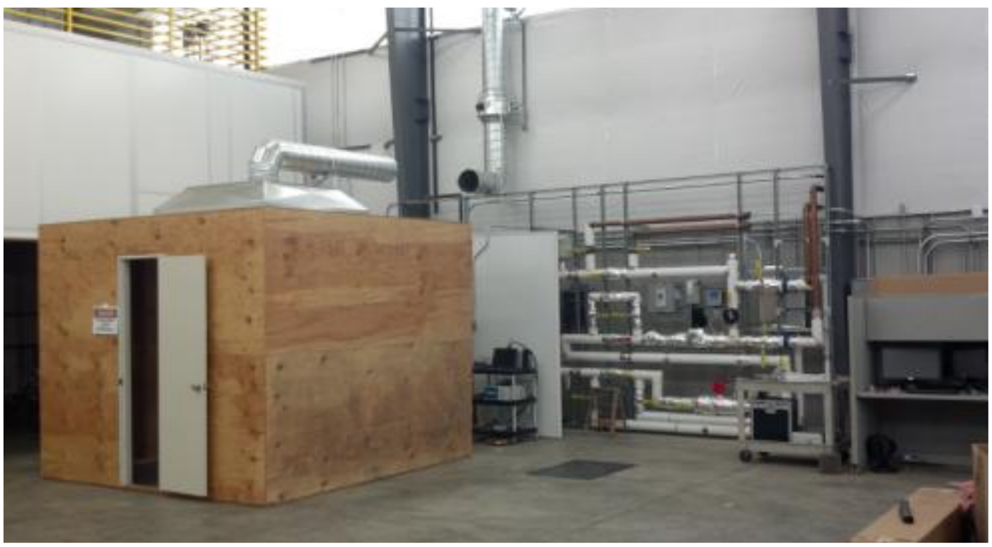
Boiler Research Project - ASHRAE Standard 155P

ET Project Number: ET11PGE5271



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FIGURES

TABLES

CONTENTS

EXECUTIVE SUMMARY

PROJECT GOAL

The main goal of this research project was to support the development of ASHRAE Standard 155P "Method of Testing for Rating Commercial Space Heating Boiler Systems." Standard 155P has not been published yet by ASHRAE. The 2010-07-26 WORKING DRAFT of the Standard was used to guide this research project.

PROJECT DESCRIPTION

A boiler test facility was constructed at PG&E's Applied Technology Services (ATS) to test commercial hot water boilers. The facility includes a boiler test chamber, closed loop piping system, a plate and frame heat exchanger and cooling tower for rejecting heat, laboratory grade sensors for measuring temperatures, flows, pressures, etc., and a data acquisition system. The tests described in Standard 155P were run on three commercial boilers: a single stage, non-condensing boiler and two modulating, condensing boilers. The Standard 155P tests run included steady state tests at high and low fire and high and low temperature, idling tests, and through flow loss tests.

PROJECT FINDINGS/RESULTS

The testing showed that the methods in Standard 155P are fundamentally sound but it also led to several key recommendations for improving the Standard such as the need to verify uniform water temperature at the boiler outlet sensor location. The testing also revealed a number of unforeseen challenges in achieving the testing tolerances required in the Standard and several lessons learned that should allow future testing at ATS and elsewhere to achieve the required testing tolerances.

The efficiency results from the testing should not be considered official ratings because not all of the Standard 155P requirements were met for a valid rating. For example, the room temperature varied more than 155P allows during some of the testing. However, the data from the testing performed does represent a valuable data set of independent 3rd party test data collected in a controlled laboratory setting, with high accuracy instrumentation.

In addition to the Standard 155P tests, supplemental testing was performed to explore options and to solve issues that arose. This testing included transient response, internal controls, and temperature stratification (see Appendix I - Supplemental Evaluations). These supplemental tests also led to several key recommendations for modifications to the standard and recommendations for future research.

Another objective was to test the spreadsheet developed by the 155P committee for reporting results and to suggest modifications to the spreadsheet. This testing represented the first use of the spreadsheets and led to several important recommendations on it.

Another objective was to develop impartial performance data on a range of different boiler types for use in energy modeling and for other purposes. The data collected from this research was used to develop detailed DOE-2 boiler models for condensing and non-condensing boilers which can now be used by utility incentive programs, design engineers, energy modelers and others.

INTRODUCTION

Commercial boilers are typically rated using the AHRI BTS-2000 rating standard. Efficiency ratings using this standard can be misleading because it only tests boilers at full load and allows boilers to be tested at unrealistic entering water temperatures (e.g. non-condensing boilers can be tested with 40^{o}F entering water). After years of development, ASHRAE Standards Project Committee 155P has a working draft procedure for testing commercial space heating boiler systems. This procedure, Standard 155P, provides a method to determine full load and part load efficiency at realistic water temperatures. Because boilers most often run at part load, developing standards which fully encompass the operating range is important. Developing these requirements will help shift the market towards more efficient equipment by providing customers with a better understanding of the boiler operation through improved efficiency ratings.

PG&E's Applied Technology Services provided the facility and personnel needed to support the continued development of Standard 155P. A boiler test apparatus was constructed to perform the testing described in Standard 155P. The apparatus was limited to natural gas fired hot water boilers to minimize construction and operation costs. The general conclusions in this report are applicable to all types of boilers.

ASSESSMENT OBJECTIVES

Test the steady state thermal efficiency, steady state combustion efficiency, idling energy input rate, and throughflow loss of individual commercial space heating boilers following ASHRAE Standard 155P in order to support development of the test standard. Include sensitivity testing to address questions regarding selected test specifications. Identify problems with the test procedures, opportunities to simplify, and any potential to intentionally skew results.

Requirements of Standard 155P may eventually be incorporated into efficiency codes and shift the market towards more efficient equipment.

DEFINITIONS AND NOMENCLATURE

RWT	Return Water Temperature. If the boiler has a recirculation pump then this is the temperature on the system side of the recirculation loop, not on the boiler side.
Tr	System return temperature. Same as RWT.
HWRT	Hot Water Return Temperature. Same as RWT.
EWT	Entering Water Temperature. If the boiler has a recirculation pump then this is the temperature on the boiler side of the recirculation loop, not on the system side.

Ti boiler inlet temperature. Same as EWT.

LWT Leaving Water Temperature. Water temperature leaving the boiler.

To system/boiler outlet temperature. Same as LWT.

PLR Part Load Ratio. The load on a boiler, typically expressed as a percentage of the maximum output capacity of the boiler.

thermal efficiency: the heat absorbed by the water or the water and steam divided by the sum of the heat value in the fuel burned and the heat equivalent of the electrical input to electrical equipment such as burners, blowers, controls, recirculating pumps, and heavy oil heaters.

combustion efficiency: 100% less the losses due to (1) dry flue gas, (2) incomplete combustion, and (3) moisture formed by combustion of hydrogen.

See Standard 155P Section 3 for additional definitions and nomenclature.

TECHNOLOGY/PRODUCT EVALUATION

All testing was performed in a laboratory setting at PG&E's Applied Technology Services in San Ramon. The objective was not to compare specific products or manufacturers, but rather to compare a range of boilers against the requirements in Standard 155P to assist ASHRAE in the continued development of the Standard.

Test units were limited to hot water, natural gas fired boilers. The design input limit for the test apparatus is 1,500,000 Btu/h. All units were installed per the manufacturer's installation and operations manuals and tuned by factory trained service technicians provided by the local representatives for the boiler manufacturers.

Table 1 contains a summary of the specifications for the test units, including the electric water heater for the throughflow tests.

TABLE 1. SUMMARY OF TEST UNITS

Unit #	Type	Input (Btu/h)	Turndown
1	Atmospheric copper fin tube	715,000	single stage
2	Condensing, cast iron	600,000	5:1
3	Condensing, stainless steel	1,500,000	20:1
Throughflow Heater (Electric)	Electric	~120,000	Fully Modulating

Test Unit 1 was an atmospheric copper fin tube boiler. It had a simple on/off controller and a rated energy input of 715,000 Btu/hr. It also included an internal recirculation pump to maintain minimum flow while the boiler was firing. No tuning was performed on this Unit.

Test Unit 2 was a condensing cast iron boiler. It had a turndown ratio of 5:1 and a rated energy input of 600,000 Btu/hr. The minimum/maximum flow rates are 10/100 GPM. The minimum/maximum ΔT across the heat exchanger are 20/100 °F. There is no internal recirculation pump. Tuning was based on CO_2% in the flue gas, and was matched to manufacturer specifications at high fire and at low fire using redundant flue gas analyzers (Testo 330-2 and Lancom III). Tuning was performed by Herb Bell of Cal Hydronics.

Test Unit 3 was a condensing stainless steel boiler. It had a turndown ratio of 20:1 and a rated energy input of 1,500,000 Btu/hr. The minimum recommended flow is 25 GPM. There is no internal recirculation pump. Tuning was based on flue gas composition, matching O_2%, CO (ppm), and NOx (ppm) to manufacturer specifications at several firing rates over the operating range of the boiler. The unit was tuned by Luke Hoover of Southland Industries. The Unit was tuned according to the Lancom III flue gas analyzer. At 100% firing rate, parameters were adjusted by manually adjusting the intake valve. At all other firing rates, parameters were adjusted by changing the voltage supplied to the VFD controlling the intake fan.

Units 2 and 3 were forced draft, with the intake fans connected to a VFD controlled by the boilers internal controller.

TECHNICAL APPROACH/TEST METHODOLOGY

TEST CONDITIONS

Test conditions will follow ASHRAE Standard 155P Section 7. Test conditions for both steady state thermal efficiency and combustion efficiency tests are the same. A brief description of test conditions specified in the standard follows, but does not include all test conditions outlined by the standard. Significant deviations during the PG&E testing are noted.

For all tests, the boiler will be erected in accordance with the manufacturer's directions. The test gas shall be natural gas. Based on the standard, the actual higher heating value (HHV) shall be determined to an accuracy of ± 1% by use of a calorimeter, gas chromatography, or by using bottled gas of a known calorific value. For our purposes, the HHV was determined using data from the PG&E California Gas Transmission website as described in Appendix B. The high fire test shall be conducted at 100% ±2% of the boiler manufacturer's maximum input specified on the rating plate of the packaged boiler or boiler-burner unit. The low fire test where required by Section 4 shall be conducted at 100% ± 2% of the boiler manufacturer's minimum input specified on the rating plate of the packaged boiler or boiler-burner unit. Optional intermediate fire tests for a step-modulating boiler may be conducted at up to three input rates between low and high fire.

STEADY STATE THERMAL EFFICIENCY AND COMBUSTION EFFICIENCY TEST CONDITIONS

The flue gas temperature will not vary from the initial test reading by more than the values shown below in Table 2 at any time during the test:

TABLE 2. FLUE GAS TEMPERATURE DURING STEADY STATE TESTS

Temperature at start of test	Allowable variation in temperature
	Natural gas
°F	°F
T ≤300	5.0
300< T ≤400	7.0
400< T ≤500	9.0

The room air temperature and inlet air temperature will be between 65°F and 100°F at all times during the test, except low return water temperature tests where temperatures will not exceed 85°F. The room air temperature and inlet air temperature shall not differ by more than 5°F at any time during the test. The relative humidity shall not exceed 80%.

The oil or power gas burner shall be adjusted to within ± 0.1 percentage points of the carbon dioxide specified by the manufacturer. The maximum variation during a test shall be ± 0.1 percentage points. A gas burner shall not produce carbon monoxide exceeding 0.04% (air free basis).

The high water temperature test temperature rise (Tout-Tin) shall be 40°F ±4°F, and the outlet temperature will be 180°F ± 5°F at all times during the test. The low water temperature test temperature rise (Tout-Tin) shall be 40°F ±4°F, and the outlet temperature shall be 120°F ±2.5°F at all times during the test. The optional water temperature test temperature rise (Tout-Tin) shall be 40°F ±4°F. The outlet temperature shall be maintained within ±2.5°F of the selected temperature at all times during the test. For all low fire and intermediate fire tests, the water mass flow rate shall be within ± 2% of the flow rate required to achieve a test rig temperature rise of 40 ºF at the required firing rate.

IDLING TEST CONDITIONS

The water flow rate shall be the full fire steady state test flow rate ±15%. The water temperature controller's differential shall be no greater than 10°F. The setpoint of the controller shall be adjusted so that the midpoint of the highest and lowest outlet water temperatures observed over a cycle is as listed in Table 3.

TABLE 3. MIDPOINT TEMPERATURES FOR IDLING TEST

Room temperature	High temperature idle test midpoint temperature	Low temperature idle test midpoint temperature
≤ 75°F	180°F ± 5°F	120°F ± 5°F
> 75°F	105°F ± 5°F above room temperature	45°F ± 5°F above room temperature

Output is not measured, and shall be assumed to be zero.

THROUGHFLOW LOSS TEST CONDITIONS

The water flow rate shall be the full fire steady state test flow rate ±15%. The boiler inlet water temperature will be maintained as listed in Table 4 for the duration of the test.

TABLE 4. BOILER INLET WATER TEMPERATURES FOR THROUGHFLOW TEST

Room temperature	High temperature throughflow test	Low temperature throughflow test
≤ 75°F	180°F ± 5°F	120°F ± 5°F
> 75°F	105°F ± 5°F above room temperature	45°F ± 5°F above room temperature

TEST PLAN

The full test plan is included in the Appendix, but a shortened version is included here.

In general, test procedures follow ASHRAE Standard 155P Section 8. Testing required by Standard 155P includes steady state thermal efficiency, steady state combustion efficiency, and idling tests The required tests are shown in Table 5 below. Other optional tests were performed on select units to support the development of the Standard, described in further detail below. A summary for each test is provided below.

TABLE 5. STANDARD 155P REQUIRED (R) AND OPTIONAL (O) TESTS

	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	Throughfl
Steam or high RWT hot water	R	R	R	R	O	O	O	R	R	O
Other RWT 1***	O	O	O	O	O	O	O	O		
Other RWT 2***	O	O	O	O	O	O	O	O		
Other RWT 3***	O	O	O	O	O	O	O	O		
Other RWT 4***	O	O	O	O	O	O	O	O		
Low RWT hot water	R*	R*	R*	R*	O	O	O	R*	O	O

*Required for low 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 return water temperatures tested at intermediate firing rates.
***When steady-state tests are conducted at 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.

Table 6 shows the completed tests for the three commercial boilers tested.

TABLE 6. SUMMARY OF TESTS FOR EACH TEST UNIT

Test Unit	Steady State Efficiency				Idling Tests		Throughflow Loss
	High Fire High Temp	High Fire Low Temp	Low Fire High Temp	Low Fire Low Temp	High Temp	Low Temp	High Temp
Unit 1	✓		✓		✓	✓	✓
Unit 2	✓	✓	✓	✓	✓	✓	
Unit 3	✓		✓	✓	✓		

SETUP / TUNING

Before beginning testing the boilers were tuned by manufacturers' representatives. The manufacturers' representatives also trained the PG&E test operators on how to operate the boilers. Topics include:

Safety procedures including safe startup and shutdown

Manual control of firing rate – required for steady state testing, particularly at low and intermediate fire

Adjusting internal firing controls (deadband and PID gains)

STEADY STATE THERMAL EFFICIENCY TEST

The system is warmed up until the specified outlet water temperature is met. The burner is adjusted to the required input rate and the water flow rate is set. Data is recorded at no less than 15 minute intervals. Once a state of equilibrium is reached with constant readings during a 30 minute interval, the test period begins and no further burner adjustments are made. The test period is at least two hours.

For condensing boilers, flue condensate is collected for use in calculating combustion efficiency. Flue condensate mass is measured at regular intervals to minimize evaporation loss from the sample.

STEADY STATE COMBUSTION EFFICIENCY TEST

The combustion efficiency test is conducted at the same time as the thermal efficiency test. The test procedure and test conditions are the same as that for the thermal efficiency test described above. Additional data are collected for use in calculating combustion efficiency. Refer to Section 9 of Standard 155P for a list of all data recorded.

IDLING TEST

During the idling test, the burner or heating elements are actuated by a water temperature controller for the duration of the test.

There are 2 potential idling tests for each boiler: high temperature and low temperature. Each idling test can be performed with a cold start or hot start option:

Cold Start – Starting from cold start, begin the idling test (set the flow rate to the required flow and the firing controller to the required setpoint). By recording the data for each cycle after changing the setpoint we can see how many cycles are required to achieve a stable idling energy input rate.

Hot Start - Idle the boiler at a setpoint at least 30°F above the required setpoint for at least 1 hour then change the setpoint to the required setpoint. By recording the data for each cycle after changing the setpoint we can see how many cycles are required to achieve a stable idling energy input rate.

The Cold Start and Hot Start Idling Tests were not required by the standard, but were included in the Test Plan as supplemental tests. The standard only requires a number of "Stabilization Cycles" before the official test period begins.

THROUGHFLOW LOSS TEST

The throughflow loss test is conducted after an extended warm up or one of the other tests to maintain temperature stabilization. The boiler is turned off, valve positions are adjusted to include the electric water heater, and the heater is turned on. The heater output is adjusted until it is able to maintain the outlet water temperature within ± 2°F of the setpoint for a stabilization period of at least one hour. The throughflow test continues 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.

TEST APPARATUS

The Test Apparatus is located inside the PG&E ATS Advanced Technology Performance Lab with access to data acquisition equipment, electricity, gas, water, and drainage. Testing is limited to gas-fired water boilers. The boilers are placed inside a test chamber which provides exhaust ventilation and sufficient air for combustion. The boiler loop is operated as a closed loop system and includes a recirculation loop. Flow rate of the loop is controlled by a VFD on the main pump.

The boiler return water temperature is controlled using a cooling tower and heat exchanger for cooling, and an electric water heater for heating. The cooling tower and heat exchanger are located outside of the building in close proximity to the test apparatus.

The plumbing schematic for the Boiler Test apparatus is shown in Figure 1 below. The schematic indicates the cooling tower has a VFD but it actually does not.

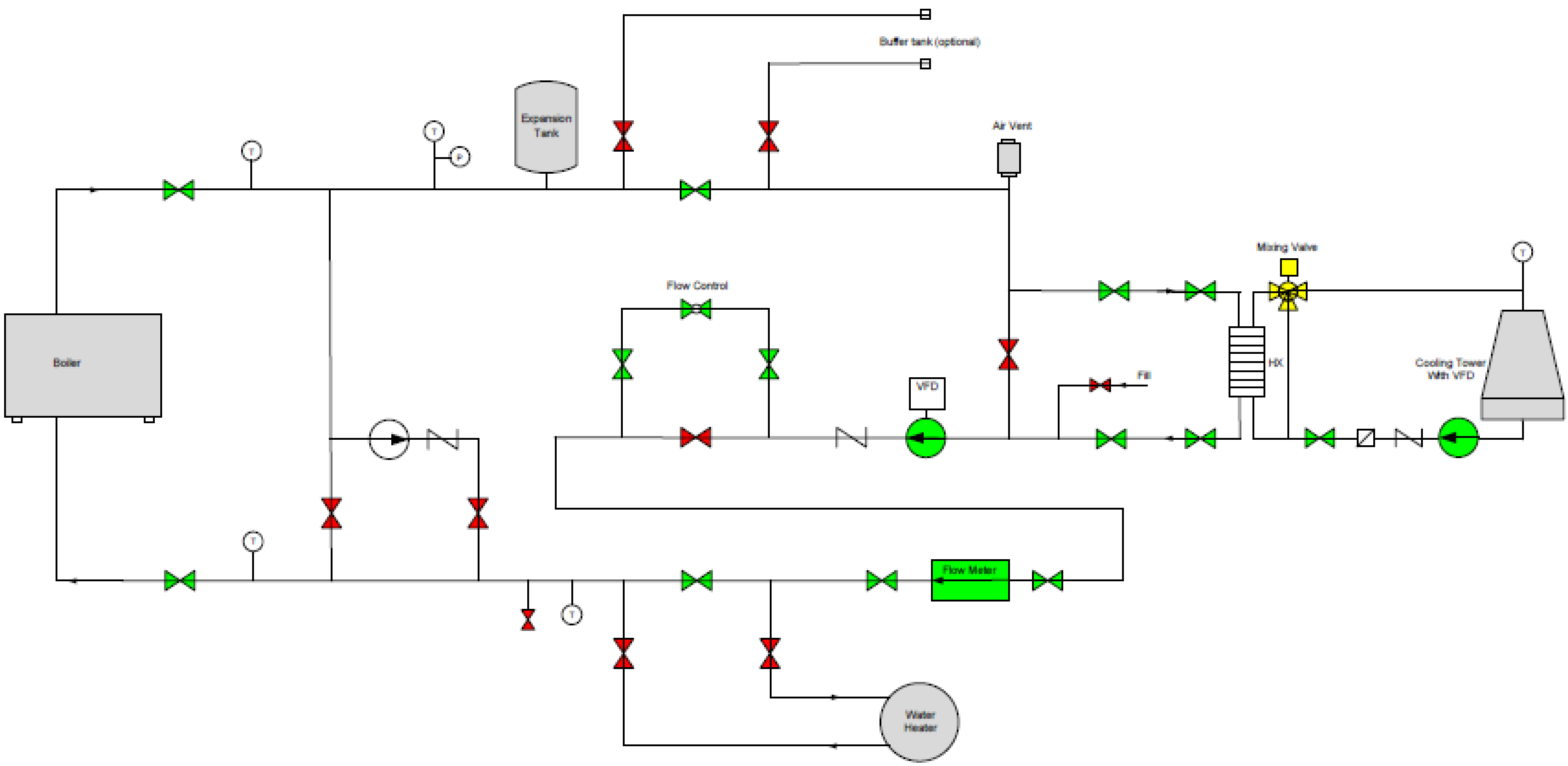


FIGURE 1. BOILER TEST APPARATUS – PIPING SCHEMATIC

FIGURE 2. BOILER TEST APPARATUS

Figure 2 (above) is an overview of the interior portion of the test apparatus, with chamber shifted outward for loop construction. A close up of the uninsulated plumbing is included in Figure 3 (below).

FIGURE 3. BOILER TEST APPARATUS – INTERIOR PLUMBING

FIGURE 4. BOILER TEST APPARATUS – TEST CHAMBER

In Figure 4, the Test Chamber is in place and connected to the exhaust duct. In addition to providing sufficient air for combustion and removing exhaust gases, the chamber easily rolls away to facilitate boiler installation, removal, and maintenance.

Photographs of the exterior portion of the Test Apparatus are included in Figure 4 and Figure 5.

FIGURE 5. TEST APPARATUS – HEAT EXCHANGER AND COOLING TOWER

Hot water supplied by the test unit flows through a heat exchanger, which acts as a variable load in conjunction with a cooling tower. A 3 way mixing valve is controlled by an actuator to vary the flow rate through the heat exchanger while keeping the flow rate through the cooling tower constant. In addition, a gate valve is installed between the cooling tower and cold water inlet to provide manual fine-tuning of the return water temperature.

FIGURE 6. TOWER 3-WAY MIXING VALVE AND BYPASS SYSTEM

The cooling tower and heat exchanger were sized based on operating conditions outlined in Table 7 below.

TABLE 7. COOLING TOWER OPERATING CONDITIONS

Hot side	low temperature
EWT	120
LWT	80
ΔT	40
Btuh	1,500,000
GPM	75
Cold Side	
ΔT	40
HX approach	10
2nd approach	10
EWT	70
LWT	110
GPM	75.00
cooling tower	
range	40
EWT	110
LWT	70
GPM	75.00
ambient	60
approach	10
tons	100

MEASUREMENTS AND INSTRUMENTATION

Section 5 of ASHRAE Standard 155P was used as a guideline for instrumentation requirements. Additional measurements were necessary for the feedback control system. Table 8 shows instrumentation requirements:

TABLE 8. MEASUREMENT AND INSTRUMENTATION REQUIREMENTS (TABLE 2 FROM STANDARD 155P)

Property Measured	Item Measured	Minimum Resolution	Minimum Accuracy
Temperature	Air	1 °F	± 1 °F
	Water	0.2 °F	± 0.2 °F[1]
	Flue Gas	2 °F	± 2 °F
Pressure	Atmospheric	0.05" hg	±0.05" hg
	Steam	0.1" hg	± 0.2" hg
	Fuel Oil	5 psi	± 5 psi
	Firebox	0.01" water	±0.01" water
		0.02" water	±0.02" water
	Vent	0.01" water	±0.01" water
	Flue	0.01" water	±0.01" water
	Gas	0.1" water	±0.1" water
Mass or Volume	Oil	0.25% of hourly rate	± 0.25% of hourly rate
	Gas	0.25% of hourly rate	± 0.25% of hourly rate
	Water	0.5 lbm	± 0.25% of hourly rate
	Condensate	0.5 lbm	± 0.25% of hourly rate
	Separator	1 oz	± 1 oz
	Feedwater	0.5 lbm.	± 0.25% of hourly rate
	Water or Feedwater	0.25% of hourly rate	± 0.25% of hourly rate
	Idling and throughflow test water flow		± 15% of steady state flow rate
Time		1 second/hr	±1 second/hr
Gas Chemistry	Carbon Dioxide	0.2% CO_2	± 0.1% CO_2
	Carbon Monoxide	0.01% CO	± 0.01% CO
Gas Optics	Smoke	1 Bacharach	±½ Bacharach
Calorific value	Heat content of natural gas	2 Btu/ft^3	± 1% of reading
	Heat content of oil		± 1% of reading
Relative Humidity		1.0%	± 2% of full scale
Electrical power	Watts		± 1% of reading
Electrical energy	kWh		± 1% of reading

1. An acceptable alternative is to use an inlet or outlet water temperature sensor having an accuracy of ± 1°F and a differential temperature sensor (e.g., multi-junction thermopile) having an accuracy of ±0.3°F.

WATER TEMPERATURE SENSORS

RTD and thermocouple temperature probes were used for water temperature measurements. Prior to testing, all of the RTD and thermocouple temperature probes were calibrated against a laboratory standard (Hart 1502A) in a hot block and an ice bath.

