *configuration, any load profile, and any oversizing ratio while minimizing the testing burden required the use of numerous computational procedures. Many of the procedures developed to enable generation of a full performance map from a small number of test results are elucidated in Informative Appendix C. A particular concern was the determination of cyclic performance. Cyclic tests are expensive and require accurate measurement of output under continuously varying conditions yet are critical to seasonal efficiency. To address this, the project committee designed and oversaw the completion of tests that validated a linear input-output model for this operating regime (also described in Informative Appendix C).*

Where the standard allows a datum to be determined through tests or through computations, the guiding principle used was that the calculated datum should be conservative, that is, should result in no lower estimate of energy use than that resulting from an accurate test.

The control volume for this standard is the boiler system. The building distribution loop is external to this control volume, so for complete accounting of energy use, heat losses from the building loop must be included in the building load.

A related ASHRAE Research Project, RP-1196, has developed software that automates the application of the results of this test method to specific buildings.

3. DEFINITIONS AND NOMENCLATURE

3.1 Definitions

boiler, modular: a steam or hot water heating assembly consisting of a grouping of individual low pressure packaged boilers, commonly referred to as modules, intended to be installed as a unit. Modules may be under one jacket or may be individually jacketed. ~~The individual modules shall be limited to a maximum input of 400,000 Btu/hr (117.24 kW).~~

boiler, steam and hot water*:* a low pressure packaged boiler which can be sold as a steam or hot water boiler simply by changing the controls.

<u>***boiler loop:*** pipes and devices connected to the boiler and through which water flows during conduct of the idling tests, not including attached piping and devices through which water does not flow during the test, such as dead legs and expansion tanks.</u>

rating, high <u>inlet</u>~~return~~ water temperature: the calculation used when a boiler rated for use in applications with ~~return~~ <u>inlet</u> water temperatures above 120°F (48.9°C) at design conditions.

rating, low <u>inlet</u>~~return~~ water temperature*:* the calculation used when a boiler rated for use in applications with <u>inlet</u> ~~return~~ water temperatures of 120°F (48.9°C) or lower at design conditions.

recirculation loop: a by-pass pipe <u>system</u> ~~including a pump and check valve~~ <u>used</u> to divert water leaving the boiler back into the <u>inlet</u>~~return~~ in order to maintain the <u>required boiler water flow rate</u> and/or the boiler inlet water temperature<u>.</u> ~~above the minimum required by the manufacturer.~~

***temperature rise, boiler*:** The difference between the boiler inlet ("return") water temperature downstream of the recirculation loop, if present, and the boiler test rig outlet ("supply") water temperature.

***temperature rise, test rig*:** The difference between the test rig inlet ("return") temperature upstream of the recirculation loop, if present, and the test rig outlet water temperature. If there is no recirculation loop, the test rig temperature rise is equal to the boiler temperature rise.

3.2 Nomenclature

E_{in} electrical energy consumed by resistance heating elements during the applicable test, kWh

E_{pump} electrical energy consumed during the applicable test by the pump(s) used to in a recirculation loop in order to maintain the required flow rate through the boiler, kWh. boiler flow or inlet water temperature at or above the minimum required by the manufacturer, kWh

$E_{pump, nom}$ nominal energy consumed by the pump in a recirculation loop in order to maintain boiler flow or inlet water temperature at or above the minimum required by the manufacturer, calculated for steam and water boilers tested only in steam mode, kWh

E_{WH} electrical energy consumed by water heater during throughflow loss test, kWh

F water flow rate through boiler during steady state test, gpm (m^3/hr)

f_{xs} fraction of excess air in flue gas (dimensionless)

$G_{l,ss}$ latent heat gain due to condensation in flue, percent

h relative humidity of the air supplied for combustion, percent/100

$\dot{m}_{blr,\min}$ manufacturer's minimum mass flow rate as specified in the manufacturer's instructions shipped with the boiler, if greater than the mass flow rate corresponding to normal rating condition with 40°F (22.2 ºC) rise, lbm/h, (kg/h)

m_c mass of flue condensate per cycle, lbm.(kg)

$m_{cond,ss}$ mass of flue condensate collected during condensate collection test, lbm.(kg)

$\dot{m}_{fluegas}$ flue gas mass flow rate, lbm/h (kg/h)

m_{oil} mass of oil burned, lbm (kg)

$\dot{m}_{rating}$ mass flow rate at rating conditions for boilers not requiring a recirculation loop to meet the manufacturer's minimum flow rate or minimum entering water temperature, lbm/h (kg/h)

$$\dot{m}_{rating} = \frac{\dot{q}_{in,ss,rated}}{c_{p,water}\left(T_{out,rating} - T_{in,rating}\right)}$$

P_{ws} saturation pressure of liquid water, psia (kPa absolute)

$\dot{q}_{in,aux}$ auxiliary energyelectrical power input to electrical equipment including burners, controls, mechanical draft fans, and recirculating pumps used to keep the boiler mass flow rate or inlet water temperature above the minimum required by the manufacturer, and heavy oil heaters, kW

$\dot{q}_{in,idle,rated}$ rated idling energy input rate including auxiliary power, Btu/h (kW). Auxiliary power includes electric power supplied to the boiler, the burner, the boiler controls, the blower, and any the pump. connected to the system (e.g. recirc pump, system pump).

$\dot{q}_{out,ss}\left\langle T_{out,test}\right\rangle$ steady state output at an intermediate temperature rating point

$\dot{q}_{out,ss,higher}\langle T\rangle$ steady-state output at the higher of two tested firing rates used for interpolation, for the temperature (boiler outlet or inlet~~return~~) defined in the relevant section of the standard and adjusted for flow rate as required in the relevant section of the standard.

$\dot{q}_{out,ss,lower}\langle T\rangle$ steady-state output at the lower of two tested firing rates used for interpolation, for the temperature (boiler outlet or ~~return~~inlet) defined in the relevant section of the standard and adjusted for flow rate as required in the relevant section of the standard.

R_h relative humidity of the air supplied for combustion, percent

~~RWT Return Water Temperature~~

Ta Absolute inlet air temperature R(K)

T_{air} ~~burner~~ inlet air temperature, °F (°C)

$T_{idle, rated, low}$ rating temperature for low temperature idling test, = 120°F (48.9ºC)

T_{in} Temperature of the water entering the boiler~~test rig inlet water temperature,~~ °F (°C) (see Figure 6~~A~~)

T_{out} boiler ~~and test rig~~ outlet (“supply”)water temperature, °F (°C)

T_r absolute test room temperature, °R (°K)

~~T_{return} Temperature of water entering boiler. For boilers tested without a recirculating loop, T_{return} = T_{in}.~~

$T_{inlet~~return~~,min}$ manufacturers’ minimum entering water temperature as specified in the manufacturer’s instructions shipped with the boiler, °F (°C)

$T_{inlet~~return~~, rating}$ boiler entering water temperature at rating conditions. ~~For systems not requiring a recirculation loop, T_{in} = T_{return} =140°F (60°C) for high return water temperature rating and 80°F (26.7°C) for low return water temperature rating.~~ °F (°C)

$T_{inlet~~return~~,trans,nom}$ nominal inlet~~return~~ water temperature at which boiler transitions between non-condensing and condensing operation, °F (°C)

T_{rise} rise in water temperature from boiler~~test rig~~ inlet to boiler~~test rig~~ outlet, °F (°C)

Tstd standard temperature to measure natural gas heat value, = 60°F (16°C)

T_{thru} boiler inlet~~return~~ water temperature while undergoing throughflow.

4. REQUIREMENTS

4.1 Types of Tests

Table 1. Required (R) and Optional (O) Tests

Boiler Type		Steady State Tests								Other tests	
		Single stage burner	Two-stage burner		Step-modulating burner					All	
		High fire	High fire	Low fire	High fire	Int fire 1**	Int fire 2**	Int fire 3**	Low fire	Idling	Throughflo

Steam	Steam ~~or high RWT hot water~~	R	R	R	R	O	O	O	R	R	O
Hot Water	High boiler inlet water temperature (IWT)	R	R	R	R	O	O	O	R	R	O
	Other I~~R~~WT 1***	O	O	O	O	O	O	O	O		
	Other I~~R~~WT 2***	O	O	O	O	O	O	O	O		
	Other I~~R~~WT 3***	O	O	O	O	O	O	O	O		
	Other I~~R~~WT 4***	O	O	O	O	O	O	O	O		
	Low I~~R~~WT ~~hot water~~	R*	R*	R*	R*	O	O	O	R*	O	O

*Required for low inlet~~return~~ water temperature and condensing boilers only.
**Tests may be conducted for up to three intermediate firing rates. The same intermediate firing rates shall be used for all inlet~~return~~ water temperatures tested at intermediate firing rates.
***When steady-state tests are conducted at inlet~~return~~ water temperatures other than the required high and low temperatures, such tests shall include, at a minimum, tests at high and low fire, and may include tests at up to three intermediate firing rates.

4.1.1 Required and Optional Tests. The required tests specified in Table 1. "Required (R), and Optional (O) Tests," shall be conducted. The optional tests shown in Table 1. "Required (R) Tests" shall be conducted when the requirements specified for each optional test are met.

4.1.1.1 Steady State Tests

a. Steady state tests shall be conducted at high boiler inlet~~return~~ water temperature (I~~R~~WT), unless the manufacturer's instructions shipped with the boiler state the ~~return~~boiler inlet water temperature must not exceed 120°F (48.9 °C). Also,
b. Steady state test shall be conducted at low inlet~~return~~ water temperature hot water if ~~either or~~ both of the following conditions are present:
   - the manufacturer's instructions shipped with the boiler ~~state~~ do not advise against operation with boiler inlet water temperature of ~~that return water temperatures of~~ ~~12~~80°F (26.7~~48.9~~ °C) or lower ~~are allowed~~.
   - The manufacturer's instructions shipped with the boiler state that the boiler is a condensing boiler.
c. Each steady-state test conducted shall include a jacket loss determination and a combustion efficiency test.
d. When requested and specified by the boiler manufacturer, steady-state tests shall also be conducted at up to four alternate ~~return~~ boiler inlet water temperatures rating points.

4.1.1.2 Idling and Throughflow Tests

a. Idling tests shall be conducted at high ~~return~~ boiler inlet water temperature, unless the manufacturer's instructions shipped with the boiler state the return water temperature must not exceed 120°F (48.9 °C), in which case the idling tests shall be conducted at low <u>boiler inlet</u>~~return~~ water temperature. Also,

b. Idling tests shall be conducted at low return water temperature, if requested by the manufacturer and if either or both of the following conditions are present:
   - the manufacturer's instructions shipped with the boiler state that <u>boiler inlet</u>~~return~~ water temperatures of 120°F (48.9°C) or lower are allowed.
   - the boiler is a condensing boiler.

c. Throughflow loss tests at high <u>boiler inlet</u>~~return~~ water temperature shall be conducted on a hot water boiler, if requested by the manufacturer.

d. Throughflow loss tests at low <u>boiler inlet</u>~~return~~ water temperature shall be conducted on hot water boilers, if requested by the manufacturer and where either or both of the following conditions are present:
   - the manufacturer's instructions shipped with the boiler state that <u>boiler inlet</u>~~return~~ water temperatures of 120°F (48.9 °C) or lower are allowed.
   - the boiler is a condensing boiler.

   ***Informative Note*:** The throughflow loss test quantifies jacket and flue losses as a result of water flow through boilers or boiler modules that are not firing.

4.2 Calculated Results

4.2.3 Interpolation and Extrapolation of Test Results

4.2.3.1. Steady-state output as a function of water flow rate for a fixed firing rate and <u>boiler inlet</u>~~return~~ water temperature shall be calculated using the procedures in Section 12.1.

4.2.3.2 Steady-state output as a function of <u>boiler inlet</u>~~return~~ water temperature for a fixed firing rate and water flow rate shall be calculated using the procedures in Sections 12.2.

4.2.3.6 Part load performance when cycling between minimum steady-state input rate and idling energy input rate at a fixed flow rate and constant outlet or <u>boiler inlet</u>~~return~~ water temperature shall be calculated using the procedures in Section 12.6.

4.2.3.7 Part load performance when modulating between tested steady-state input rates at fixed outlet or <u>boiler inlet</u>~~return~~ water temperature, and with fixed water flow rate or fixed temperature rise, shall be calculated using the procedures in Section 12.7.

5. INSTRUMENTS

Instruments shall have the resolution and accuracy listed in Table 2 at the measurement condition <u>and shall be used within the range of their calibration</u>. Instruments shall be calibrated at least once per year, and a record shall be kept containing, at least, the date of calibration, the method of calibration, and the traceability to National Institute of Standards and Technology standards or equivalent national standards.

Table 2. (IP)

Property Measured	Item Measured	Minimum Resolution	Minimum Accuracy	***Informative Note:*** Example of Instrument Type	***Informative Note:*** Approximate Range of Readings
Temperature	Room Air	0.2°F	± 1°F	Thermometer, Thermocouple, RTD	60 - 100°F
	Inlet Water	1°F	± 1°F	Thermocouple or RTD	75 - 140°F
	Outlet Water	1°F	± 1°F	Thermocouple or RTD	130 - 190°F
	Surface	0.1°F	± 2°F	Thermocouple or RTD	65 - 800°F
	Flue Gas	1°F	± 2°F	Thermocouple Grid	350 - 650°F
	Fuel Gas	1°F	± 1°F	Thermometer or RTD	30 -100°F
Pressure	Atmospheric	0.05"hg	±0.05"hg	Barometer	28 - 31"hg
	Steam	Greater of 0.1 in H_2O or 10% of observed value	Greater of ±0.1 in H_2O or ±10% of observed value	Manometer, Bourdon Tube Gage	0 - 5 psi
	Fuel Oil	5 psi	± 5 psi	Bourdon Tube Gage	80 - 250 psi
	Fuel Gas	≤14 in H_2O: 0.1 in H_2O >14 in H_2O: 0.01 psi	≤14 in H_2O: ±0.1 in H_2O >14 in H_2O: ±0.05 psi	Manometer	0-14 in H_2O 0.5 - 15 psi
	Firebox	Greater of 0.02 in H_2O or 10% of observed value	Greater of ±0.02 in H_2O or ±10% of observed value	Draft Gage	As needed
	Vent	0.01" water	±0.01" water	Draft Gage	0 - 0.5" water
	Flue/Vent Connector	0.01" water	±0.01" water	Draft Gage	0 - 0.5" water
Mass or Volume	Oil	0.25% of hourly rate	± 0.25% of hourly rate	Scale, Burette or Flow Meter	Size for Rated Flow

	Gas	Greater of 1 ft^3 or 0.25% of hourly rate	± 1% of hourly rate	Volume Meter	Size for Rated Flow
	Flue Condensate	Greater of 0.5 lb. or 0.5% of measured weight	Greater of ±0.5 lb. or ±0.5% of measured weight	Scale	As Needed
	Steady State Water Flow	0.5% of hourly rate	± 5% of hourly rate	Flow Meter	As Needed
	Idling and Throughflow Test Water Flow	0.5% of hourly rate	± 5% of steady state flow rate	Flow Meter	As Needed
Time	Test Period	1 second/hr.	±1 second/hr.	Stopwatch	0 - 3 hr.
Gas Chemistry	Carbon Dioxide	0.1% CO_2	± 0.1% CO_2	CO_2 Analyzer	0 to 15% CO_2
	Carbon Monoxide	1 ppm	Greater of ±10 ppm or ±5% of reading	CO Analyzer	0 to 500 ppm CO
	Oxygen	0.1% O_2	±0.1% O_2	O_2 Analyzer	0-20% O_2
Gas Optics (for oil)	Smoke	1 Smoke Spot	±½ Smoke Spot	Smoke Spot[1]	0 – 7
Heating Value	Natural Gas	2 Btu/ft^3	± 1% of reading	Calorimeter or Gas Chromatograph	970-1100 Btu/ft^3
	Fuel Oil	1 Btu/lb.	± 1% of reading	See Section 7.3.1.1	18500-20500 Btu/lb.
Humidity	Relative Humidity	5.0%	± 5% of full scale	Psychrometer	10-90 %
Electrical power	Watts	1 Watt	± 1% of reading		
Electrical energy	kWh	Greater of 0.01 kWh or 0.5% of the reading	± 1% of reading		
Room Air Velocity	ft/min	1 ft/min	±5 ft/min at 50 ft/min	Vane Anemometer	10-50 ft/min

Note 1- Smoke measurement shall be consistent with ASTM Standard D2156-09(2013).

~~Table 2. (IP)~~

~~Property Measured~~	~~Item Measured~~	~~Minimum Resolution~~	~~Minimum Accuracy~~	~~*Informative Note:* Example of Instrument Type~~	~~*Informative Note:* Approximate Range of Readings~~
~~Temperature~~	~~Room Air~~	~~0.2°F~~	~~± 1°F~~	~~Thermometer, Thermocouple, RTD~~	~~60 - 100°F~~
	~~Inlet Water~~	~~1 °F~~	~~± 1°F~~	~~Thermocouple or RTD~~	~~75 - 140°F~~
	~~Outlet Water~~	~~1 °F~~	~~± 1°F~~	~~Thermocouple or RTD~~	~~130 - 190°F~~
	~~Surface~~	~~0.1°F~~	~~± 2°F~~	~~Thermocouple or RTD~~	~~65 - 800°F~~
	~~Flue Gas~~	~~1°F~~	~~± 2°F~~	~~Thermocouple Grid~~	~~350 - 650°F~~
	~~Fuel Gas~~	~~1 °F~~	~~± 1 °F~~	~~Thermometer or RTD~~	~~30 -100°F~~
~~Pressure~~	~~Atmospheric~~	~~0.05"hg~~	~~±0.05"hg~~	~~Barometer~~	~~28 - 31"hg~~
	~~Steam~~	~~Greater of 0.1 in H_2O or 10% of observed value~~	~~Greater of ±0.1 in H_2O or ±10% of observed value~~	~~Manometer, Bourdon Tube Gage~~	~~0 – 5 psi~~
	~~Fuel Oil~~	~~5 psi~~	~~± 5 psi~~	~~Bourdon Tube Gage~~	~~80 - 250 psi~~
	~~Fuel Gas~~	~~≤14 in H_2O: 0.1 in H_2O >14 in H_2O: 0.01 psi~~	~~≤14 in H_2O: ±0.1 in H_2O >14 in H_2O: ±0.05 psi~~	~~Manometer~~	~~0-14 in H_2O 0.5 – 15 psi~~
	~~Firebox~~	~~Greater of 0.02 in H_2O or 10% of observed value~~	~~Greater of ±0.02 in H_2O or ±10% of observed value~~	~~Draft Gage~~	~~As needed~~
	~~Vent~~	~~0.01" water~~	~~±0.01" water~~	~~Draft Gage~~	~~0 – 0.5" water~~
	~~Flue/Vent Connector~~	~~0.01" water~~	~~±0.01" water~~	~~Draft Gage~~	~~0 – 0.5" water~~
~~Mass or Volume~~	~~Oil~~	~~0.25% of hourly rate~~	~~± 0.25% of hourly rate~~	~~Scale, Burette or Flow Meter~~	~~Size for Rated Flow~~

	~~Gas~~	~~Greater of 1 ft^3 or 0.25% of hourly rate~~	~~± 1% of hourly rate~~	~~Volume Meter~~	~~Size for Rated Flow~~
	~~Flue Condensate~~	~~Greater of 0.5 lb or 0.5% of measured weight~~	~~Greater of ±0.5 lb or ±0.5% of measured weight~~	~~Scale~~	~~As Needed~~
	~~Steady State Water Flow~~	~~0.5% of hourly rate~~	~~± 5% of hourly rate~~	~~Water Meter~~	~~As Needed~~
	~~Idling and Throughflow Test Water Flow~~		~~± 5% of steady state flow rate~~	~~Flow Meter~~	~~As Needed~~
~~Time~~	~~Test Period~~	~~1 second/hr~~	~~±1 second/hr~~	~~Stopwatch~~	~~0 - 3 hr.~~
~~Gas Chemistry~~	~~Carbon Dioxide~~	~~0.1% CO_2~~	~~± 0.1% CO_2~~	~~CO_2 Analyzer~~	~~0 to 15% CO_2~~
	~~Carbon Monoxide~~	~~1 ppm~~	~~Greater of ±10 ppm or ±5% of reading~~	~~CO Analyzer~~	~~0 to 500 ppm CO~~
	~~Oxygen~~	~~0.1% O_2~~	~~±0.1% O_2~~	~~O_2 Analyzer~~	~~0-20% O_2~~
~~Gas Optics (for oil)~~	~~Smoke~~	~~1 Smoke Spot~~	~~±½ Smoke Spot~~	~~Smoke Spot[1]~~	~~0 – 7~~
~~Heating Value~~	~~Natural Gas~~	~~2 Btu/ft^3~~	~~± 1% of reading~~	~~Calorimeter or Gas Chromatograph~~	~~970-1100 Btu/ft^3~~
	~~Fuel Oil~~		~~± 1% of reading~~	~~See Section 7.3.1.1~~	~~18500-20500 Btu/lb~~
~~Humidity~~	~~Relative Humidity~~	~~5.0%~~	~~± 5% of full scale~~	~~Psychrometer~~	~~10-90 %~~
~~Electrical power~~	~~Watts~~		~~± 1% of reading~~		
~~Electrical energy~~	~~kWh~~		~~± 1% of reading~~		
~~Room air velocity~~	~~ft/min~~	~~1 ft/min~~	~~±5 ft/min at 50 ft/min~~	~~Vane Anemometer~~	~~10-50 ft/min~~