ATS engineers also performed post-calibration on all thermocouples and RTD's relevant to the boiler test. An uncertainty analysis was performed using the root-sum-square method, including the following:

1. Deviation of the measured temperatures from PG&E calibration standards
2. Uncertainty in PG&E's calibration standards themselves

3. Uncertainty introduced by the hot block, used to create an environment at a tightly controlled temperature for calibration above 32F

Details of the post-calibration analysis are included in Appendix B. In summary, the analysis found that most of the water temperature sensors used met the +/-0.2°F accuracy requirement for most of the temperatures seen during the actual testing. However, a couple of the sensors were found to be outside the 0.2°F requirement at some of the temperatures they experienced. The worst case appears to be the boiler outlet temperature sensor which could have been off by 0.4°F during high temperature testing.

Pressure sensors were calibrated against a portable pneumatic calibrator.

WATER FLOW METER

A Badger Meter M-2000 Detector flow meter was used. This is a full bore mag meter with a factory stated accuracy of +/- 0.25%, which is within the requirements of the standard. The water flow meter was also calibrated against PG&E Coriolis flow standards.

GAS FLOW METER

An Elster American Meter AL-1400 Remanufactured Diaphragm Meter was used. PG&E's Fremont Meter Shop provided calibration data for the gas meter. According to the engineers at the Fremont Meter Shop, this meter was found to have an error of only 8/100 of 1%, which is well within the accuracy requirements of the Standard.

GAS HIGHER HEATING VALUE

The HHV was determined using data from the PG&E California Gas Transmission website as described in Appendix B. Statistical analysis of a month of daily data from the website shows that the standard deviation of this data is 2.5 Btu/ft3 which is 0.25% of the average. Standard 155P calls for +/-1% accuracy. Four standard deviations on the daily data is 1% accuracy and encompasses 99.99% of the data.

Additional sensor details and calibration information is provided in Appendix B.

THOUGHTS ON SENSOR ACCURACIES

Sensor accuracy was not a focus of this research project because it was not raised as a concern by the Standard 155P committee when the research plan was being developed. Consequently little of the limited time and funding for this research was spent on sensor accuracy. After testing was completed sensor accuracy became a central focus of the 155P committee. Therefore, the ATS team has spent some time delving into this issue and is now confident that instrumentation is available to meet the Standard 155P requirements. Furthermore, testing accuracy can be enhanced without violating NIST traceability by performing as much on site "through-system" calibration as possible, e.g. by placing inlet and outlet water temperature sensors in a bath and adjusting sensor calibrations to be consistent with a known reference standard.

DATA ACQUISITION SYSTEM

The instrumentation was connected to multiple rack-mounted CompactRIO modules from National Instruments. The signal conditioning modules included different units for RTDs, thermocouples, and both analog and digital input/output modules. The CompactRIO device includes an Ethernet connection that enables the system to be accessed from anywhere on the local network.

A local computer connected to the Ethernet network ran a program written in National Instrument's LabVIEW graphical programming language. This program was developed to read all the measurement devices, display the readings and additional calculated values on screen, and save the data to disk for later analysis, as well as control the loop flow rate and boiler return water temperature. The system was programmed such that the pump VFD and cooling tower mixing valve could be controlled manually by the user, or set to automatically maintain a user-selected value. The scan rate for sampling from the CompactRIO modules and updating the screen was set at 1 Hz. Data were logged every 30 seconds, exceeding the required recording intervals of Standard 155P.

Two types of data were recorded separately from the CompactRIO system: power measurements and flue gas measurements. Power measurements were logged directly to ELITEpro energy dataloggers, and downloaded post-test. Flue gas measurements were logged to a separate file via LAND Instruments' proprietary flue gas analyzer software. Data sources were combined post-test to perform efficiency analyses.

RESULTS

Detailed interpretation of the test results is included in the following section on Data Analyses. This section summarizes the conditions and data obtained during testing.

TEST UNIT 1

UNIT SETUP

A software thermostat was developed in National Instruments LabVIEW to command the boiler to fire. This demonstrated the flexibility of the data acquisition system because the expensive alternative involved shopping for, purchasing, and installing a hardware thermostat. Through the CompactRIO hardware, a digital out signal was wired to a relay which sent a fire command to the boiler depending on a user-selected temperature setpoint and deadband in the software. Additionally, directly controlling and monitoring the boiler's state from LabVIEW simplified data acquisition and post-processing.

Flue gas measurements for this outdoor atmospheric boiler proved difficult since it does not have a flue. In order to sample at a suitable location where the gases would not be diluted by outside air, the boiler would have to be permanently damaged by creating an access port through the sidewall. Because of this limitation, steady state combustion efficiency data was not captured for this boiler.

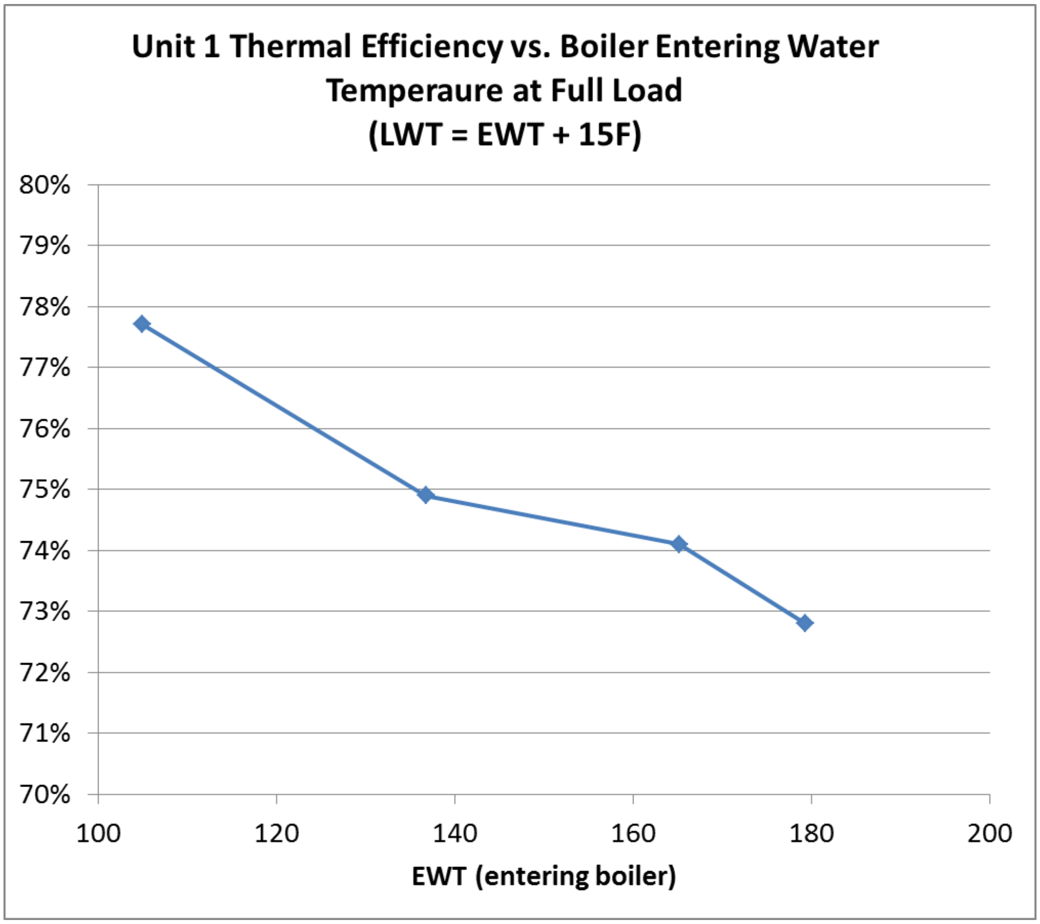
STEADY STATE TEST RESULTS

Standard 155P only requires a high temperature steady state test (RWT=140F, LWT = 180F) for this type of boiler, i.e. low temperature and low fire tests are not required. However, additional tests were conducted at various return water temperatures to capture additional data. Table 9 contains a summary of the test results. Note that while the 155P high temperature test calls for 140/180 (40^{o}F ΔT) at the system inlet/outlet, the boilers onboard recirculation pump is sized for a 15^{o}F ΔT so the boiler inlet temperature at 180 LWT is actually 165^{o}F, not 140^{o}F. Standard 155P allows boilers to be tested with recirculation pumps if required or provided by the manufacturer so testing the boiler under these conditions is a valid 155P test.

Analysis follows Section 10.1 of Standard 155P.

TABLE 9. UNIT 1 STEADY STATE TEST RESULTS SUMMARY

	System Inlet Temperature (°F)						
	80	**110**	**140**	**155**	Unit		Informative Note
10.1.2	**Rated Steady State Gross Output Rate,q˙out, water mode, Btu/h**						
Q	23.63	22.09	22.34	22.84	gpm		flow rate
To	119.96	151.54	179.77	193.93	F		system outlet temp
Tr	104.97	136.81	165.21	179.37			boiler inlet temp
Ti	79.48	108.84	138.29	153.01	F		system inlet temp
cp,water	1	1	1	1	Btu/lbF		specific heat of water
PH20	45.39	51.96	67.11	78.29	psi		water pressure
ρTave	62.01	61.56	61.03	60.74	lb/ft3		water density
q˙out,ss	475943.8	465707	453691.7	455367.4	Btu/h		
10.1.3.	**Heat Input Rate, qin,ss, Btu/h**						
10.1.3.2.	**Gas-Fired Boilers**						
Vgas	635	640	1250	625	cf		cubic feet of gas
Pgas	6.22	6.20	6.10	6.16	in H20		gas pressure
Patm	14.46	14.47	14.48	14.46	psia		ambient pressure
Tgas	91.62	87.99	81.88	71.42	F		gas temperature
P Factor	1.00	1.00	1.00	1.00			pressure correction factor for gas
T Factor	0.94	0.95	0.96	0.98			temperature correction factor for gas
Cs	0.94	0.95	0.96	0.98			non-standard conditions gas correction factor
HHVgas	1022	1022	1019	1022	Btu/cf		
ttest	1.000	1.000	2.000	1.000	hrs		
q˙in,ss	611258.2	620398.2	611094.3	624463.4	Btu/h		
10.1.4	**Test Efficiency, η0, Percent**						
η0	77.9	75.1	74.2	72.9	%		
10.1.5.	**Standard auxiliary energy input rate, qin,aux,ss, kW**						
qin,aux,ss	0.375	0.376	0.369	0.371	kW		
10.1.6.	**Rated Steady State Thermal Efficiency, Including Parasitic Losses, Percent**						
ηss,therma	77.7	74.9	74.1	72.8	%		



IDLING TEST RESULTS

Analysis of the idling test results follows Section 10.3 of Standard 155P. Standard 155P only requires a high temperature idling test. A low temperature idling test is optional, even for condensing boilers. However, both a high and low temperature idling test were run on Unit 1 for information purposes. The low temperature idling test was conducted on September 29, 2011, and the high temperature idling test was conducted on September 30, 2011. Summaries of the test results are available in Table 10 and Table 11 below.

TABLE 10. UNIT 1 IDLING TEST RESULTS – LOW TEMPERATURE TEST

10.3.1.	**Test Heat Input Rate, $q_{in,idle,test}$, Btu/h**		
10.3.1.2.	**Gas-Fired Boilers**		
Vgas	20	cf	cubic feet of gas
P_{gas}	8.47	in H20	gas pressure
Patm	14.45	psia	ambient pressure
T_{gas}	80.00	F	gas temperature
P Factor	1.00		pressure correction factor for gas
T Factor	0.96		temperature correction factor for gas
Cs	0.97		non-standard conditions gas correction factor
HHVgas	1022	Btu/cf	
t_{test}	4.62	hrs	
$q_{in,idle,test}$	4273.5	Btu/h	
% input	0.6%		$q_{in,idle,test}$ / nominal full load input (715,000 Btu/hr)
10.3.2.	**Corrected Idling Heat Input Rate, $q_{in,idle,corr}$, Btu/h**		
10.3.2.3.	**Low Water Temperature Hot Water**		
	110	F	standard rating condition for outlet water temp during low temp idling test
	75	F	standard rating condition for room air temp during idling test
T_{out}	118.6	F	test rig outlet water temp
T_{room}	77.9	F	test room temp
$q_{in,idle,corr}$	3677.2	Btu/h	
10.3.3.	**Idling Parasitic Losses, $L_{P,idle}$, kW**		
$q_{in,aux,idle}$	0.357	kW	
10.3.4.	**Rated Idling Energy Input Rate, $q_{in,idle,rated}$ Btu/h**		
$q_{in,idle,rated}$	4894.4	Btu/h	Low Temp

TABLE 11. UNIT 1 IDLING TEST RESULTS – HIGH TEMPERATURE TEST

10.3.1.	**Test Heat Input Rate, $q_{in,idle,test}$, Btu/h**		
10.3.1.2.	**Gas-Fired Boilers**		
Vgas	12	cf	cubic feet of gas
P_{gas}	8.57	in H20	gas pressure
Patm	14.48	psia	ambient pressure
T_{gas}	68.20	F	gas temperature
P Factor	1.01		pressure correction factor for gas
T Factor	0.98		temperature correction factor for gas
Cs	0.99		non-standard conditions gas correction factor
HHVgas	1022	Btu/cf	
t_{test}	0.52	hrs	
$q_{in,idle,test}$	23391.9	Btu/h	
% input	3.3%		$q_{in,idle,test}$ / nominal full load input (715,000 Btu/hr)
10.3.2.	**Corrected Idling Heat Input Rate, $q_{in,idle,corr}$, Btu/h**		
10.3.2.2.	**High Water Temperature Hot Water**		
	180	F	standard rating condition for outlet water temp during high temp idling test
	75	F	standard rating condition for room air temp during idling test
T_{out}	179.3914	F	test rig outlet water temp
T_{room}	70.29688	F	test room temp
$q_{in,idle,corr}$	22514.01	Btu/h	
10.3.3.	**Idling Parasitic Losses, $L_{P,idle}$, kW**		
$q_{in,aux,idle}$	0.352	kW	
10.3.4.	**Rated Idling Energy Input Rate, $q_{in,idle,rated}$ Btu/h**		
$q_{in,idle,rated}$	23715.0	Btu/h	High Temp

THROUGHFLOW LOSS TEST RESULTS

The table below contains a summary of the data gathered over a two hour test period with Unit 1. Note that total energy source used through two hours is actually the average energy source rate over two hours. This could be revised in the data sheets in the future.

TABLE 12: UNIT 1 THROUGHFLOW LOSS TEST RESULTS SUMMARY

Throughput Loss Data Summary		
Total Energy Source Used Thru 2 Hours	4.2715	KW
Avg. Thermal Energy Fed, Btu/hr	14578.63	
Avg. Thermal Energy Fed, % to Max		
Average Inlet Water Temperature	179.7	°F

VALID TEST CRITERIA

In order for a test to be a valid Standard 155P test it must meet the tolerance requirements in Standard 155. The figure below shows some of the ways in which the tests on Unit 1 may not have meet the Standard 155P criteria. In summary:

1. The measured gas input at full fire was only about 83% of the nameplate. Standard 155P requires it to be within 2% of nameplate.
2. Flue pressure was not measured so it may not have met the test criteria.
3. CO_2 and CO were not measured and may not have met the test criteria.

Test Requirement	High temprature, High Fire	High temprature, Low Fire	Low temprature, High Fire
7.5.1. High Fire. The high fire test shall be conducted at 100% ±2% of the boiler manufacturer's maximum input specified on the rating plate of the packaged boiler or boiler-burner unit. **7.5.2 Low Fire**. The low fire test where required by Section 4 shall be conducted at 100% ± 2% of the boiler manufacturer's minimum input specified on the rating plate of the packaged boiler or boiler-burner unit	FAIL. 83%	N/A	FAIL. 85%
7.5.3 Intermediate Fire. Optional intermediate fire tests for a step-modulating boiler may be conducted at up to threeinput rates between low and high fire	N/A	N/A	N/A
7.6.1.1.1 Light Oil or Power Gas. The draft in the firebox shall be maintained within ± 10% of the manufacturer's specificationduring the test	N/A	N/A	N/A
7.6.1.1.3 Atmospheric Gas. The draft shall be as established by a 4-ft.(1.22m) or 5-ft.(1.52 m) stack attached to the draft hood outlet, as specified in 7.2.2.1 and 7.2.2.2. If the manufacturer provides a dedicated venting arrangement, the boiler shall be tested with the arrangement having the least draft loss	N/A	N/A	N/A
7.6.1.2 Forced Draft (Light Oil, Heavy Oil, or Power Gas). The pressure in the flue connection shall be maintained within ±10% of the the manufacturer's specified condition during the test	FAIL. mfg. spec. condition unknown; flue pressure not measured;	N/A	FAIL. Not recorded.
7.6.1.3 Outdoor Boiler (Water Only). The pressure in the stack connection shall be maintained at 0.00 (+ 0.02 - 0.00) inches of water [0.0 (+5.0 - 0.0)Pa], unless the manufacturer requests a higher pressure. This higher pressure shall then be determined in a preliminary test with the standard venting means in place. All tests will then be conducted at the higher pressure ± .02 inches of water (± 5.0 Pa)	N/A	N/A	N/A
7.6.2. Flue Gas Temperature. The flue gas temperature shall not vary from the initial test reading by more than the values shown below at any time during the test:	PASS	N/A	PASS
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 water temperature tests, the temperatures shall not exceed 85°F (29.4 °C). The room air temperature and inlet air temperature shall not differ by more than 5°F (2.8ºC) at any time during the test	PASS	N/A	PASS
7.6.4. Carbon Dioxide In Flue Gas. The oil or power gas burner shall be adjusted to within ± 0.1 percentage points of the carbon dioxide specified by the manufacturer. The maximum variation during a test shall be ± 0.1 percentage points	FAIL. CO_2 not measured	N/A	FAIL. CO_2 not measured
7.6.6. Carbon Monoxide in Flue Gas. A gas burner shall not produce carbon monoxide exceeding 0.04% (air free basis).	FAIL. CO not measured	N/A	FAIL. CO not measured
7.7. Additional Test Requirements for Water, Steady State: Water temperature: High temperature HWRT=: 180+-5F, dT = 40+-4F; Low temperature HWRT = 120+-5F, dT = 40+-4F	PASS	N/A	PASS
8.2.2.1.4. Steady state test:warm up: Readings may be started as soon as the water temperature conditions are met. Once started, readings shall continue uninterrupted at intervals of not less than 15 minutes.	PASS	N/A	FAIL. No data from warm up period
8.2.2.1.6. Steady state test:warm up: A state of equilibrium shall have been reached when consistent readings are obtained during a 30 minute period.	PASS	N/A	FAIL. Only 1 hour data recorded
8.2.2.2.1. Steady state: test period: The test period shall start when a state of equilibrium 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.	PASS	N/A	PASS

TEST UNIT 2

UNIT SETUP

Unit 2 had the necessary connections to record flue gas temperatures and composition. As required in 155P, a grid of nine evenly spaced thermocouples was inserted into the flue connection to record an average flue gas temperature during testing. A LAND Instruments Lancom III flue gas analyzer sampled flue gas downstream of the thermocouple grid and provided information on the chemical makeup of the exhaust gases.

The boiler's existing flue condensate connections were used to collect condensing flue gas in a glass beaker.

These additional instruments provided data necessary for the combustion efficiency analysis.

STEADY STATE TEST RESULTS

Four types of steady state tests were conducted on Unit 2:

- High Temperature / High Fire
- Low Temperature / High Fire
- High Temperature / Low Fire
- Low Temperature / Low Fire

Analysis follows Section 10.1 of Standard 155P.

The High Fire tests, performed in November, did not use the mixing loop that was added to eliminate the boiler outlet temperature stratification issue (see Appendix I - Supplemental Evaluations). Low Fire tests were performed in December after the mixing loop was added, but the system inlet temperature RTD was disconnected. The Evaluations section provides more information about the integration of the mixing loop to reduce temperature stratification in the pipes for accurate water temperature measurements. In Table 13 below, note that the system inlet temperature Ti is excluded in the low fire tests, and the boiler inlet temperature Tr was used in calculations.

TABLE 13. UNIT 2 STEADY STATE THERMAL EFFICIENCY TEST RESULTS SUMMARY

	Test Condition (Firing State / Temperature)						
	Hi / Hi	Hi / Lo	Lo / Hi	Lo / Lo	Unit		Informative Note
	11/9/2011	11/9/2011	12/22/2011	12/27/2011			
10.1.2	**Rated Steady State Gross Output Rate,q˙out, water mode, Btu/h**						
Q	24.00	26.20	6.18	6.22	gpm		flow rate
To	181.66	120.22	181.50	121.23	F		system outlet temp
Tr	142.43	79.58	143.21	79.97			boiler inlet temp
Ti	142.47	79.58			F		system inlet temp
cp,water	1	1	1	1	Btu/lbF		specific heat of water
PH20	52.03	42.50	43.97	43.93	psi		water pressure
ρTave	60.97	62.00	60.96	62.00	lb/ft3		water density
q˙out,ss	460063.68	529696.63	115625.99	127527.53	Btu/h		
10.1.3.	**Heat Input Rate, qin,ss, Btu/h**						
10.1.3.2.	**Gas-Fired Boilers**						
Vgas	1085	1215	65.5	260.9	cf		cubic feet of gas
Pgas	6.32	6.24	6.97	6.81	in H20		gas pressure
Patm	14.61	14.58	14.65	14.65	psia		ambient pressure
Tgas	62.56	65.79	60.68	51.22	F		gas temperature
P Factor	1.01	1.01	1.01	1.01			pressure correction factor for gas
T Factor	1.00	0.99	1.00	1.02			temperature correction factor for gas
Cs	1.00	1.00	1.01	1.03			non-standard conditions gas correction factor
HHVgas	1018	1018	1019	1019	Btu/cf		
ttest	2.000	2.000	0.500	2.000	hrs		
q˙in,ss	554938.11	616085.48	135181.54	137044.67	Btu/h		
10.1.4	**Test Efficiency, η0, Percent**						
η0	82.9	86.0	85.5	93.1	%		
10.1.5.	**Standard auxiliary energy input rate, qin,aux,ss, kW**						
qin,aux,ss	0.350	0.415	0.132	0.132	kW		
10.1.6.	**Rated Steady State Thermal Efficiency, Including Parasitic Losses, Percent**						
ηss,therma	82.7	85.8	85.3	92.8	%		

TABLE 14. UNIT 2 STEADY STATE COMBUSTION EFFICIENCY TEST RESULTS SUMMARY

	Test Condition (Firing State / Temperature)						
	Hi / Hi	Hi / Lo	Lo / Hi	Lo / Lo	Unit		Informative Note
	11/9/2011	11/9/2011	12/22/2011	12/27/2011			
10.2.2.	Steady State Flue Loss for Gas Fired Boilers, Lf, Percent						
Tf	711.79	689.02	603.36	562.66	R		absolute flue gas temp
Tr	524.51	524.81	520.07	512.96	R		absolute test room temp
CO2	11.10	11.40	7.49	7.34	%		
h	41.27	37.30	15.00	46.50	%		relative humidity
Lf	16.65	15.44	13.11	12.67	%		
10.2.4	Steady state latent heat gain due to condensation in flue, Gl,ss, Percent						
hfg	1053.3	1053.3	1053.3	1053.3	Btu/lbm		latent heat of vaporization
mcond,ss	0.01	0.01	0.04	14.64	lbm		mass of flue condensate
qin,cond,ss	1051592	1229879.8	64488.82	270886.65	Btu		fuel energy input during test
Gl,ss	0.001	0.001	0.072	5.691	%		
10.2.5.	Steady state heat loss due to hot condensate going down drain, Lcond,ss, Percent						
Gl,ss	0.001	0.001	0.072	5.691			
cp,water	1	1	1	1	Btu/lbmF		specific heat of water
Tflue,ss	252.1	229.4	143.7	103.0	F		steady state flue gas temp
Tair	62.6	64.4	63.6	55.0	F		burner inlet air temperature
Lcond,ss	0.000	0.000	0.003	0.143	%		
10.2.6.	Rated condensing steady state combustion efficiency, ηss,comb, Percent						
ηss,comb	83.3	84.6	87.0	92.9	%		
10.2.7.	Radiation and Unaccounted for Loss, Lu, Percent						
Lu	0.44	-1.42	1.42	-0.17	%		
10.2.8.	Nominal Jacket Loss Rate, Btu/h						
q˙jacket,nom	2457.0	0.0	1922.2	0.0	Btu/h		

IDLING TEST RESULTS

The high temperature idling test was conducted on December 28, 2011, and the low temperature idling test was conducted on December 29, 2011. Summaries of the test results are available in Table 15 and Table 16 below.

TABLE 15. UNIT 2 IDLING TEST RESULTS – HIGH TEMPERATURE TEST

10.3.1.	**Test Heat Input Rate, $q_{in,idle,test}$, Btu/h**		
10.3.1.2.	**Gas-Fired Boilers**		
Vgas	59.1875	cf	cubic feet of gas
P_{gas}	7.79	in H20	gas pressure
Patm	14.65	psia	ambient pressure
T_{gas}	57.47	F	gas temperature
P Factor	1.02		pressure correction factor for gas
T Factor	1.00		temperature correction factor for gas
Cs	1.02		non-standard conditions gas correction factor
HHVgas	1019	Btu/cf	
t_{test}	8.68	hrs	
$q_{in,idle,test}$	7093.0	Btu/h	
% input	1.2%		$q_{in,idle,test}$ / nominal full load input (600,000 Btu/hr)
10.3.2.	**Corrected Idling Heat Input Rate, $q_{in,idle,corr}$, Btu/h**		
10.3.2.2.	**High Water Temperature Hot Water**		
	180	F	standard rating condition for outlet water temp during high temp idling test
	75	F	standard rating condition for room air temp during idling test
T_{out}	179.4124	F	test rig outlet water temp
T_{room}	75.06365	F	test room temp
$q_{in,idle,corr}$	7137.217	Btu/h	
10.3.3.	**Idling Parasitic Losses, $L_{P,idle}$, kW**		
$q_{in,aux,idle}$	0.007	kW	
10.3.4.	**Rated Idling Energy Input Rate, $q_{in,idle,rated}$ Btu/h**		
$q_{in,idle,rated}$	7161.2	Btu/h	High Temp

TABLE 16. UNIT 2 IDLING TEST RESULTS – LOW TEMPERATURE TEST

10.3.1.	**Test Heat Input Rate, $q_{in,idle,test}$, Btu/h**		
10.3.1.2.	**Gas-Fired Boilers**		
Vgas	25	cf	cubic feet of gas
P_{gas}	7.74	in H20	gas pressure
Patm	14.60	psia	ambient pressure
T_{gas}	55.44	F	gas temperature
P Factor	1.01		pressure correction factor for gas
T Factor	1.01		temperature correction factor for gas
Cs	1.02		non-standard conditions gas correction factor
HHVgas	1019	Btu/cf	
t_{test}	7.37	hrs	
$q_{in,idle,test}$	3528.6	Btu/h	
% input	0.6%		$q_{in,idle,test}$ / nominal full load input (600,000 Btu/hr)
10.3.2.	**Corrected Idling Heat Input Rate, $q_{in,idle,corr}$, Btu/h**		
10.3.2.3.	**Low Water Temperature Hot Water**		
	110	F	standard rating condition for outlet water temp during low temp idling test
	75	F	standard rating condition for room air temp during idling test
T_{out}	120.6	F	test rig outlet water temp
T_{room}	65.3	F	test room temp
$q_{in,idle,corr}$	2235.8	Btu/h	
10.3.3.	**Idling Parasitic Losses, $L_{P,idle}$, kW**		
$q_{in,aux,idle}$	0.005	kW	
10.3.4.	**Rated Idling Energy Input Rate, $q_{in,idle,rated}$ Btu/h**		
$q_{in,idle,rated}$	2253.4	Btu/h	Low Temp

VALID TEST CRITERIA

In order for a test to be a valid Standard 155P test it must meet the tolerance requirements in Standard 155. The figure below shows some of the ways in which the tests on Unit 2 may not have meet the Standard 155P criteria. In summary:

1. The measured gas input at full fire and low fire was not within 2% of nameplate.
2. Inlet air temperature was too cold.