~~Note 1- Smoke measurement shall be consistent with ASTM Standard D2156-09(2013).~~

Table 2. (SI)

Property Measured	Item Measured	Minimum Resolution	Minimum Accuracy	***Informative Note:*** Example of Instrument Type	***Informative Note:*** Approximate Range of Readings
Temperature	Room Air	0.1°C	± 0.5°C	Thermometer, Thermocouple, RTD	16 - 38°C
	Inlet Water	0.5°C	± 0.5°C	Thermocouple or RTD	24 - 60°C
	Outlet Water	0.5°C	± 0.5°C	Thermocouple or RTD	54 - 88°C
	Surface	0.05°C	± 1°C	Thermocouple or RTD	18 - 425°C
	Flue Gas	0.5°C	± 1°C	Thermocouple Grid	175 - 340°C
	Fuel Gas	0.5°C	± 0.5°C	Thermometer or RTD	0 -38°C
Pressure	Atmospheric	170 Pa	±170 Pa	Barometer	95 – 105 kPa
	Steam	Greater of 25 Pa or 10% of observed value	Greater of ±25 Pa or ±10% of observed value	Manometer, Bourdon Tube Gage	0 - 34 kPa
	Fuel Oil	34 kPa	± 34 kPa	Bourdon Tube Gage	550 - 1700 kPa
	Fuel Gas	≤3.5 kPa: 25 Pa >3.5 kPa: 69 Pa	≤3.5 kPa: ±25 Pa >3.5 kPa: ±69 Pa	Manometer	0-3.5 kPA 3.5 - 103 kPA
	Firebox	Greater of 5 Pa or 10% of observed value	Greater of ±5 Pa or ±10% of observed value	Draft Gage	As needed
	Vent	2.5 Pa	±2.5 Pa	Draft Gage	0 – 125 Pa
	Flue/Vent Connector	2.5 Pa	±2.5 Pa	Draft Gage	0 – 125 Pa
Mass or Volume	Oil	0.25% of hourly rate	± 0.25% of hourly rate	Scale, Burette or Flow Meter	Size for Rated Flow
	Gas	Greater of .028 m^3 or 0.25% of hourly rate	± 1% of hourly rate	Volume Meter	Size for Rated Flow

	Flue Condensate	Greater of 0.23 kg or 0.5% of measured weight	Greater of ±0.23 kg or ±0.5% of measured weight	Scale	As Needed
	Steady State Water Flow	0.5% of hourly rate	0.5% of hourly rate	Flow Meter	As Needed
	Idling and Throughflow Test Water Flow	0.5% of hourly rate	± 5% of steady state flow rate	Flow Meter	As Needed
Time	Test Period	1 second/hr	±1 second/hr	Stopwatch	0 - 3 hr.
Gas Chemistry	Carbon Dioxide	0.1% CO_2	± 0.1% CO_2	CO_2 Analyzer	0 to 15% CO_2
	Carbon Monoxide	1 ppm	Greater of ±10 ppm or ±5% of reading	CO Analyzer	0 to 500 ppm CO
	Oxygen	0.1% O_2	±0.1% O_2	O_2 Analyzer	0-20% O_2
Gas Optics (for oil)	Smoke	1 Smoke Spot	±½ Smoke Spot	Smoke Spot[1]	0 - 7
Heating Value	Natural Gas	74.5 kJ/m^3	± 1% of reading	Calorimeter or Gas Chromatograph	36.1 –41.0 MJ/m^3
	Fuel Oil	3 kJ/kg	± 1% of reading	See Section 7.3.1.1	43000-47700 kJ/kg
Humidity	Relative Humidity	5.0%	± 5% of full scale	Psychrometer	10-90 %
Electrical power	Watts	1 Watt	± 1% of reading		
Electrical energy	kWh	Greater of 0.01 kWh or 0.5% of the reading	± 1% of reading		
Room Air Velocity	m/s	0.005 m/s	0.025 m/s at 0.25 m/s	Vane Anemometer	0.5-0.25 ft/min

Note 1- Smoke measurement shall be consistent with ASTM Standard D2156-09(2013).

~~Table 2. (SI)~~

~~Property Measured~~	~~Item Measured~~	~~Minimum Resolution~~	~~Minimum Accuracy~~	~~***Informative Note:*** Example of Instrument Type~~	~~***Informative Note:*** Approximate Range of Readings~~
~~Temperature~~	~~Room Air~~	~~0.1°C~~	~~± 0.5°C~~	~~Thermometer, Thermocouple, RTD~~	~~16 - 38°C~~
	~~Inlet Water~~	~~0.5°C~~	~~± 0.5°C~~	~~Thermocouple or RTD~~	~~24 - 60°C~~
	~~Outlet Water~~	~~0.5°C~~	~~± 0.5°C~~	~~Thermocouple or RTD~~	~~54 - 88°C~~
	~~Surface~~	~~0.05°C~~	~~± 1°C~~	~~Thermocouple or RTD~~	~~18 - 425°C~~
	~~Flue Gas~~	~~0.5°C~~	~~± 1°C~~	~~Thermocouple Grid~~	~~175 - 340°C~~
	~~Flue Gas~~	~~0.05°C~~	~~± 0.5°C~~	~~Thermometer or RTD~~	~~0 -38°C~~
~~Pressure~~	~~Atmospheric~~	~~170 Pa~~	~~±170 Pa~~	~~Barometer~~	~~95 – 105 kPa~~
	~~Steam~~	~~Greater of 25 Pa or 10% of observed value~~	~~Greater of ±25 Pa or ±10% of observed value~~	~~Manometer, Bourdon Tube Gage~~	~~0 – 34 kPa~~
	~~Fuel Oil~~	~~34 kPa~~	~~± 34 kPa~~	~~Bourdon Tube Gage~~	~~550 - 1700 kPa~~
	~~Fuel Gas~~	~~≤3.5 kPa: 25 Pa >3.5 kPA: 69 PA~~	~~≤3.5 kPa: ±25 Pa >3.5 kPa: ±69 Pa~~	~~Manometer~~	~~0-3.5 kPA 3.5 – 103 kPA~~
	~~Firebox~~	~~Greater of 5 Pa or 10% of observed value~~	~~Greater of ±5 Pa or ±10% of observed value~~	~~Draft Gage~~	~~As needed~~
	~~Vent~~	~~2.5 Pa~~	~~±2.5 Pa~~	~~Draft Gage~~	~~0 – 125 Pa~~
	~~Flue/Vent Connector~~	~~2.5 Pa~~	~~±2.5 Pa~~	~~Draft Gage~~	~~0 – 125 Pa~~
~~Mass or Volume~~	~~Oil~~	~~0.25% of hourly rate~~	~~± 0.25% of hourly rate~~	~~Scale, Burette or Flow Meter~~	~~Size for Rated Flow~~
	~~Gas~~	~~Greater of .028 m^3 or 0.25% of hourly rate~~	~~± 1% of hourly rate~~	~~Volume Meter~~	~~Size for Rated Flow~~
	~~Steady state water flow~~	~~0.5% of hourly rate~~	~~± 5% of hourly rate~~	~~Water Meter~~	~~As Needed~~

	~~Flue Condensate~~	~~Greater of 0.23 kg or 0.5% of measured weight~~	~~Greater of ±0.23 kg or ±0.5% of measured weight~~	~~Scale~~	~~As Needed~~
	~~Idling and Through-Flow Test Water Flow~~		~~± 5% of steady state flow rate~~	~~Flow Meter~~	~~As Needed~~
~~Time~~	~~Test Period~~	~~1 second/hr~~	~~±1 second/hr~~	~~Stopwatch~~	~~0 – 3 hr.~~
~~Gas Chemistry~~	~~Carbon Dioxide~~	~~0.1% CO_2~~	~~± 0.1% CO_2~~	~~CO_2 Analyzer~~	~~0 to 15% CO_2~~
	~~Carbon Monoxide~~	~~1 ppm~~	~~Greater of ±10 ppm or ±5% of reading~~	~~CO Analyzer~~	~~0 to 500 ppm CO~~
	~~Oxygen~~	~~0.1% O_2~~	~~±0.1% O_2~~	~~O_2 Analyzer~~	~~0-20% O_2~~
~~Gas Optics (for oil)~~	~~Smoke~~	~~1 Smoke Spot~~	~~±½ Smoke Spot~~	~~Smoke Spot[1]~~	~~0 – 7~~
~~Heating Value~~	~~Natural Gas~~	~~74.5 kJ/m^3~~	~~± 1% of reading~~	~~Calorimeter or Gas Chromatograph~~	~~36.1 – 41.0 MJ/m^3~~
	~~Fuel Oil~~		~~± 1% of reading~~	~~See Section 7.3.1.1~~	~~43000-47700 kJ/kg~~
~~Humidity~~	~~Relative Humidity~~	~~5.0%~~	~~± 5% of full scale~~	~~Psychrometer~~	~~10-90 %~~
~~Electrical power~~	~~Watts~~		~~± 1% of reading~~		
~~Electrical energy~~	~~kWh~~		~~± 1% of reading~~		
~~Room air velocity~~	~~m/s~~	~~0.005 m/s~~	~~0.025 m/s at 0.25 m/s~~	~~Vane anemometer~~	~~0.5-0.25 ft/min~~

~~Note 1- Smoke measurement shall be consistent with ASTM Standard D2156-09(2013).~~

6.2 Vent Connection

6.2.3.1 Horizontal Discharge. When the vent gases discharge horizontally, attach a length of straight vent pipe that is the greater of two times the nominal vent diameter or the additional length necessary for this horizontal vent length to comply with the minimum vent length specified in the manufacturer's instructions shipped with the boiler. All venting, prior to the final vertical section and its connecting tee or elbow, shall be the smallest diameter allowed by the manufacturer's instructions shipped with the boiler, except it shall be no smaller than the flue collar on the boiler. Attach an elbow or tee to the horizontal vent pipe. Adding pipe between the flue collar and the elbow or tee is allowed, if it is necessary for the test vent to clear obstructing boiler parts. To the elbow or tee, attach a vertical length of vent that is the greater of five times the vent pipe diameter or 5 feet (1.5 m), as shown in Figures 4A and 4C. If needed, apply a concentric orifice at the flue connection to obtain the minimum vent pressure specified in the manufacturer's installation instructions. The vent must freely discharge to atmosphere. Connect no additional vent piping.

The plane of the thermocouple grid shall be three pipe diameters from the vent termination, and the flue gas sampling point shall be two diameters from the vent termination as shown in Figures 4A and 4C.

For condensing boilers, a ~~pipe and~~condensate trap shall be applied to the tee attached below the final vertical section of vent pipe. Flue gas condensate from this ~~pipe and~~ trap shall be combined with condensate from the boiler in one or more smooth, non-porous collection containers. The collection containers shall have a vent opening to the atmosphere.

When needed to collect liquid condensate entrained in the flue gas, the final vertical section and its connecting tee or elbow pipe diameter shall be increased to the largest industry diameter that does not cause the vent velocity to fall below 400 ft/min (2.54 m/s) when operating at maximum input. For a specific fuel, firing rate, excess air level, flue gas temperature, flue pipe diameter, and barometric pressure, the flue gas velocity can be calculated using methods provided in the ASHRAE Handbook [Chimney, Vent, and Fireplace Systems Chapter, HVAC Systems and Equipment Handbook]. Measurement of flue gas velocity for the purpose of selecting flue diameter is not required. This same flue diameter can be used during testing at lower input rates.

All vent pipe connections shall be carefully sealed before the insulation is applied. For boilers without combustion air preheat, a minimum of R-7 foil-faced insulation, suitable for the temperature, shall be applied from the boiler to the vent termination, as shown in Figure 4A. For boilers with combustion air preheat, a minimum of R-7 foil-faced insulation, suitable for the temperature, shall be applied to all venting between the combustion air entrance for preheat and the vent termination, as shown in Figure 4C. Do not insulate the combustion air preheat venting.

If dilution air is introduced into the flue gases before the plane of the thermocouple and flue gas sampling points in the vent, utilize an alternate plane of thermocouple grid and flue gas sampling point located downstream from the heat exchanger and upstream from the point of dilution air. Attach a length of vent that is the greater of five times the vent pipe diameter or 5 feet (1.5 m) or the minimum vent length specified in the manufacturer's instructions shipped with the boiler, as shown in Figure 3. The vent shall be the smallest diameter allowed by the manufacturer's instructions shipped with the boiler, except it shall be no smaller than the flue collar on the boiler. Vent insulation is not required, if the plane of the thermocouple grid and flue gas sampling are located at a point before the flue gases enter the vent.

6.3 Steam Piping

A typical set-up is shown diagrammatically in Figure 5. Connect to the boiler risers and other near-boiler piping as specified in the manufacturer's instructions shipped with the boiler. ~~If risers and headers are required but not specified in the manufacturer's instructions shipped with the boiler, and the internal cross sectional area of the header shall be the sum of the internal cross section area~~

of the risers, rounded up to the next nominal pipe size. If risers and headers are required but are not specified in the manufacturer's instructions shipped with the boiler, the risers shall be the same size as the steam outlet connections and the internal cross section of the headers shall be the sum of the internal cross section area of the risers, rounded up to the next nominal pipe size.

6.4 Water Piping

6.4.1 Steady State Test. The water outlet shall be connected to the boiler outlet (supply) connection of the boiler.Piping and attached devices between the boilr and at least ten pipe diameters upstream of Tin and between the boiler and at least ten pipe diameters downstream of Tout shall be insulated to a minimum of R7. shall be thoroughly insulated between the temperature sensors and the boiler, since no allowance is made for heat losses in the piping. The water inlet shall be connected to the boiler inlet (return) connection of the boiler. Provision shall be made for heat rejection and control of the inlet water temperature. A recirculation loop, shown diagrammatically in Figure 6A, may be used to obtain the required temperature rise, or boiler water flow rate, specified by 7.7.1**.** The required piping arrangement is shown diagrammatically in Figure 6A. If a recirculation loop is used, the recirculation loop pump used shall have a close-coupled design such that the impeller is on the same shaft as the electric motor that drives the pump and the motor has a face on one end which matches the face on the pump casing that is mounted against the motor case and all recirculation loop devises and piping to and from the boiler shall be insulated to a minimum of R7.

6.4.2 Idling Test. The pumped by-passboiler loop piping and devices between the boiler inlet and outlet shall be installed insultated to a minimum of R7. between the boiler inlet and outlet. A flow meter shall be installed in the bypass boiler loop piping to confirm the requirements of Section 7.9.2.1. See Figure 6B for a typical idling test configuration. The boiler loop pump used shall have a close-coupled design such that the impeller is on the same shaft as the electric motor that drives the pump and the motor has a face on one end which matches the face on the pump casing that is mounted against the motor case. Water in the by-pass piping shall not exceed 10 gallons (37.9 L), plus 1 gallon (3.8 L) per 100,000 Btu/hr (29.3 kW) of full fire input capacity over 1,000,000 Btu/hr (293.1 kW). The volume of pipes, valves, fittings, flowmeters and pumps shall be calculated based on their nominal pipe size internal diameter and measured length. If the boiler loop includes a storage tank, the storage tank volume shall be based on the nameplate capacity or, in the absence of nameplate capacity, shall be based on the tare tank water weight, the measured volume of water required to fill the tank, or tank dimensions.

Exception: If the idling test cannot be conducted because the manufacturer's maximum water temperature limit control setting as specified in the manufacturer's instructions shipped with the boiler is exceeded, the amount of water in the boiler loop shall be increased to the volume that will allow as necessary to enable the test to be conducted.

6.4.3 Throughflow Loss Test. The idling test boiler loop described in Section 6.4.2 or Section 6.4.4 shall be used and provided with a means to offset the throughflow loss of the boiler by adding heat to maintain the required inlet water temperature. All piping and components between the means to maintain the required inlet water temperature and the boiler loop shall be insulated to a minimum of R7. The energy consumed to maintain the required inlet water temperature shall be measurable in kWh. Informative note: A well-insulated, small electric water heater with no storage volume or an electric immersion element with continuously variable output located ~~inserted~~ in the boiler ~~recirculation~~ loop is recommended.

6.4.4 Optional Combined Set-up for Steady State, Idling, and Throughflow Tests. In lieu of the piping shown in Figures 6A and 6B, the set-up shown in Figure 6C may be used for Steady State, Idling, and Throughflow Tests. During the Steady State Test, control of the boiler outlet water temperature is accomplished by adjusting the rate of heat dissipation from the heat rejection device. During conduct of the Idling Test, the heat rejection system shall be isolated from the boiler loop by closing the isolation valves shown in Figure 6C. The boiler loop and boiler loop pump shall meet the requirements specified in Section 6.4.2. and Section 6.4.3. With this combined set-up, a flow meter shall be installed in the boiler loop if required by Section 7.7.1.2.

6.5.5 Boiler Jackets

6.5.5.1 With the boiler operating under steady state conditions described in 7.6, use a source of smoke to identify all jacket openings into which ambient air is clearly drawn. Other jacket openings having an area greater than $0.5 in^2$ ($3.2 cm^2$), which are not known to be needed for combustion air, ventilation, or draft control may be sealed with tape. For atmospheric boilers, record a flue CO_2 reading before and after sealing these openings. If the difference between these two readings is greater than 0.3%, identify and remove the tape which is causing this difference.

6.5.5.2 Install a thermocouple in the center of each opening having a cross sectional area greater than $0.5 in^2$ which was not sealed and which did not have air flowing into it during conduct of the smoke test. If smoke test was inconclusive, install a thermocouple in the opening. When an opening is greater than 9 square inches ($58 cm^2$), subdivide it into equal size, smaller areas in accordance with 6.5.5. Place one thermocouple at the center of each area. Louver fields shall be divided into smaller equal sized areas in accordance with 6.5.5 based on the area encompassed by the outermost louvers (Figure 8). A thermocouple shall then be placed in the louver closest to the center of each area. Thermocouple(s) shall not be located outside of the outer jacket surface nor more than 1/8" (3.2 mm) inside the opening (Figure 9). Record the area of each opening (A_{OX}) and the vertical distance from the bottom of the boiler to the center of the opening (H_{OX}). For non-circular openings, also record the perimeter of the opening (P_{OX}).

6.5.5.3 Boilers drawing flue gas dilution air from within jacket. For boilers having draft diverters, or other openings, which draw dilution air from within the jacket, install thermocouples to measure the temperature of this dilution air ~~on a plane perpendicular~~ on the plane of the opening ±1/8" (3.18 mm). ~~to its flow as close as practical to where this air starts to mix with the flue gas from each of these openings.~~When an opening is greater than $9 in^2$ ($58 cm^2$), subdivide it into equal size areas as shown in the Table below. Place one thermocouple at the center of each area. ~~Temperature sensors shall not be located outside of the outer jacket surface nor more than 1/8" (3.2 mm) inside the opening~~. Record the cross-sectional area of the dilution opening at this plane(s) (AD) and the height from the bottom of the boiler to the center of this opening(s) (HD).

6.5.6 Energy Consumed

6.5.6.3 Electricity. A ~~wattmeter or~~ watt-hour meter shall be connected as necessary to record the input to all electrical equipment. For an electric boiler, a separate wattmeter shall measure the input to the steam or water. A ~~wattmeter or~~ watt-hour meter shall be used to record the input to the electric water heater in the throughflow loss test. One or more ~~A single watt meter or~~ watt-hour meters shall be used to measure electrical energy ~~power~~ consumption of all components which draw electric power ~~simultaneously~~.

6.5.8 Additional Instruments, Steam

6.5.8.4 Water Temperature Control. For the idling test, a water temperature controller shall be located in the standard connection below the water line recommended by the manufacturer in the manufacturer's instructions shipped with the boiler. The controller differential shall have an accuracy of ± 1.0°F (0.5°C) and the setpoint shall have a repeatability of ± 0.5°F (0.25°C).

6.5.9 Additional Instruments, Water

6.5.9.1 Water Temperatures. The inlet water temperature (Tin) shall be measured with a single sensor located as shown in Figure 6A and the greater of ~~approximately~~ 12 inches (30.5 cm) or 4 pipe diameters ±1 pipe diameter upstream of the boiler inlet~~.~~ and downstream of all heat rejection devices, pumps, and mixing locations, such as recirculation loop connections. When a recirculation loop is used, water exiting the recirculation loop must flow through the branch of 4 tee's as shown in Figure 6A. Water exiting the boiler outlet must flow through a branch of 4 tees as shown in Figure 6A and the outlet water temperature (Tout) shall be measured with a single sensor located as shown in Figure 6A.

~~To insure well mixed flow at the inlet temperature sensor, the sensor shall be downstream of the system pump, which shall be downstream of any heat rejection devices or mixing valves, i.e., no heat rejection or mixing devices are allowed between the pump and the boiler. The outlet water temperature (Tout) shall be measured with a single sensor located upstream of any heat rejection devices or mixing valves. To insure uniform temperature at Tout, water from the boiler must go through the branch of 4 tee's. before reaching Tout. A sidestream mixing pump may be inserted in order to achieve the required tee velocity. Energy delivered to the water by the mixing pump shall be included in the auxiliary energy input rate. All plumbing heated from at least 10 diameters upstream of Tin to at least 10 diameters downstream of Tout shall be insulated. (see Figure 6A).~~

~~**Water Flow Rate Measurement**. Water flow rate measurements shall meet the requirements of Section 5. In the high fire test the water flow rate can be measured directly or calculated by heat balance using the calculation procedure in Section 10.8.~~

6.5.9.2 Water Temperature Control. For the idling test, a water temperature control shall be located in the standard connection recommended ~~by the manufacturer~~ in the manufacturer's instructions shipped with the boiler.

7. TEST CONDITIONS

7.1 General

7.1.1 The boiler shall be installed as described in Section 6, and the instrumentation shall be as described in Section 5. Refer to Figures 1 through 11 when equipping the boiler with the apparatus and instrumentation. The equipment shall be adjusted to the test requirements or conditions described in this section.

7.1.2 For modulating boilers, all requirements in this section shall be met at both high fire and low fire as follows:

a. Where the manufacturer's instructions shipped with the boiler specify no burner adjustments at low fire, first obtain the high fire conditions as described in this section. Then adjust the firing rate to the required low or intermediate firing rate using the control input that would normally modulate the boiler.
b. Where the manufacturer's instructions shipped with the boiler specify burner adjustments at both high and low fire, first obtain the required high fire and low fire conditions as described in this section. Then, if tests at intermediate firing rates are being performed, adjust the firing rate to the required intermediate firing rate using the control input that would normally modulate the boiler.
c. If burner adjustments are required between tests to compensate for changing conditions (such as barometric pressure or higher heating value), the laboratory shall confirm that the requirements in (a) and (b) above are met at both high and low fire before proceeding with the next test.

7.6 Steady State Test Conditions – Steam and Water

7.6.3 Air Temperatures. The room air temperature and inlet air temperature shall be between 65°F (18.3°C) and 100°F (37.8°C) at all times during the test and during burner adjustments, except that, for low ~~return~~ boiler inlet water temperature tests, the temperatures shall not exceed 85°F (29.4 °C). The room air temperature and inlet air temperature shall not differ from each other by more than 5°F (2.8ºC) at any time during ~~the~~any given test.

7.7 Additional Test Requirements for Water, Steady State

7.7.1.1 Water Temperatures. The ~~test rig~~boiler temperature rise (T_{out}-T_{in}) and the outlet temperature shall be within the temperature tolerances in Table 3 at all times during each test. Exception: If the boiler manufacturer's instructions shipped with the boiler prohibit operation at the boiler water flow rate and/or inferred inlet temperature shown in Table 3, increase the boiler water flow rate to a point just sufficient to meet the manufacturer's requirements, while maintaining the outlet temperature at the value shown in Table 3 (boiler rise will be less than that shown in Table 3). This can be accomplished by means of a recirculation loop as shown in Figure 6A, or by otherwise increasing the water flow rate through the boiler.

Table 3. Outlet Water Temperature and ~~Test Rig~~Boiler Temperature Rise (IP Version)

Test	**Outlet Temp**	**Outlet Temp Tolerance**	**~~Test Rig~~Boiler Rise (Tout-Tin) (NOTE 1)**	**~~Test Rig~~Boiler Rise Tolerance**
High Fire / High Temp	180ºF	± 2.5°F	40ºF	± 24°F
High Fire / Low Temp	120ºF	±2. 5°F	40ºF	± 24°F
High Fire / Optional Temp	Between 120ºF and 180ºF	± 2.5°F	40ºF	± 24°F
Low and Intermediate Fire / High Temp	180ºF	± 2.5°F	40ºF	± 24°F
Low and Intermediate Fire / Low Temp	120ºF	± 2.5°F	40ºF	± 24°F
Low and Intermediate Fire / Optional Temp	Between 120ºF and 180ºF	± 2.5°F	40ºF	

NOTE 1: ~~Test rig~~Boiler rise may be lower in order to meet manufacturers recommended minimum flow rate b~~B~~ased on manufacturer's instructions shipped with the boiler.

Table 3. Outlet Water Temperature and ~~Test Rig~~Boiler Temperature Rise (SI Version)

Test	**Outlet Temp**	**Outlet Temp Tolerance**	**~~Test Rig~~Boiler Rise (Tout-Tin) (NOTE 1)**	**~~Test Rig~~Boiler Rise Tolerance**
High Fire / High Temp	82.2ºC	± 1.4~~2.8~~°C	22.2ºC	± 1.1~~2.2~~°C
High Fire / Low Temp	48.9ºC	±1.4°C	22.2ºC	± 1.1~~2.2~~°C
High Fire / Optional Temp	Between 48.9ºC and 82.2ºC	± 1.4°C	22.2ºC	± 1.1~~2.2~~°C
Low and Intermediate Fire / High Temp	82.2ºC	± 1.4~~2.8~~°C	22.2ºC	± 1.1~~2.2~~°C
Low and Intermediate Fire / Low Temp	48.9ºC	± 1.4~~2.8~~°C	22.2ºC	± 1.1~~2.2~~°C
Low and Intermediate Fire / Optional Temp	Between 48.9ºC and 82.2ºC	± 1.4~~2.8~~°C	22.2ºC	

NOTE 1: Test rig rise may be lower in order to meet manufacturers recommended minimum flow rate. Based on manufacturer's instructions shipped with the boiler.

7.7.1.2 Verification of Manufacturer's minimum recommended flow rate. ~~**Recirculating Loop.**~~ If the boiler manufacturer's instructions shipped with the boiler specify a minimum flow rate through the boiler, the flow meter shown in Figure 6 shall be used to verify that this flow rate is met or exceeded during the conduct of all tests. ~~does not recommend operating at the required~~

~~test rig inlet water temperature or at the flow rate required to produce a boiler temperature rise equal to the required test rig temperature rise for the given firing rate, then a recirculating loop shall be installed as shown in Figure 6A and shall maintain the return water temperature at or above the manufacturer's minimum return water temperature and the flow rate through the boiler at or above the manufacturer's minimum flow rate at all times. The outlet water temperature downstream of the recirculating loop connector and the test rig temperature rise from the feedwater inlet, upstream of the recirculating loop connector, to the outlet shall meet the requirements of Table 3. Recirculation loop flow rate (boiler flow rate) shall be calculated from test rig flow rate (test rig flow times test rig ΔT divided by boiler ΔT) and shall be maintained above the manufacturer's recommended minimum flow rate during testing. Alternatively, instead of a recirculation loop, the flow through the boiler is measured directly and maintained above the recommended minimum flow rate.~~

7.9.2 Water

7.9.2.1 Water Flow Rate. The water flow rate during the entire test period shall be the high fire flow rate as calculated in 10.8 ± 15%. When the piping shown in Figures 6A and 6B is used, this shall be confirmed using a flow meter. When the piping setup shown in Figure 6C is used, this requirement shall be deemed met if no adjustments to boiler loop valves or boiler loop pump speed are made between the Steady State and Idling Tests.

7.9.4 Air Temperatures. The room air temperature and inlet air temperature shall be between 65°F (18.3°C) and 100°F (37.8°C) at all times during the idling test, except that, for low return water temperature idling tests, the temperatures shall not exceed 85°F (29.4°C). The room air temperature and inlet air temperature shall not differ from each other by more than 5°F (2.8°C) at any time during any given test.

7.10 Throughflow Loss Test Conditions, Water

7.10.1 Water Flow Rate. The water flow rate shall be the full fire steady state test flow rate ±15%. When the piping shown in Figures 6A and 6B is used, this shall be confirmed using a flow meter. When the piping setup shown in Figure 6C is used, this requirement shall be deemed met if no adjustments to boiler loop valves or boiler loop pump speed are made between the Steady State and Throughflow Tests.

8. TEST PROCEDURES

8.1. Steady State Tests for Determining Efficiency and Output

8.1.3 If the manufacturer's instructions shipped with the boiler specifies that a boiler model can be used either as a steam boiler or as a water boiler, it shall be tested as a steam boiler, and the procedures in Section 11 shall be used to calculate performance in a hot water mode. The jacket loss rate shall be tested in a steam mode, and the jacket loss in a hot water mode shall be taken as equal to the jacket loss rate in a steam mode.

8.2. Steady State Combustion Efficiency Test

8.2.1. Steam

8.2.1.1. Warm-Up Period

8.2.1.1.2 The burner shall be adjusted to the required input rate as specified in Section 4.1.1.3. Oil or non-atmospheric gas shall be adjusted to produce the required vent or firebox pressure as specified in Section 7.6.1 and CO_2 or O_2 as specified in Section 7.6.5. After the warm-up period has started, if further burner adjustment is necessary, the warm-up period shall be restarted.

8.2.1.2 Test Period

8.2.1.1.1 The test period shall start when a steady state has been reached, and the last reading of the warm-up period shall be the first reading of the test period. ~~No further burner adjustment shall be made.~~ For non-atmospheric burners, the average of all CO_2 or O_2 readings during the test period shall not differ from the first reading by greater than the tolerance specified below:

8.2.2 Water

8.2.2.1 Warm-Up Period

8.2.2.1.1 With all required test apparatus properly connected, and with the boiler and piping filled with water such that water flows through the system, the burner shall be started and the system warmed up until the outlet water temperature approaches the outlet temperature specified in Section 7.7. After the warm-up period has started, if further burner adjustment is necessary, the warm-up period shall be restarted.

8.2.2.2 Test Period

8.2.2.2.1 The test period shall start when steady state has been reached, and the last reading of the warm-up period shall be the first reading of the test period. ~~No further burner adjustment shall be made.~~ For non-atmospheric burners, the average of all CO_2 or O_2 readings during the test period shall not differ from the first reading by greater than the tolerance specified in Section 8.2.1.2.1.

8.2.4 Jacket Loss Test

8.2.4.1 Outer Surface Convective and Radiative Loss – The following test procedure shall be performed at all inputs and boiler inlet~~return~~ water temperatures (~~RWT~~IWT) at which steady state efficiencies are measured. All measurements described in this section shall be recorded following the conclusion of the final steady state test described in Section 8.2.1 or 8.2.2~~8.8.8~~.

Exceptions:

1. The jacket loss rates (as energy per unit time) identified at higher input rates are allowed to apply at lower input rates for the same boiler inlet ~~return~~ water temperature. The absolute jacket loss rate identified at higher boiler inlet ~~return~~ water temperatures are allowed to apply at lower boiler inlet ~~return~~ water temperatures for the same input rate.

8.2.4.3 Jacket Internal Convection Flow Loss

~~**8.2.4.3.1** Use a source of smoke to identify all jacket openings into which ambient air is clearly drawn. Other jacket openings having an area greater than 0.5in^2 (3.2 cm^2), which are not known to be needed for combustion air, ventilation, or draft control may be sealed with tape. For atmospheric boilers, record a flue CO_2 reading before and after sealing these openings. If the difference between these two readings is greater than 0.3%, identify and remove the tape which is causing this difference.~~

~~Install a thermocouple in the center of each opening having a cross sectional area greater than 0.5 in^2 which was not sealed and which did not have air flowing into it during conduct of the smoke test. If smoke test was inconclusive, install a thermocouple in the opening. When an opening is greater than 9 square inches (58 cm^2), subdivide it into equal size, smaller areas in accordance with 6.5.5. Place one thermocouple at the center of each area. Louver fields shall be divided into smaller equal sized areas in accordance with 6.5.5 based on the area encompassed by the outermost louvers (Figure 8). A thermocouple shall then be placed in the louver closest to the center of each area. Thermocouple(s) shall not be located outside of the outer jacket surface nor more than 1/8" (3.2 mm) inside the opening (Figure 9). Record the area of each opening (A_{OX}) and the vertical distance from the bottom of the boiler to the center of the opening (H_{OX}). For non-circular openings, also record the perimeter of the opening (P_{OX})~~

8.2.4.3.1 Record the temperature of the air exiting each jacket opening (T_{OX}) using the thermocouples installed in Section 6.5.2.2.

8.3.1 Steam or Water

8.3.1.1 Burner adjustment shall be made prior to the idling test. No further adjustments shall be made during the test.

8.3.1.2 The burner or heating elements shall be actuated by a water temperature controller meeting the requirements in Section 7.9 for the duration of the test.

The test shall ~~include a~~be immediately preceeded by a minimum of 1~~one stabilization~~ cycle for stabilization if the cycle time exceeds 10 minutes. If the average cycle time is equal to or less than 10 minutes, then the test shall be immediately preceeded by 3 ~~stabilization~~cycles for stabilization~~are required~~.

~~Stabilization cycle(s) shall be followed immediately by test cycles.~~ Recording data during the stabilization cycles is not required.

Two test cycles, following the cycles for stabilization, are permitted if the idling energy input rates, measured in total energy consumed during a cycle divided by the cycle period, for two consecutive cycles are within 5% of each other. If this condition is not met, then 6 test cycles, following the cycles for stabilization are required. ~~are permitted if the following criteria are met:~~

~~a. Average cycle time is greater than 10 minutes, and~~

~~b. Either:~~

~~a. idling energy input rate measured in energy per unit time of two consecutive cycles are within 5% of each other, or~~

~~b. idling energy input fraction rate of two consecutive cycles, measured in energy per unit time divided by the full fire input, are within 0.1% of each other.~~

~~If these criteria are not met, then 6 test cycles are required.~~ Test cycles must be consecutive with each other and with the stabilization cycle(s). ~~The idle test input rate shall be calculated as the average of the test cycles.~~ Total energy input and total time for the test cycles shall be measured for the calculations in Section 10.6. Closure of the controller call for heat contact shall indicate the end of one cycle and the start of the next. For electric boilers that do not cycle in a 32-hour period, the last 24 hours shall be the test period.

8.4 Throughflow Loss Test

8.4.1 The throughflow loss test shall be performed immediately after conducting the idling test (to maintain temperature stabilization).

8.4.2 The boiler shall be turned off, valve positions shall be adjusted to direct the ~~idling loop~~boiler water flow through the electric water heater, and the heater shall be turned on. The heater output shall be adjusted until it is able to maintain the outlet water temperature within ± 2°F (± 1°C) of the setpoint (see Section 7.10.2 for setpoint) for a stabilization period of at least one hour. The throughflow test shall then be continued for a test period of two hours to determine the average input rate from the electric heater required to offset the throughflow loss rate of the boiler.

9 DATA TO BE RECORDED

9.2 Idling Test

9.2.1 Steam or Water. For steam or water idling tests the following items shall be recorded before the start of the test:

Date of Test
Manufacturer
Boiler model number
Name of person conducting test
Burner model number
Oil analysis - H, C, API Gravity and Btu/Lb. (kJ/kg)
Gas Higher Heating Value, Btu/ ft^3 (MJ/m^3)
Gas manifold pressure, in. w.c. (Pa)
Gas line pressure, in. w.c. (Pa), and temperature, ºF (ºC), at meter
Controller differential
Controller temperature setpoint
Boiler loop water volume in gallons (liters)

9.2.3 Water. The following data shall be recorded at the intervals shown:

Time
Fuel fed per cycle, lbm.(oil), ft^3 (gas) (kg oil, m^3 gas),
Electric heating element energy fed per cycle, kWh (electric)
Room air temperature every 15 minutes.
Outlet water temperature at least every minute.
Water temperature controller actuation, time on, time off
Electrical equipment energy used, kWh, per cycle (includes all pumps connected to the idling boiler loop)

9.3 Throughflow Loss Test

9.3.2 The following data shall be recorded at the intervals shown:

Time
Room air temperature every 15 minutes.
InletBoiler outlet water temperature every 5 minutes.
Test rig flow rate every 15 minutes
Electric water heater energy used, kWh, over duration of test.

10 CALCULATION OF RATED PERFORMANCE FROM TEST RESULTS

10.1 Combustion Efficiency. The following items shall be calculated for each steady state test required by Section 4.1 and for each optional steady state test that is conducted. Section 10.1.3 shall be used to calculate combustion efficiency for non-condensing boilers, and Section 10.1.6 shall be used to calculate combustion efficiency for condensing boilers.

10.1.1 Averaging and Totaling of Recorded Values. All data shall be recorded as prescribeddescribed in Section 9.

10.1.1.1 Measurements to be Averaged (Mean) Over the Test Period. For the following parameters (if recorded), the average (mean) of the values recorded during the test period shall be used for the calculations in this section:

Room air temperature, T_{room}
InletTest air temperature, T_{air}
Inlet water temperature, T_{in}
Boiler temperature, T_{blr}
Outlet water temperature, T_{out}
Flue gas temperature, T_{flue}
Fuel gas temperature
Atmospheric pressure, P_{baro}
Steam pressure, P_{steam}
Steam temperature
Gas pressure
Flue gas CO_2
Flue gas CO

Flue gas O_2
Relative humidity, R_h

10.1.4 Steady State Flue Loss for Gas Fired Boilers, L_f, Percent

IP:

$$L_f = \frac{1}{379}\left(C_1 + C_2 + C_3 + C_4\right) + 5.04\left(T - P\right)$$

where:

$$C_1 = \left(\frac{PU}{1000}\right)\left[16.2\left(T_f - T_r\right) + 6.53*10^3 \ln\frac{T_r}{T_f} + 1.41*10^6\left(T_r^{-1} - T_f^{-1}\right)\right]$$

$$C_2 = \left(\frac{P}{10}\right)\left[1 - \frac{U}{100}\right]\left[9.47\left(T_f - T_r\right) + 3.47*10^3 \ln\frac{T_r}{T_f} + 1.16*10^6\left(T_r^{-1} - T_f^{-1}\right)\right]$$

$$C_3 = \left(\frac{P}{10}\right)\left[\frac{U - CO_2}{CO_2}\right]\left[9.46\left(T_f - T_r\right) + 3.29*10^3 \ln\frac{T_r}{T_f} + 1.07*10^6\left(T_r^{-1} - T_f^{-1}\right)\right]$$

$$C_4 = \left[\frac{T - P}{10} + 0.0017hA\right]\left[1 + \frac{P}{A}\left(\frac{U - CO_2}{CO_2}\right)\right]\left[19.86\left(T_f - T_r\right) + 7.5*10^3 \ln\frac{T_f}{T_r} + 1194\left(T_r^{1/2} - T_f^{1/2}\right)\right]$$

where:

$$C_1 = \left(\frac{PU}{1000}\right)\left[16.2\left(T_f - T_a\right) + 6.53*10^3 \ln\frac{T_a}{T_f} + 1.41*10^6\left(T_a^{-1} - T_f^{-1}\right)\right]$$

$$C_2 = \left(\frac{P}{10}\right)\left[1 - \frac{U}{100}\right]\left[9.47\left(T_f - T_a\right) + 3.47*10^3 \ln\frac{T_a}{T_f} + 1.16*10^6\left(T_a^{-1} - T_f^{-1}\right)\right]$$

$$C_3 = \left(\frac{P}{10}\right)\left[\frac{U - CO_2}{CO_2}\right]\left[9.46\left(T_f - T_a\right) + 3.29*10^3 \ln\frac{T_a}{T_f} + 1.07*10^6\left(T_a^{-1} - T_f^{-1}\right)\right]$$

$$C_4 = \left[\frac{T - P}{10} + 0.0017\frac{R_h}{100}A\right]\left[1 + \frac{P}{A}\left(\frac{U - CO_2}{CO_2}\right)\right]\left[19.86\left(T_f - T_a\right) + 7.5*10^3 \ln\frac{T_f}{T_a} + 1194\left(T_a^{1/2} - T_f^{1/2}\right)\right]$$

where:

A= 9.4 SCF per 1,000 Btu of gas burned
CO_2 = CO_2 in flue gases, percent of total dry constituents in the flue gas, shall be measured, or calculated per:

$$CO_2 = U_{gas} \cdot \frac{\left(20.9 - O_{2,meas}\right)}{20.9}$$

P = 8.47 SCF per 1,000 Btu of gas burned

T= 10.42 SCF per 1,000 Btu of gas burned
U_{gas} = Ultimate CO_2 of the flue gas = 11.9%

SI:

$$L_f = 9.82 * 10^{-2}\left(C_1 + C_2 + C_3 + C_4\right) + 187.7\left(T - P\right)$$

~~where:~~

$$C_1 = \left(\frac{PU}{1000}\right)\left[29.2\left(T_f - T_r\right) + 6.53*10^3 \ln\frac{T_r}{T_f} + 7.83*10^5\left(T_r^{-1} - T_f^{-1}\right)\right]$$

$$C_2 = \left(\frac{P}{10}\right)\left[1 - \frac{U}{100}\right]\left[17.05\left(T_f - T_r\right) + 3.47*10^3 \ln\frac{T_r}{T_f} + 6.44*10^5\left(T_r^{-1} - T_f^{-1}\right)\right]$$

$$C_3 = \left(\frac{P}{10}\right)\left[\frac{U - CO_2}{CO_2}\right]\left[17.03\left(T_f - T_r\right) + 3.29*10^3 \ln\frac{T_r}{T_f} + 5.49*10^5\left(T_r^{-1} - T_f^{-1}\right)\right]$$

$$C_4 = \left[\frac{T - P}{10} + 1.74*10^3 hA\right]\left[1 + \frac{P}{A}\left(\frac{U - CO_2}{CO_2}\right)\right]\left[35.75\left(T_f - T_r\right) + 7.5*10^3 \ln\frac{T_f}{T_r} + 1.602*10^3\left(T_r^{1/2} - T_f^{1/2}\right)\right]$$

where:

$$C_1 = \left(\frac{PU}{1000}\right)\left[29.2\left(T_f - T_a\right) + 6.53*10^3 \ln\frac{T_a}{T_f} + 7.83*10^5\left(T_a^{-1} - T_f^{-1}\right)\right]$$

$$C_2 = \left(\frac{P}{10}\right)\left[1 - \frac{U}{100}\right]\left[17.05\left(T_f - T_a\right) + 3.47*10^3 \ln\frac{T_a}{T_f} + 6.44*10^5\left(T_a^{-1} - T_f^{-1}\right)\right]$$

$$C_3 = \left(\frac{P}{10}\right)\left[\frac{U - CO_2}{CO_2}\right]\left[17.03\left(T_f - T_a\right) + 3.29*10^3 \ln\frac{T_a}{T_f} + 5.49*10^5\left(T_a^{-1} - T_f^{-1}\right)\right]$$

$$C_4 = \left[\frac{T - P}{10} + 1.74*10^3 \frac{R_h}{100} A\right]\left[1 + \frac{P}{A}\left(\frac{U - CO_2}{CO_2}\right)\right]\left[35.75\left(T_f - T_a\right) + 7.5*10^3 \ln\frac{T_f}{T_a} + 1.602*10^3\left(T_a^{1/2} - T_f^{1/2}\right)\right]$$

where:

A= 9.44
P= 8.65
T= 10.23
U= 13.75

10.2.2 Jacket Internal Convective Flow Loss. The jacket loss rate due to cooling air flow out of the top of the jacket may be assumed to be at a default value of 300 Btu/ft^2 hr or a loss rate measurement may be performed as per the following sections.