3. CO_2 readings were not within ± 0.1 percentage points of the carbon dioxide specified by the manufacturer.
4. High temperature idling test differential was set to 20°F, not 10°F as required.

Test Requirement	High temprature, High Fire	High temprature, Low Fire	Low temprature, High Fire	Low temprature, Low Fire	High temprature, Idling	Low temprature, Idling
7.5.1. High Fire. The high fire test shall be conducted at 100% ±2% of the boiler manufacturer's maximum input specified on the rating plate of the packaged boiler or boiler-burner unit. **7.5.2 Low Fire**. The low fire test where required by Section 4 shall be conducted at 100% ± 2% of the boiler manufacturer's minimum input specified on the rating plate of the packaged boiler or boiler-burner unit	FAIL. 93%	FAIL. 111%	PASS	FAIL. 114%	N/A	N/A
7.5.3 Intermediate Fire. Optional intermediate fire tests for a step-modulating boiler may be conducted at up to threeinput rates between low and high fire	N/A	N/A	N/A	N/A	N/A	N/A
7.6.1.1.1 Light Oil or Power Gas. The draft in the firebox shall be maintained within ± 10% of the manufacturer's specificationduring the test	N/A	N/A	N/A	N/A	N/A	N/A
7.6.1.1.3 Atmospheric Gas. The draft shall be as established by a 4-ft.(1.22m) or 5-ft.(1.52 m) stack attached to the draft hood outlet, as specified in 7.2.2.1 and 7.2.2.2. If the manufacturer provides a dedicated venting arrangement, the boiler shall be tested with the arrangement having the least draft loss	N/A	N/A	N/A	N/A	N/A	N/A
7.6.1.2 Forced Draft (Light Oil, Heavy Oil, or Power Gas). The pressure in the flue connection shall be maintained within ±10% of the the manufacturer's specified condition during the test	FAIL. mfg. spec. condition unknown; flue pressure measured (about 0.1), but unit unknown, assume InWG;	FAIL. mfg. spec. condition unknown; flue pressure measured (about 0.1), but unit unknown, assume InWG;	FAIL. Not recorded.	FAIL. mfg. spec. condition unknown; flue pressure measured (about 0.3-0.6), but unit unknown, assume InWG;	N/A	N/A
7.6.1.3 Outdoor Boiler (Water Only). The pressure in the stack connection shall be maintained at 0.00 (+ 0.02 - 0.00) inches of water [0.0 (+5.0 - 0.0)Pa], unless the manufacturer requests a higher pressure. This higher pressure shall then be determined in a preliminary test with the standard venting means in place. All tests will then be conducted at the higher pressure ± .02 inches of water (± 5.0 Pa)	N/A	N/A	N/A	N/A	N/A	N/A
7.6.2. Flue Gas Temperature. The flue gas temperature shall not vary from the initial test reading by more than the values shown below at any time during the test:	PASS	PASS	PASS	PASS	N/A	N/A
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 water temperature tests, the temperatures shall not exceed 85°F (29.4 °C). The room air temperature and inlet air temperature shall not differ by more than 5°F (2.8ºC) at any time during the test	FAIL. Avg. inlet temperature is 62.4 F	FAIL. Avg. inlet temp 62F	FAIL. Avg inlet 64.4 F	FAIL. Avg inlet 55.3F	N/A	N/A
7.6.4. Carbon Dioxide In Flue Gas. The oil or power gas burner shall be adjusted to within ± 0.1 percentage points of the carbon dioxide specified by the manufacturer. The maximum variation during a test shall be ± 0.1 percentage points	FAIL. CO_2 too high	FAIL. CO_2 too low	FAIL. CO_2 too high	FAIL. CO_2 too low	N/A	N/A
7.6.6. Carbon Monoxide in Flue Gas. A gas burner shall not produce carbon monoxide exceeding 0.04% (air free basis).	FAIL. Air free basis is not measured, flue CO is 0.5%	FAIL. Air free basis is not measured, flue CO is 0.05%	FAIL.Air free basis is not measured, flue CO is 0.5%	FAIL.Air free basis is not measured, flue CO is 0.06%	N/A	N/A
7.7. Additional Test Requirements for Water, Steady State: Water temperature: High temperature HWRT=: 180+-5F, dT = 40+-4F; Low temperature HWRT = 120+-5F, dT = 40+-4F	PASS	PASS	PASS	PASS	N/A	N/A
8.2.2.1.4. Steady state test:warm up: Readings may be started as soon as the water temperature conditions are met. Once started, readings shall continue uninterrupted at intervals of not less than 15 minutes.	PASS	PASS	PASS	PASS	N/A	N/A
8.2.2.1.6. Steady state test:warm up: A state of equilibrium shall have been reached when consistent readings are obtained during a 30 minute period.	PASS	PASS	PASS	PASS	N/A	N/A
8.2.2.2.1. Steady state: test period: The test period shall start when a state of equilibrium 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.	PASS	PASS	PASS	PASS	N/A	N/A
7.9.2.1 Idling test water flow rate: The water flow rate shall be the full fire steady state test flow rate ±15%	N/A	N/A	N/A	N/A	PASS	PASS
7.9.2.2.1 Idling test water temperature: The water temperature controller's differential shall be no greater than 10°F (	N/A	N/A	N/A	N/A	FAIL. controller's differential not recorded. Max DT > 20 F	PASS
7.9.2.2. Idling test water temperature setpoint:The setpoint of the controller shall be adjusted so that the midpoint of the highest and lowest outlet water temperatures observed over a cycle is as follows	N/A	N/A	N/A	N/A	PASS	PASS
8.4.1.1. The idling test shall be initiated following a steady state test or an extended warm up period	N/A	N/A	N/A	N/A	FAIL. Tested cold start	FAIL. Tested cold start
8.4.1.2. Idling Test: 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 minimum of three stabilization cycles followed by a minimum of six test cycles. For boilers with a differential less than 8ºF (4.4ºC) the burner on time in the last test cycle must be within 5% of the burner on time of the first test cycle. Closure of the controller 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	N/A	N/A	N/A	N/A	FAIL. 1. only have 1 stablizing cycle; 2. the cycle on time is not recorded. Can only be read from graph by either observing the water temperature or the elc. Energy use. The last cycle's burner on time is 3'30", first cycle's burner on time is 4'. The difference is 14%, larger than 5%.	FAIL. 1. only have 1 stablizing cycle; 2. the cycle on time is not recorded. Can only be read from graph by either observing the water temperature or the elc. Energy use. The last cycle's burner on time is 0'30", first cycle's burner on time is 1'. The difference is 50%, larger than 5%.
8.4.3.3. Idling Test:Outlet water temperature shall be monitored at intervals of one minute or less. The controller setpoint shall be adjusted prior to the stabilization cycles so that the midpoint of the highest and lowest outlet water temperatures observed over a cycle is as specified in Section 7.9.2.2.2, taking into account the fact that the difference between the highest and lowest temperatures will be larger than the controller differential. No adjustments shall be made to the controller setpoint or differential during the stabilization cycles or test cycles	N/A	N/A	N/A	N/A	FAIL. Control setpoint not recorded.	FAIL. Control setpoint not recorded.

TEST UNIT 3

UNIT SETUP

Unit 3 also had the necessary connections to record flue gas temperatures and composition. The same grid of nine evenly spaced thermocouples used on Unit 2 was inserted into the flue connection to record an average flue gas temperature during testing. A LAND Instruments Lancom III flue gas analyzer sampled flue gas downstream of the thermocouple grid and provided information on the chemical makeup of the exhaust gases.

The boiler's existing flue condensate connections were used to collect condensing flue gas in a glass beaker.

These additional instruments provided data necessary for the combustion efficiency analysis.

Our standard Test Chamber setup used on Units 1 and 2 was not suitable for this boiler. This was the largest Test Unit, and it required a significant flow rate of combustion air. As a result, at high fire, the exhaust air carried flue gas condensate out of the flue gas stack and discharged it into the test chamber. To maintain personnel safety and equipment integrity, the exhaust duct was directly connected and the Test Chamber was not used. A photo of the setup during installation is included in Figure 7 below.

FIGURE 7. UNIT 3 FLUE DUCT TO PREVENT OVERSPRAY OF FLUE CONDENSATE

STEADY STATE TEST RESULTS

Three types of steady state tests were conducted on Unit 3:

- High Temperature / High Fire
- High Temperature / Low Fire
- Low Temperature / Low Fire

Analysis follows Section 10.1 of Standard 155P. All tests utilized the mixing loop, which was added while testing Unit 2 to prevent boiler outlet temperature stratification.

The Low Temperature / High Fire test was not successfully completed on this boiler. Sufficient cooling was not available through the cooling tower to maintain an 80 °F return water temperature at high fire. The cooling tower is sized correctly to reject the heat load, so the inability to provide sufficient cooling could be due to several possible causes. Some potential causes could be the following:

- The calculated flow rate through the heat exchanger is much less than design. This could be caused either by degradation in the cooling tower pump, or the three way mixing valve could be leaking to the bypass side.

- Additional plumbing may have increased the head required at the pump discharge which could also reduce the flow rate below the pump's original capacity.
- There may be a physical obstruction restricting flow.

Two Low Temperature / Low Fire tests were conducted to compare the effect of minimum flow on efficiency: one at the manufacturer specified minimum flow rate, and the other at the flow rate required to achieve 40 °F temperature rise at low fire. The test at the flow required to achieve 40 °F temperature rise was performed on January 19, 2012, and the test at the manufacturer's minimum suggested flow was performed on January 20, 2012.

Summaries of these tests are available in Table 17 and Table 18 below.

TABLE 17. UNIT 3 STEADY STATE THERMAL EFFICIENCY TEST RESULTS SUMMARY

	Test Condition (Firing State / Temperature)						
	Hi / Hi	Lo / Hi	Lo / Lo	Lo / Lo	Unit		Informative Note
	1/18/2012	1/18/2012	1/19/2012	1/20/2012			
10.1.2	Rated Steady State Gross Output Rate,q'out, water mode, Btu/h						
Q	59.83	3.79	3.83	24.98	gpm		flow rate
To	180.11	180.72	118.27	120.56	F		system outlet temp
Tr	140.28	141.18774	80.332931	114.9479	F		boiler inlet temp
cp,water	1	1	1	1	Btu/lbF		specific heat of water
PH20	42.33	42.46	43.13	43.44	psi		water pressure
ρTave	61.01	60.99	62.01	61.76	lb/ft3		water density
q˙out,ss	1166289.8	73401.32	72318.896	69415.418	Btu/h		
10.1.3.	Heat Input Rate, qin,ss, Btu/h						
10.1.3.2.	Gas-Fired Boilers						
Vgas	2620	171.6	95	75.5	cf		cubic feet of gas
Pgas	6.18	9.60	9.46	9.54	in H20		gas pressure
Patm	14.71	14.66	14.60	14.50	psia		ambient pressure
Tgas	49.56	56.18	46.41	54.55	F		gas temperature
P Factor	1.02	1.02	1.02	1.01			pressure correction factor for gas
T Factor	1.02	1.01	1.03	1.01			temperature correction factor for gas
Cs	1.04	1.03	1.04	1.02			non-standard conditions gas correction factor
HHVgas	1020	1020	1020	1020	Btu/cf		
ttest	2.008	2.000	1.283	1.000	hrs		
q˙in,ss	1379888.2	90001.336	78822.161	78622.145	Btu/h		
10.1.4	Test Efficiency, η0, Percent						
η0	84.5	81.6	91.7	88.3	%		
10.1.5.	Standard auxiliary energy input rate, qin,aux,ss, kW						
qin,aux,ss	0.759	0.085	0.075	0.075	kW		
10.1.6.	Rated Steady State Thermal Efficiency, Including Parasitic Losses, Percent						
ηss,therma	84.4	81.3	91.5	88.0	%		

TABLE 18. UNIT 3 STEADY STATE COMBUSTION EFFICIENCY TEST RESULTS SUMMARY

	Test Condition (Firing State / Temperature)					
	Hi / Hi	Lo / Hi	Lo / Lo	Lo / Lo	Unit	Informative Note
	1/18/2012	1/18/2012	1/19/2012	1/20/2012		
10.2.2.	**Steady State Flue Loss for Gas Fired Boilers, Lf, Percent**					
Tf	629.75	591.33	538.83	573.46	R	absolute flue gas temp
Tr	514.42	522.47	510.95	518.73	R	aboslute test room temp
CO2	7.63	6.49	6.22	6.61	%	
h	38.37	39.85	46.94	72.11	%	relative humidity
Lf	15.66	13.97	11.71	14.10	%	
10.2.4	**Steady state latent heat gain due to condensation in flue, Gl,ss, Percent**					
hfg	1053.3	1053.3	1053.3	1053.3	Btu/lbm	latent heat of vaporization
mcond,ss	0	1.0165568	7.65	2.95	lbm	mass of flue condensate
qin,cond,ss	2478126	317949.96	102630.87	77722.982	Btu	fuel energy input during test
Gl,ss	0.000	0.337	7.853	3.992	%	
10.2.5.	**Steady state heat loss due to hot condensate going down drain, Lcond,ss, Percent**					
Gl,ss	0.000	0.337	7.853	3.992		
cp,water	1	1	1	1	Btu/lbmF	specific heat of water
Tflue,ss	170.1	131.7	79.2	113.8	F	steady state flue gas temp
Tair	49.0	61.0	49.2	56.9	F	burner inlet air temperature
Lcond,ss	0.000	0.012	0.123	0.119	%	
10.2.6.	**Rated condensing steady state combustion efficiency, ηss,comb, Percent**					
ηss,comb	84.3	86.4	96.0	89.8	%	
10.2.7.	**Radiation and Unaccounted for Loss, Lu, Percent**					
Lu	-0.18	4.80	4.27	1.48	%	
10.2.8.	**Nominal Jacket Loss Rate, Btu/h**					
q˙jacket,nom	0.0	4321.4	3367.3	1167.0	Btu/h	

IDLING TEST RESULTS

Two High Temperature Idling Tests were conducted on Unit 3. The first was at the default manufacturer's controller differential of 4 °F, performed on January 20, 2012. The other was at the maximum differential allowed by Standard 155P of 10 °F, performed on January 25, 2012. These conditions allow comparison of the difference in energy input between the manufacturer's default and the Standard requirements. A summary of the test results is available in Table 19 below. As expected the 4°F differential (1/20/2012) has a higher idling loss rate than the 10°F differential. Presumably this is due to the pre-purge and post-purge losses that occur more frequently with the lower differential.

TABLE 19. UNIT 3 IDLING TEST RESULTS

Test Date	1/20/2012	1/25/2012		
10.3.1.	**Test Heat Input Rate, $q_{in,idle,test}$, Btu/h**			
10.3.1.2.	**Gas-Fired Boilers**			
Vgas	24.875	41.35	cf	cubic feet of gas
P_{gas}	10.02	9.89	in H20	gas pressure
Patm	14.45	14.68	psia	ambient pressure
T_{gas}	58.86	62.57	F	gas temperature
P Factor	1.01	1.02		pressure correction factor for gas
T Factor	1.00	1.00		temperature correction factor for gas
Cs	1.01	1.02		non-standard conditions gas correction factor
HHVgas	1020	1019	Btu/cf	
t_{test}	2.48	4.76	hrs	
$q_{in,idle,test}$	10317.1	9015.4	Btu/h	
% input	0.7%	0.6%		$q_{in,idle,test}$ / nominal full load input (1,500,000 Btu/hr)
10.3.2.	**Corrected Idling Heat Input Rate, qin,idle,corr, Btu/h**			
10.3.2.2.	**High Water Temperature Hot Water**			
	180	180	F	standard rating condition for outlet water temp during high temp idling test
	75	75	F	standard rating condition for room air temp during idling test
T_{out}	180.9505	179.6943	F	test rig outlet water temp
T_{room}	61.81111	66.99427	F	test room temp
$q_{in,idle,corr}$	9092.638	8399.452	Btu/h	
10.3.3.	**Idling Parasitic Losses, LP,idle, kW**			
$q_{in,aux,idle}$	0.010	0.007	kW	
10.3.4.	**Rated Idling Energy Input Rate, qin,idle,rated Btu/h**			
$q_{in,idle,rated}$	9127.7	8422.7	Btu/h	High Temp

VALID TEST CRITERIA

In order for a test to be a valid Standard 155P test it must meet the tolerance requirements in Standard 155. The figure below shows some of the ways in which the tests on Unit 3 may not have meet the Standard 155P criteria. In summary:

1. The measured gas input at full fire and low fire was not within 2% of nameplate.
2. Inlet air temperature was too cold.

Test Requirement	High temprature, High Fire	High temprature, Low Fire	Low temprature, High Fire	Low temprature, Low Fire
7.5.1. High Fire. The high fire test shall be conducted at 100% ±2% of the boiler manufacturer's maximum input specified on the rating plate of the packaged boiler or boiler-burner unit. **7.5.2 Low Fire.** The low fire test where required by Section 4 shall be conducted at 100% ± 2% of the boiler manufacturer's minimum input specified on the rating plate of the packaged boiler or boiler-burner unit	FAIL, tested at 92%	FAIL, tested at 118%		PASS
7.5.3 Intermediate Fire. Optional intermediate fire tests for a step-modulating boiler may be conducted at up to threeinput rates between low and high fire	N/A	N/A	N/A	N/A
7.6.1.1.1 Light Oil or Power Gas. The draft in the firebox shall be maintained within ± 10% of the manufacturer's specificationduring the test	N/A	N/A	N/A	N/A
7.6.1.1.3 Atmospheric Gas. The draft shall be as established by a 4-ft.(1.22m) or 5-ft.(1.52 m) stack attached to the draft hood outlet, as specified in 7.2.2.1 and 7.2.2.2. If the manufacturer provides a dedicated venting arrangement, the boiler shall be tested with the arrangement having the least draft loss	N/A	N/A	N/A	N/A
7.6.1.2 Forced Draft (Light Oil, Heavy Oil, or Power Gas). The pressure in the flue connection shall be maintained within ±10% of the the manufacturer's specified condition during the test	FAIL, mfg. spec.condition unknow	FAIL, mfg. spec. condition unknow		FAIL, mfg. spec. condition unknow
7.6.1.3 Outdoor Boiler (Water Only). The pressure in the stack connection shall be maintained at 0.00 (+ 0.02 - 0.00) inches of water [0.0 (+5.0 - 0.0)Pa], unless the manufacturer requests a higher pressure. This higher pressure shall then be determined in a preliminary test with the standard venting means in place. All tests will then be conducted at the higher pressure ± .02 inches of water (± 5.0 Pa)	N/A	N/A	N/A	N/A
7.6.2. Flue Gas Temperature. The flue gas temperature shall not vary from the initial test reading by more than the values shown below at any time during the test:	PASS	PASS		PASS
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 water temperature tests, the temperatures shall not exceed 85°F (29.4 °C). The room air temperature and inlet air temperature shall not differ by more than 5°F (2.8ºC) at any time during the test	FAIL. Avg. inlet air temp 49.1 F, romo temp 54.8	FAIL. Avg. inlet temp 60.1, room temp. 62.7		FAIL. Avg. inlet temp. 49.2, room air temp. 51.3
7.6.4. Carbon Dioxide In Flue Gas. The oil or power gas burner shall be adjusted to within ± 0.1 percentage points of the carbon dioxide specified by the manufacturer. The maximum variation during a test shall be ± 0.1 percentage points	FAIL. Reading is 7.6%, mfg. spec. unknown	FAIL. Avg.reading is 6.4%. Mfg. spec. unknown		FAIL. Avg.reading is 6.%. Mfg. spec. unknown
7.6.6. Carbon Monoxide in Flue Gas. A gas burner shall not produce carbon monoxide exceeding 0.04% (air free basis).	FAIL. Reading is 0.5%	FAIL. No reading		FAIL. No reading
7.7. Additional Test Requirements for Water, Steady State: Water temperature: High temperature HWRT=: 180+-5F, dT = 40+-4F; Low temperature HWRT = 120+-5F, dT = 40+-4F	PASS	PASS		PASS
8.2.2.1.4. Steady state test:warm up: Readings may be started as soon as the water temperature conditions are met. Once started, readings shall continue uninterrupted at intervals of not less than 15 minutes.	PASS	PASS		PASS, short test
8.2.2.1.6. Steady state test:warm up: A state of equilibrium shall have been reached when consistent readings are obtained during a 30 minute period.	FAIL. Warm up have steady ready for 20 min.	FAIL. Warm up period only lasted 5 min.		PASS
8.2.2.2.1. Steady state: test period: The test period shall start when a state of equilibrium 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.	PASS	PASS		PASS

DATA ANALYSES

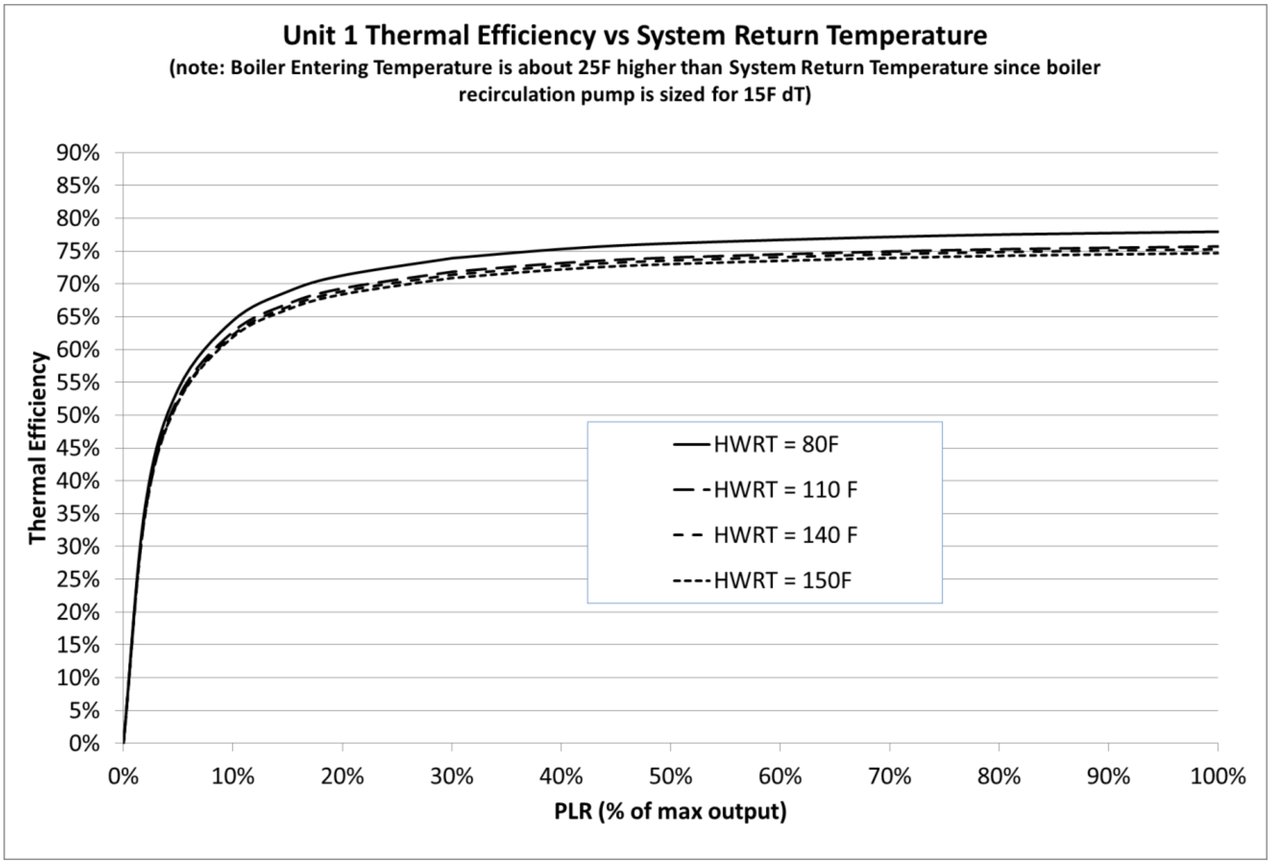
The data was analyzed in a number of different ways. The first step was a detailed analysis using the Standard 155P Report Forms, which are available to committee members in excel and are still in draft form. Reporting the data on the report forms required numerous calculations using Section 10 of the Standard. The Report Forms and supporting calculations are included in Appendix A.

The data was also plotted in numerous ways to visualize the results. Data was also compared to manufacturers published efficiency data. Finally, the data was converted into DOE-2.2 curve coefficients for use in future energy simulations. See below for details of each of these analyses.