10.2.2.1 Density of ambient air, ρ_{amb}, lbm/ft^3

$\rho_{amb} = 1.325 \times (P_{baro}/(T_{room} + 460))$

where:
P_{baro} = Barometric pressure, inches Hg
T_{room} = Room temperature, °F(°C)

10.2.2.2 Density of air exiting jacket opening "x," ρ_{OX}, lbm/ft^3

$\rho_{OX} = 1.325 \times (P_{baro}/(T_{OX} + 460))$

where:
P_{baro} = Barometric pressure, inches Hg
T_{OX} = Temperature of air exiting jacket opening "x," °F (°C)

10.2.2.3 Mean density of air inside jacket between entrance into jacket and opening "x," ρ_{mX}, lbm/ft^3

$\rho_{mX} = (\rho_{amb} + \rho_{OX}) / 2$

10.2.2.4 Hydraulic area of opening "x," A_{OXH}, ft^2

10.2.2.4.1 Hydraulic diameter of opening "x", D_{OXH}, (in):

For a circular opening: D_{OXH} = Actual diameter of opening "x" (in)
For other openings: $D_{OXH} = 4A_{OX}/P_{OX}$
~~For a circular opening: $A_{OXH} = A_{OX}$~~
~~For other openings: $A_{OXH}=4A_{OX}/P_{OX}$~~
where:
A_{OX} = Actual area of opening "x" (ft^2)
P_{OX} = Perimeter of opening "x" (ft)
Note: For annular openings P_{OX} is the sum of the inner and outer perimeters.

10.2.2.4.2 Hydraulic area of opening "x", A_{OXH}, ft^2

$A_{OXH} = (3.14D_{OXH}^2)/(4 \times 144)$

10.3 Standard auxiliary energy input rate, $\dot{q}_{in,aux,ss}$, Btu/hr (kW)

SI

$$\dot{q}_{in,aux,ss} = \frac{E_{burner} + E_{controls} + E_{fan} + E_{htr} + E_{pump}}{t_{test}} \ (kW)$$

IP

$$\dot{q}_{in,aux,ss} = \frac{E_{burner}+E_{controls}+E_{fan}+E_{htr}+E_{pump}}{t_{test}} \ 3413 (Btu/hr)$$

10.5 Rated Steady State Thermal Efficiency, Including Auxiliary Inputs, $\eta_{ss,thermal}$, %

IP and SI:

$$\eta_{ss,thermal} = \frac{100 \cdot \dot{q}_{out,ss}}{\dot{q}_{in,ss} + \dot{q}_{in,aux,ss}}$$

10.8 Calculation of boiler water mass flow rate during steady state test, $\dot{m}_{rating}$, lbm/hr(kg/hr)

$$\dot{m}_{rating} = \frac{\dot{q}_{in,out,ss}}{c_{p,water}\left(T_{out,rating} - T_{in,rating}\right)}$$

~~**10.8 Calculation of flow rate during steady state test, F, gpm (m³/hr)**~~

~~IP:~~ $$F = \frac{\left(\dot{q}_{out,ss}\right)}{(489.7)\left(T_{out} - T_{return}\right)}$$

~~where 489.7 = Constant product of specific heat, density, and min/hr~~

~~SI:~~ $$F = 0.8791\frac{\left(\dot{q}_{out,ss}\right)}{\left(T_{out} - T_{return}\right)}$$

~~where 0.8791 = s/hr divided by product of specific heat, density~~

11 CALCULATION OF HOT WATER RATINGS FROM STEAM TEST RESULTS

If steam and hot water boiler is tested in steam mode only, the calculations in this section shall be used to determine the rated performance in hot water mode.

11.1 Steady State Performance

The equations in this subsection shall be used to calculate the steady state performance in hot water mode for fuel fired steam and hot water boilers tested only in steam mode. For electric boilers, the rated steady state performance in hot water mode shall be equal to the rated performance in steam mode.

11.1.10 Nominal Ratio of Water and Flue Gas Heat Capacity Rates in Hot Water Mode, C_r (dimensionless)

IP:

~~$$C_{r,water} = \frac{\min\left(40, 40 * \frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}, 180 - T_{return,\min}\right)}{T_{flame,nom} - T_{flue,ss,steam}}$$~~

$$C_{r,water} = \frac{\min\left(40, 40 * \frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}, 180 - T_{in,\min}\right)}{T_{flame,nom} - T_{flue,ss,steam}}$$

SI:

~~$$C_{r,water} = \frac{\min\left(22.2, 22.2 * \frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}, 82.2 - T_{return,\min}\right)}{T_{flame,nom} - T_{flue,ss,steam}}$$~~

$$C_{r,water} = \frac{\min\left(22.2, 22.2 * \frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}, 82.2 - T_{in,\min}\right)}{T_{flame,nom} - T_{flue,ss,steam}}$$

11.1.11 Nominal Flue Gas Temperature in Hot Water Mode, °F (°C)

IP:

~~$$T_{flue,nom,ss,water} = T_{flame,nom} - \varepsilon_{water}\left[T_{flame,nom} - \max\left(140, \left(180 - 40 * \frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}\right), T_{return,\min}\right)\right]$$~~

$$T_{flue,nom,ss,water} = T_{flame,nom} - \varepsilon_{water}\left[T_{flame,nom} - \max\left(140, \left(180 - 40 * \frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}\right), T_{in,\min}\right)\right]$$

SI:

~~$$T_{flue,nom,ss,water} = T_{flame,nom} - \varepsilon_{water}\left[T_{flame,nom} - \max\left(60, \left(60 - 22.2 * \frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}\right), T_{return,\min}\right)\right]$$~~

$$T_{flue,nom,ss,water} = T_{flame,nom} - \varepsilon_{water}\left[T_{flame,nom} - \max\left(60, \left(60 - 22.2 * \frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}\right), T_{in,\min}\right)\right]$$

11.1.15 Auxiliary Inputs, $\dot{q}_{in,aux}$, in kW

~~$$\dot{q}_{in,aux} = \frac{E_{burner} + E_{controls} + E_{fan} + E_{htr} + E_{pump,nom}}{t_{test}}$$~~

$$\dot{q}_{in,aux} = \frac{E_{burner} + E_{controls} + E_{fan}}{t_{test}}$$

~~where:~~

~~$E_{pump,nom}$ = nominal rate of electrical energy consumption by recirculation loop pump used to keep boiler flow rate or boiler entering water temperature above manufacturer's required minimum, kW~~

11.2 Idling Energy Input Rate

The equations in this subsection shall be used to calculate the idling performance in hot water mode for steam and hot water boilers tested only in steam mode. ***Informative Note:*** These equations are conservative in that they do not reflect the typical quadratic relationship between idling energy input rate and the temperature difference between the boiler and boiler room.

11.2.2 Auxiliary Inputs, $\dot{q}_{in,aux,idle}$, in kW

~~$$\dot{q}_{in,aux,idle} = \frac{E_{burner,idle} + E_{controls,idle} + E_{fan,idle} + E_{htr,idle} + E_{pump,nom}}{t_{test}}$$~~

$$\dot{q}_{in,aux,idle} = \frac{E_{burner,idle} + E_{controls,idle} + E_{fan,idle} + E_{pump}}{t_{test}}$$

~~where:~~

~~**$E_{pump,nom}$ = nominal rate of electrical energy consumption by recirculation loop pump, kW, from 11.1.15.**~~ ~~$E_{pump,nom} = 0.85VA\sqrt{\varphi}$~~

~~where:~~

~~0.85 = assumed power factor~~
~~V = pump nameplate voltage~~
~~A = pump nameplate full load amps~~
~~Φ = number of phases~~

12. INTERPOLATION AND EXTRAPOLATION OF TEST RESULTS

12.1 Steady State Output as a Function of Water Flow Rate for a Fixed Firing Rate and Boiler Inlet~~Return~~ Water Temperature

The calculations in this section shall be used to compute the steady state output as a function of water flow rate given test data at one water flow rate. The quantities in Sections 12.1.1 through 12.1.6 shall be computed based on test data for the tested flow rate.

12.1.1 Nominal adiabatic flame temperature, T_{flame}, °F (°C)

IP:

$$T_{flame,nom}(^{o}F) = 845.75 f_{xs}^{2} - 2333.1 f_{xs} + 3643.9$$

SI:

$$T_{flame,nom}(^{o}C) = 469.9 f_{xs}^{2} - 1296.2 f_{xs} + 2006.6$$

Where: f_{xs} = fraction of excess air in flue gas (dimensionless), Section 11.1.1

12.2 Steady State Output as a Function of ~~Return~~ Boiler Inlet Water Temperature for a Fixed Firing Rate and Water Flow Rate

12.2.1 Heat input. The steady-state heat input of a hot water boiler set at one firing rate shall be assumed to be constant regardless of water temperature.

12.2.2 Electrical equipment input. The steady-state energy input of the electrical equipment on a hot water boiler at one firing rate shall be assumed to be constant regardless of water temperature.

12.2.3 Output. The steady-state output of a hot water boiler as a function of ~~return~~inlet water temperature at one firing rate, and one water flow rate shall be calculated using the equations in this subsection.

12.2.3.1 Performance shall not be extrapolated to ~~return~~inlet water temperatures below 80°F or the minimum entering water temperature recommended by the manufacturer in the manufacturer's instructions shipped with the boiler, whichever is higher, nor above 180°F or the maximum entering water temperature recommended by the manufacturer, whichever is lower. Performance shall not be extrapolated to outlet water temperatures above the maximum leaving water temperature recommended by the manufacturer in the manufacturer's instructions shipped with the boiler.

12.2.3.2 Transition point between non-condensing and condensing operation.

12.2.3.2.1 Nominal ~~return~~ inlet water temperature at which condensation begins, ~~T_{return}~~$T_{inlet,trans,nom}$, °F (°C).

The boiler return water temperature at which condensation begins shall be interpolated from Table 4. Percent excess air shall be calculated according to Section 11.1.1.

Table 4-IP. Nominal inlet~~return~~ water temperature at which condensation begins, $T_{inlet\,\sout{return},trans,nom}$, °F

Excess Air (%)	Natural gas	#2 oil	#4 oil	#5 oil	#6 oil
0	133.8	118.5	116.8	116.5	114.0
10	130.6	115.4	113.7	113.4	111.0
20	127.7	112.6	110.9	110.7	108.2
30	125.0	110.1	108.4	108.1	105.7
40	122.5	107.8	106.1	105.8	103.5
50	120.2	105.6	104.0	103.7	101.4
70	116.2	101.8	100.2	99.9	97.6
100	111.0	97.0	95.4	95.1	92.9
150	104.0	90.5	89.0	88.8	86.7
200	98.5	85.5	84.0	83.8	81.8

Table 4-SI. Nominal inlet~~return~~ water temperature at which condensation begins, $T_{inlet\,\sout{return},trans,nom}$, °C

Excess Air (%)	Natural gas	#2 oil	#4 oil	#5 oil	#6 oil
0	56.6	48.1	47.1	46.9	45.6
10	54.8	46.3	45.4	45.2	43.9
20	53.1	44.8	43.8	43.7	42.4
30	51.7	43.4	42.4	42.3	41.0
40	50.3	42.1	41.2	41.0	39.7
50	49.0	40.9	40.0	39.8	38.5
70	46.8	38.8	37.9	37.7	36.5
100	43.9	36.1	35.2	35.1	33.8
150	40.0	32.5	31.7	31.5	30.4
200	37.0	29.7	28.9	28.8	27.6

Informative note: These tables assume that the ambient air humidity is 0.004 lbm/lbm dry air and that condensation begins when the inletreturn water temperature is 5°F below the dew point of the flue gases. They are based on the following fuel compositions:

Natural gas: 93.4% methane, 3.0% ethane, 0.7% propane, 1.2% CO_2, 1.3% nitrogen, 0.4% C_4H_{10}.

Liquid fuels:

% by weight	# 2 oil	#4 oil	#5 oil	#6 oil
C	85.035	87.85	88	88.186
H	12.965	12.15	12	10.805
O	0	0	0	0.05

12.2.3.2.2 Nominal temperature rise through boiler at tested input rates.

IP:

$$T_{blr\,rise} = \min\left(40; 40\frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}; T_{out} - T_{in,\min}\right)$$

$$T_{rise} = \min\left(40; 40\frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}; T_{out} - T_{in,\min}\right)$$

SI:

$$T_{blr\,rise} = \min\left(22.2; 22.2\frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}; T_{out} - T_{in,\min}\right)$$

$$T_{rise} = \min\left(22.2; 22.2\frac{\dot{m}_{rating}}{\dot{m}_{blr,\min}}; T_{out} - T_{in,\min}\right)$$

12.2.3.2.3 Nominal outlet water temperature at which condensation begins, $T_{outlet,trans}$.

The nominal outlet water temperature at which the transition between the condensing and non-condensing regions occurs is:

$$T_{out,trans,nom} = T_{in,trans,nom} + T_{blr\,rise}$$

$$T_{out,trans,nom} = T_{in,trans,nom} + T_{rise}$$

12.2.3.3 Steady state output as a function of inlet~~return~~ water temperature between the high temperature rating point and the transition to condensing operation, for fixed input rate and water flow rate.

12.2.3.3.1 Boilers for which the only test conducted in the non-condensing region is the high temperature rating test.

For a non-condensing boiler or for a condensing boiler at leaving water temperatures down to and including the transition to condensing operation, output as a function of inlet~~return~~ water temperature shall be calculated as:

$$\dot{q}_{out,ss}\left\langle T_{return}\right\rangle = \dot{q}_{in,ss}\left(\frac{100-L_f}{100}\right)\left(\frac{T_{flame,nom}-T_{return}}{T_{flame,nom}-T_{return,rated,high}}\right)\dot{q}_{jacket,nom}$$

$$\dot{q}_{out,ss}\left\langle T_{in}\right\rangle = \dot{q}_{in,ss}\left(\frac{100-L_f}{100}\right)\left(\frac{T_{flame,nom}-T_{in}}{T_{flame,nom}-T_{in,rated,high}}\right)-\dot{q}_{jacket,ss}$$

where:
T_{flame} is calculated according to Section 12.1.1.
L_f and $\dot{q}_{jacket,nom}$ are calculated according to equations in Section 10.2.

12.2.3.3.2 Boilers for which more than one test is conducted in the non-condensing region.

Outputs shall first be adjusted to the same water flow rate using the procedures in Section 12.1. Output between tested inlet~~return~~ water temperatures shall then be calculated as:

$$\dot{q}_{OUT,SS}\left\langle T_{return}\right\rangle = \dot{q}_{out,ss}\left\langle T_{return,lower}\right\rangle \left(\frac{T_{return}-T_{return,lower}}{T_{return,higher}-T_{return,lower}}\right)\left(\dot{q}_{out,ss}\left\langle T_{return,lower}\right\rangle \dot{q}_{out,ss}\left\langle T_{return,higher}\right\rangle\right)$$

$$\dot{q}_{OUT,SS}\left\langle T_{return}\right\rangle = \dot{q}_{out,ss}\left\langle T_{in,lower}\right\rangle - \left(\frac{T_{in}-T_{in,lower}}{T_{in,higher}-T_{in,lower}}\right)\left(\dot{q}_{out,ss}\left\langle T_{in,lower}\right\rangle - \dot{q}_{out,ss}\left\langle T_{in,higher}\right\rangle\right)$$

Output at the nominal inlet ~~return~~ water temperature at which condensation begins shall be calculated according to Section 12.2.3.3.1 and output between the lowest non-condensing inlet

~~return~~ water temperature tested, and the nominal inlet ~~return~~ water temperature at which condensation begins shall then be calculated according to this subsection.

12.2.3.4 Steady state output as a function of leaving water temperature between the transition to condensing operation and the low temperature rating point.

12.2.3.4.1 Boilers for which more than one test is conducted in the condensing region.
Outputs shall first be adjusted to the same water flow rate using the procedures in Section 12.1. Output between tested inlet ~~return~~ water temperatures shall then be calculated as:

~~$$\dot{q}_{OUT,SS}\left\langle T_{return}\right\rangle = \dot{q}_{OUT,SS}\left\langle T_{return,lower}\right\rangle - \left(\frac{T_{return}-T_{return,lower}}{T_{return,higher}-T_{return,lower}}\right)\left(\dot{q}_{OUT,SS}\left\langle T_{return,lower}\right\rangle - \dot{q}_{OUT,SS}\left\langle T_{return,higher}\right\rangle\right)$$~~

$$\dot{q}_{OUT,SS}\left\langle T_{in}\right\rangle = \dot{q}_{OUT,SS}\left\langle T_{in,lower}\right\rangle - \left(\frac{T_{in}-T_{in,lower}}{T_{in,higher}-T_{in,lower}}\right)\left(\dot{q}_{OUT,SS}\left\langle T_{in,lower}\right\rangle - \dot{q}_{OUT,SS}\left\langle T_{in,higher}\right\rangle\right)$$

Output at the nominal inlet ~~return~~ water temperature at which condensation begins shall be calculated according to Section 12.2.3.3.1 and output between the highest condensing inlet ~~return~~ water temperature tested, and the nominal inlet ~~return~~ water temperature at which condensation begins shall then be calculated according to this subsection.

12.2.3.4.2 Boilers tested at high temperature and low temperature rating points only.

Output as a function of inlet ~~return~~ water temperature for a fixed firing rate and water flow rate shall be calculated as:

~~$$\dot{q}_{OUT,SS}\left\langle T_{return}\right\rangle = \dot{q}_{OUT,SS}\left\langle T_{return,rated,low}\right\rangle - \left(\frac{T_{return}-T_{return,rated,low}}{T_{return,trans}-T_{return,rated,low}}\right)\left(\dot{q}_{OUT,SS}\left\langle T_{return,rated,low}\right\rangle - \dot{q}_{OUT,SS}\left\langle T_{return,trans,nom}\right\rangle\right)$$~~

$$\dot{q}_{OUT,SS}\left\langle T_{in}\right\rangle = \dot{q}_{OUT,SS}\left\langle T_{in,rated,low}\right\rangle - \left(\frac{T_{in}-T_{in,rated,low}}{T_{in,trans}-T_{in,rated,low}}\right)\left(\dot{q}_{OUT,SS}\left\langle T_{in,rated,low}\right\rangle - \dot{q}_{OUT,SS}\left\langle T_{in,trans,nom}\right\rangle\right)$$

12.6 Part Load Performance when Cycling below the Minimum Steady-State Input Rate at a Fixed Flow Rate

12.6.1 For constant outlet water temperature

The energy input of a boiler at a given water flow rate and outlet water temperature, T_{out}, when the burner is cycling between its minimum steady-state input rate and its idling energy input rate to meet a given load, $\dot{q}_{out}$, shall be calculated by linear interpolation of input as a function of output between the steady state point and the idling point for that T_{out} and flow rate. The minimum steady-state input rate is the full load input rate for single stage boilers and the low fire point for boilers with modulating controls.