UNIT 1

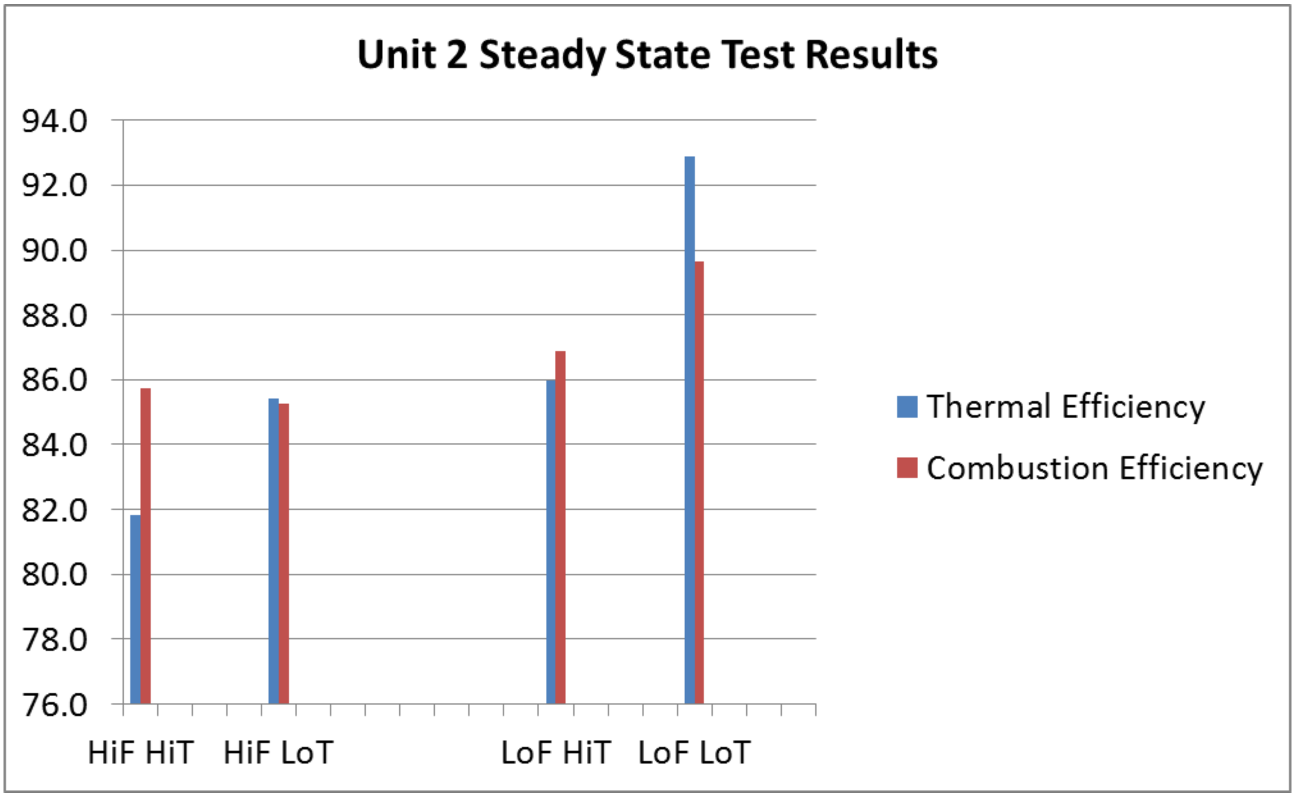
The figure below shows the linear interpolation of the steady state tests and idling tests for Unit 1 using the interpolation procedures in Standard 155P. Steady state full load tests were conducted at four system return temperatures. It is important to note that since this is not a condensing boiler it should not be operated in practice at boiler entering water temperatures below about 140^{o}F.

Only one idling test was conducted (at 180^{o}F) so this result was used in the interpolation of all the steady state tests. One might expect to have significantly better interpolation results for the lower temperature curves if lower temperature idling tests were run but that was not the case for unit 2 (see Data Analysis for Unit 2).

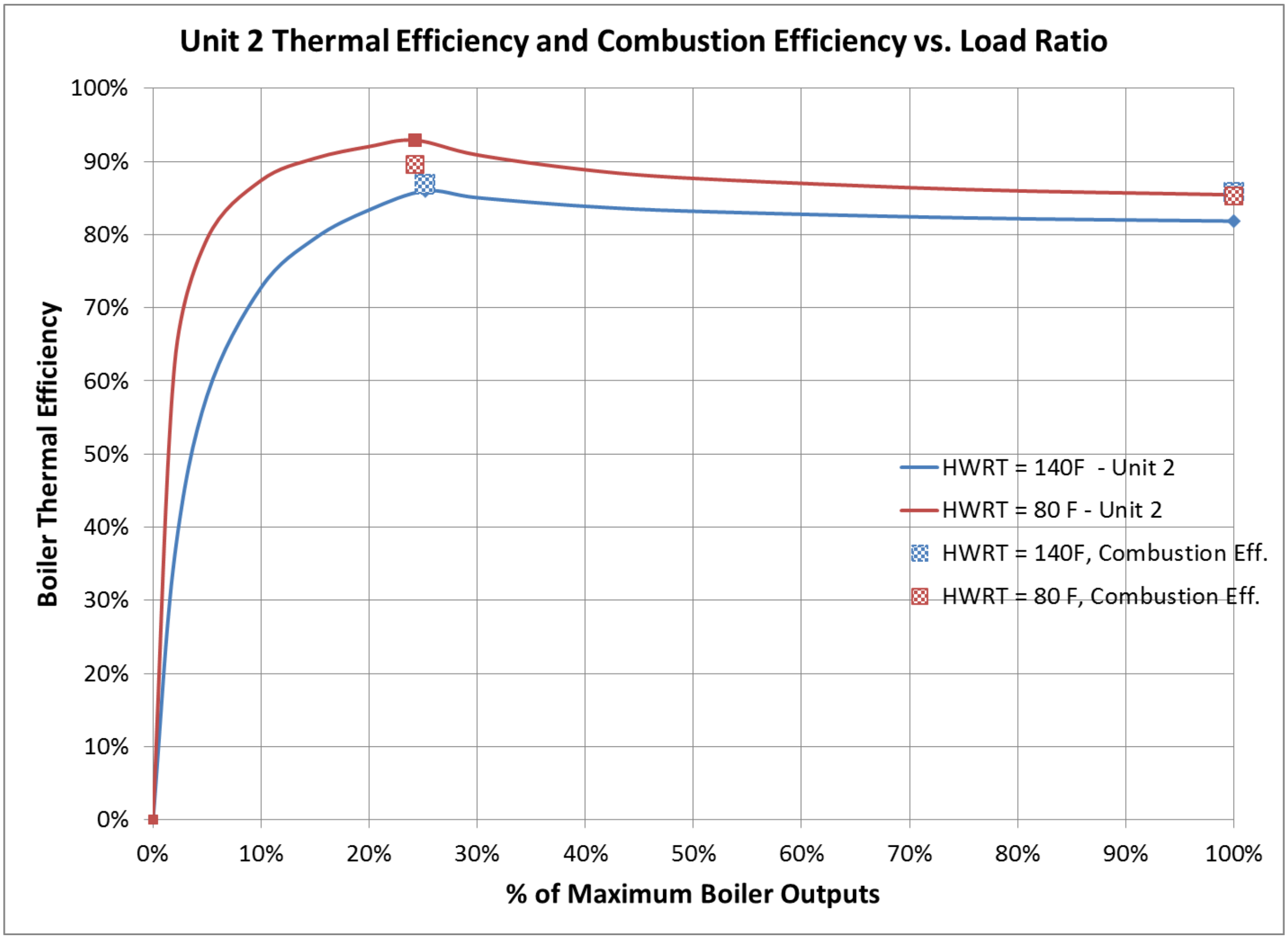

Unit 1 Thermal Efficiency vs System Return Temperature
(note: Boiler Entering Temperature is about 25F higher than System Return Temperature since boiler recirculation pump is sized for 15F dT)
Thermal Efficiency
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
PLR (% of max output)
HWRT = 80F
HWRT = 110 F
HWRT = 140 F
HWRT = 150F

UNIT 2

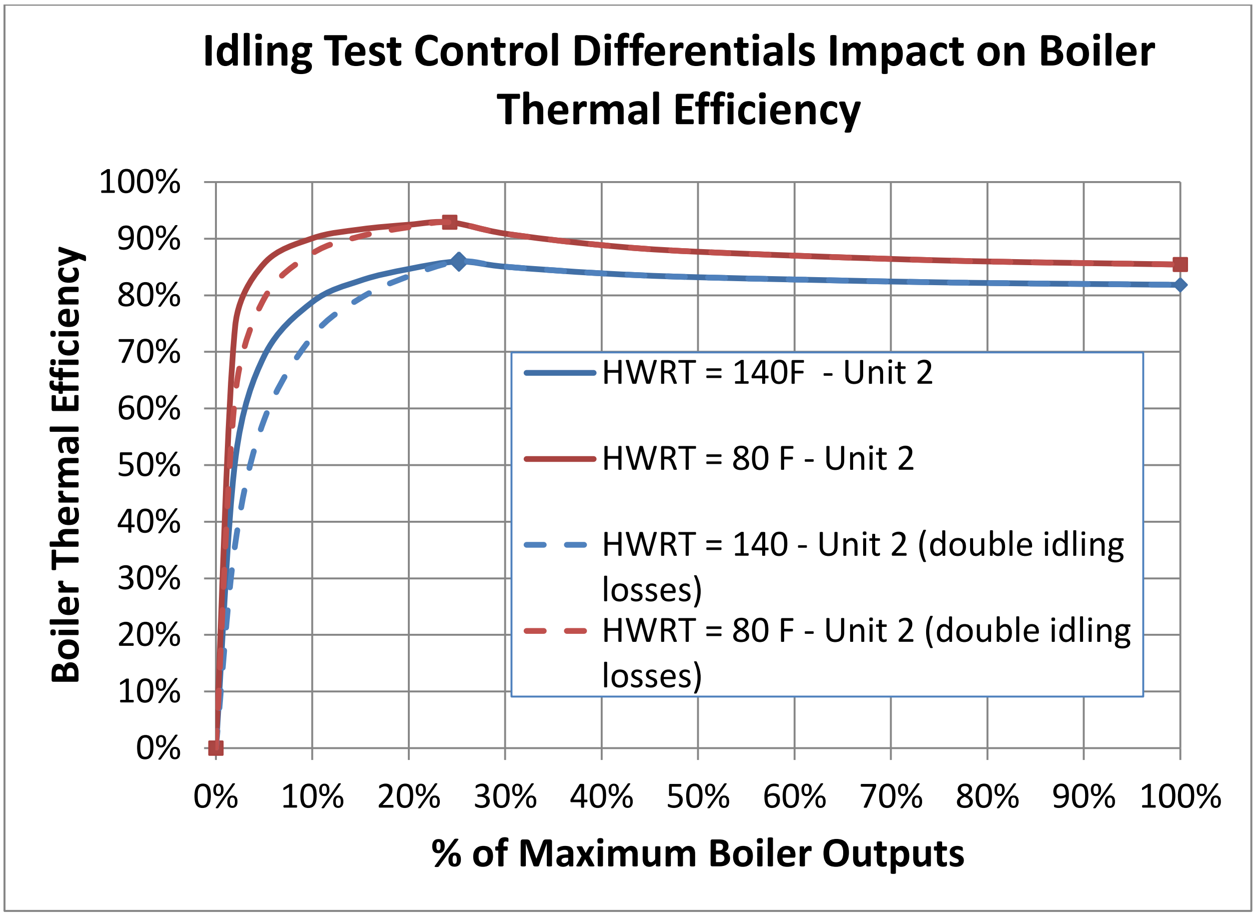
The figure below shows the thermal and combustion efficiency steady state test results for Unit 2. Theoretically, combustion efficiency must always be higher than thermal efficiency. One would also expect a consistent pattern between combustion efficiency and thermal efficiency but there is no clear relationship between the combustion and thermal efficiencies. At high fire/high temperature, the combustion efficiency is a couple points higher, which makes sense but at low fire and low temperature the thermal efficiency is a couple points higher, which of course is not possible.



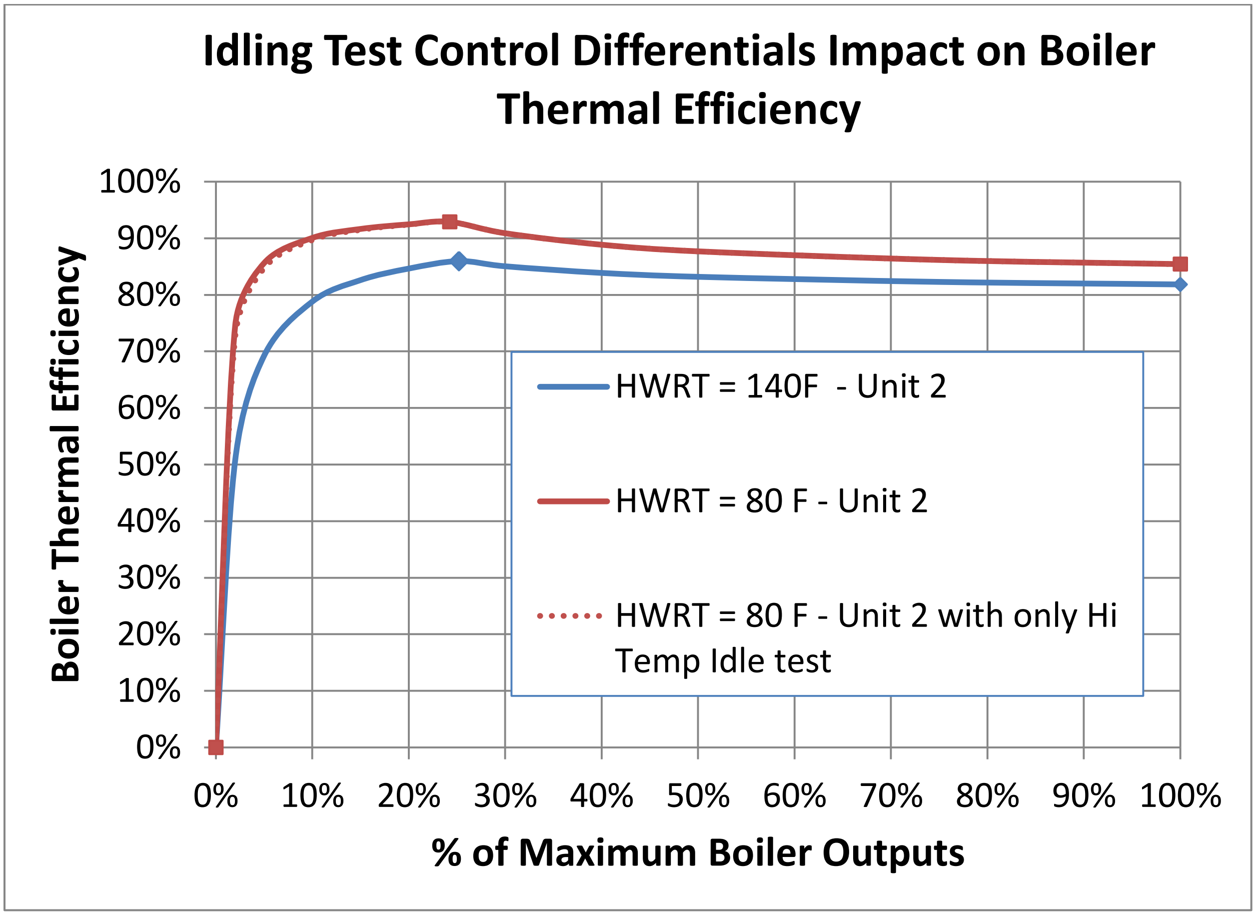
The figure below shows the results of the linear interpolation for the steady state and idling points (0% output). It also shows the combustion efficiency points for comparison.



The figure below shows the potential impact of idling controller differential on the thermal efficiency interpolation. The idling tests for Unit 2 were inadvertently run with a differential of 20°F (180°F +/- 10°F). The standard requires a differential of no more than 10°F (180°F +/- 5°F). A smaller differential would increase the idling losses since there will be more cycles per hour and thus more pre-purge/post-purge losses. The solid lines in the figure are the tested data (20°F differential). The dashed lines are interpolation assuming the idling losses are double the measured losses. This is of course extreme because idling losses include jacket losses which are largely unaffected by differential. This basically shows that even if the jacket losses were doubled the curves are not very significantly impacted.



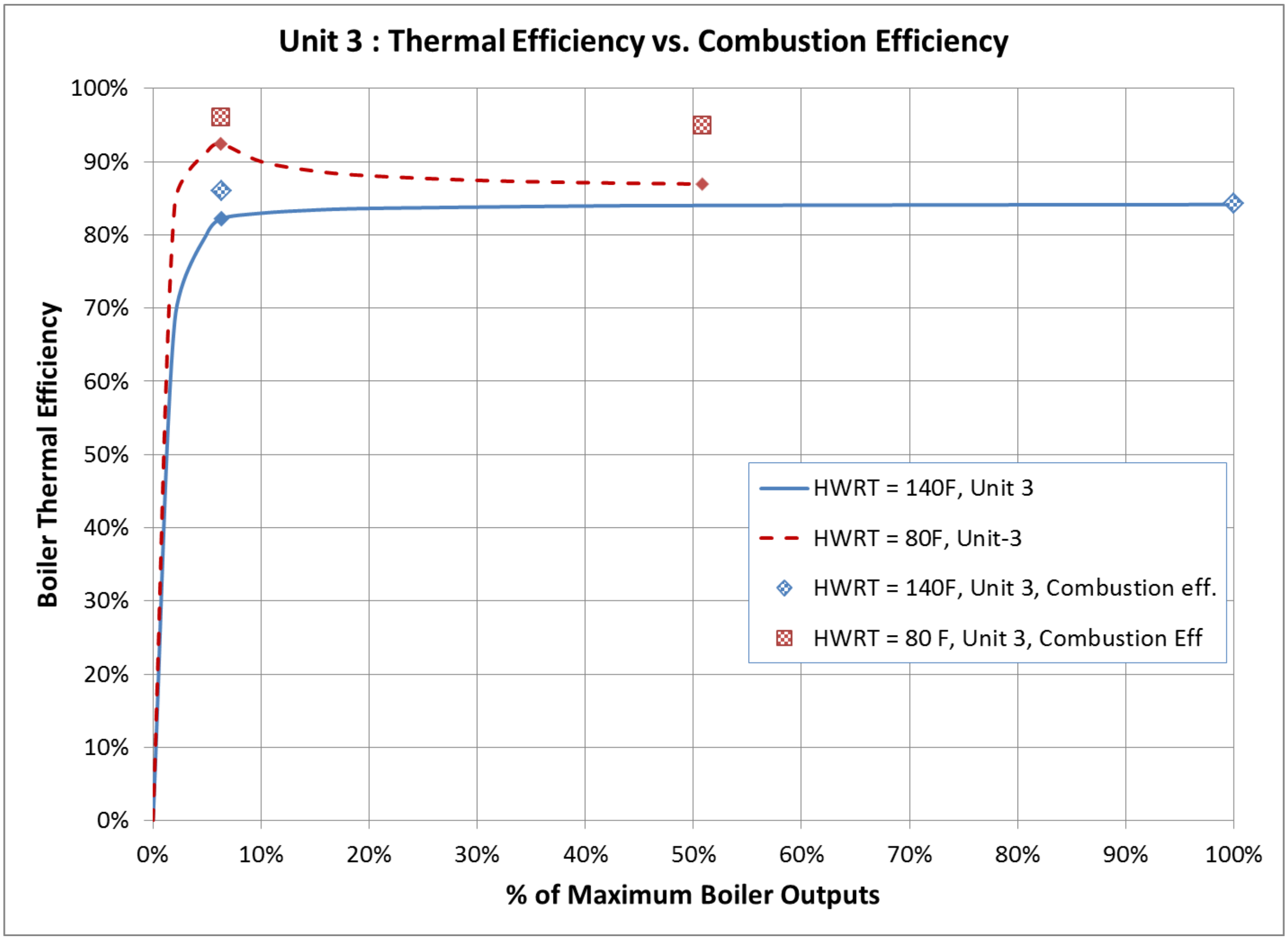
The figure below shows the impact of the 2nd idling test on the interpolation results. The standard only requires one idling test, at high temperature. It allows a second idling test at low temperature. The solid red line shows the interpolation results for the low temperature test using the low temperature idling test results. The dotted red line shows the low temperature results using the high temperature idling test results. Clearly, in this case at least, there was no benefit to running the low temperature idling test, since the high temperature test produced the same interpolation results.



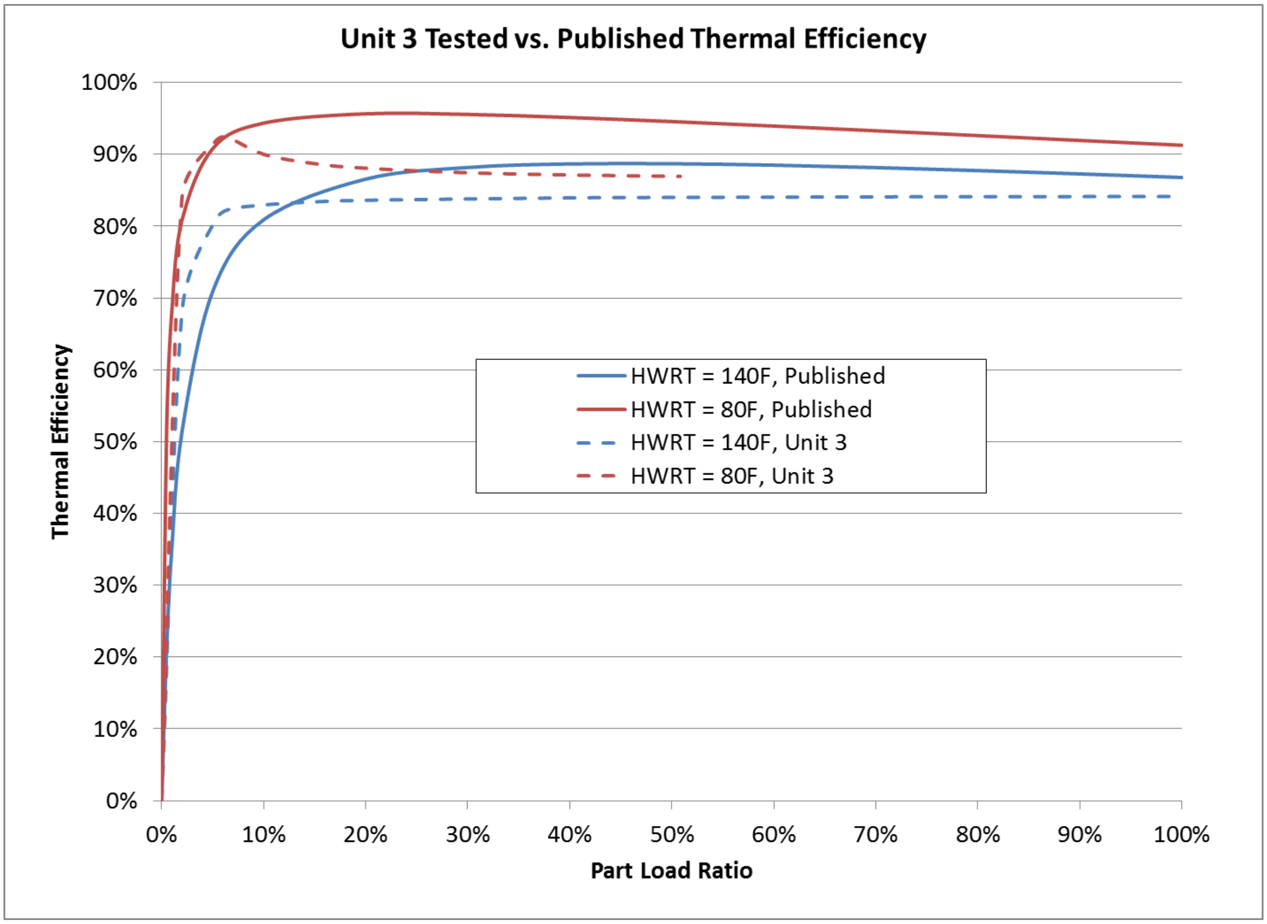
UNIT 3

The figure below shows the tested combusion and thermal efficiency results for Unit 3. The heat rejection system (cooling tower, pumps, heat exchanger, etc) were unable to reject enough heat at low temperature to run the high fire / low temperature test. Instead an intermediate fire / low temperature test was run.

The combustion efficiency is higher than the thermal efficiency, as expected, but there is no clear pattern for how much higher.



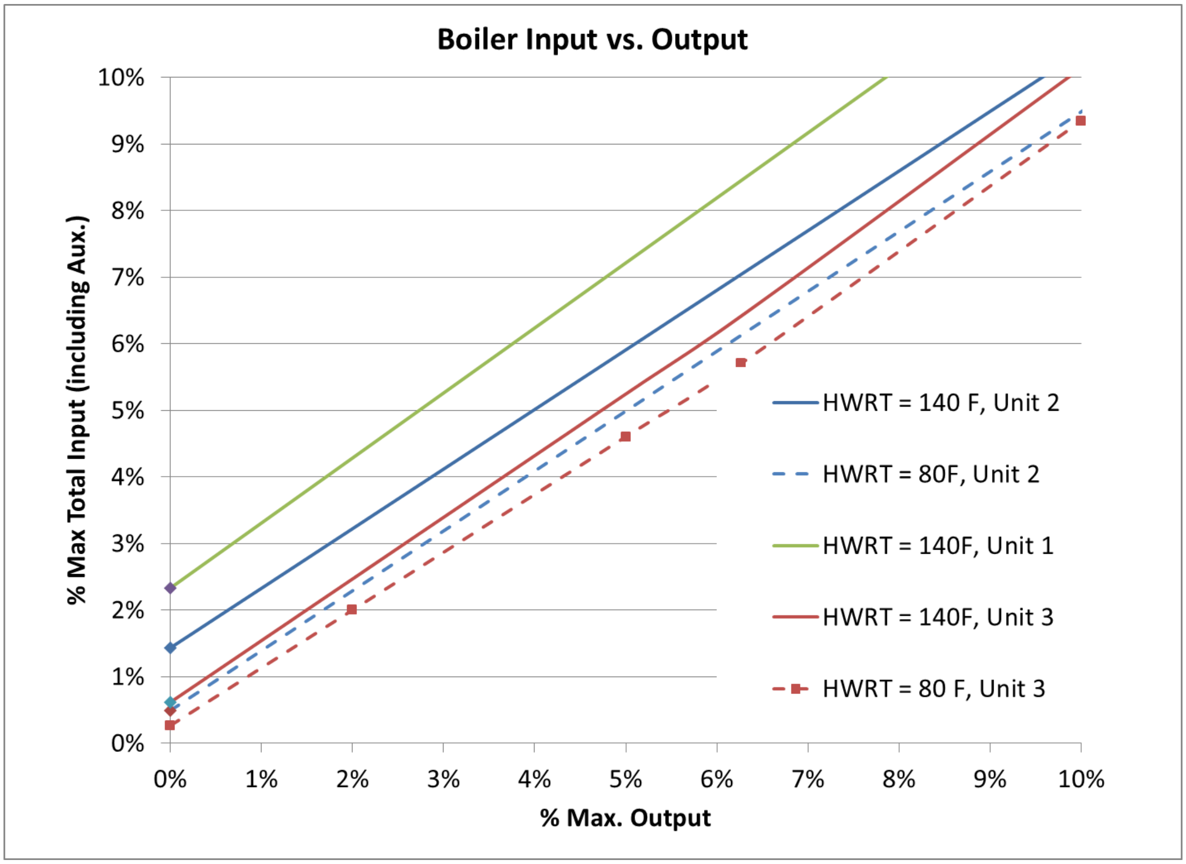
The figure below compares the tested results for Unit 3 with some published marketing data available from the Unit 3 manufacturer. The test results appear to be lower efficiency, at least at the higher firing rates, than the manufacturers data.



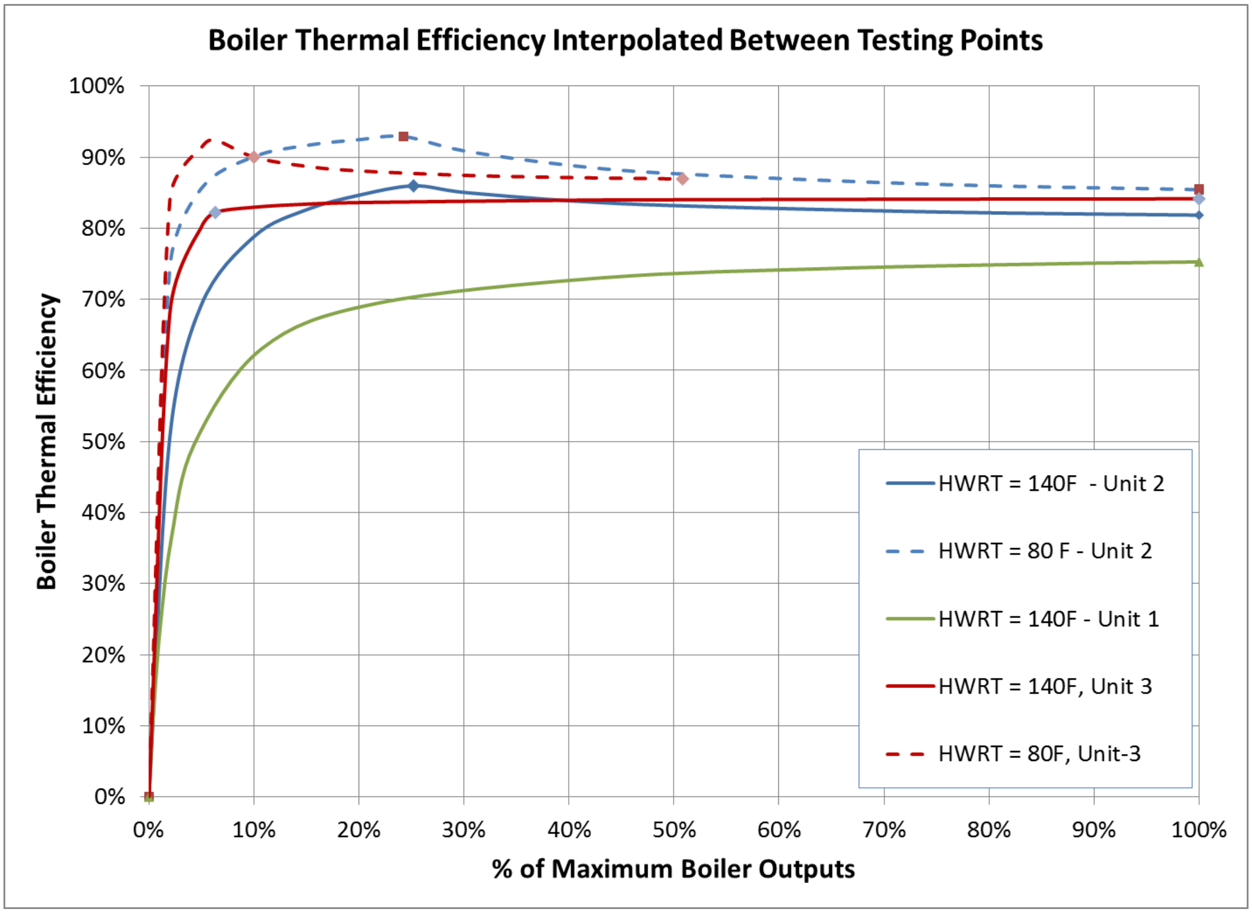
Comparison Between Units

Idling Losses

The figure below shows the idling losses for each of the 3 units tested. Note that the idling losses for unit 2 at high temperature were tested with a 20°F differential, not 10°F as required. So these losses should probably be a little higher than shown here.

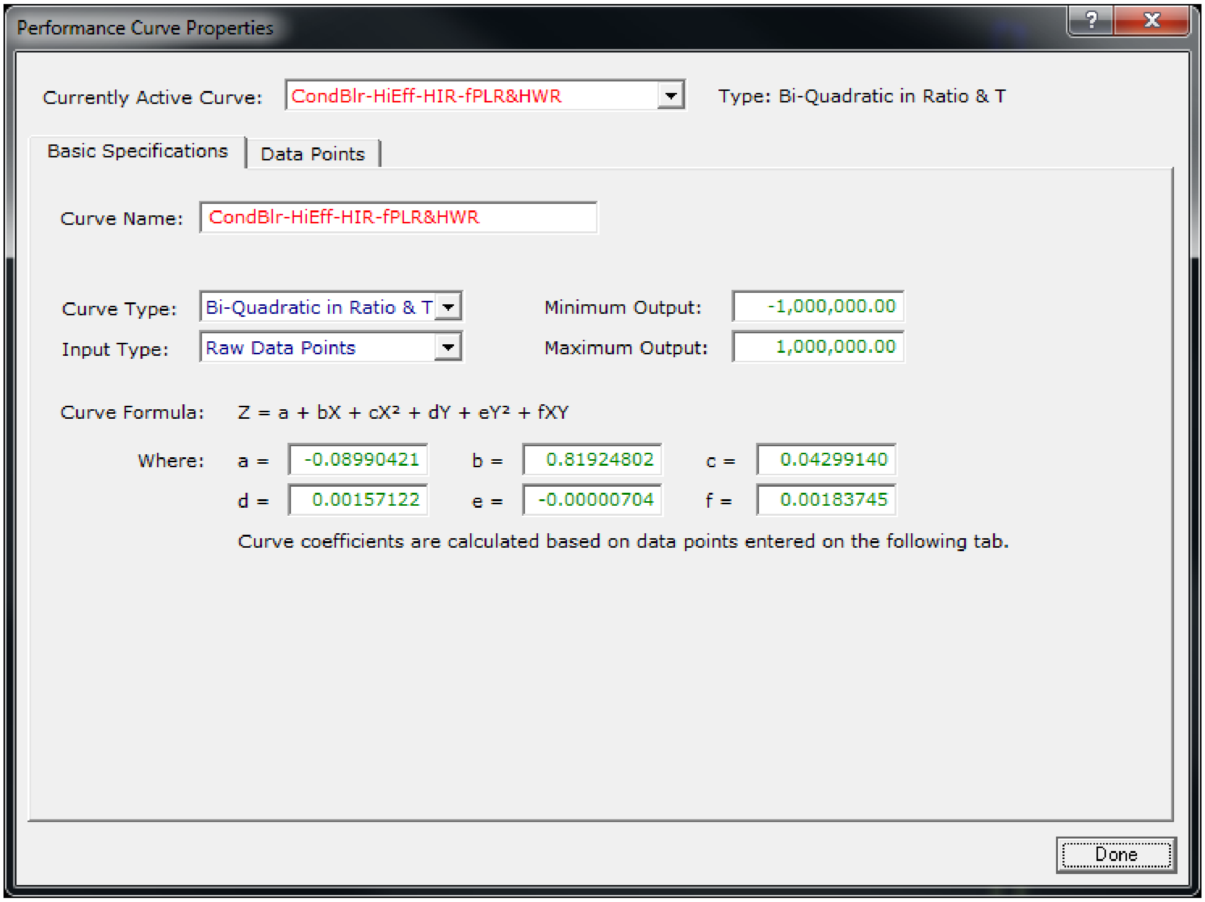


The figure below shows the thermal efficiency results for all 3 boilers. The solid lines are the high temperature results and the dashed lines are the low temperature results. The fact that the unit 2 and unit 3 curves cross each other is likely due to the fact that they were tested at different part load ratios. Unit 2 was tested at 20% since it is 5:1 and unit 3 was tested at 5% since it is 20:1. The interpolation procedures in the Standard are intentionally conservative and likely under-estimate the efficiency between test points. Had intermediate test points be run for unit 3 at say 20% they may be been higher efficiency than the unit 2 test points at 20%.

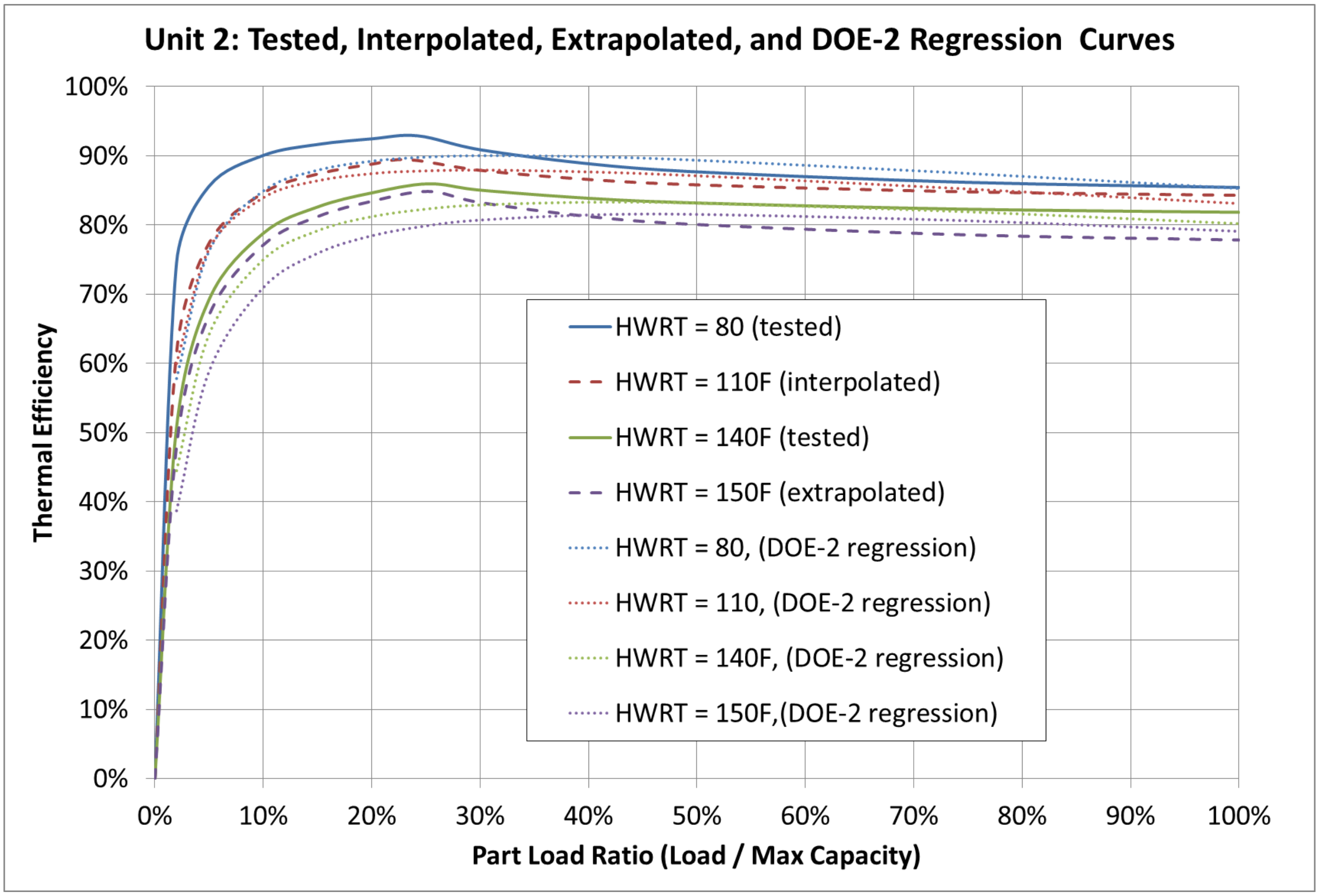


DOE-2.2 Boiler Curves

One of the goals of this research was to develop DOE-2 boiler performance curves for use in energy simulations. DOE-2.2 has two boiler models: a condensing boiler and a non-condensing model. The condensing model is actually more accurate and is appropriate for both condensing and non-condensing boilers. This model uses an equation for modifying the design point boiler efficiency as a function of both boiler entering water temperature and part load ratio. The curve has 6 coefficients that must be provided. The current DOE-2 default for this curve is shown below.



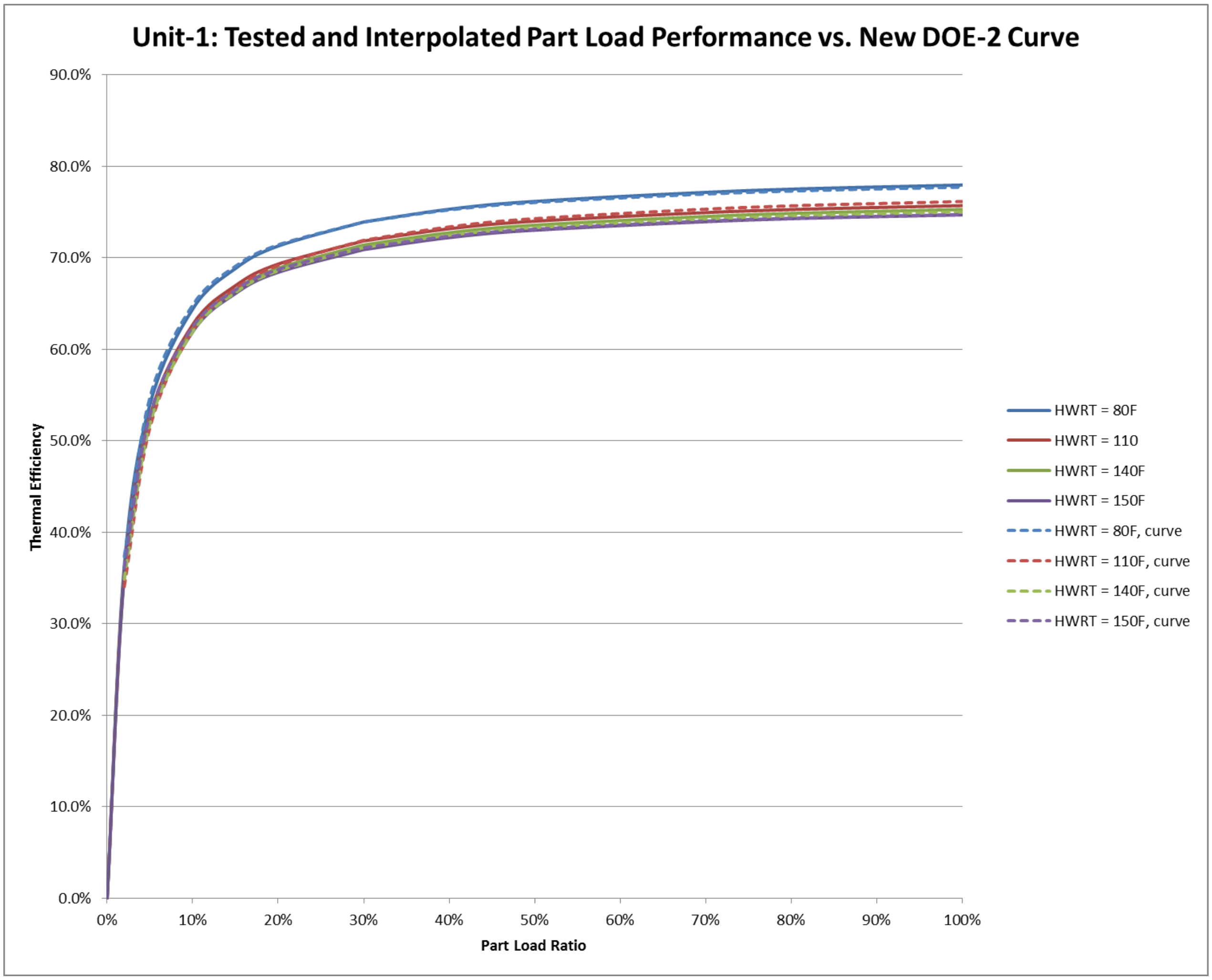
The figure below shows test results for Unit 2 at high (140 HWRT) and low (80 HWRT). It also shows the calculated results for 110°F HWRT using the interpolation procedures in section 10 of the Standard. It also shows the calculated results for 150°F HWRT using the extrapolation procedures in section 12 of the Standard. This set of tested, interpolated and extrapolated data was then fed into a regression to develop DOE-2 curve coefficients. The results of the DOE-2 regression are then plotted for various HWRTs on the figure.



DOE-2.2 curve coefficient for Unit 2:

f	e	d	c	b	a
0.00093126	6.10005E-06	-0.001213242	0.115399844	0.799743068	0.07003822

Similarly DOE-2.2 curve coefficients were developed for Unit 1. The figure below shows that the curve coefficients for Unit 1 closely match the test data used to generate the coefficients.



The following text snippets can be pasted into a text file and then imported into eQuest in order to use the Unit 1 and Unit 2 DOE-2 curves.

```
Curve based on unit-1
****************************************
"TE SingleStageATMCondBoiler" = CURVE-FIT
  TYPE          = BI-QUADRATIC-RATIO&T
  INPUT-TYPE     = COEFFICIENTS
  COEFFICIENTS    = ( -0.012625, 0.935632, 5.13322e-016, 0.000661718,
      -2.83634e-006, 0.00056479 )
  ..

Curve based on unit – 2
****************************************
"TE MultiStageForceDraftCondBlr" = CURVE-FIT
  TYPE          = BI-QUADRATIC-RATIO&T
  INPUT-TYPE     = COEFFICIENTS
  COEFFICIENTS    = ( 0.0700382, 0.799743, 0.1154, -0.00121324, 6.1e-006,
      0.00093126 )
```

..

There was insufficient test data for Unit 3 to develop statistically significant DOE-2.2 curve coefficients. However, we were able to create curve coefficients from the Unit 3 manufacturers published data.

```
Curve based on unit – 3 manufacturer's data
****************************************
"TE CondBlr-High Eff-HIR-fPLR&HWR" = CURVE-FIT
  TYPE            = BI-QUADRATIC-RATIO&T
  INPUT-TYPE      = DATA
  INDEPENDENT-1   = ( 0.05, 0.2, 0.4, 0.6, 0.8, 1, 0.05, 0.2, 0.4, 0.6, 0.8,
      1, 0.05, 0.2, 0.4, 0.6, 0.8, 1, 0, 0 )
  INDEPENDENT-2   = ( 60, 60, 60, 60, 60, 60, 100, 100, 100, 100, 100, 60,
      160, 160, 160, 160, 160, 160, 60, 160 )
  DEPENDENT       = ( 0.0488846, 0.198175, 0.3994, 0.608339, 0.8156,
      1.02246, 0.0514, 0.210154, 0.420641, 0.6375, 0.850864, 1.07229,
      0.05604, 0.225686, 0.4513, 0.6768, 0.90307, 1.13065, 0.04, 0.04 )
        ..
```

Data Analyses Conclusions

Analyses on the data have shown that the Standard 155P test methods and the ATS Test Facility both provide reasonable results that are consistent with expected test results. The results showed similar results to existing rating data (from BTS-2000) and to manufacturers published data but also showed that neither the rating data nor the manufacturer's data tell the whole story of boiler efficiency and thus reinforces the need for Standard 155P. For example, the testing corroborates BTS-2000 ratings that show that condensing boilers are more efficient than non-condensing boilers but the testing also goes beyond BTS-2000 by showing the strong relationships between entering water temperature and efficiency and between load ratio and efficiency.

In addition to validating Standard 155P and the ATS Test Facility, the data analysis has also resulted in a set of DOE-2.2 boiler curves based on high quality and impartial performance data that can now be used to accurately simulate various boiler system designs and control strategies.

Recommendations

Three sets of recommendations have come out of this research: recommended changes to Standard 155P, recommendations to improve the ATS boiler test facility, and recommendations for future research at ATS, or elsewhere, to support Standard 155P. Each set of recommendations is described below.

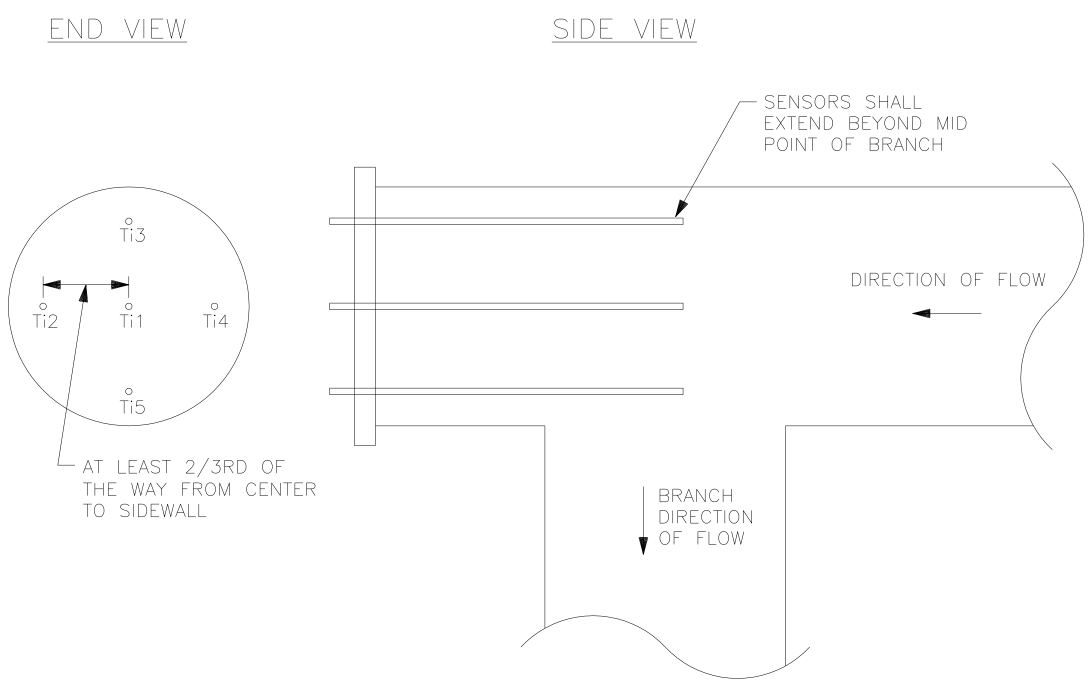
Recommended Changes to Standard 155P

Over 60 recommended changes to Standard 155P were generated as a result of this research and have been submitted to the Standard Committee for consideration. The full list of recommendations is imbedded in the Working Draft of the Standard using Word Track Changes. Unfortunately, the Working Draft is only available to members of the committee and designated individuals and thus could not be included in this public report. Some of the recommendations are described below.

Stratification

Recommended language on stratification: "For boilers where the minimum firing rate is less than 50% of high fire rate, Tout shall consist of an array of 5 temperature sensors, per Figure X. Data from all 5 sensors shall be recorded and must agree within 1°F during testing. The average value shall be used in calculations… To insure that outlet temperature is uniform at the location of the outlet temperature array, mixing devices such as valves and sidestream mixing pumps may be inserted between the boiler outlet and the outlet temperature sensor air. Any electric power consumed by mixing devices shall be included in the auxiliary energy input rate."

Figure 8. Proposed Figure X for Inclusion in Standard 155



Steady State Efficiency Tests

For atmospheric boilers, it may be extremely difficult to perform combustion efficiency analysis. Unit 1 was an atmospheric boiler, and would have to be damaged to create a reasonable flue gas sampling location.

Measuring the firebox draft would also require the boilers to be damaged. For this reason, the firebox draft measurement was excluded for all tests.

There are conflicting requirements for measuring flue gas condensate. Since the procedure is designed to run the thermal and combustion efficiency tests concurrently, recording intervals need to be consistent. The intervals as listed inconsistently by the standard are as follows:

- Section 9.1.4.1. – Record at 30 minute intervals
- Section 9.2.2. – Single measurement at end of test
- Section 8.2.3. – Record at 30 minute intervals

While the purpose of the recirculation loop is to maintain manufacturer suggested minimum flow rates, the practicality of integrating the recirculation loop should be examined. The location of the loop and the flow measurement device is such that there is no way to verify the boiler flow rate when the recirculation loop is in use. In addition, there is interest in further examination of manufacturer minimum flow rates, so data collected at less-than-minimum recommended flows is useful. Removing the recirculation loop would also reduce the cost to construct the test apparatus because it would reduce the total plumbing, reduce the number of valves, eliminate a pump, and eliminate two temperature sensors (System Inlet and System Outlet).