IP:

$$\dot{q}_{in,cyc}\left\langle T_{out}\right\rangle = (\dot{q}_{in,ss} + 3413*\dot{q}_{in,aux,ss})\left(\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\left\langle T_{out}\right\rangle}\right) + \left(\dot{q}_{in,idle,corr}\left\langle T_{out}\right\rangle + 3413*\dot{q}_{in,aux,idle}\left\langle T_{out}\right\rangle\right)\left(1-\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\left\langle T_{out}\right\rangle}\right)$$

SI:

$$\dot{q}_{in,cyc}\left\langle T_{out}\right\rangle = (\dot{q}_{in,ss} + \dot{q}_{in,aux,ss})\left(\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\left\langle T_{out}\right\rangle}\right) + \left(\dot{q}_{in,idle,corr}\left\langle T_{out}\right\rangle + \dot{q}_{in,aux,idle}\left\langle T_{out}\right\rangle\right)\left(1-\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\left\langle T_{out}\right\rangle}\right)$$

12.6.2 For constant inlet ~~return~~ water temperature

The energy input of a boiler at a given water flow rate and inlet ~~return~~ water temperature, T~~return~~inlet, when the burner is cycling between steady-state low fire and idle to meet a given load, $\dot{q}_{out}$, shall be calculated by linear interpolation of input as a function of output between the steady state point and the idling point for that T~~return~~inlet and flow rate. The minimum steady-state input rate is the full load input rate for single stage boilers and the low fire input rate for boilers with modulating controls.

IP:

$$\dot{q}_{in,cyc}\left\langle T_{return}\right\rangle = (\dot{q}_{in,ss} + 3413*\dot{q}_{in,aux,ss})\left(\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\left\langle T_{return}\right\rangle}\right)$$

$$+\left(\dot{q}_{in,idle,C}\left\langle T_{return}\right\rangle + 3413*\dot{q}_{in,aux,idle}\left\langle T_{return}\right\rangle\right)\left(1-\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\left\langle T_{return}\right\rangle}\right)$$

$$\dot{q}_{in,cyc}\left\langle T_{in}\right\rangle = (\dot{q}_{in,ss} + 3413*\dot{q}_{in,aux,ss})\left(\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\left\langle T_{in}\right\rangle}\right)$$

$$+\left(\dot{q}_{in,idle,C}\left\langle T_{in}\right\rangle + 3413*\dot{q}_{in,aux,idle}\left\langle T_{in}\right\rangle\right)\left(1-\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\left\langle T_{in}\right\rangle}\right)$$

SI:

$$\dot{q}_{in,cyc}\left\langle T_{return}\right\rangle = (\dot{q}_{in,ss} + \dot{q}_{in,aux,ss})\left(\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\left\langle T_{return}\right\rangle}\right)$$

$$+\left(\dot{q}_{in,idle,C}\left\langle T_{return}\right\rangle + \dot{q}_{in,aux,idle}\left\langle T_{return}\right\rangle\right)\left(1-\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\left\langle T_{return}\right\rangle}\right)$$

$$\dot{q}_{in,cyc}\langle T_{in}\rangle = (\dot{q}_{in,ss} + \dot{q}_{in,aux,ss})\left(\frac{\dot{q}_{out}}{\dot{q}_{out,ss}\langle T_{in}\rangle}\right) + \left(\dot{q}_{in,idle,C}\langle T_{in}\rangle + \dot{q}_{in,aux,idle}\langle T_{in}\rangle\right)\left(1 - \frac{\dot{q}_{out}}{\dot{q}_{out,ss}\langle T_{in}\rangle}\right)$$

12.7 Part Load Performance when Modulating between Tested Steady State Input Rates at Fixed Outlet (or Inlet~~Return~~) Water Temperature and with Fixed Water Flow Rate or Variable Flow Rate and Fixed Temperature Rise

12.7.2 For constant water flow rate and inlet ~~return~~ water temperature:

The output for all steady-state tests conducted shall first be adjusted to the flow rate to be analyzed using the calculations in Section 12.1. The performance of a boiler with modulating control at any given ~~return~~ inlet water temperature, ~~T_{return}~~ T_{inlet}, when the burner is modulating between the tested steady-state input rates to meet a given load, $\dot{q}_{out}$, shall then be calculated by linear interpolation of input as a function of output between the tested input rates.

IP:

$$\dot{q}_{in,\mathrm{mod}}\langle T_{return}\rangle = (\dot{q}_{in,ss,higher} + 3413 * \dot{q}_{in,aux,higher})\left(\frac{\dot{q}_{out} - \dot{q}_{out,ss,lower}\langle T_{return}\rangle}{\dot{q}_{out,ss,higher}\langle T_{return}\rangle - \dot{q}_{out,ss,lower}\langle T_{return}\rangle}\right)$$

$$+ (\dot{q}_{in,ss,lower} + 3413 * \dot{q}_{in,aux,lower})\left(1 - \left(\frac{\dot{q}_{out} - \dot{q}_{out,ss,lower}\langle T_{return}\rangle}{\dot{q}_{out,ss,higher}\langle T_{return}\rangle - \dot{q}_{out,ss,lower}\langle T_{return}\rangle}\right)\right)$$

$$\dot{q}_{in,\mathrm{mod}}\langle T_{in}\rangle = (\dot{q}_{in,ss,higher} + 3413 * \dot{q}_{in,aux,higher})\left(\frac{\dot{q}_{out} - \dot{q}_{out,ss,lower}\langle T_{in}\rangle}{\dot{q}_{out,ss,higher}\langle T_{in}\rangle - \dot{q}_{out,ss,lower}\langle T_{in}\rangle}\right) + (\dot{q}_{in,ss,lower} + 3413 * \dot{q}_{in,aux,lower})\left(1 - \left(\frac{\dot{q}_{out} - \dot{q}_{out,ss,lower}\langle T_{in}\rangle}{\dot{q}_{out,ss,higher}\langle T_{in}\rangle - \dot{q}_{out,ss,lower}\langle T_{in}\rangle}\right)\right)$$

SI:

$$\dot{q}_{in,\mathrm{mod}}\langle T_{return}\rangle = (\dot{q}_{in,ss,higher} + \dot{q}_{in,aux,higher})\left(\frac{\dot{q}_{out} - \dot{q}_{out,ss,lower}\langle T_{return}\rangle}{\dot{q}_{out,ss,higher}\langle T_{return}\rangle - \dot{q}_{out,ss,lower}\langle T_{return}\rangle}\right)$$

$$+ (\dot{q}_{in,ss,lower} + \dot{q}_{in,aux,lower})\left(1 - \left(\frac{\dot{q}_{out} - \dot{q}_{out,ss,lower}\langle T_{return}\rangle}{\dot{q}_{out,ss,higher}\langle T_{return}\rangle - \dot{q}_{out,ss,lower}\langle T_{return}\rangle}\right)\right)$$

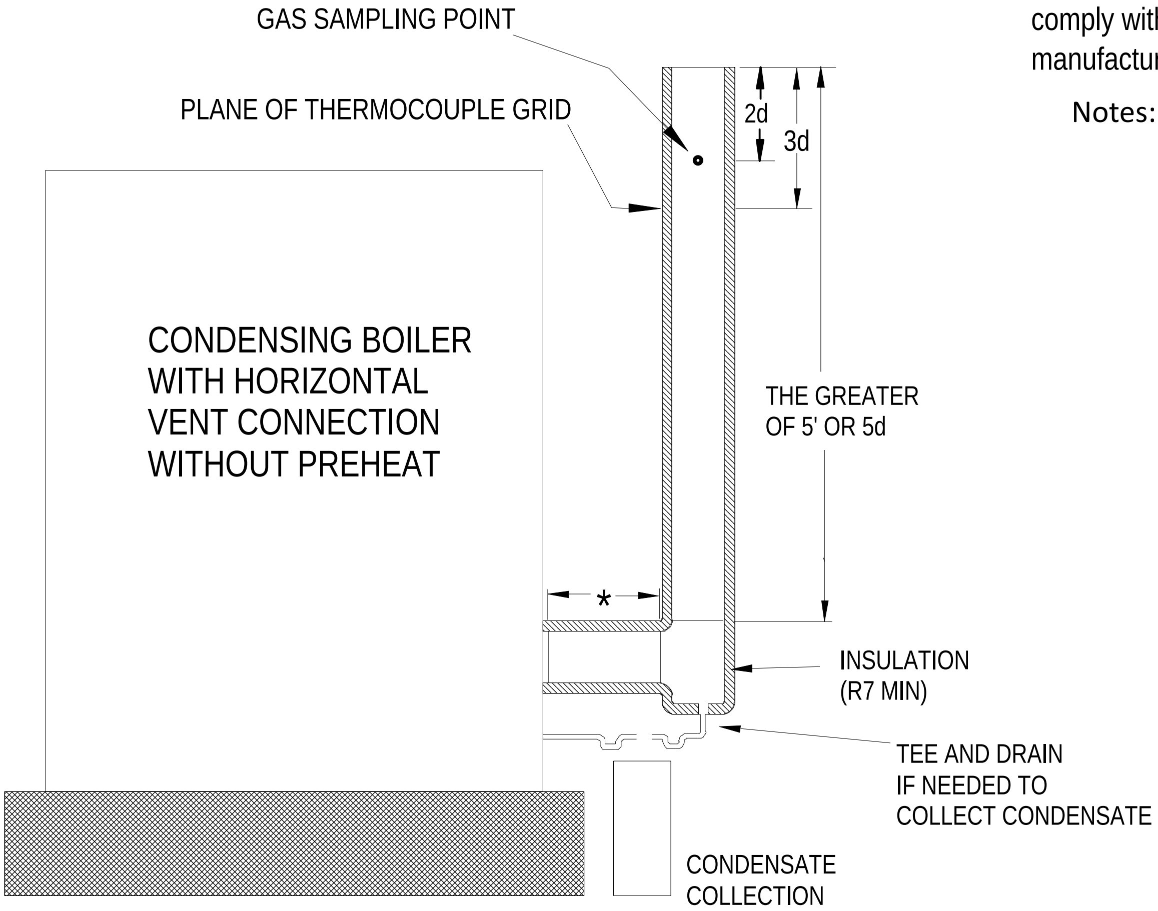
$$\dot{q}_{in,\text{mod}}\langle T_{in}\rangle = (\dot{q}_{in,ss,higher} + \dot{q}_{in,aux,higher})\left(\frac{\dot{q}_{out} - \dot{q}_{out,ss,lower}\langle T_{in}\rangle}{\dot{q}_{out,ss,higher}\langle T_{in}\rangle - \dot{q}_{out,ss,lower}\langle T_{in}\rangle}\right)$$
$$+ (\dot{q}_{in,ss,lower} + \dot{q}_{in,aux,lower})\left(1 - \left(\frac{\dot{q}_{out} - \dot{q}_{out,ss,lower}\langle T_{in}\rangle}{\dot{q}_{out,ss,higher}\langle T_{in}\rangle - \dot{q}_{out,ss,lower}\langle T_{in}\rangle}\right)\right)$$

where $\dot{q}_{out,ss,higher}\langle T_{in}\rangle$ and $\dot{q}_{out,ss,lower}\langle T_{in}\rangle$ have been adjusted to the appropriate constant flow rate.

12.7.3 For constant outlet water temperature and temperature rise.
The output for each steady-state test conducted shall first be adjusted, if necessary, to the flow rate required to provide a constant boiler temperature rise, T_{out} – T<u>in</u>~~return~~, using the calculations in Section 12.1 The performance of a boiler with modulating control at any given outlet water temperature, T_{out}, when the burner is modulating between the tested steady-state input rates to meet a given load, $\dot{q}_{out}$, shall then be calculated by linear interpolation of input as a function of output between the tested input rates using the equations in 12.7.1, where $\dot{q}_{out,ss,higher}\langle T_{out}\rangle$ and $\dot{q}_{out,ss,lower}\langle T_{out}\rangle$ have been adjusted to the appropriate flow rates for a constant temperature rise.

12.7.4 For constant <u>inlet</u> ~~return~~ water temperature and temperature rise.
The output for each steady-state test conducted shall first be adjusted, if necessary, to the flow rate required to provide a constant boiler temperature rise, T_{out} – T~~return~~<u>in</u>, using the calculations in Section 12.1. The performance of a boiler with modulating control at any given <u>inlet</u> ~~return~~ water temperature, T<u>in</u>~~return~~, when the burner is modulating between the tested steady-state input rates to meet a given load, $\dot{q}_{out}$, shall then be calculated by linear interpolation of input as a function of output between the tested input rates using the equations in 12.7.2, where $\dot{q}_{out,ss,higher}\langle T_{in}\rangle$ and $\dot{q}_{out,ss,lower}\langle T_{in}\rangle$ have been adjusted to the appropriate flow rates for a constant temperature rise.

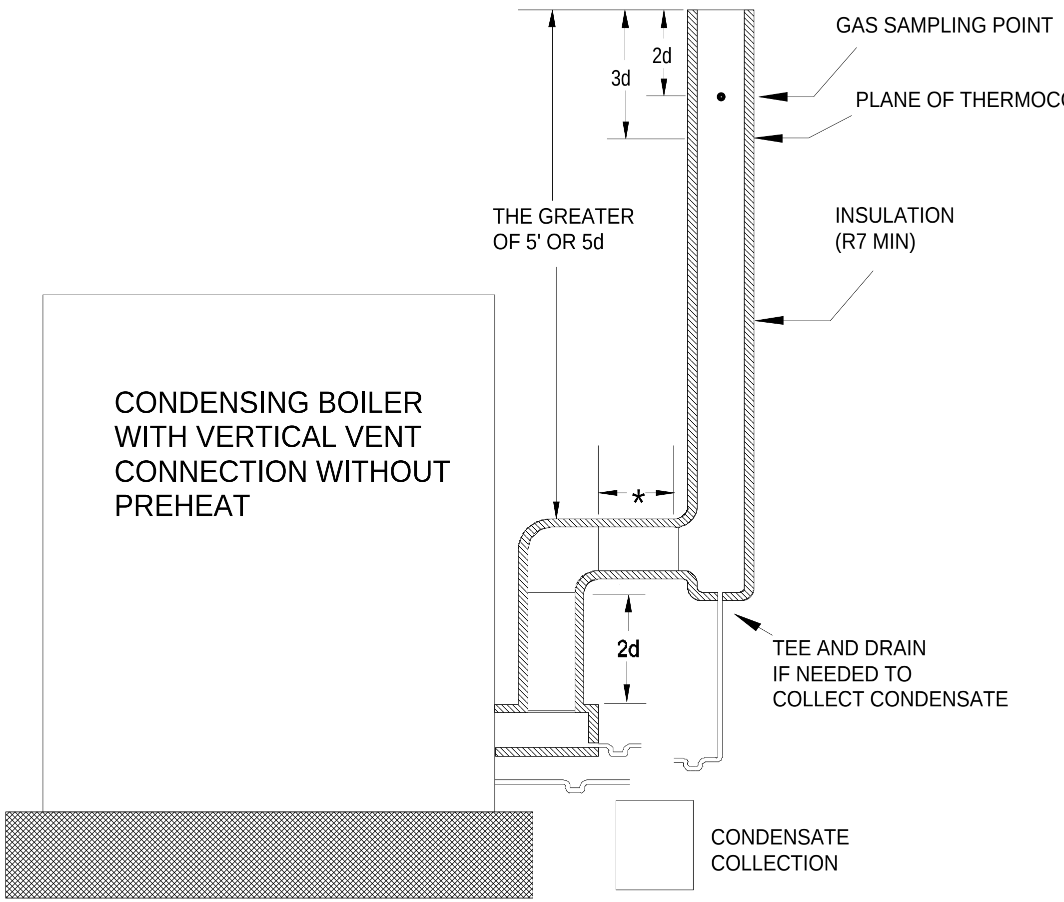
13. TEST FLUE ARRANGEMENTS



* The greater of 2d (d=nominal vent diameter) or the additional length necessary for the total vent length to comply with the minimum specified in the manufacturer's instructions shipped with the boiler.

Notes: All venting, prior to final vertical section and its connecting tee or elbow, shall be the smallest diameter allowed by the manufacturer's instructions shipped with the boiler, except it shall be no smaller than the vent connection to the boiler.
The vent must freely discharge to atmosphere. Connect no additional piping.
If needed, apply a concentric orifice at the flue connection to obtain the minimum vent pressure specified in the manufacturer's installation instructions.
Insulate all venting external to the boiler jacket and all vent pipe with a minimum of R7.
When needed to collect liquid condensate entrained in the flue gas, the final vertical section and its connecting tee or elbow pipe diameter shall be increased to the largest industry diameter that does not cause the vent velocity to fall below 400 ft/min when operating at high fire input.

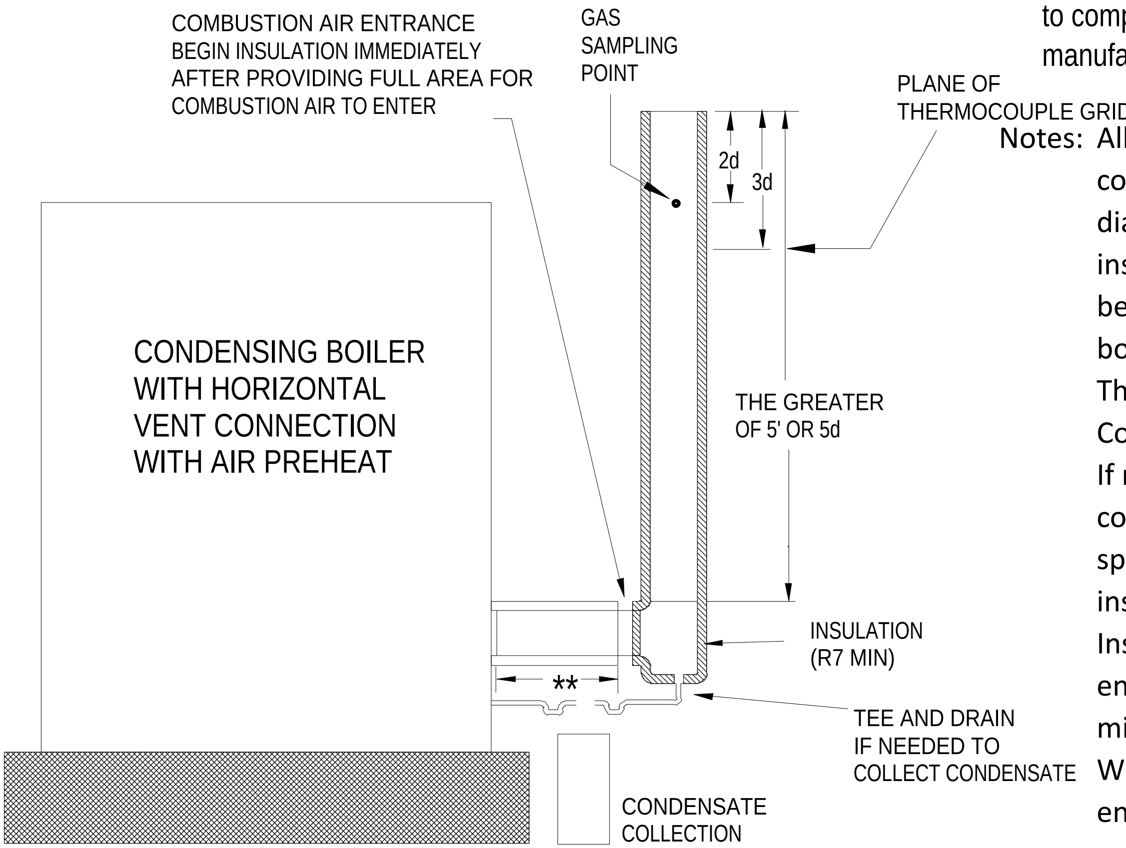
Figure 4A Test Vent - Boilers with Horizontal Vent, Positive Vent Pressure, and <u>WITHOUT</u> Combustion Air Preheat.



* The greater of 2d (d=nominal vent diameter) or the additional length necessary for the total vent length to comply with the minimum specified in the manufacturer's instructions shipped with the boiler.

Notes: All venting, prior to final vertical section and its connecting tee or elbow, shall be the smallest diameter allowed by the manufacturer's instructions shipped with the boiler, except it shall be no smaller than the vent connection to the boiler.
The vent must freely discharge to atmosphere. Connect no additional piping.
If needed, apply a concentric orifice at the flue connection to obtain the minimum vent pressure specified in the manufacturer's installation instructions.
Insulate all venting external to the boiler jacket and all vent pipe with a minimum of R7.
When needed to collect liquid condensate entrained in the flue gas, the final vertical section and its connecting tee or elbow pipe diameter shall be increased to the largest industry diameter that does not cause the vent velocity to fall below 400 ft/min when operating at high fire input.