Idling Test

Recording burner on-time is very labor intensive without a data acquisition system. The test operator must be on alert and monitoring system temperatures at all times, and be prepared to time the next firing cycle. Even with a data acquisition system, the boiler's internal controls may not provide a "firing status" output, in which case a test operator would still be required to manually measure the firing time. These data are deemed necessary for examining the performance of the boiler. At this time, there is no alternative method for capturing these data, but this should be explored as a means to simplify the test procedures.

Eliminate the Recirculation Loop Requirement

While the purpose of the recirculation loop is to maintain manufacturer suggested minimum flow rates, the practicality of integrating the recirculation loop should be examined. The location of the loop and the flow measurement device is such that there is no way to verify the boiler flow rate when the recirculation loop is in use. In addition, there is interest in further examination of manufacturer minimum flow rates, so data collected at less-than-minimum recommended flows is useful. Removing the recirculation loop would also reduce the cost to construct the test apparatus because it would reduce the total plumbing, reduce the number of valves,

eliminate a pump, and eliminate two temperature sensors (System Inlet and System Outlet).

Therefore the Standard should allow lowering ΔT instead of installing recirc loop (the boiler does not know the difference):

- Recirculation loop 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 can be measured directly and maintained above the recommended minimum flow rate. In this case, Tin and test rig GPM will be calculated (instead of measured) based on actual Tr, actual Tout, actual boiler flow and assumed test rig temperature rise of 40.0°F. For example, if Tout is measured at 180.5°F, boiler flow is measured at 10.25 GPM and Tr is measured at 159.0°F, then Tin would be calculated to be 140.5°F and test rig flow rate would be calculated to be 5.51 GPM

DATA SHEET

The data sheet should be revised to match the requirements of the test procedure. Examples include:

- For steady state efficiency tests, the data sheet has 5 minute data intervals for the warm-up period. There is no requirement in the standard to increase sampling frequency during the warm-up period.
- For steady state efficiency tests, the test period sampling interval for the flue condensate is 15 minutes, which again conflicts with the Standard.
- For idling tests, the data sheet includes 6 warm-up cycles and 6 test cycles. The standard requires 3 warm-up cycles and 6 test cycles.
- For idling tests, the data sheet includes fields for minutes and seconds for the "burner on" time and "cycle time." To capture this data, a more advanced data acquisition system is needed, as well as an output from the boiler reporting its firing rate. The DAS could trigger based on a change in value of the firing rate and record at a high sampling rate until the firing rate went back to 0. Then it could report the time. Using a less complex system that takes data at regular intervals is not sufficient to capture this data unless the sampling rate is very high, but that would create very large data files. In the absence of a DAS, labor costs are high, as the test operator must be on constant alert and record times down to the second.
- For throughflow loss tests, the recording intervals should be entered as values to match the standard. Currently, these are blank fields and it is up to the test operator to enter the recording interval.
- For throughflow loss tests Throughput Data Summary table, note that "Total energy source used through two hours" is actually the average energy source rate over two hours in kW. This should be revised in the data sheets.

RECOMMENDATIONS TO IMPROVE THE ATS BOILER TEST FACILITY

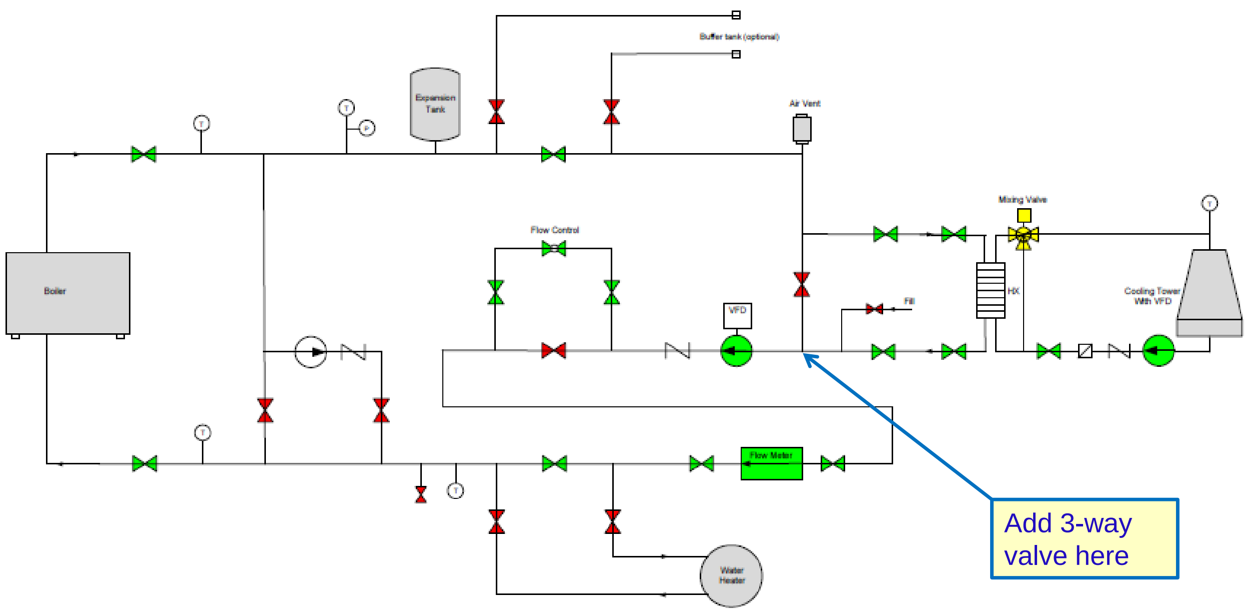
1. Gas Meter - To perform any transient testing, a gas meter that can output higher resolution gas data would be required. While the current meter has a dial that can be read in approximately 0.25 cubic foot increments, the pulse output for the data acquisition system is only 5 cubic foot increments, which is insufficient resolution. At low fire, it may take several minutes to use 5 cubic feet of gas so gas usage data will not be available at a high enough frequency to provide adequate information about the system performance. Even for the steady state testing and idling testing, 5 ft3 increments may not be sufficient resolution for low firing rates. One option is to use a webcam or some other automated device for reading the dial positions (see http://www.eissq.com/BallandPlate/appendix/dial_reader.html). Another option is to switch to another meter type.
2. Room Temperature - The test lab is unconditioned space. For tests occurring during summer months, this is acceptable, but it has not been possible to meet the room air temperature requirements for several of the tests during cool winter months. The test chamber should be insulated and outfitted with a method of heating and cooling for environmental control. Doing so would allow much more versatility in comparing boiler performance in varying environmental conditions. Another option is to condition the entire building, rather than just the test chamber. There happen to be a couple large packaged air conditioning units in the building for other testing that may be suitable for conditioning the building. Converting to ducted intake air (see below) will make it easier to condition the building.
3. Heat Rejection Control - During low fire tests, maintaining the return water temperature is labor intensive. There is a 3-way mixing valve on the cooling tower which controls the cooling water flow rate through the heat exchanger. Low system flow rates during low fire tests are extremely sensitive to changes in heat exchanger cooling water flow rate. The actuator controlling the 3-way valve has proven inadequate to reliably provide automatic control of return water temperature. A gate valve was added to the cooling water loop to provide very fine manual adjustments to the flow rate. While this has made it possible to meet test specifications, it is a labor intensive process to make minute adjustments and maintain the temperature. Additionally, because the cooling tower is outside, its capacity changes throughout the day and inherently requires constant attention from the test operator to maintain return water temperature. Further development of the cooling tower's 3-way mixing valve control system may help with the sensitivity of the return water temperature. Clearly one problem is the long distance and large volume of water between the 3-way valve and the boiler entering temperature sensor—the time lag between a valve adjustment and the effect being seen at the sensor is too long for PID control. Another problem may be the 3-way valve selection—it may not have sufficient valve authority. Options for improving heat rejection control include:

a. Use the existing electric water heater for automatic control. The 3-way valve can be fixed in a position that slightly overcools the boiler entering water. A PID loop would then control the electric heater to maintain boiler entering water temperature. The water heater is much closer to the boiler compared to the 3-way valve so this should improve controllability.

b. Reselect the existing 3-way valve or automate the gate valve.

c. Add a 3-way mixing valve just upstream of the system pump as shown in Figure 9. This valve would also be closer to the boiler than the existing 3-way and may be easier to automate or have quicker response than the electric heater.

FIGURE 9. NEW 3-WAY VALVE FOR BETTER HEAT REJECTION CONTROL



d. Automate the pump VFD to maintain HWST. A valve or electric heater should still automatically maintain the entering water temperature but also automating the VFD to maintain leaving water temperature may reduce the burden on the operators. The pump loop should probably be slower than the valve/heater control loop to prevent loop fighting.

e. Reconfigure the piping to get the heat exchanger closer to the boiler or add a heat exchanger.

4. Circuit Breaker - The maximum amp draw of the electric water heater is greater than the capacity of the panel, causing the breaker to trip if the water temperature is significantly different from the set point. Heat rejection control and throughflow testing could be facilitated by upgrading the panel providing power to the electric water heater.

5. Data Acquisition System - It would be useful to spend extra time linking the boiler's electronics into the data acquisition system. Depending on the test unit, this could provide additional information that can be used for reviewing the boiler's internal controls (e.g. firing rate) and comparing to the test operations and measurements.

6. Storage Tank - Add a storage tank to the system to add mass as a method to better simulate a real world distribution system where a building would have greater length of piping. The test apparatus was built to accommodate a storage tank for this purpose so adding a tank is relatively easy at this point.

7. Intake Air Temperature Control – Being able to vary the combustion intake air temperature is important for testing how the combustion air temperature affects

boiler performance. Currently the combustion air comes directly from the room so there is really no way to control intake temperature other than controlling the room temperature. One option is to put a variable electric heater in a section of ductwork that can be attached to the boiler intake. The combustion air would still come from the room but could be heated above room temperature. Another option is to duct the combustion air from outdoors with a heater in the ductwork. This may allow a greater range of inlet air temperatures if the outdoor temperature is below the room temperature. It also may allow the room temperature to be more easily controlled because no combustion air openings in the room would be required.

RECOMMENDATIONS FOR FUTURE RESEARCH

Many ideas for additional testing were generated throughout the project. Below is a sample of possible research.

SENSOR ACCURACY

The biggest concern the 155P Committee has is sensor accuracy for the thermal efficiency tests, in particular the accuracy of the inlet/outlet water temperature sensors, the water flow meter and the gas flow meter. Even if the sensor cutsheets and calibration sheets indicate that the sensors meet the required accuracy, committee members are skeptical that the actual performance of the sensors will meet the accuracy claimed on paper. Members are also skeptical that the HHV data available from the PG&E website is accurate at any given moment.

Therefore we propose to research sensor accuracy in more depth as it pertains to 155P testing. The research will include literature review and laboratory testing. We will compare a number of different sensors and calibration procedures. We will test multiple sensors of the same type and sensors of different types. Temperature sensors will be compared in parallel. Water and gas flow meters will be compared in series. Water flow meters will also be compared to a weigh tank. Sensors to be tested include the following.

TEMPERATURE SENSORS

- Differential thermopiles (e.g. Delta-T Company Differential Temperature Transducer)
- Matched RTDs
- Unmatched digital RTDs (e.g. Thermal Probes)

WATER FLOW METERS

- Full bore mag meters
- Coriolis meters
- Weigh tank

GAS FLOW METERS

- Diaphragm type meters

- Roots type meters

GAS HIGHER HEATING VALUE

- Utility provided data
- Calorimeter
- Gas chromatograph
- bottled gas of a known calorific value

In addition to testing various sensors, we will also focus on developing new test methods that could be included in 155P to insure sensor accuracy. Such methods could include statistical analysis and requiring boiler inlet/outlet sensor to be placed together in a hot bath and shown to agree within say 0.2^{o}F at both the expected inlet and outlet temperatures for a given steady state test.

MIXING DEVICES

One of the recommendations from this research is to require a temperature sensor array at the outlet to verify good mixing. The mixing devices used would then be up to the tester as long as the array of sensors agreed within the required tolerance. The committee has expressed a preference for a prescriptive mixing device rather than an array of sensors. The feeling is that an array of high accuracy sensors would be more expensive than a simple mixing device. The goal of this research would then be to test a number of simple mixing devices and compare them to an array of high accuracy sensors to verify that they provide adequate mixing. Mixing devices to be tested could include:

- Sections of smaller diameter straight pipe to determine if a minimum velocity or Reynolds number is sufficient.
- Valves (e.g. two ball valves at different orientations with a minimum ΔP across the assembly)
- Static mixers (e.g. http://www.stamixco.com/)
- Side stream mixing pump

COMBUSTION EFFICIENCY FACTORS

Several members of the committee now believe that sensor accuracy issues make thermal efficiency too difficult to directly measure accurately. Thus the 155P committee is now considering allowing or requiring thermal efficiency to be extrapolated from combustion efficiency test data, rather than requiring or allowing thermal efficiency tests to be run. The default factors for extrapolating from combustion efficiency to thermal efficiency do not exist right now. Without these default factors thermal efficiency may be deleted entirely from the Standard. This would be unfortunate because combustion efficiency alone does not give the total picture of boiler efficiency – it relies on theoretical equations and does not account for jacket losses.

In order to develop combustion-to-thermal efficiency default factors, thermal and combustion efficiency will be tested on several types of boilers and varying loads and temperatures. To develop these factors it is critical that the thermal efficiency sensors used in the research are known to be highly accurate. Thus sensor calibration and redundancy will be important (see recommended Sensor Accuracy research above).

IDLING FACTORS

In addition to the combustion-to-thermal efficiency default factors, there is also discussion in the 155P committee of allowing the use of default idling factors rather than running idling tests. This would reduce the testing burden since one idling test for a well-insulated condensing boiler can take multiple days to run. Again, these default idling factors do not currently exist but could be developed with further testing at ATS.

JACKET LOSSES

Another option the Committee is considering for calculating thermal efficiency, rather than directly measuring it, is to measure combustion efficiency and measure jacket losses, since thermal efficiency is basically a combination of these two. The Committee is currently developing test procedures for measuring jacket losses. In order for the Standard to be submitted for public review the jacket loss test procedure will need to be tested and compared to direct measurement of thermal efficiency.

RELAX TESTING TOLERANCES

One of the complaints about the Standard is the fact that many of the testing tolerances are difficult to achieve and that if something goes out of tolerance then the test is not valid, which of course, increases the testing burden. Indeed many of the tests we conducted in this research did not meet all the 155P tolerances. We proposed to do a detailed sensitivity analysis on some of the test tolerances to see if they can be relaxed. For example, the high fire, high temperature test requires the outlet temperature to be 180°F +/- 5°F and the ΔT to be 40°F +/- 4°F. We may find however, that as long as the inlet temperature is maintained at 140 +/- 5°F that the ΔT can vary by as much as +/- 10°F and still provide fairly uniform efficiency results.

Another testing tolerance that was difficult to achieve in the testing conducted, was maintaining the flue gas CO2 within ± 0.1 percentage points of the carbon dioxide specified by the manufacturer. Not only are testers allowed to retune for every test but they are sometimes required to do so to meet this criteria. Again, sensitivity analysis may show that allowing a larger variation in CO2 concentration does not significantly change boiler efficiency but does reduce the testing burden. Further testing in this area may also lead to a more clearly defined CO2 tolerance, i.e. some manufacturers may specify tighter tolerances than others in order to game the ratings. Defining the CO2 tolerance in the standard could level the playing field in this regard.

AMBIENT TEMPERATURE EFFECTS AND NEW TEST PROCEDURES

While the focus of the 155P committee is to further reduce the burden of 155P, there are members of the committee who believe that 155P has already been watered down too far and there is a need to establish more comprehensive test procedures.

Indeed this research at ATS has provided some glimpses that 155P testing may not be sufficient to adequately characterize how a boiler will operate in a typical commercial application. For example, 155P allows the tester to retune the boiler before every test and thus does not account for the fact that efficiency may degrade in the field when a boiler is tuned at one ambient temperature during start up and operated at other temperatures. Thus one focus of further research would be to characterize the effect of ambient temperature on efficiency and to develop new test methods for possible inclusion in future versions of 155P or other standards. The testing would consist of tuning boilers at one set of room and inlet temperature conditions then testing the boiler at different temperature conditions and different loads.

One outcome of this research might be a new optional test procedure that could be added to the standard for testing ambient temperature effects. It would specify that the boiler is tuned at one temperature then tested at that temperature and at other temperature(s).

Boiler manufacturers recognize that ambient temperature affects performance and some manufacturers have developed advanced control algorithms to account for ambient temperature and optimize performance (e.g. O2 Trim). These are controls that dynamically adjust the air-fuel ratio based on measured temperature or flue gas conditions. Currently, however, 155P does not allow these manufacturers any way to "take credit" for these technologies. A new test procedure for ambient temperature effects would allow them to "take credit" and would encourage manufacturers to include temperature compensation with their controls and to develop new and better techniques for temperature compensation.

Dynamic Boiler Testing

None of the 155P tests actually tests the boilers under their own control with a real load. For the steady state tests the firing rate is locked. For the idling tests the boiler is under its own control but there is no load so this gives little indication of how a boiler will operate under non-zero loads. The standard assumes that a boiler serving a load above its minimum firing rate will operate at steady state, i.e. it will not over-fire and cycle off. The supplemental testing done on Unit 3 and field experience indicates that this is not always the case. Depending on how robust the boiler's internal controls are and how variable the load is can determine whether or not a boiler cycles above minimum fire. These two factors—controls stability and load variability—affect each other and can cause a boiler system to perform far worse than the 155P tests might indicate. When a boiler cycles off the supply temperature to the load quickly falls which can cause the valves to open. When the boiler cycles back on the valves may not compensate in time and the boiler may have to ramp up. Then when the valves do compensate for the higher water temperature the boiler may have to cycle off. Thus boiler controls instability can cause load instability and vice versa.

New research on boiler internal controls would consist of subjecting boilers under their own control to different load profiles and seeing how the boilers respond to the varying loads. In the same way that new test procedures for ambient temperature effects may expose boilers that do not respond well to ambient temperature, new test procedures for actual load control may expose boilers that do not have good firing control algorithms. Exposing poor firing controls will of course encourage manufacturers to develop better controls.

Possible Dynamic Testing Procedures

1. Above minimum flow

The load will be adjusted by modulating the boiler pump speed. The tower speed will be fixed at a speed high enough to meet 100% load at the given HWS/R temperatures and outdoor wetbulb (default 100% speed). The mixing valve will maintain the test rig incoming temperature, Ti, at setpoint. Note that the mixing valve control will not be very stable if the boiler firing control is not very stable or the boiler is cycling between low fire and no fire. This is ok as it probably approximates the behavior of coil control valves responding to HWST fluctuations from boiler firing. The mixing valve PID should probably be fairly slow since coil valves will not respond quickly.

2. At minimum flow

The minimum pump speed will correspond to the boiler minimum flow rate. When the pump speed gets to minimum flow the mixing valve will modulate from current position to full bypass, i.e. it will switch from maintaining HWRT to modulating over the range from current position to full bypass (no load).

If the boiler has no minimum flow requirement then there is only one region of control, i.e. only the pump speed is needed to modulate the load. The minimum pump speed is the lowest speed at which the pump will still spin (e.g. 3 Hz). To modulate load below minimum pump speed the pump will cycle off

3. Slow Test – Full Range
    a. With the boiler maintaining HWST at setpoint and the mixing valve maintaining Ti at setpoint, and the minimum flow controls active
    b. Slowly modulate the load from 100% load (max pump speed) to 0% load over 60 minutes.
        i. Max pump speed is the steady state high fire flow rate
    c. Wait 5 minutes
    d. Shut off the pump (if not off)
    e. Wait 10 minutes
    f. Turn on the pump and slowly raise the load from 0% to 100% over 60 minutes.
4. Fast Tests – Small Range

The slow test simulates a system with lots of relatively small valves. The fast test simulates a system with relatively few valves where the opening/closing or a single valve has a larger impact on the boiler load.

    a. Modulate the pump speed between speeds corresponding to 30% and 40% of the high fire flow rate in cycles of 5 minutes. Note that the mixing valve PID loop may need to be adjusted for faster response. If the range is below the min pump speed then modulate the mixing valve rather than the pump speed.
    b. Repeat with other ranges and cycle times, depending on boiler turndown and how the boiler responds to the tests conducted.

5. Mass Effects

Add a large buffer tank (e.g. 100 gallons) to the boiler loop and divert all flow through the tank. Repeat Slow Test and Fast Tests with buffer tank.

DEVELOP DATA TO SUPPORT UTILITY PROGRAMS AND ENERGY CODES

The lack of realistic full load rating data and any part load rating data for boilers is severely hampering the development of utility incentive programs and energy codes for boilers. For example, currently all savings values in both the PG&E deemed and calculated programs are relative to a baseline combustion efficiency of 80% as defined in CA 2010 Title 20. This is based on testing done at the full load firing rate. Data obtained by Enovity and others has shown that typical yearly space heating operation is not at full load. Unbiased test data at firing rates that more accurately match customer operation will result in more accurate savings calculations for deemed work papers and calculated incentive boiler product offerings. Another example, is the current utility incentive program for O2 Trim Control. There is very little 3rd party data available to corroborate the savings assumptions inherent in that program.

The tests conducted at ATS are one of the few sources of independent 3rd party test data available. However, this is a fairly limited data set and there are still some questions about the accuracy of some of the test data. A more complete data set of boiler performance data covering more boiler types and more operating conditions would be extremely valuable for developing more and better utility incentive programs.

This data set could also used in analyses to support improvements in energy standards such as CA Title 20. This could occur independently of any action in the DOE or ASHRAE/AHRI.

PROVIDE DATA FOR VALIDATING ENERGY MODELING SOFTWARE PROGRAMS

A more complete data set of boiler performance data could be used to validate and improve the boiler algorithms and default parameters in eQuest, DOE-2, and EnergyPlus.

OTHER IDEAS FOR FUTURE RESEARCH

- Compare flue gas sampling locations. On Unit 2, manufacturer representatives sampled flue gas immediately at the flue outlet while tuning the boiler. The standard requires sampling to occur downstream of the thermocouple grid.
- Test the effects of different flue connections on combustion efficiency (negative draft, positive draft, or an exhaust hood).
- Perform cold-start and hot-start parametric runs of the idling test.
- Perform the Idling Test at flow rates other than the full fire flow rate.
- Conduct the Idling Test at various room temperatures.
- Test necessity of the standard warm-up period.
- Test the effect of ambient temperatures on efficiency.
- Test the effect of ambient conditions on tuning – tune at low end but run test at high end and vice versa.

- Experiment with boiler tuning and retuning.
- Test the flue damper's effect on efficiency.
- Compare results to other standards.
- Test boiler control algorithms, vary PID gains.
- Additional varying load tests – slow variation, fast variation.

FINAL THOUGHTS

A state-of-the-art test facility was constructed at PG&E's Applied Technology Services in San Ramon. The facility is able to collect boiler test data beyond the capabilities of many existing test facilities. Results of this research allow PG&E to drive the development of new procedures and standards for boiler efficiency, driving a market shift towards more efficient gas use. ASHRAE Standard 155P will continue development with the results obtained, and with the goal of eventually being accepted as the required test standard.

In addition to providing feedback on the draft Standard, useful data were collected on the operating characteristics of three test units. These results will be used to refine testing procedures, improve efficiency requirements, and continue to drive the demand for better boilers.

The end of this project is really the beginning of a vast testing potential for hot water boilers. Answering one question inevitably led to two more questions, and the research facility at ATS provides unlimited potential to search for the answers.