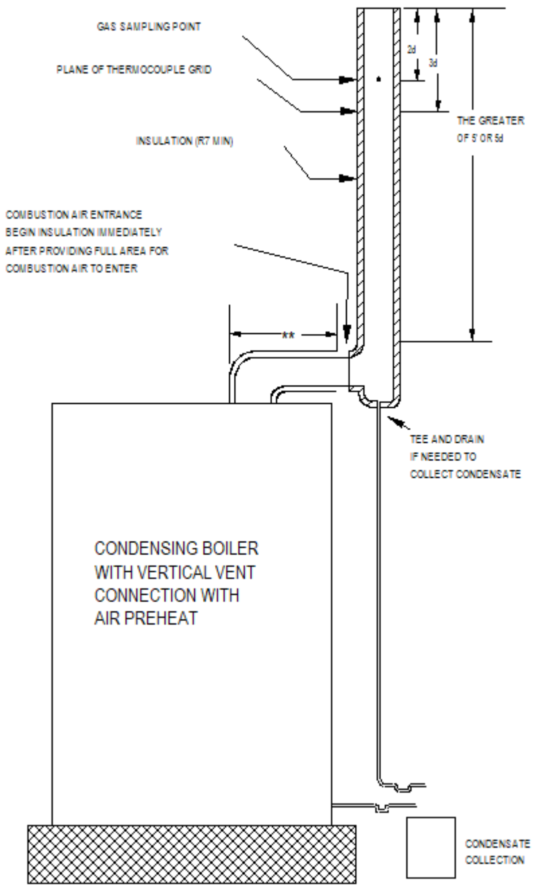
Figure 4B Test Vent - Boilers with Vertical Vent, Positive Vent Pressure, and <u>WITHOUT</u> Combustion Air Preheat



* The greater of 2d (d=nominal vent diameter) or the additional length necessary for the total vent length to comply with the minimum specified in the manufacturer's instructions shipped with the boiler.

Notes: All venting, prior to final vertical section and its connecting tee or elbow, shall be the smallest diameter allowed by the manufacturer's instructions shipped with the boiler, except it shall be no smaller than the vent connection to the boiler.
The vent must freely discharge to atmosphere. Connect no additional piping.
If needed, apply a concentric orifice at the flue connection to obtain the minimum vent pressure specified in the manufacturer's installation instructions.
Insulate all venting between the combustion air entrance for preheat and the vent discharge with a minimum of R7.
When needed to collect liquid condensate entrained in the flue gas, the final vertical section and its connecting tee or elbow pipe diameter shall be increased to the largest industry diameter that does not cause the vent velocity to fall below 400 ft/min when operating at high fire input.

Figure 4C Test Vent - Boilers with Horizontal Vent, Positive Vent Pressure, and <u>WITH</u> Combustion Air Preheat.



** The greater of 2d (d=nominal vent diameter) or the additional length necessary for the total vent length to comply with the minimum specified in the manufacturer's instructions shipped with the boiler. In needed, apply a concentric orifice at the flue connection to obtain the minimum vent pressure specified in the manufacturer's installation instructions. Insulate all venting external to the boiler jacket and all vent pipe with a minimum of R7

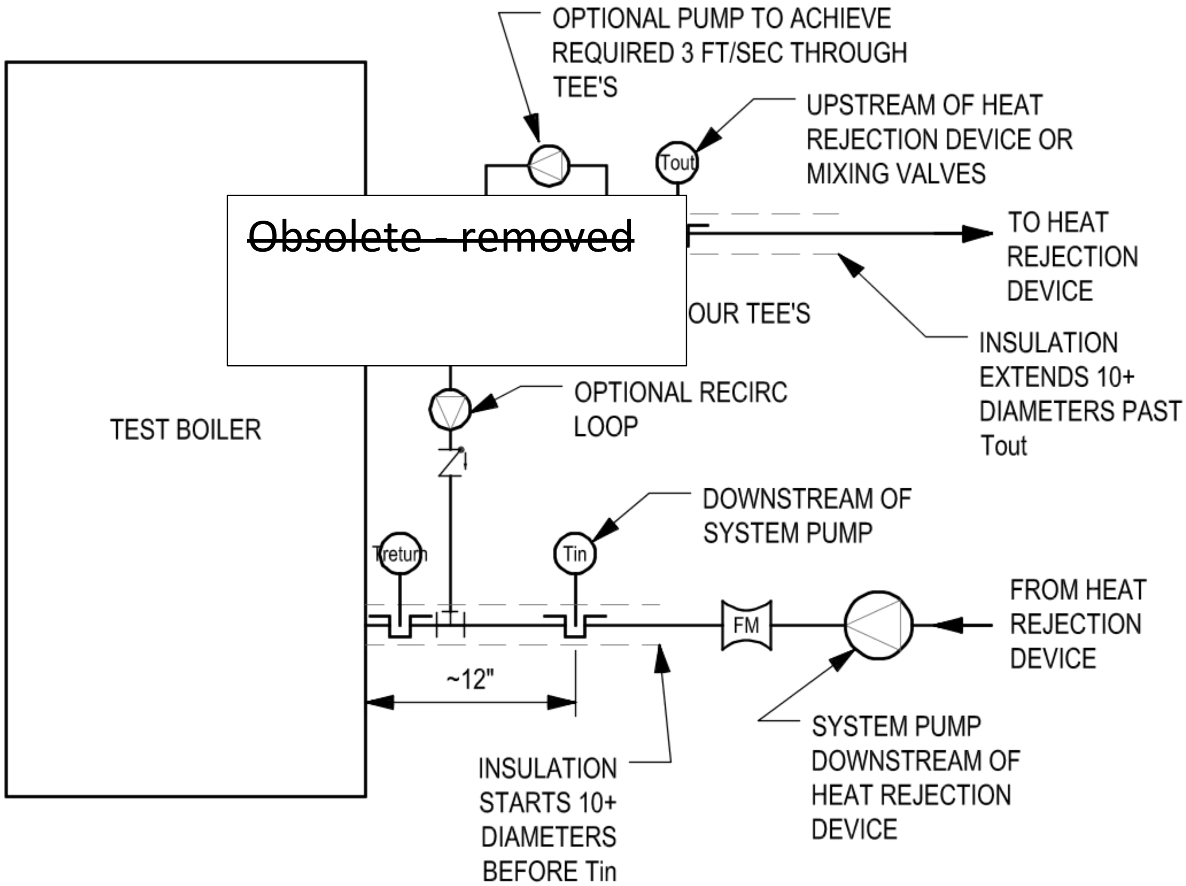
Notes: All venting, prior to final vertical section and its connecting tee or elbow, shall be the smallest diameter allowed by the manufacturer's instructions shipped with the boiler, except it shall be no smaller than the vent connection to the boiler.

The vent must freely discharge to atmosphere. Connect no additional piping.

When needed to collect liquid condensate entrained in the flue gas, the final vertical section and its connecting tee or elbow pipe diameter shall be increased to the largest industry diameter that does not cause the vent velocity to fall below 400 ft/min when operating at high fire input.

Figure 4D Test Vent - Boilers with Vertical Vent, Positive Vent Pressure, and <u>WITH</u> Combustion Air Preheat.

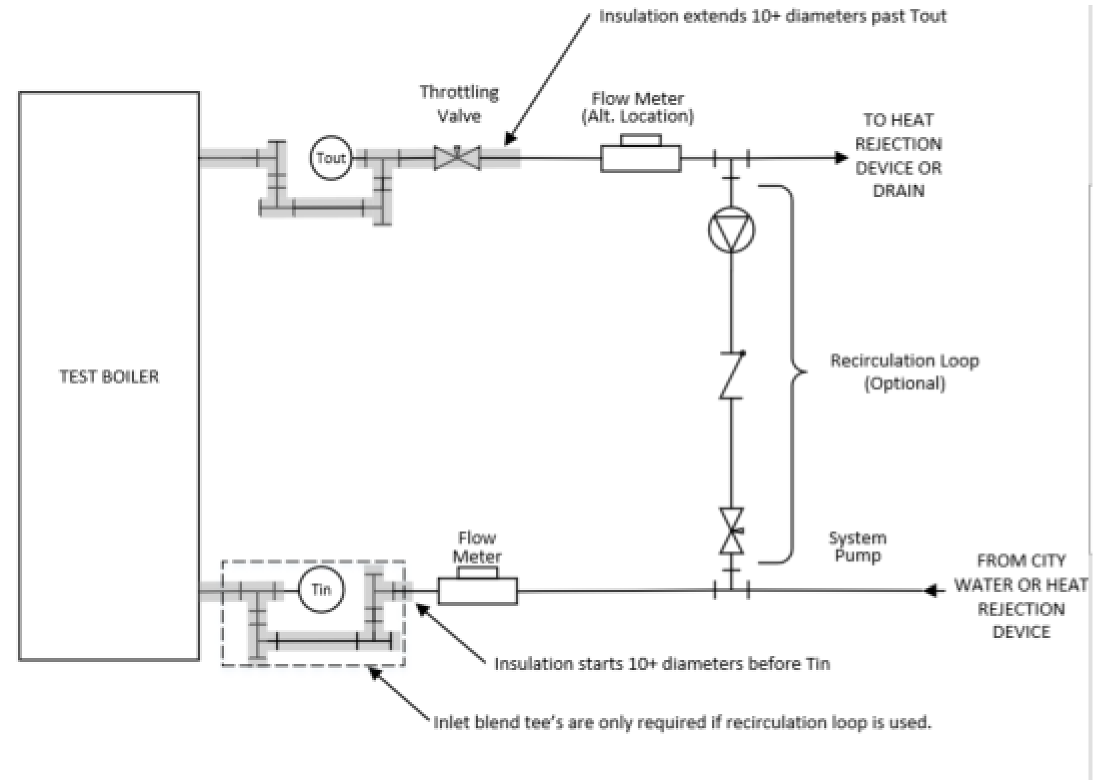
14 Piping and Other Figures



~~Note: The heat rejection device can include a water-to-air or water-to-water heat exchanger. It can also include a system with discharge of hot water and supply of conditioned water at the required inlet temperature from an alternative heat source. Recirculation of boiler outlet water to the boiler inlet return piping to meet the required Tin is acceptable and is considered as part of the heat rejection system.~~

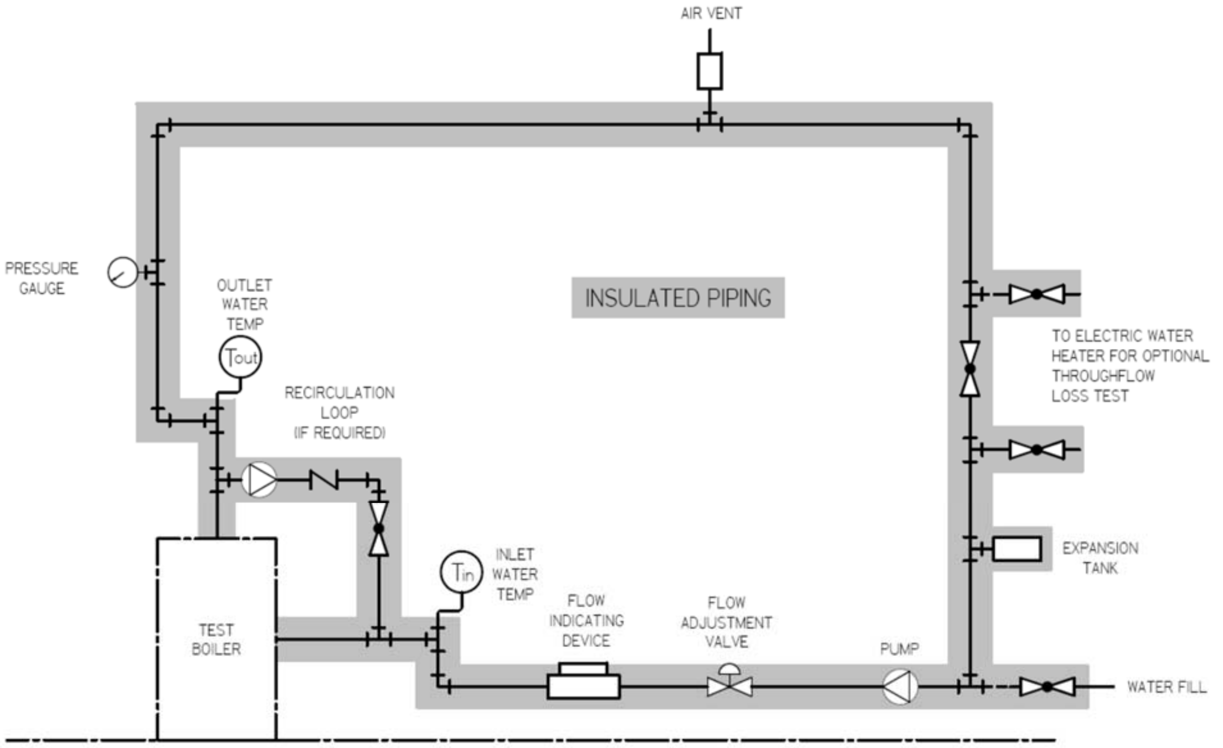
~~If the optional pump is used to achieve the required velocity through the tee's as shown, it is not required to directly measure this velocity, it can be determined by calculation using the pump characteristic curves and predicted pressure drop in the tee's. It is necessary to demonstrate that the 3 ft/sec requirement is clearly met.~~

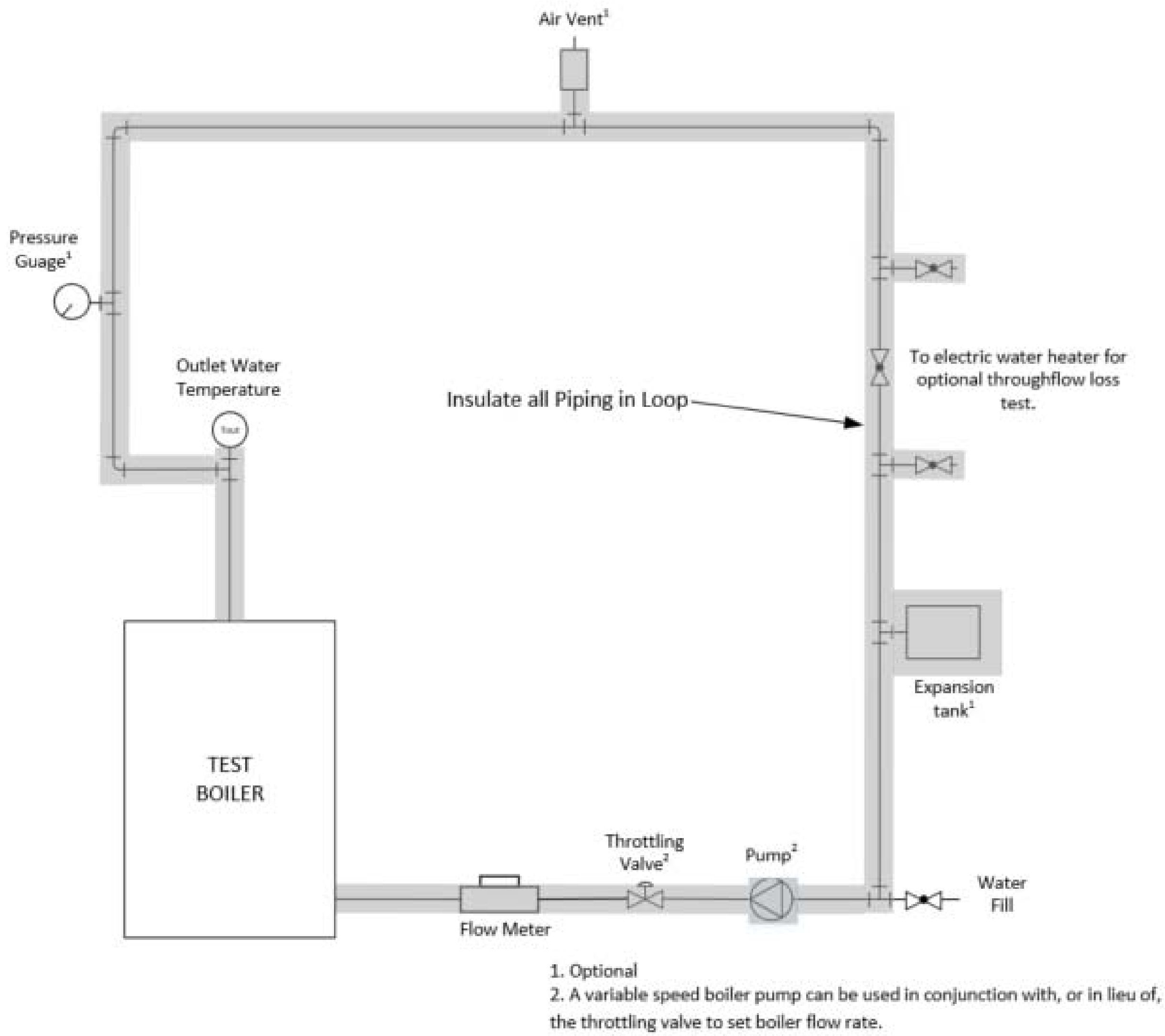
~~**Figure 6A Required Piping Arrangement for Steady-State Test, Hot Water Boilers.**~~



Note: The heat rejection device can include a water-to-air or water-to-water heat exchanger. It can also include a system with discharge of hot water and supply of conditioned water at the required inlet temperature from an alternative heat source. Recirculation of boiler outlet water to the boiler inlet piping to meet the required Tin is acceptable.

Figure 6A Required Piping Arrangement for Steady-State Test, Hot Water Boilers.


AIR VENT
PRESSURE GAUGE
OUTLET WATER TEMP
Tout
INSULATED PIPING
RECIRCULATION LOOP (IF REQUIRED)
TO ELECTRIC WATER HEATER FOR OPTIONAL THROUGHFLOW LOSS TEST
EXPANSION TANK
INLET WATER TEMP
Tin
TEST BOILER
FLOW INDICATING DEVICE
FLOW ADJUSTMENT VALVE
PUMP
WATER FILL



<u>Figure 6B Suggested Piping Arrangement for Idling Test, Hot Water.</u>

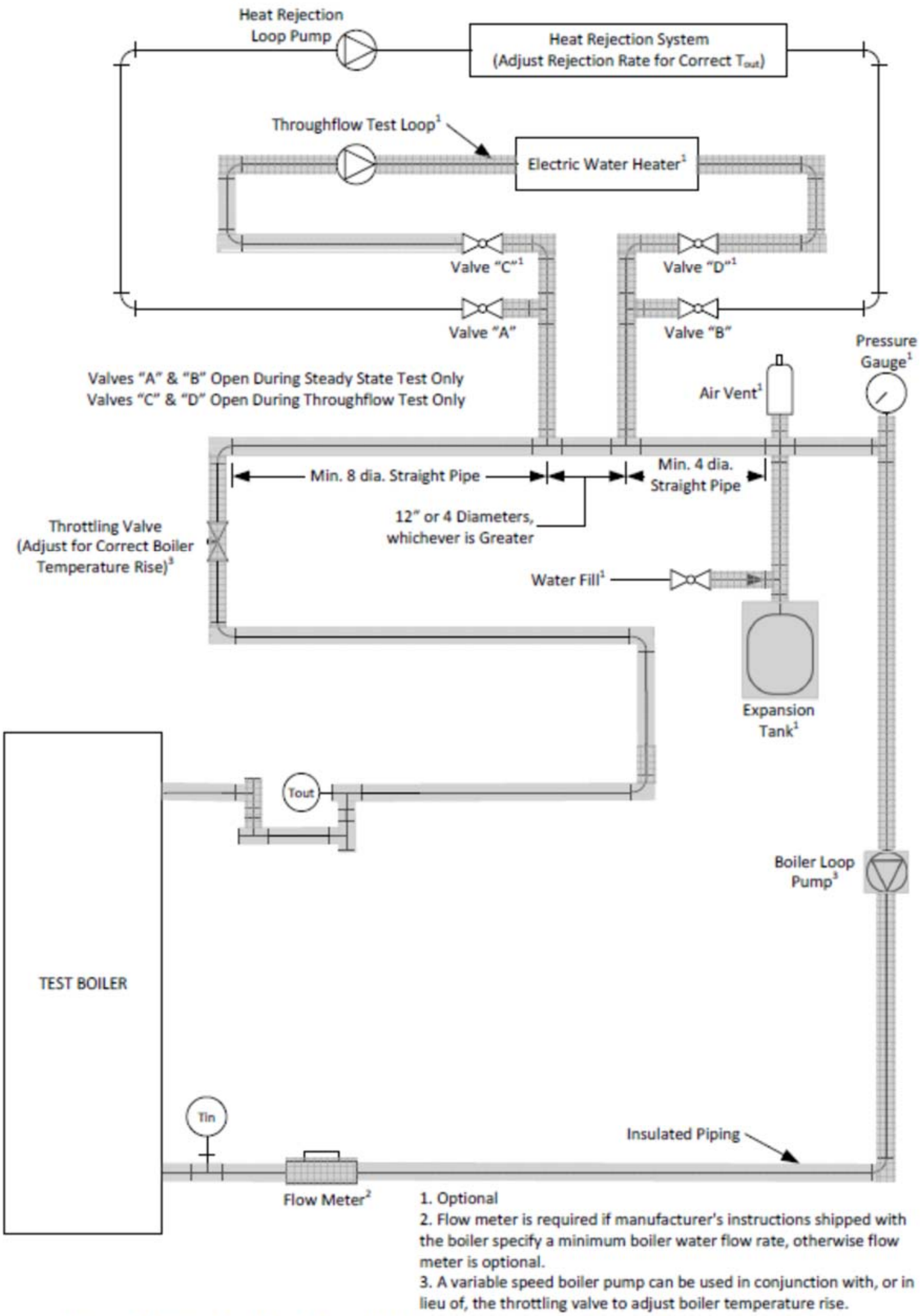
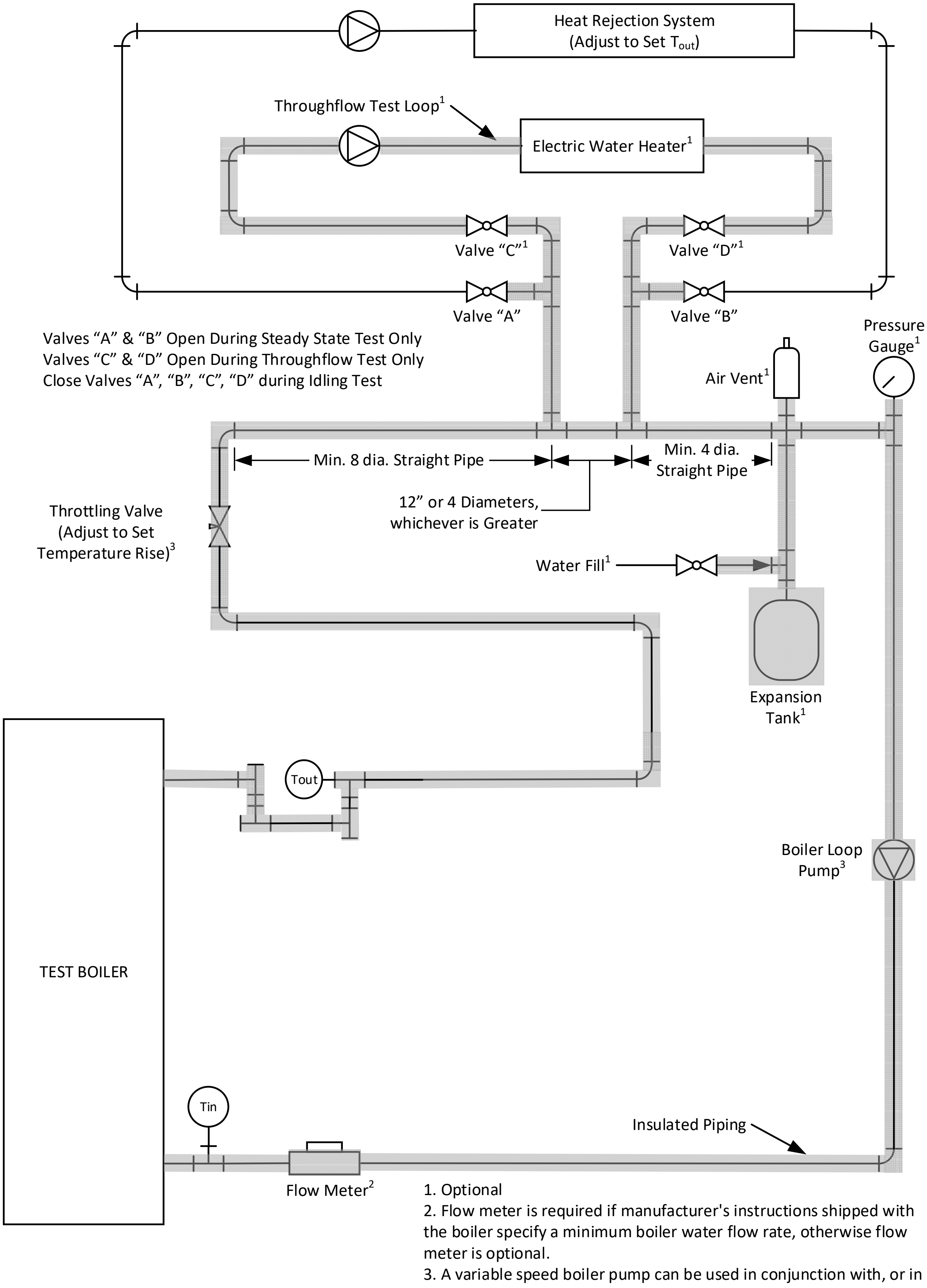


Figure 6C: Optional Combined Piping Arrangement for Hot Water Steady State, Idling Test, and Throughflow Tests



1. Optional
2. Flow meter is required if manufacturer's instructions shipped with the boiler specify a minimum boiler water flow rate, otherwise flow meter is optional.
3. A variable speed boiler pump can be used in conjunction with, or in lieu of, the throttling valve to adjust boiler temperature rise.

Figure 6C: Optional Combined Piping Arrangement for Hot Water Steady State, Idling Test, and Throughflow Tests

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX C
INTERPOLATION AND EXTRAPOLATION OF TEST RESULTS

This appendix provides background information on the interpolation and extrapolation methods used in Section 12.

C.1. Steady-State Output as a Function of Water Flow Rate for Fixed Firing Rate and Boiler Inlet ~~Return~~ Water Temperature (Section 12.1)

Section 12.1 provides a means to compute the change in steady-state output rate ($\dot{q}_{out}$) as a function of water flow rate ($\dot{m}_{water}$) for fixed firing rate ($\dot{q}_{in}$) and inlet ~~return~~ water temperature (I~~R~~WT) (that is, the temperature of the water entering the boiler). The direction of this extrapolation is shown by the dotted black arrows in Figure C.2.

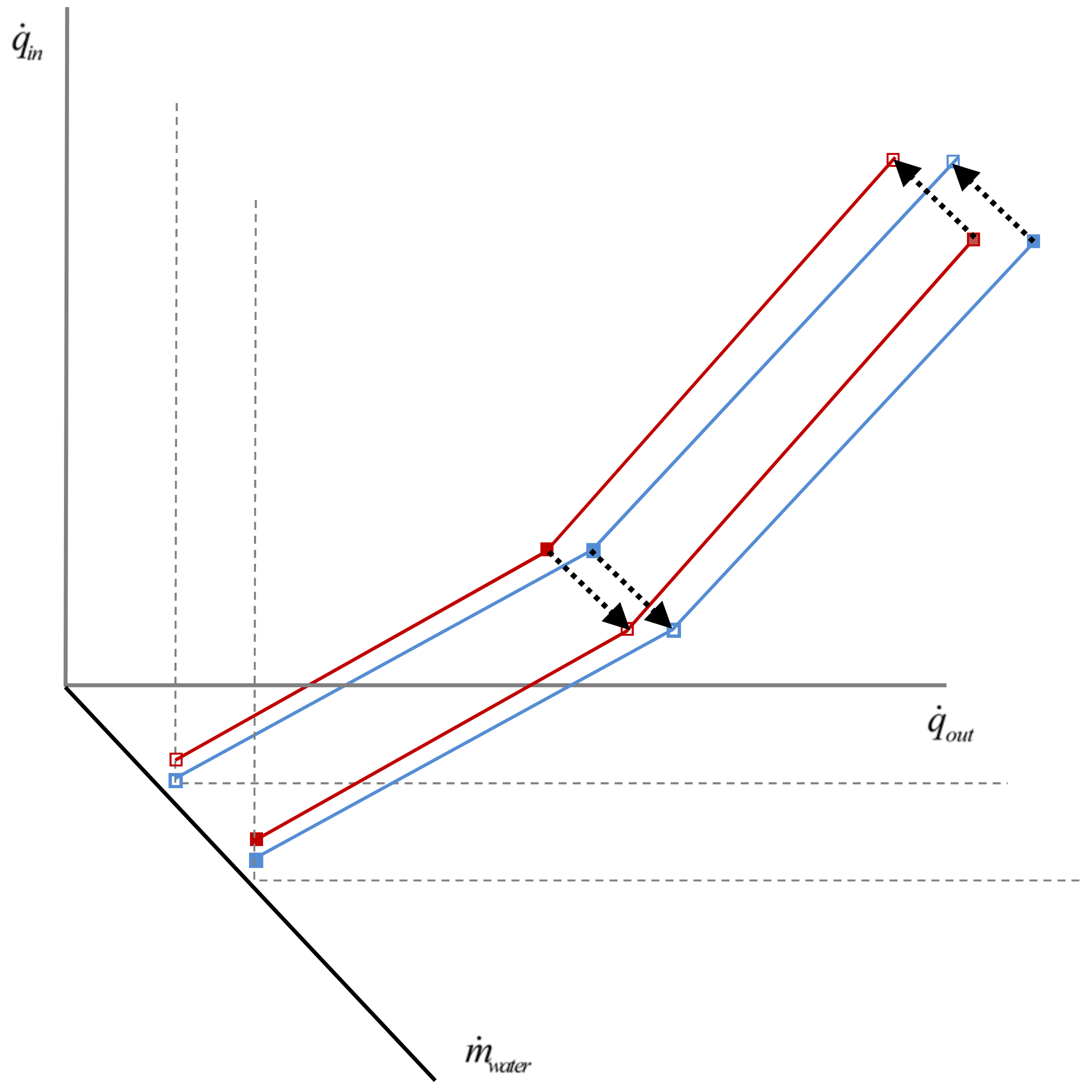


Figure C.1. Steady-state output as a function of water flow rate for a fixed firing rate and boiler inlet ~~return~~ water temperature.

C.2. Steady-State Output as a Function of Inlet ~~Return~~ Water Temperature for a Fixed Firing Rate and Water Flow Rate

Section 12.2 provides a means to compute the change in steady-state output rate ($\dot{q}_{out}$) as a function of ~~RWT~~IWT for fixed firing rate ($\dot{q}_{in}$) and water flow rate ($\dot{m}_{water}$). The direction of this interpolation or extrapolation is shown by the dotted black arrows in Figure C.3.

The calculations first determine the temperature at which condensation begins, since the rate of change of efficiency as a function of inlet ~~return~~ water temperature changes at that point. The primary assumptions implicit in the calculation of the ~~RWT~~IWT at which condensation begins are:

- That condensation begins when the inlet ~~return~~ water temperature is 5°F (2.8°C) below the saturation temperature of the flue gases. In any boiler, the water in the flue gas starts to condense on the surface of the boiler heat exchanger when the surface temperature on the flue gas side falls below the saturation temperature. Since most of the heat transfer resistance is on the flue gas side, the surface temperature is typically very close to the boiler water temperature. Lab tests of a condensing boiler by one of the general interest members of the committee suggest that the rate of condensation is high enough for there to be a flow of condensate from the boiler when the inlet ~~return~~ water temperature falls 5°F (2.8°C) below the saturation temperature.
- That a "typical" heating season combustion air absolute humidity of 0.004 lbm moisture/lbm dry air (0.004 kg moisture/kg dry air) is a reasonable value for comparative ratings. (This corresponds to about 76% relative humidity at 40°F and 100% ~~RH~~ R_h at 33°F.)

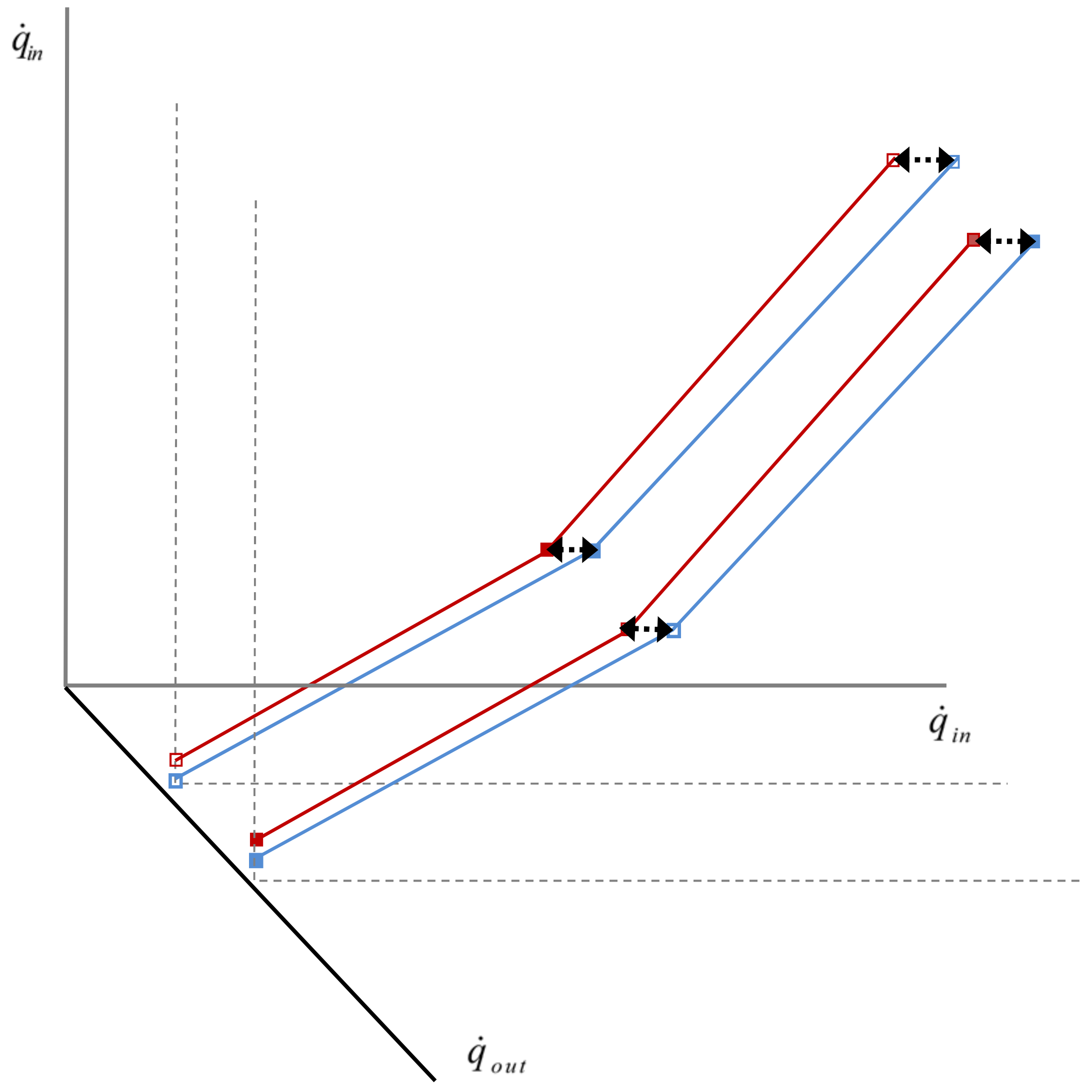


Figure C.2. Steady State Output as a Function of Inlet~~Return~~ Water Temperature for a Fixed Firing Rate and Water Flow Rate

At RWTs above the transition to condensing operation, two different methods may be used to compute output as a function of ~~RWT~~ IWT, depending on how many tests are conducted on the product.

- If only one test is conducted - at the high temperature rating point – then output at other RWTs is computed using the NTU-effectiveness method. The primary assumptions implicit in the calculations are:
  - That the number of transfer units (NTU = UA/C_{min}) does not change as the ~~RWT~~ IWT changes, for constant firing rate and water flow rate. UA is dominated by the flue-gas side convection coefficient, which is essentially constant for a constant firing rate. Moreover, changing the ~~RWT~~ IWT does not significantly change the water side convection coefficient. The flue gas heat capacity rate (C_{min}) is essentially constant because the firing rate is held constant.
  - That the effectiveness of the boiler heat exchanger is constant for constant firing rate and water flow rate. Effectiveness is a function of NTU and of the ratio of the heat capacity rates, $C_r = C_{flue\ gas}/C_{water}$. NTU is constant, as described in the previous bullet. C_r is also constant, because neither the flue gas heat capacity rate ($\dot{m}c_p$) nor the water heat capacity rate changes when the firing rate and water flow rate are held constant.
  - That the jacket loss rate does not change as ~~RWT~~ IWT changes. This assumption is necessitated because the effect of ~~RWT~~ IWT on jacket loss may vary with boiler type, for example, depending on whether the boiler is a fire tube or water tube type (water or flue gas on the outside of the heat exchanger) or whether it is a wet-backed or wet-based boiler or a dry-backed or dry-based boiler.

These assumptions allow output at other inlet ~~return~~ water temperatures down to the transition to condensing operation to be computed as described below.

By definition, the heat transferred from the flue gas to the water is equal to the effectiveness times the maximum possible heat transfer, and the output is this heat transfer minus the jacket loss. The maximum possible heat transfer is the heat capacity rate of the lower capacity fluid multiplied by the maximum temperature difference in the heat exchanger (the temperature of the entering hot fluid minus the temperature of the entering cold fluid).

$$\dot{q}_{out,ss}\left\langle T_{return}\right\rangle = \varepsilon\left[\left(\dot{m}c_p\right)_{flue\,gas}\left(T_{flame,nom}-T_{return}\right)\right]-\dot{q}_{jacket,ss}$$

$$\dot{q}_{out,ss}\left\langle T_{in}\right\rangle = \varepsilon\left[\left(\dot{m}c_p\right)_{flue\,gas}\left(T_{flame,nom}-T_{in}\right)\right]-\dot{q}_{jacket,ss}$$

By definition, effectiveness is equal to the actual heat transfer divided by the maximum possible heat transfer. The effectiveness can be determined from the observed performance of the heat exchanger at the high temperature rating condition:

$$\varepsilon = \frac{\dot{q}_{in,ss,high\ fire}\left(\frac{100-L_f}{100}\right)}{\left(\dot{m}c_p\right)_{flue\ gas}\left(T_{flame,nom}-T_{return,rated,high}\right)}$$

$$\varepsilon = \frac{\dot{q}_{in,ss,high\ fire}\left(\frac{100-L_f}{100}\right)}{\left(\dot{m}c_p\right)_{flue\ gas}\left(T_{flame,nom}-T_{in,rated,high}\right)}$$

Substituting this expression for effectiveness into the expression for output gives:

$$\dot{q}_{out,ss}\left\langle T_{return}\right\rangle = \left[\frac{\dot{q}_{in,ss,high\ fire}\left(\frac{100-L_f}{100}\right)}{\left(\dot{m}c_p\right)_{flue\ gas}\left(T_{flame,nom}-T_{return,rated,high}\right)}\right]\left(\dot{m}c_p\right)_{flue\ gas}\left(T_{flame,nom}-T_{return}\right)-\dot{q}_{jacket,ss}$$

$$\dot{q}_{out,ss}\left\langle T_{in}\right\rangle = \left[\frac{\dot{q}_{in,ss,high\ fire}\left(\frac{100-L_f}{100}\right)}{\left(\dot{m}c_p\right)_{flue\ gas}\left(T_{flame,nom}-T_{in,rated,high}\right)}\right]\left(\dot{m}c_p\right)_{flue\ gas}\left(T_{flame,nom}-T_{in}\right)-\dot{q}_{jacket,ss}$$

Simplifying gives:

$$\dot{q}_{out,ss}\left\langle T_{return}\right\rangle = \dot{q}_{in,ss}\left(\frac{100-L_f}{100}\right)\left(\frac{T_{flame,nom}-T_{return}}{T_{flame,nom}-T_{return,rated,high}}\right)-\dot{q}_{jacket,ss}$$

$$\dot{q}_{out,ss}\left\langle T_{in}\right\rangle = \dot{q}_{in,ss}\left(\frac{100-L_f}{100}\right)\left(\frac{T_{flame,nom}-T_{in}}{T_{flame,nom}-T_{in,rated,high}}\right)-\dot{q}_{jacket,ss}$$

This results in a linear change in output as a function of I~~R~~WT between the high temperature test point and the transition to condensing operation.

- If more than one test is conducted between the high temperature rating point and the transition to condensing operation, output is interpolated linearly between adjacent test points. (Output at the transition to condensing operation is computed using the NTU-effectiveness method described above, and output between the transition and the last non-condensing I~~R~~WT tested is interpolated linearly between these two points).

At I~~R~~WTs below the transition to condensing operation, output is interpolated linearly.

- If only one test is conducted -- at the low temperature rating point -- output is interpolated linearly between this point and the output at the transition to condensing operation, which is determined as described above.
- If more than one test is conducted, output is computed linearly between adjacent pairs of points. The output at the transition to condensing operation is computed as described above.

The following example illustrates the agreement between this interpolation/extrapolation technique and measured data. Figure C.4 shows typical published data for performance of a condensing boiler. Figures C.5 shows the data taken from this figure re-plotted as fractional output (output/full load input) vs. I~~R~~WT for the three separate fixed input rates (100%, 60%, and 5%). Note that the water flow rate is also nearly constant for each of these three lines (though different for each line) because the data are for a fixed temperature rise and input rate.

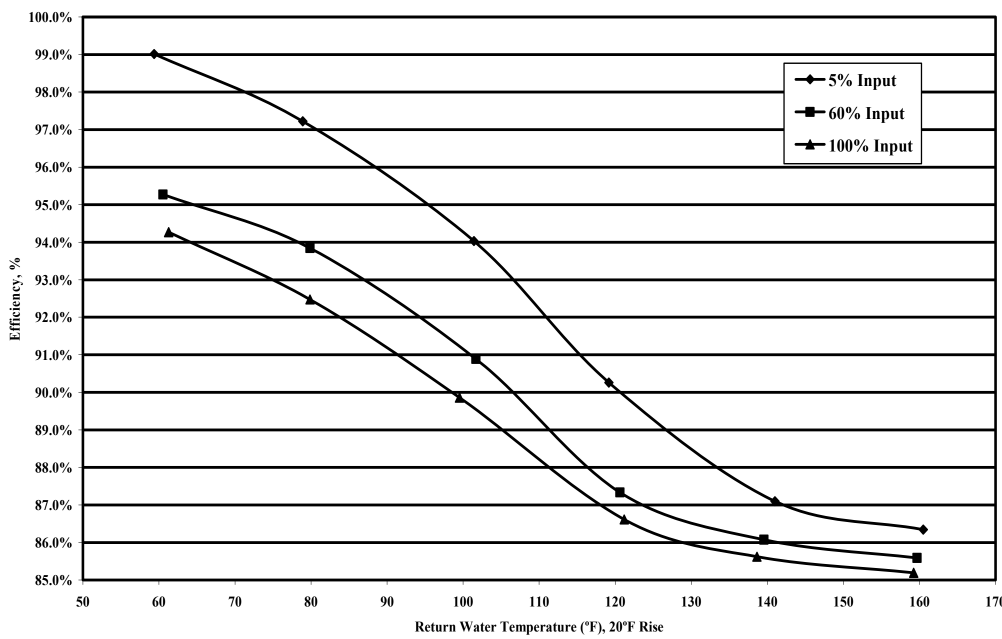


Figure C.3. Manufacturer's data for efficiency as a function of inlet ~~return~~ water temperature (constant 20°F (11.1°C) rise)

The temperature at which this boiler transitions to condensing operation was calculated using the procedures in the standard together with the target flue gas O_2 concentrations (and therefore, percent excess air) as a function of firing rate from the manufacturer's installation, operation, and maintenance manual. The transition temperatures are approximately 125.3°F (51.8°C) at a firing rate of 100%, 124.7°F (51.5°C) at 60%, and 121.4°F (49.7°C) at 5%. The output at the transition point was computed as described in this section. A straight line was drawn from the highest I~~R~~WT tested to the transition point. Another straight line was drawn from the transition point to the 80°F

(26.7°C) I~~R~~WT point. The actual performance at the intermediate water temperatures (~140°F (60°C) I~~R~~WT and ~100°F (37.8°C) I~~R~~WT) as read from the published chart is very close to that estimated from the linear relationship, as shown in Figure C.5 and Table C.1.

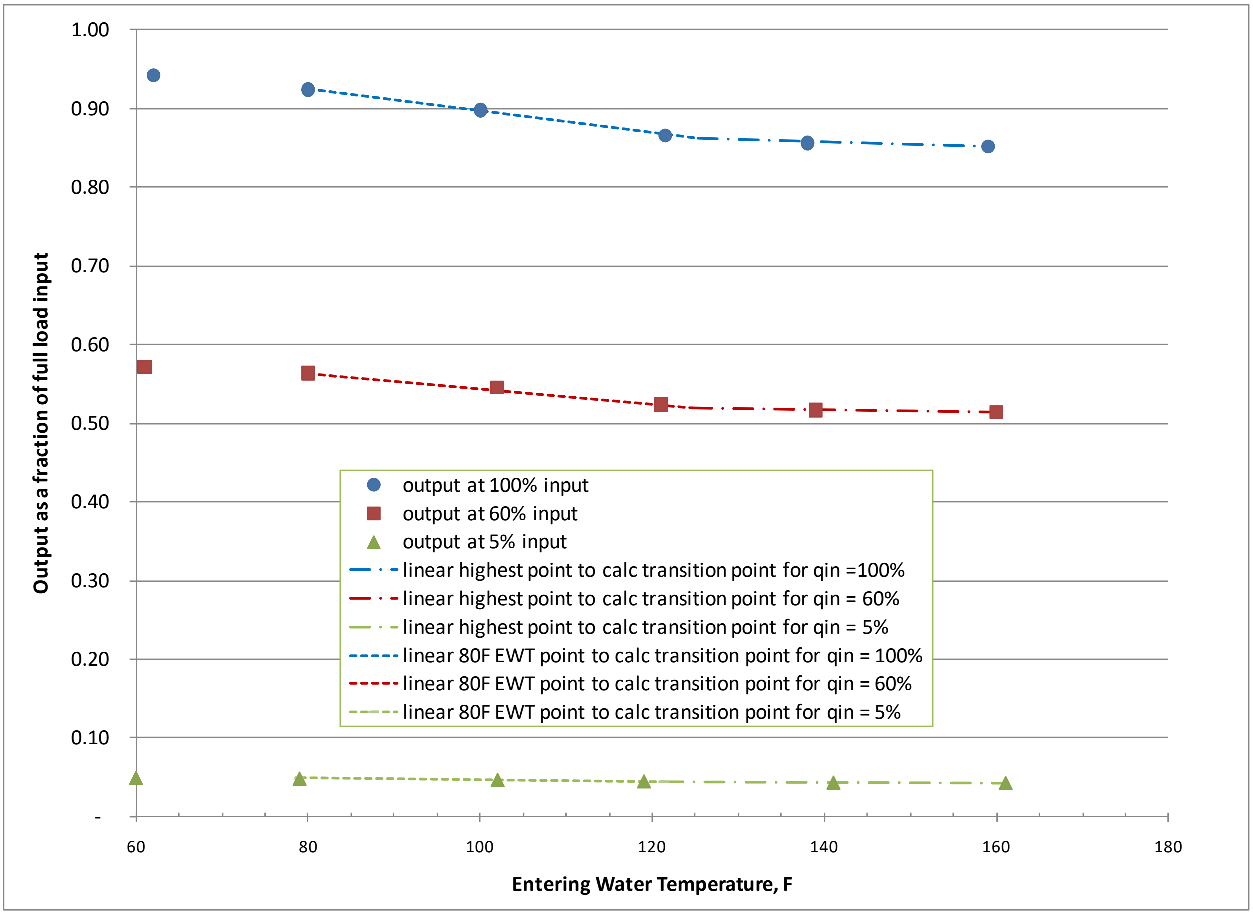


Figure C.4. Manufacturer's data re-plotted as fractional output vs. inlet ~~return~~ water temperature, for fixed firing rate and temperature rise (~fixed flow rate).

Table C.1. Comparison of actual and calculated output.

Firing rate	I~~R~~WT read (from manufacturer's chart)	Actual output (read from manufacturer's chart)	Output calculated using Std 155 methods	Deviation
100%	138	0.85600	0.85820	0.00220
100%	100	0.89800	0.89662	-0.00138
60%	139	0.51660	0.51740	0.00080
60%	102	0.54540	0.54202	-0.00338
5%	141	0.04355	0.04353	-0.00002
5%	79	0.04700	0.04603	-0.00097

Figure C.5 shows that output does not increase as rapidly from 80°F (26.7°C) I~~R~~WT to 60°F (15.6°C) I~~R~~WT as it does from the transition point to 80°F (26.7°C). Once the I~~R~~WT is low enough that all the moisture in the flue gas has condensed, lowering it further does not produce as much gain in efficiency. If the 60°F I~~R~~WT point were used in the interpolation method instead of the 80°F (26.7°C) I~~R~~WT, the output at RWTs between 60°F (15.6°C) and the transition point would be underestimated (conservative). On the other hand, if the linear relationship between the 80°F (26.7°C) I~~R~~WT point and the transition point were extrapolated back to 60°F (15.6°C) I~~R~~WT, it would overestimate the output. This standard does not allow extrapolation below 80°F (26.7°C) I~~R~~WT.

C.6. Part Load Performance When Cycling Below Minimum Steady State Input Rate at Fixed Water Flow Rate and Fixed Outlet (or Inlet~~Return~~) Water Temperature

Section 12.6 provides a means to compute the performance of a boiler when it is cycling to meet a load lower than its minimum steady-state output rate. The direction of this interpolation is shown in Figure C.10.

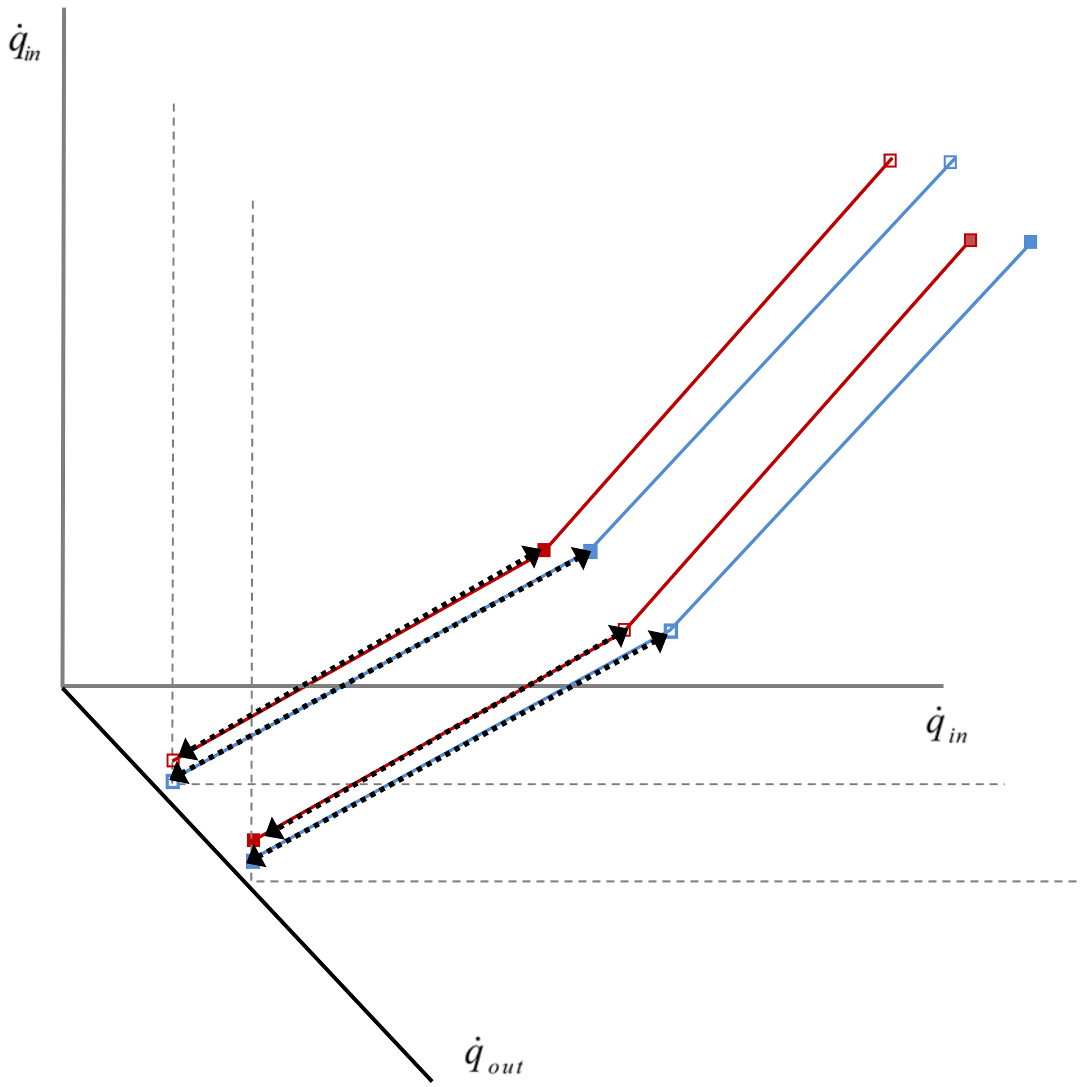


Figure C.5. Part load performance when cycling below minimum steady state input rate at fixed water flow rate and fixed outlet (or inlet ~~return~~) water temperature

C.7. Part Load Performance When Modulating Between Minimum Steady State Input Rate and Maximum Steady State Input Rate at Fixed Outlet (or Inlet~~Return~~) Water Temperature and with Fixed Water Flow Rate or Variable Water Flow Rate with Fixed Temperature Rise

Section 12.7 provides a means to compute the performance of a boiler when it is modulating to meet a load between its maximum and minimum steady-state output rates. The direction of this interpolation is shown in Figure C.17.

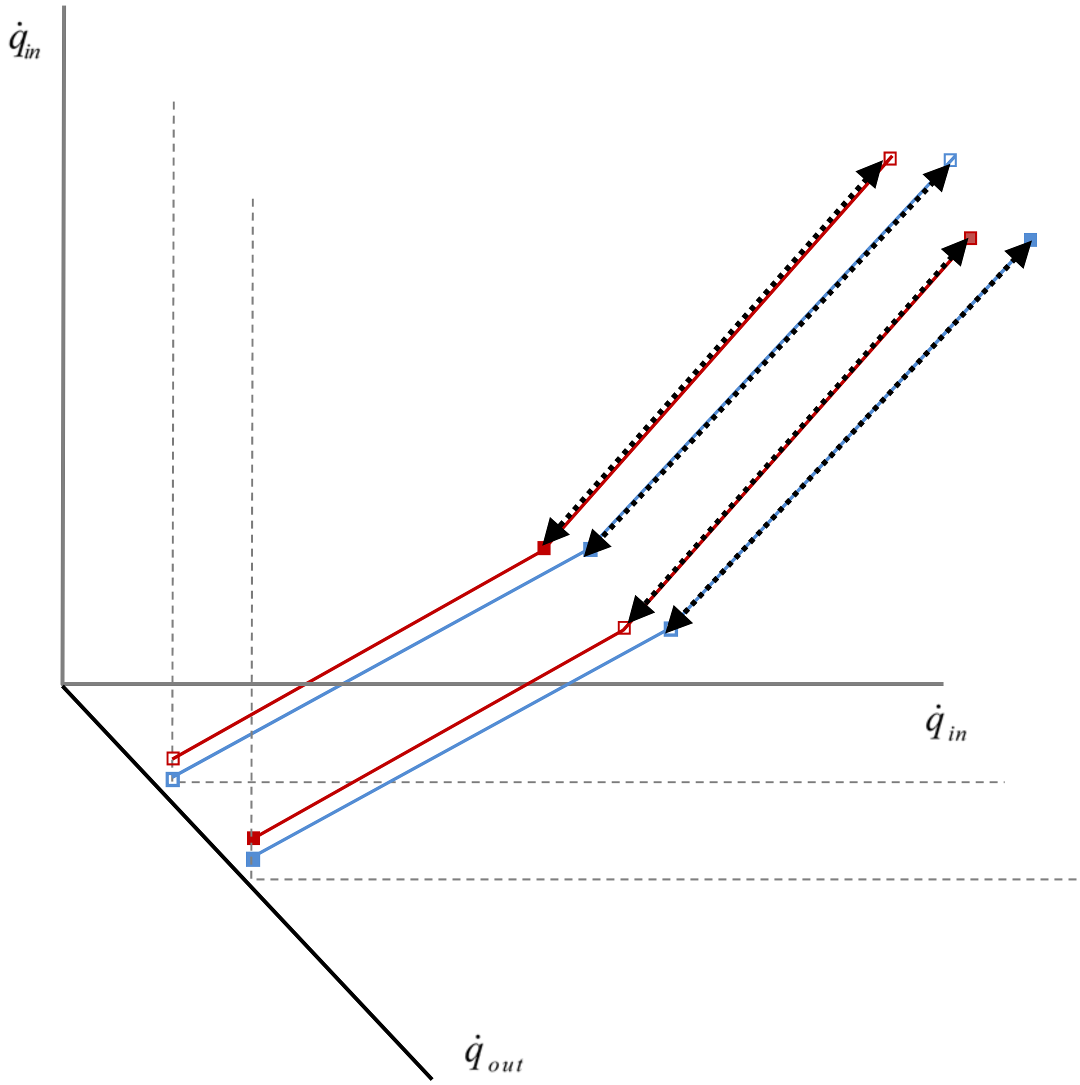


Figure C.6. Part load performance when modulating between minimum steady state input rate and maximums steady state input rate at fixed water flow rate and fixed outlet (or inlet ~~return~~) water temperature, or at variable flow rate and fixed temperature rise.

For a boiler with a two-stage burner, performance when meeting a load that is intermediate between the high and low fire outputs is computed by linear interpolation between these two points on an input-output plot.

For a step-modulating burner, two options are available. Linear interpolation between the high fire and low fire points may be used, as for two-stage burners, if only a high fire and low fire test are conducted. This is expected to be conservative because efficiency often drops somewhat at the lowest firing rates where more excess air is often needed to provide complete combustion. Thus, straight line interpolation between these two input-output points will likely result in a higher estimate of input for intermediate points than would be determined through tests.

The second option a manufacturer has is to conduct tests at intermediate firing rates. In that case, performance is determined by linear interpolation between adjacent pairs of test points. Figure C.18 illustrates the generally linear input-output relationship between high fire and low fire for a step-modulating boiler. This example uses the data read from Figure C.4 but plots them in the form of input vs. output for each <u>inlet</u> ~~return~~ water temperature.

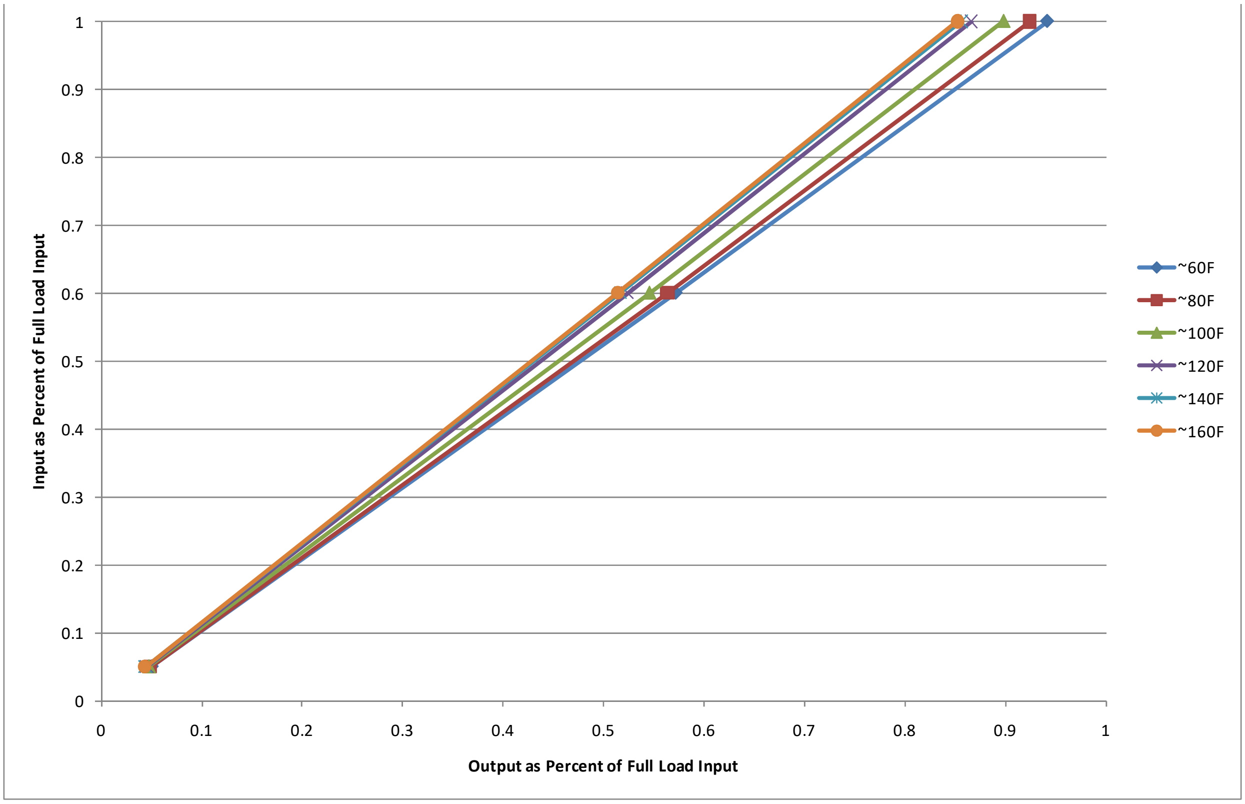


Figure C.7. Input vs. output from 5% to 100% firing rate for a fixed 20°F (11.1°C) rise and a range of <u>inlet</u> ~~return~~ water temperatures. The data are taken from Figure C.4.

Table C.2. Comparison of intermediate firing rate test input to input required to provide the same output computed by interpolation between the high and low fire test points.

<u>I</u>~~R~~WT, F	<u>I</u>~~R~~WT, C	Output at 60% input from chart	Input required to provide this output based on interpolation between 5% and 100% points	Deviation from 0.6
~60F	~15.6	0.57180	0.60595	0.00595
~80F	~26.7	0.56340	0.60867	0.00867
~100F	~37.8	0.54540	0.60638	0.00638

~120F	~48.9	0.52380	0.60398	0.00398
~140F	~60.0	0.51660	0.60314	0.00314
~160F	~71.1	0.51360	0.60252	0.00252