APPENDIX A DATA ANALYSIS

UNIT 1 – STANDARD 155P REPORT FORMS

We modified the Excel report forms provided by the 155P committee to include all the necessary calculations to fully complete the forms, i.e. all the calculations for combustion efficiency and thermal efficiency are now included in the forms. The excel files are available from Jeff Stein at Taylor Engineering: jstein@taylor-engineering.com

COVER PAGE

ASHRAE 155P Report Form - Cover Page

Test Date	*9/20/2011*	Max Input (Btu/hr)	*715,000*	Flue Damper Mfgr	
Test Facility		Min Input (Btu/hr)	*715,000*	Flue Damper Model #	
Test Location		Burner Type		Flue Damper Size	
Boiler Mfgr	*Unit-1*	Turn Down Ratio	*single stage*		
Boiler Model	*Unit-1*	Burner Mfgr		Water or Steam	
Fuel (gas, oil, elec)		Burner Model #		Heat Exchanger Type	
Indoor Boiler		VAC/Hz/Φ		Recirc Loop Req'd (Y/N)	
Outdoor Boiler		Flue Type (Vert/Horz)		Dry Mass of Boiler Wt lbs	
Condensing (Y/N)		Draft Type (Atm/Mech)		Boiler Vol. Gal	

Indicate Tests Inlcuded with Test ID number in the appropriate box and fill in the appropriate return water tem

	Return Water Temp	Steady State Tests								Other Tests	
		Single Stage Burner	Two-Stage Burner		Modulating Burner					All	
		High Fire	High Fire	Low Fire	High Fire	Int Fire 1	Int Fire 2	Int Fire 3	Low Fire	Idling	Throughflow
Steam or high RWT Hot Water	140	*SS1*								*ID1*	*TH1*
Other RWT 1											
Other RWT 2											
Other RWT 3											
Other RWT 4											
Low RWT Hot Water	80	*SS2*									

Steady State Test Results Summary:

	HiF 140F	HiF 80	HiF 110	HiF 150	LoF LoT	6	7	8	9	10
Fuel Input, Btu/hr	618,673	609,596	614,937	623,301						
Boiler Output, Btu/hr	454,017	474,772	463,306	464,305						
Elec Power Input, KW	0.37	0.38	0.38	0.38						
Thermal Efficiency, %	73.2	77.7	75.2	74.3						
mbustion Efficiency, %										

	11	12	13	14	15	16	17	18	19	20
Fuel Input, Btu/hr										
Boiler Output, Btu/hr										
Elec Power Input, KW										
Thermal Efficiency, %										
mbustion Efficiency, %										

	21	22	23	24	25	26	27	28	29	30
Fuel Input, Btu/hr										
Boiler Output, Btu/hr										
Elec Power Input, KW										
Thermal Efficiency, %										
mbustion Efficiency, %										

IdlingTest Results Summary:

	Steam or High RWT Water	*Low RWT Water*
Avg. Cycle Length, min:sec	5.194	
Avg. Thermal Energy Fed, Btu/hr	22,820	
Avg. Thermal Energy Fed, % of Max	3.69	

Throughflow Test Results Summary:

	Steam or High RWT Water	*Low RWT Water*
Avg. Thermal Energy Fed, Btu/hr	14578.6	
vg. Thermal Energy Fed, % of Max		

Tested and Interpolated Thermal Efficiency (%) at the following Input Rates and Temperatures, as applicable:

	% of Max Output							
RWT	2%	5%	10%	15%	20%	50%	75%	100%
140	25%	42%	54%	60%	63%	70%	72%	73%
80								

☐ *This boiler is capable of sustained operation at the test conditions on the attached data sheets*

STEADY STATE RESULTS

For Thermal Efficiency and Combustion Efficiency Tests

		Gas Data		OIL Data		Test Input Rate Data		Required and/or Specified Tests	
Test Date	9/20/11	HHVBtu/Ft³	1019	'HV Btu/lb Oil		Rate Units	715,000 (Btu/hr or kW)	Themal Efficiency	X
Test ID #		Sp. Gravity		'V Btu/Gal Oil		Test Rate	618,673	nbustion Efficiency	X
Technician	Taylor	Wobbe		PI Gravity Oil		Test Rate Input Relative to Nameplate Input		Water Temperature In	140 F °F / °C
oom Rel Hum %	31.1	Gas T °F	74.0	C Oil		Max X, Min , Other	% to Max Rate 87%	'ater Temperature Out	180 F °F / °C
Design CO2 %		Meter P "W.C.	6.1	H Oil					
		Baro P "Hg	29.5	Dil Nozzle Size		Elec. Equip. Power (V/HZ/PH)	120/60/1		
		Man P "W.C.	1440.4	ump Press Oil		Elec. Resistance Heater Power (V/HZ/PH)	n/a		
		Corr. Fact Gas	0.969						

30 Minute Warm-Up Period to Obtain Steady-State Conditions Prior Start of Thermal/Combustion Efficiency Test

Time: Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0						77.6	76.8					137.6	178.9	164.3	14.6	41.3	0.0							369	
0	5	0	43.8						77.9	77.2					138.7	179.7	165.2	14.4	41.0	112							369	
0	10	0	48.6						78.3	77.6					138.2	179.8	165.2	14.6	41.6	112							370	
0	15	0	53.4						78.5	77.8					138.6	179.7	165.2	14.5	41.0	112							371	
0	20	0	48.5						78.6	78.0					138.1	179.8	165.2	14.6	41.7	112							371	
0	25	0	48.5						79.6	78.7					138.2	179.2	164.7	14.5	41.1	112							371	
0	30	0	53.3						79.5	78.8					138.8	180.5	165.9	14.6	41.6	112							371	
Used																												
Ave/5 min			49.4												138.3	179.7	165.1	14.5	41.3	111.9							370.2	

2 Hour Thermal Efficiency and/or Combustion Efficiency Test Data

Time: Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0					78.8	80.2	79.3					137.8	180	165	15	42	0							370	
0	15	0	150.0					79.5	80.8	79.9					138.0	179	165	15	41	336							369	
0	30	0	149.6					80.5	82.0	81.0					138.5	180	165	15	41	335							369	
0	45	0	149.3					81.4	83.2	82.1					138.2	180	165	15	42	335							366	
1	0	0	148.9					82.8	84.8	83.7					138.4	180	165	15	41	335							367	
1	15	0	153.3					84.2	85.4	85.2					138.3	180	165	15	42	335							369	
1	30	0	148.2					85.2	86.3	86.1					138.2	180	165	15	41	335							371	
1	45	0	147.8					85.9	87.1	87.0					138.4	180	165	15	41	335							368	
2	0	0	152.3					86.7	87.9	87.8					138.4	180	165	15	41	335							370	
Used																												
Ave/15 min			156.3					82.8	84.2	83.6					138.24	179.8	165	15	42	335.1							368.7	

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Supporting Calculations for SS1:

Steady State Thermal Efficiency				
10.1.2	**Rated Steady State Gross Output Rate, $\dot{q}_{out}$, water mode, Btu/h**			
Q	22.34	gpm	flow rate	
T_o	180	F	system outlet temp	
T_i	138	F	system inlet temp	159
$c_{p,water}$	1	Btu/lbF	specific heat of water	
P_{H20}		psi	water pressure	0
ρ_{Tave}	61.02	lb/ft3	water density	
$\dot{q}_{out,ss}$	454,017	Btu/h		
10.1.3.	**Heat Input Rate, qin,ss, Btu/h**			
10.1.3.2.	**Gas-Fired Boilers**			
Vgas	625.00	acf	actual cubic feet of gas	
HHVgas	1019	Btu/cf		
t_{test}		hrs		
Appendix A				
P_{gas}	0.22	psig	gas pressure	
Proom	14.44	psia	ambient pressure	
T_{gas}	74.0	F	gas temperature	
P Factor	0.998		pressure correction factor for gas	
T Factor	0.974		temperature correction factor for gas	
Cs	0.971		non-standard conditions gas correction factor	
$\dot{q}_{in,ss}$	618,673	Btu/h		
10.1.4	**Test Efficiency, η_0, Percent**			
η_0	73.4	%		
10.1.5.	**Standard auxiliary energy input rate, $q_{in,aux,ss}$, kW**			
$q_{in,aux,ss}$	0.369	kW		
10.1.6.	**Rated Steady State Thermal Efficiency, Including Parasitic Losses, Percent**			
$\eta_{ss,thermal}$	73.2	%		

Pacific Gas and Electric Company®

For Thermal Efficiency and Combustion Efficiency Tests

		Gas Data		**OIL Data**		**Test Input Rate Data**	
Test Date	9/28/2011	HHVBtu/Ft ^{3}	1022	'HV Btu/lb Oil		Rate Units	715,000 (Btu/hr or kW)
Test ID #		Sp. Gravity		'V Btu/Gal Oil		Test Rate	609,596
Technician	enjamin Taylc	Wobbe		PI Gravity Oil			
oom Rel Hum %	28.4	Gas T °F	91.6	C Oil			
Design CO2 %		Meter P "W.C.	6.2	H Oil			
		Baro P "Hg	29.4	Dil Nozzle Size			
		Man P "W.C.	6.2219	ump Press Oil			
		Corr. Fact Gas					

Test Rate Input Relative to Nameplate Input

Max	Min	Other	% to Max Rate
			85%

Elec. Equip. Power (V/HZ/PH)

Elec. Resistance Heater Power (V/HZ/PH)

Required and/or Specified Tests

Themal Efficiency	x	
nbustion Efficiency		
Water Temperature In	105	°F / °C
ater Temperature Out	120	°F / °C

30 Minute Warm-Up Period to Obtain Steady-State Conditions Prior Start of Thermal/Combustion Efficiency Test

Operational Data

Time: Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs
0	0	0	0.0											
0	5	0												
0	10	0												
0	15	0												
0	20	0												
0	25	0												
0	30	0												
Used														
Ave/5 min														

Water Temp Data / Water Boilers / Steam Boilers / Electrical Consumption

Time: Hours	Min's	Sec's	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0														
0	5	0														
0	10	0														
0	15	0														
0	20	0														
0	25	0														
0	30	0														
Used																
Ave/5 min																

2 Hour Thermal Efficiency and/or Combustion Efficiency Test Data

Hours	Min's	Sec's	Thermal Energy Fed	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs
0	0	0	0.0		-10.0			88.0	90.7	90.3				
0	15	0	160.0		-10.0			88.6	90.6	90.4				
0	30	0	155.0					88.5	86.8	86.0				
0	45	0	160.0					88.8	87.0	86.3				
1	0	0	160.0					89.1	87.5	87.0				
1	15	0												
1	30	0												
1	45	0												
2	0	0												
Used														
Ave/15 min			158.8					89	88.5	88.0				1.4

Hours	Min's	Sec's	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	80	120.3				0							376	-999
0	15	0	79	119.9				354							375	-999
0	30	0	80	120.1				354							375	-999
0	45	0	79	120.0				354							375	-999
1	0	0	80	120.2				354							376	-999
1	15	0														
1	30	0														
1	45	0														
2	0	0														
Used																
Ave/15 min			80	120				353.9							375.4	####

Pacific Gas and Electric Company®

Steady State Thermal Efficiency

10.1.2	**Rated Steady State Gross Output Rate, $\dot{q}_{out}$, water mode, Btu/h**			
Q	23.59	gpm	flow rate	
T_o	120	F	system outlet temp	
T_i	80	F	system inlet temp	99.8406
$c_{p,water}$	1	Btu/lbF	specific heat of water	
P_{H20}		psi	water pressure	0
ρ_{Tave}	61.92	lb/ft3	water density	
$\dot{q}_{out,ss}$	474,772	Btu/h		
10.1.3.	**Heat Input Rate, qin,ss, Btu/h**			
10.1.3.2.	**Gas-Fired Boilers**			
Vgas	635	acf	actual cubic feet of gas	
HHVgas	1022	Btu/cf		
t_{test}		hrs		
Appendix A				
P_{gas}	0.22	psig	gas pressure	
Proom	14.42	psia	ambient pressure	
T_{gas}	91.62	F	gas temperature	
P Factor	0.996		pressure correction factor for gas	
T Factor	0.943		temperature correction factor for gas	
Cs	0.939		non-standard conditions gas correction factor	
$\dot{q}_{in,ss}$	609,596	Btu/h		
10.1.4	**Test Efficiency, η_0, Percent**			
η_0	77.9	%		
10.1.5.	**Standard auxiliary energy input rate, $q_{in,aux,ss}$, kW**			
$q_{in,aux,ss}$	0.375	kW		
10.1.6.	**Rated Steady State Thermal Efficiency, Including Parasitic Losses, Percent**			
$\eta_{ss,thermal}$	77.7	%		

Pacific Gas and Electric Company®

For Thermal Efficiency and Combustion Efficiency Tests

Gas Data

Test Date	9/28/2011
Test ID #	
Technician	enjamin Taylc
oom Rel Hum %	28.4
Design CO2 %	
HHVBtu/Ft³	1022
Sp. Gravity	
Wobbe	
Gas T °F	91.6
Meter P "W.C.	6.2
Baro P "Hg	29.5
Man P "W.C.	6.2066
Corr. Fact Gas	

OIL Data

'HV Btu/lb Oil	
'V Btu/Gal Oil	
PI Gravity Oil	
C Oil	
H Oil	
Dil Nozzle Size	
ump Press Oil	

Test Input Rate Data

Rate Units	715,000	(Btu/hr or kW)
Test Rate	614,937	

Test Rate Input Relative to Nameplate Input

Max	Min	Other	% to Max Rate
			86%

Elec. Equip. Power (V/HZ/PH)	
Elec. Resistance Heater Power (V/HZ/PH)	

Required and/or Specified Tests

Themal Efficiency	x	
nbustion Efficiency		
Water Temperature In	105	°F / °C
ater Temperature Out	120	°F / °C

Jeff Stein: shouldn't this be SCF (standard ft3)?

Jeff Stein: add columns for btu-in, btu-out and thermal efficiency

30 Minute Warm-Up Period to Obtain Steady-State Conditions Prior Start of Thermal/Combustion Efficiency Test

Time: Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0																									
0	5	0																										
0	10	0																										
0	15	0																										
0	20	0																										
0	25	0																										
0	30	0																										
Used																												
Ave/5 min																												

2 Hour Thermal Efficiency and/or Combustion Efficiency Test Data

Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0					86.1	84.6	85.1					109	151.2				0								
0	15	0						87.1	87.2	87.2					109	150.2												
0	30	0						88.0	86.9	87.2					110	152.8												
0	45	0						88.9	88.0	88.2					110	151.9												
1	0	0						89.6	89.2	89.1					109	151.6												
1	15	0																										
1	30	0																										
1	45	0																										
2	0	0																										
Used																												
Ave/15 min			160.0					88	87.2	87.4				1.4	109	152				331.3							375.5	

Steady State Thermal Efficiency

10.1.2	**Rated Steady State Gross Output Rate, $\dot{q}_{out}$, water mode, Btu/h**			
Q	22.09	gpm	flow rate	
T_o	152	F	system outlet temp	
T_i	109	F	system inlet temp	130.4351
$c_{p,water}$	1	Btu/lbF	specific heat of water	
P_{H20}		psi	water pressure	0
ρ_{Tave}	61.92	lb/ft3	water density	
$\dot{q}_{out,ss}$	463,306	Btu/h		
10.1.3.	**Heat Input Rate, qin,ss, Btu/h**			
10.1.3.2.	**Gas-Fired Boilers**			
Vgas	640	acf	actual cubic feet of gas	
HHVgas	1022	Btu/cf		
t_{test}		hrs		
Appendix A				
P_{gas}	0.22	psig	gas pressure	
Proom	14.43	psia	ambient pressure	
T_{gas}	91.62	F	gas temperature	
P Factor	0.997		pressure correction factor for gas	
T Factor	0.943		temperature correction factor for gas	
Cs	0.940		non-standard conditions gas correction factor	
$\dot{q}_{in,ss}$	614,937	Btu/h		
10.1.4	**Test Efficiency, η_0, Percent**			
η_0	75.3	%		
10.1.5.	**Standard auxiliary energy input rate, $q_{in,aux,ss}$, kW**			
$q_{in,aux,ss}$	0.376	kW		
10.1.6.	**Rated Steady State Thermal Efficiency, Including Parasitic Losses, Percent**			
$\eta_{ss,thermal}$	75.2	%		

For Thermal Efficiency and Combustion Efficiency Tests

		Gas Data		**OIL Data**		**Test Input Rate Data**		**Required and/or Specified Tests**	
Test Date	9/28/2011	HHVBtu/Ft³	1022	'HV Btu/lb Oil		Rate Units	715,000 (Btu/hr or kW)	Themal Efficiency	x
Test ID #		Sp. Gravity		'V Btu/Gal Oil		Test Rate	623,301	nbustion Efficiency	
Technician	enjamin Taylo	Wobbe		PI Gravity Oil		Test Rate Input Relative to Nameplate Input		Water Temperature In	105 °F / °C
oom Rel Hum %	28.4	Gas T °F	71.4	C Oil		Max / Min / Other	% to Max Rate 87%	ater Temperature Out	120 °F / °C
Design CO2 %		Meter P "W.C.	6.2	H Oil					
		Baro P "Hg	29.5	Dil Nozzle Size		Elec. Equip. Power (V/HZ/PH)			
		Man P "W.C.	6.2066	ump Press Oil		Elec. Resistance Heater Power (V/HZ/PH)			
		Corr. Fact Gas							

30 Minute Warm-Up Period to Obtain Steady-State Conditions Prior Start of Thermal/Combustion Efficiency Test

Time: Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	Operational Data: To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water Temp Data: Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Water Boilers: Feed water Gal	Water Level In	Steam Boilers: Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Electrical Consumption: Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0																									
0	5	0																										
0	10	0																										
0	15	0																										
0	20	0																										
0	25	0																										
0	30	0																										
Used																												
Ave/5 min																												

2 Hour Thermal Efficiency and/or Combustion Efficiency Test Data

Hours	Min's	Sec's	Thermal Energy Fed	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0						73.1	73.2					154	195.2				0								
0	15	0							72.9	72.8					156	197.3												
0	30	0							73.0	73.1					151	191.9												
0	45	0							72.5	72.1					150	191.5												
1	0	0							72.2	71.8					156	196.5												
1	15	0																										
1	30	0																										
1	45	0																										
2	0	0																										
Used																												
Ave/15 min			156.3						72.7	72.6				1.4	154	194				342.6							375.5	

Steady State Thermal Efficiency

10.1.2	**Rated Steady State Gross Output Rate, $\dot{q}_{out}$, water mode, Btu/h**				
Q	22.84	gpm	flow rate		
T_o	194	F	system outlet temp		
T_i	154	F	system inlet temp		174.0196
$c_{p,water}$	1	Btu/lbF	specific heat of water		
P_{H20}		psi	water pressure		0
ρ_{Tave}	61.92	lb/ft3	water density		
$\dot{q}_{out,ss}$	464,305	Btu/h			
10.1.3.	**Heat Input Rate, qin,ss, Btu/h**				
10.1.3.2.	**Gas-Fired Boilers**				
Vgas	625	acf	actual cubic feet of gas		
HHVgas	1022	Btu/cf			
t_{test}		hrs			
Appendix A					
P_{gas}	0.22	psig	gas pressure		
Proom	14.43	psia	ambient pressure		
T_{gas}	71.42	F	gas temperature		
P Factor	0.997		pressure correction factor for gas		
T Factor	0.978		temperature correction factor for gas		
Cs	0.976		non-standard conditions gas correction factor		
$\dot{q}_{in,ss}$	623,301	Btu/h			
10.1.4	**Test Efficiency, η_0, Percent**				
η_0	74.5	%			
10.1.5.	**Standard auxiliary energy input rate, $q_{in,aux,ss}$, kW**				
$q_{in,aux,ss}$	0.376	kW			
10.1.6.	**Rated Steady State Thermal Efficiency, Including Parasitic Losses, Percent**				
$\eta_{ss,thermal}$	74.3	%			

Idling Results

For Boiler Idling Test

		Gas Data		OIL Data	
Test Date	9/30/2011	HHVBtu/Ft³	1022	HHV Btu/lb Oil	
Test ID #		Sp. Gravity		HHV Btu/Gal Oil	
Technician	Taylor	Wobbe		API Gravity Oil	
Rel Hum %	60.7	Gas T °F	68.3	C Oil	
Design CO2 %		Meter P "W.C.	7.146	H Oil	
		Baro P "Hg	29.44	Oil Nozzle Size	
		Man P "W.C.	1413	Pump Press Oil	
		Corr. Fact Gas	0.983		

Boiler Equilibrium Conditior		
Rate Units	Btu/hr	(Btu/hr or kW)
Test Rate	22,820	
% to Max Input	3.2%	
CO2 %		

Required and/or Specified Tests		
Idling Test		
Midpoint Setting	180	°F / °C
Control Differential	3	°F / °C

Room air (every 15 min) and Outlet Water Temperature (every minute) to be recorded per section 9.3 separately and Summaried on this Data Sheet

row

	Boiler Stabilization Cycle 1	Boiler Stabilization Cycle 2	Boiler Stabilization Cycle 3	Boiler Stabilization Cycle 4	Boiler Stabilization Cycle 5	Boiler Stabilization Cycle 6
Burner On Min's	3	0	0	0	0	
Burner On Sec's	30	13	11	11	11	
Total Cycle Min's	4	4	4	4	5	
Total Cycle Sec's	0	20	40	50	10	
Max Water Out (°F)	182.3131	185.992	185.997	186.143	185.781	
Min Water Out (°F)	78.23751	175.45	176.688	176.777	177.054	
Midpoint (°F)	130.2753	180.721	181.343	181.46	181.418	
Room Temp (°F)	70.10315	70.4185	70.2115	70.3031	70.2147	

	Boiler Idling Cycle 1	Boiler Idling Cycle 2	Boiler Idling Cycle 3	Boiler Idling Cycle 4	Boiler Idling Cycle 5	Boiler Idling Cycle 6
Burner On Min's	0	0	0	0	0	0
Burner On Sec's	12	11	11	11	11	11
Total Cycle Min's	4	5	5	5	5	5
Total Cycle Sec's	40	0	10	0	10	20
		#	#	#	#	#
Max Water Out (°F)	185.7	186.2	185.5	185.3	184.5	186.5
Min Water Out (°F)	176.7	176.7	176.8	176.7	176.7	176.8
Midpoint (°F)	181.2	181.5	181.2	181.0	180.6	181.6
Room Temp (°F)	70.2	70.3	70.3	70.4	70.2	70.4

	Hr	Min	Sec
Total Test Duration		31	10
Total Time Burner On		0	67
Avg. Cycle Length		5.167	1.667
Avg. Burner On Time		0	11.17

Total Thermal Energy Fed Thru 6 Cycles	11.79641751	Ft³, Gal, or KW
Total Elec. Equip. Energy Used Thru 6 Cycles	0.355319672	KW
Avg. Max Outlet Water Temp	185.6	°F
Avg. Minimum Outlet Water Temp	176.7	°F
Avg. Midpoint Water Temp	181.2	°F

Avg. Thermal Energy Fed, Btu/hr	22,820
Thermal Energy, % Nameplate Input	3.2%
Water flow rate (gpm)	
Full Fire Water flow rate (gpm)	

Pacific Gas and Electric Company®

SUPPORTING CALCS:

10.3.1.	**Test Heat Input Rate, $q_{in,idle,test}$, Btu/h**		
10.3.1.2.	**Gas-Fired Boilers**		
Vgas	11.79641751	cf	cubic feet of gas
HHVgas	1027	Btu/cf	
t_{test}	0.5	hrs	
Appendix A			
P_{gas}	0.257243976	psig	gas pressure
Patm	14.4232872	psia	ambient pressure
T_{gas}	68.29985114	F	gas temperature
P Factor	1.00		pressure correction factor for gas
T Factor	0.98		temperature correction factor for gas
Cs	0.98		non-standard conditions gas correction factor
$q_{in,idle,test}$	22,932	Btu/h	
10.3.2.	**Corrected Idling Heat Input Rate, $q_{in,idle,corr}$, Btu/h**		
10.3.2.2.	**High Water Temperature Hot Water**		
	180	F	standard rating condition for outlet water temp during high temp idling test
	75	F	standard rating condition for room air temp during idling test
T_{out}	181.2	F	test rig outlet water temp
T_{room}	70.3	F	test room temp
$q_{in,idle,corr}$	21,714	Btu/h	
10.3.2.3.	**Low Water Temperature Hot Water**		
			standard rating condition for outlet water temp during low temp idling test
			standard rating condition for room air temp during idling test
			test rig outlet water temp
			test room temp
10.3.3.	**Idling Parasitic Losses, $L_{P,idle}$, kW**		
$q_{in,aux,idle}$	0.355319672	kW	
10.3.4	**Rated Idling Energy Input Rate, $q_{in, idle,rated}$**		
qin, idle,ratec	22,926.91	Btu/h	

THROUGHFLOW RESULTS

For Boiler Throughflow Loss Test

Test Date	9/30/2011
Test ID #	
Technician	Taylor
Rel Hum %	43.1732

Inlet Water Temp	180	°F / °C
Control Differential	3	°F / °C

Boiler Stabilization Test - 1 Hour Min

Time: Hours	Time: Min's	Heater Inlet Wat (°F)	Outlet Water Ten (°F)	Room Air Temp (°F)	Test Rig Flow Rat (GPM)
0	0	170.1		74.2	22.4
0	5	175.5			
0	10	177.6			
0	15	178.2		0.0	0.0
0	20	178.6			
0	25	180.2			
0	30	180.2		0.0	0.0
0	35	180.1			
0	40	180.1			
0	45	180.1		74.0	22.5
0	50	180.1			
0	55	180.0			
1	0	180.0		0.0	0.0

Boiler Throughput Loss Test- 2 Hr Min

Time: Hours	Time: Min's	Heater Inlet Wat (°F)	Heater Outlet Wa (°F)	Room Air Temp (°F)	Test Rig Flow Rate
0	0	179.7		74.2	22.4
0	5	179.7			
0	10	179.7			
0	15	179.7		74.3	22.4
0	20	179.6			
0	25	179.7			
0	30	179.7		74.3	22.4
0	35	179.6			
0	40	179.7			
0	45	179.7		74.0	22.5
0	50	179.7			
0	55	179.7			
1	0	179.7		74.1	22.4
1	5	179.7			
1	10	179.7			
1	15	179.7		74.1	22.5
1	20	179.7			
1	25	179.7			
1	30	179.7		74.1	22.4
1	35	179.7			
1	40	179.6			
1	45	179.7		74.1	22.4
1	50	179.7			
1	55	179.7			
2	0	179.7		74.0	22.5

Throughput Loss Data Summary

otal Energy Source Used Thru 2 Hours	4.2715	KW
Avg. Thermal Energy Fed, Btu/hr	14578.6	
Avg. Thermal Energy Fed, % to Max		
Average Inlet Water Temperature	179.694	°F
Outlet Water Temperature Setpoint		°F

Unit 2 – Standard 155P Report Forms

Cover Page

ASHRAE 155P Report Form - Cover Page

Test Date	*12/1/2011*	Max Input (Btu/hr)	*600,000*	Flue Damper Mfgr	*none*
Test Facility	*PG&E San Ramon*	Min Input (Btu/hr)	*120,000*	Flue Damper Model #	*none*
Test Location	*San Ramon CA*	Burner Type		Flue Damper Size	*none*
Boiler Mfgr	*Anonymous*	Turn Down Ratio	*5:1*		
Boiler Model	*Anonymous*	Burner Mfgr	*?*	Water or Steam	*water*
Fuel (gas, oil, elec)	*gas*	Burner Model #	*?*	Heat Exchanger Type	*?*
Indoor Boiler	*yes*	VAC/Hz/Φ		Recirc Loop Req'd (Y/N)	*10 GPM*
Outdoor Boiler	*no?*	Flue Type (Vert/Horz)	*?*	Dry Mass of Boiler Wt lbs	*?*
Condensing (Y/N)	*yes*	Draft Type (Atm/Mech)	*Mech*	Boiler Vol. Gal	*?*

Indicate Tests Inlcuded with Test ID number in the appropriate box and fill in the appropriate return water tem

	Return Water Temp	Steady State Tests								Other Tests	
		Single Stage Burner	Two-Stage Burner		Modulating Burner					All	
		High Fire	High Fire	Low Fire	High Fire	Int Fire 1	Int Fire 2	Int Fire 3	Low Fire	Idling	Throughflow
Steam or high RWT Hot Water	140				*SS1*				*SS3*	*ID1*	
Other RWT 1											
Other RWT 2											
Other RWT 3											
Other RWT 4											
Low RWT Hot Water	80				*SS2*				*SS4*	*ID2*	

Steady State Test Results Summary:

	HiF HiT	HiF LoT		LoF HiT	LoF LoT	6	7	8	9	10
Fuel Input, Btu/hr	558,309	612,797		133,794	136,532					
Boiler Output, Btu/hr	457,932	524,742		115,402	127,255					
Elec Power Input, KW	0.35	0.41		0.13	0.13					
Thermal Efficiency, %	81.8	85.4		86.0	92.9					
mbustion Efficiency, %	85.7	85.2		86.9	89.6					

	11	12	13	14	15	16	17	18	19	20
Fuel Input, Btu/hr										
Boiler Output, Btu/hr										
Elec Power Input, KW										
Thermal Efficiency, %										
mbustion Efficiency, %										

	21	22	23	24	25	26	27	28	29	30
Fuel Input, Btu/hr										
Boiler Output, Btu/hr										
Elec Power Input, KW										
Thermal Efficiency, %										
mbustion Efficiency, %										

IdlingTest Results Summary:

	Steam or High RWT Water	*Low RWT Water*
Avg. Cycle Length, min:sec	73.5	43.58
Avg. Thermal Energy Fed, Btu/hr	8,012	3,016
Avg. Thermal Energy Fed, % of Max	1.44	0.5

Throughflow Test Results Summary:

	Steam or High RWT Water	*Low RWT Water*
Avg. Thermal Energy Fed, Btu/hr	0	
vg. Thermal Energy Fed, % of Max		

Tested and Interpolated Thermal Efficiency (%) at the following Input Rates and Temperatures, as applicable:

	% of Max Output							
RWT	2%	5%	10%	15%	20%	50%	75%	100%
140	36%	58%	73%	80%	83%	83%	82%	82%
80	62%	79%	87%	90%	92%	88%	86%	85%

☐ *This boiler is capable of sustained operation at the test conditions on the attached data sheets*

Steady State Results

For Thermal Efficiency and Combustion Efficiency Tests

Test Date	11/12/11	**Gas Data**		**OIL Data**		**Test Input Rate Data**	
Test ID #		HHVBtu/Ft³	1018	'HV Btu/lb Oil		Rate Units	600,000 (Btu/hr or kW)
Technician	Ben Taylor	Sp. Gravity		'V Btu/Gal Oil		Test Rate	558,309
oom Rel Hum %	6.2	Wobbe		PI Gravity Oil		Test Rate Input Relative to Nameplate Input	
Design CO2 %	n/a	Gas T °F	62.6	C Oil		Max: X, Min: , Other:	% to Max Rate: 93%
		Meter P "W.C.	9.2	H Oil		Elec. Equip. Power (V/HZ/PH)	120/60/1
		Baro P "Hg	29.8	Dil Nozzle Size		Elec. Resistance Heater Power (V/HZ/PH)	n/a
		Man P "W.C.		ump Press Oil			
		Corr. Fact Gas	1.011				

Required and/or Specified Tests

Themal Efficiency	x	
nbustion Efficiency	x	
Water Temperature In	140	F °F / °C
'ater Temperature Out	180	F °F / °C

30 Minute Warm-Up Period to Obtain Steady-State Conditions Prior Start of Thermal/Combustion Efficiency Test

Time: Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0		11			253.1	62.8	63.2					141.6	181.1	181.2			0.0							428	0.1
0	5	0	45.0		11			252.8	64.0	63.7					141.7	180.8	181.1			120							421	0.1
0	10	0	45.0		11			252.8	62.7	63.6					141.6	181.4	181.2			121							424	0.1
0	15	0	45.0		11			252.7	62.9	63.9					141.9	181.3	181.1			120							420	0.1
0	20	0	45.0		11			252.7	62.6	64.2					141.8	181.2	181.4			120							418	0.1
0	25	0	45.0		11			252.4	63.5	64.4					142.0	181.4	181.3			120							385	0.1
0	30	0	45.0		11			252.9	63.0	64.4					141.9	181.5	181.6			120							340	0.1
Used																												
Ave/5 min			45.0												141.8	181.2	181.3			120.3							405.1	

2 Hour Thermal Efficiency and/or Combustion Efficiency Test Data

Time: Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0		11.07	0.5		252.9	63.0	64.4					141.9	181	182			0							340	0.1
0	15	0	140.0		11.03			252.7	60.9	67.6					141.8	181	181			360							352	0.1
0	30	0	135.0		11.07			253.1	61.9	64.7					142.2	182	182			359							352	0.1
0	45	0	135.0		11.10			251.8	61.9	64.6					142.5	181	181			361							350	0.1
1	0	0	135.0		11.12			249.6	62.3	64.7					142.4	181	182			361							351	0.1
1	15	0	135.0		11.15			250.6	62.0	64.7					142.8	182	182			360							350	0.1
1	30	0	135.0		11.18			252.2	63.8	65.4					142.6	182	182			360							350	0.1
1	45	0	135.0		11.14			252.6	63.1	65.1					142.5	181	181			359							350	0.1
2	0	0	135.0		11.16	0.5		251.8	62.8	65.6					143.1	181	182			359							345	0.1
Used																												
Ave/15 min			135.6		11.1			251.9	62.4	65.2					142.4	181.4	182			359.9							348.9	0.1

Pacific Gas and Electric Company®

supporting calculations for SS1:

Steady State Thermal Efficiency				
10.1.2	**Rated Steady State Gross Output Rate, $q^{\cdot}_{out}$, water mode, Btu/h**			
Q	23.99	gpm	flow rate	
T_o	181	F	system outlet temp	
T_i	142	F	system inlet temp	162
$c_{p,water}$	1	Btu/lbF	specific heat of water	
P_{H20}		psi	water pressure	0
ρ_{Tave}	61.02	lb/ft3	water density	
$q^{\cdot}_{out,ss}$	457,932	Btu/h		
10.1.3.	**Heat Input Rate, qin,ss, Btu/h**			
10.1.3.2.	**Gas-Fired Boilers**			
Vgas	542.5	acf	actual cubic feet of gas	
HHVgas	1018	Btu/cf		
t_{test}		hrs		
Appendix A				
P_{gas}	0.331817652	psig	gas pressure	
Proom	14.59806922	psia	ambient pressure	
T_{gas}	62.6	F	gas temperature	
P Factor	1.016		pressure correction factor for gas	
T Factor	0.995		temperature correction factor for gas	
Cs	1.011		non-standard conditions gas correction factor	
$q^{\cdot}_{in,ss}$	558,309	Btu/h		
10.1.4	**Test Efficiency, η_0, Percent**			
η_0	82.0	%		
10.1.5.	**Standard auxiliary energy input rate, $q_{in,aux,ss}$, kW**			
$q_{in,aux,ss}$	0.349	kW		
10.1.6.	**Rated Steady State Thermal Efficiency, Including Parasitic Losses, Percent**			
$\eta_{ss,thermal}$	81.8	%		

Pacific Gas and Electric Company®

Steady State Combustion Efficiency

10.2.2.	**Steady State Flue Loss for Gas Fired Boilers, L_f, Percent**		
T_f	711.6	R	absolute flue gas temp
T_r	524.9	R	absolute test room temp
CO_2	11.1	%	% by volume
h	6.2	%	relative humidity
A	9.4		
P	8.47		
T	10.42		
U	11.9		
C_1	175.6		
C_2	964.3		
C_3	77.3		
C_4	466.9		
L_f	14.272	%	
10.2.3.	**Rated non-condensing steady state combustion efficiency, $\eta_{ss,comb}$, Percent**		
$\eta_{ss,comb}$	85.7	%	
10.2.4	**Steady state latent heat gain due to condensation in flue, $G_{l,ss}$, Percent**		
h_{fg}	1,053.3	Btu/lbm	latent heat of vaporization
$m_{cond,ss}$	-	lbm/hr	mass flow rate of flue condensate
$q_{in,cond,ss}$	558,309	Btu	fuel energy input during test
$G_{l,ss}$	0.000	%	
10.2.5.	**Steady state heat loss due to hot condensate going down drain, $L_{cond,ss}$, Percent**		
$G_{l,ss}$	0.000		
$c_{p,water}$	1	Btu/lbmF	specific heat of water
$T_{flue,ss}$	251.9	F	steady state flue gas temp
T_{air}	65.2	F	burner inlet air temperature
$L_{cond,ss}$	0.000	%	
10.2.6.	**Rated condensing steady state combustion efficiency, $\eta_{ss,comb}$, Percent**		
$\eta_{ss,comb}$	85.7	%	
10.2.7.	**Radiation and Unaccounted for Loss, Lu, Percent**		
Lu	3.7	%	for non condensing test
Lu	3.7	%	for condensing test
10.2.8.	**Nominal Jacket Loss Rate, Btu/h**		
$q^{\cdot}_{jacket,nom}$	20,697	Btu/h	for non condensting test
$q^{\cdot}_{jacket,nom}$	20,697	Btu/h	for condensing test

For Thermal Efficiency and Combustion Efficiency Tests

Test Date	11/2/2011	**Gas Data**	
Test ID #		HHVBtu/Ft^3	1018
Technician		Sp. Gravity	
oom Rel Hum %	40.8	Wobbe	
Design CO2 %	n/a	Gas T °F	65.8
		Meter P "W.C.	6.4
		Baro P "Hg	29.7
		Man P "W.C.	
		Corr. Fact Gas	

OIL Data

'HV Btu/lb Oil	
'V Btu/Gal Oil	
PI Gravity Oil	
C Oil	
H Oil	
)il Nozzle Size	
ump Press Oil	

Test Input Rate Data

Rate Units	600,000	(Btu/hr or kW)
Test Rate	612,797	

Test Rate Input Relative to Nameplate Input

Max	Min	Other	% to Max Rate
			102%

Elec. Equip. Power (V/HZ/PH)	
Elec. Resistance Heater Power (V/HZ/PH)	

Required and/or Specified Tests

Themal Efficiency	x	
nbustion Efficiency		
Water Temperature In		°F / °C
'ater Temperature Out		°F / °C

Jeff Stein: add columns for btu-in, btu-out and thermal efficiency

Jeff Stein: shouldn't this be SCF (standard ft3)?

30 Minute Warm-Up Period to Obtain Steady-State Conditions Prior Start of Thermal/Combustion Efficiency Test

Time: Hours	Min's	Sec's	Thermal Energy Fed Ft^3, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
				Operational Data											*Water Temp Data*					*Water Boilers*		*Steam Boilers*			*Electrical Consumption*			
0	0	0	0.0		11.3			230	64.9	64.9					80	121	121.3			0							339.0	0.1
0	5	0	50.0		11.3			229	65.1	65.2					80	121	120.3			131							340.0	0.1
0	10	0	50.0		11.3			230	65.0	65.3					80	120	120.9			131							414.0	0.1
0	15	0	50.0		11.3			229	64.7	64.9					80	121	120.0			131							413.0	0.1
0	20	0	50.0		11.3			229	64.9	65.0					80	121	120.7			131							415.0	0.1
0	25	0	55.0		11.3			229	64.9	65.0					80	120	120.7			132							414.0	0.1
0	30	0	50.0		11.4			229	65.1	65.1					80	120	119.9			131							415.0	0.1
Used																												
Ave/5 min			50.8		11.3			229.3	64.9	65.1					80.0	120.5	120.5			130.9							392.9	0.1

2 Hour Thermal Efficiency and/or Combustion Efficiency Test Data

Hours	Min's	Sec's	Thermal Energy Fed Ft^3, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0		11.4	0.5		229	65.1	65.1					80	120	120			0							415.0	0.1
0	15	0	150.0		11.4			230	64.7	65.5					80	120	121			393.1							413.0	0.1
0	30	0	150.0		11.4			229	64.4	65.6					80	120	121			392.1							415.0	0.1
0	45	0	155.0		11.4			229	65.0	65.3					80	120	121			393.0							415.0	0.1
1	0	0	150.0		11.4			229	65.4	65.4					80	120	121			393.6							415.0	0.1
1	15	0	150.0		11.4			229	64.7	65.3					79	120	120			391.6							417.0	0.1
1	30	0	150.0		11.4			229	64.5	65.2					79	120	120			391.7							414.0	0.1
1	45	0	150.0		11.3			229	63.2	64.6					79	119	120			393.0							417.0	0.1
2	0	0	155.0		11.2	0.5		229	62.7	64.2					79	119	119			393.0							412.0	0.1
Used																												
Ave/15 min			151.3		11.4			229	64.4	65.1				1.4	80	120	120			392.6							414.8	0.1

For Thermal Efficiency and Combustion Efficiency Tests

Test Date	12/22/11		
Test ID #			
Technician			
oom Rel Hum %	15.0		
Design CO2 %	n/a		

Gas Data

HHVBtu/Ft³	1019
Sp. Gravity	
Wobbe	
Gas T °F	60.7
Meter P "W.C.	7.0
Baro P "Hg	29.8
Man P "W.C.	
Corr. Fact Gas	

OIL Data

'HV Btu/lb Oil	
'V Btu/Gal Oil	
PI Gravity Oil	
C Oil	
H Oil	
Dil Nozzle Size	
ump Press Oil	

Test Input Rate Data

Rate Units	120,000	(Btu/hr or kW)
Test Rate	133,794	

Test Rate Input Relative to Nameplate Input

Max	Min	Other	% to Max Rate
			111%

Elec. Equip. Power (V/HZ/PH)	
Elec. Resistance Heater Power (V/HZ/PH)	

Required and/or Specified Tests

Themal Efficiency	x	
nbustion Efficiency		
Water Temperature In		°F / °C
ater Temperature Out		°F / °C

Jeff Stein:
add columns for btu
btu-out and therma
efficiency

30 Minute Warm-Up Period to Obtain Steady-State Conditions Prior Start of Thermal/Combustion Efficiency Test

Time — Operational Data — Water Temp Data — Water Boilers — Steam Boilers — Electrical Consumption

Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0																	0.0								
0	5	0																										
0	10	0																										
0	15	0																										
0	20	0																										
0	25	0																										
0	30	0			7			144.0	62.8	60.1					143.5	182	182			31							132	
Used																												
Ave/5 min			#####												143.5	181.9	181.9			31.1							132.0	

2 Hour Thermal Efficiency and/or Combustion Efficiency Test Data

Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0		7.36	0.05		144.0	62.8	60.1					143.5	182	182			0.0							132	0.0
0	15	0	35.0		7.51			143.6	61.1	60.5					142.7	181	181			92							131	0.0
0	30	0	30.0		7.61			143.3	64.8	60.2					143.6	182	182			92							132	0.0
0	45	0																										
1	0	0																										
1	15	0																										
1	30	0																										
1	45	0																										
2	0	0																										
Used																												
Ave/15 min			32.5		7.5			143.6	62.9	60.3					143.3	181.7	182			92.0							131.7	

For Thermal Efficiency and Combustion Efficiency Tests

		Gas Data		**OIL Data**		**Test Input Rate Data**		*Required and/or Specified Tests*	
Test Date	12/27/2011	HHVBtu/Ft^3	1019	'HV Btu/lb Oil		Rate Units	120,000 (Btu/hr or kW)	Themal Efficiency	x
Test ID #		Sp. Gravity		'V Btu/Gal Oil		Test Rate	136,532	nbustion Efficiency	
Technician		Wobbe		PI Gravity Oil		Test Rate Input Relative to Nameplate Input		Water Temperature In	°F / °C
oom Rel Hum %	15.0	Gas T °F	51.2	C Oil		Max: ; Min: ; Other:	% to Max Rate: 114%	ater Temperature Out	°F / °C
Design CO2 %	n/a	Meter P "W.C.	7.0	H Oil					
		Baro P "Hg	29.9	Dil Nozzle Size		Elec. Equip. Power (V/HZ/PH)			
		Man P "W.C.		ump Press Oil		Elec. Resistance Heater Power (V/HZ/PH)			
		Corr. Fact Gas							

Jeff Stein:
shouldn't this be SCF (standard ft3)?

Jeff Stein:
add columns for btu-in, btu-out and thermal efficiency

30 Minute Warm-Up Period to Obtain Steady-State Conditions Prior Start of Thermal/Combustion Efficiency Test

Time: Hours	Min's	Sec's	Thermal Energy Fed Ft^3, Gal, or KW	To Test Rate	CO2	CO As Meas.	CO Air free	Flue Gas Temp	Inlet Air Temp	Room Air Temp	Draft Smoke Pipe	Draft firebox	Smoke (Oil)	Flue Conden.	Water In	Water Out	Recirc Return	Boiler Rise	Test Rig Rise	Feed water	Water Level	Press. Steam	Cond. Steam	Separator Wt	Recirc Pump	Boiler El. Eq.	Total Electric	Flue connector
			Operational Data												*Water Temp Data*					*Water Boilers*		*Steam Boilers*			*Electrical Consumption*			
				%	%	%	%	°F	°F	°F	"W.C.	"W.C.	#	Lbs	°F	°F	°F	°F	°F	Gal	In	psig	Lbs	Lbs	W	W	W	"W.C
0	0	0	0.0		-10.0			103	50.9	48.8					80	121	120.6			0								0.3
0	5	0	10.0		-10.0			103	50.9	49.0					80	121	121.1			31								0.3
0	10	0	10.0		-10.0			103	51.0	49.2					80	121	121.4			31								0.3
0	15	0	10.0		-10.0			103	51.5	49.7					80	122	121.8			31								0.5
0	20	0	10.0		-10.0			103	51.3	49.7					81	122	121.8			31								0.2
0	25	0	10.0		-10.0			104	51.7	50.5					81	122	121.9			31								0.5
0	30	0	15.0		7.2			104	52.1	50.4					80	122	122.0			31								0.5
Used																												
Ave/5 min			10.8		-7.5			103.3	51.3	49.6					80.2	121.6	121.5			31.0								

2 Hour Thermal Efficiency and/or Combustion Efficiency Test Data

Hours	Min's	Sec's	Thermal Energy Fed	To Test Rate	CO2	CO As Meas.	CO Air free	Flue Gas Temp	Inlet Air Temp	Room Air Temp	Draft Smoke Pipe	Draft firebox	Smoke (Oil)	Flue Conden.	Water In	Water Out	Recirc Return	Boiler Rise	Test Rig Rise	Feed water	Water Level	Press. Steam	Cond. Steam	Separator Wt	Recirc Pump	Boiler El. Eq.	Total Electric	Flue connector
0	0	0	0.0		7.2	0.06		104	52.1	50.4					80	122	122			0							131.0	0.5
0	15	0	30.0		7.2			104	52.8	51.0					80	122	122			95.7							132.0	0.3
0	30	0	35.0		7.3			103	53.2	51.5					80	121	121			92.5							131.0	0.3
0	45	0	30.0		7.3			103	53.7	52.5					80	121	122			91.3							131.0	0.2
1	0	0	35.0		7.4			103	55.9	53.5					80	121	121			91.9							132.0	0.3
1	15	0	30.0		7.4			103	55.6	53.8					80	121	121			93.7							132.0	0.6
1	30	0	35.0		7.4			103	56.8	55.1					80	121	121			93.6							132.0	0.3
1	45	0	30.0		7.4			103	58.1	55.8					80	121	121			92.5							133.0	0.3
2	0	0	35.0		7.5			103	59.0	56.6					80	121	121			93.2							132.0	0.0
Used																												
Ave/15 min			32.5		7.3			103	55.3	53.4				0.5	80	121	121			93.0							131.8	0.3

Pacific Gas and Electric Company®

For Thermal Efficiency and Combustion Efficiency Tests

Gas Data		OIL Data		Test Input Rate Data	
Test Date	12/27/2011	HHVBtu/Ft³	1019	'HV Btu/lb Oil	
Test ID #		Sp. Gravity		'V Btu/Gal Oil	
Technician		Wobbe		PI Gravity Oil	
oom Rel Hum %	15.0	Gas T °F	51.2	C Oil	
Design CO2 %	n/a	Meter P "W.C.	7.0	H Oil	
		Baro P "Hg	29.9	Dil Nozzle Size	
		Man P "W.C.		ump Press Oil	
		Corr. Fact Gas			

Test Input Rate Data

Rate Units: 120,000 (Btu/hr or kW)

Test Rate: 136,532

Test Rate Input Relative to Nameplate Input

Max: | Min: | Other: | % to Max Rate: 114%

Elec. Equip. Power (V/HZ/PH):

Elec. Resistance Heater Power (V/HZ/PH):

Required and/or Specified Tests

Themal Efficiency: x

nbustion Efficiency:

Water Temperature In: °F / °C

ater Temperature Out: °F / °C

Jeff Stein: shouldn't this be SCF (standard ft3)?

Jeff Stein: add columns for btu-in, btu-out and thermal efficiency

30 Minute Warm-Up Period to Obtain Steady-State Conditions Prior Start of Thermal/Combustion Efficiency Test

Time: Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
			Operational Data												Water Temp Data					Water Boilers		Steam Boilers			Electrical Consumption			
0	0	0	0.0		-10.0			103	50.9	48.8					80	121	120.6			0								0.3
0	5	0	10.0		-10.0			103	50.9	49.0					80	121	121.1			31								0.3
0	10	0	10.0		-10.0			103	51.0	49.2					80	121	121.4			31								0.3
0	15	0	10.0		-10.0			103	51.5	49.7					80	122	121.8			31								0.5
0	20	0	10.0		-10.0			103	51.3	49.7					81	122	121.8			31								0.2
0	25	0	10.0		-10.0			104	51.7	50.5					81	122	121.9			31								0.5
0	30	0	15.0		7.2			104	52.1	50.4					80	122	122.0			31								0.5
Used																												
Ave/5 min			10.8		-7.5			103.3	51.3	49.6					80.2	121.6	121.5			31.0								

2 Hour Thermal Efficiency and/or Combustion Efficiency Test Data

Hours	Min's	Sec's	Thermal Energy Fed Ft³, Gal, or KW	To Test Rate %	CO2 %	CO As Meas. %	CO Air free %	Flue Gas Temp °F	Inlet Air Temp °F	Room Air Temp °F	Draft Smoke Pipe "W.C.	Draft firebox "W.C.	Smoke (Oil) #	Flue Conden. Lbs	Water In °F	Water Out °F	Recirc Return °F	Boiler Rise °F	Test Rig Rise °F	Feed water Gal	Water Level In	Press. Steam psig	Cond. Steam Lbs	Separator Wt Lbs	Recirc Pump W	Boiler El. Eq. W	Total Electric W	Flue connector "W.C
0	0	0	0.0		7.2	0.06		104	52.1	50.4					80	122	122			0							131.0	0.5
0	15	0	30.0		7.2			104	52.8	51.0					80	122	122			95.7							132.0	0.3
0	30	0	35.0		7.3			103	53.2	51.5					80	121	121			92.5							131.0	0.3
0	45	0	30.0		7.3			103	53.7	52.5					80	121	122			91.3							131.0	0.2
1	0	0	35.0		7.4			103	55.9	53.5					80	121	121			91.9							132.0	0.3
1	15	0	30.0		7.4			103	55.6	53.8					80	121	121			93.7							132.0	0.6
1	30	0	35.0		7.4			103	56.8	55.1					80	121	121			93.6							132.0	0.3
1	45	0	30.0		7.4			103	58.1	55.8					80	121	121			92.5							133.0	0.3
2	0	0	35.0		7.5			103	59.0	56.6					80	121	121			93.2							132.0	0.0
Used																												
Ave/15 min			32.5		7.3			103	55.3	53.4				0.5	80	121	121			93.0							131.8	0.3

IDLING TEST RESULTS

For Boiler Idling Test

		Gas Data		OIL Data		Boiler Equilibrium Condition		Required and/or Specified Tests	
Test Date	##########	HHVBtu/Ft³	1019	HHV Btu/lb Oil		Rate Units	600,000 (Btu/hr or kW)	Idling Test	
Test ID #		Sp. Gravity		HHV Btu/Gal Oil		Test Rate	8,012		
Technician	Ben Taylor	Wobbe		API Gravity Oil		% to Max Inout		Midpoint Setting	°F / °C
Rel Hum %	40	Gas T °F	57.46	C Oil		CO2 %		Control Differential	°F / °C
Design CO2 %		Meter P "W.C.	6.152	H Oil					
		Baro P "Hg	29.87	Oil Nozzle Size					
		Man P "W.C.	50	Pump Press Oil					
		Corr. Fact Gas							

Room air (every 15 min) and Outlet Water Temperature (every minute) to be recorded per section 9.3 separately and Summaried on this Data Sheet

row

	Boiler Stabilization Cycle 1	Boiler Stabilization Cycle 2	Boiler Stabilization Cycle 3	Boiler Stabilization Cycle 4	Boiler Stabilization Cycle 5	Boiler Stabilization Cycle 6
Burner On Min's						3
Burner On Sec's						30
Total Cycle Min's						63
Total Cycle Sec's						30
Max Water Out (°F)						191.2
Min Water Out (°F)						169.8
Midpoint (°F)						180.5
Room Temp (°F)						65.4

	Boiler Idling Cycle 1	Boiler Idling Cycle 2	Boiler Idling Cycle 3	Boiler Idling Cycle 4	Boiler Idling Cycle 5	Boiler Idling Cycle 6
Burner On Min's	4	3	3	4	4	3
Burner On Sec's	0	30	30	0	30	30
Total Cycle Min's	70	73	75	75	74	73
Total Cycle Sec's	0	30	0	30	0	0
		#	#	#	#	#
Max Water Out (°F)	191.3	191.3	191.3	191.3	191.0	191.0
Min Water Out (°F)	169.8	169.7	169.7	169.8	169.8	169.8
Midpoint (°F)	180.5	180.5	180.5	180.6	180.4	180.4
Room Temp (°F)	73.8	78.8	79.4	79.7	79.3	78.2

	Hr	Min	Sec
Total Test Duration		440	60
Total Time Burner On		21	120
Avg. Cycle Length	0	73.33	10
Avg. Burner On Time		3.5	20

Total Thermal Energy Fed Thru 6 Cycles	55	Ft³, Gal, or KW
Total Elec. Equip. Energy Used Thru 6 Cycles	0.001	KW
Avg. Max Outlet Water Temp	191.2	°F
Avg. Minimum Outlet Water Temp	169.8	°F
Avg. Midpoint Water Temp	180.5	°F

Avg. Thermal Energy Fed, Btu/hr	8,012
Avg. Thermal Energy Fed, % to Max	1.3%
Water flow rate (gpm)	24.0
Full Fire Water flow rate (gpm)	24.0

For Boiler Idling Test

		Gas Data		OIL Data		Boiler Equilibrium Condition		Required and/or Specified Tests	
Test Date	###########	HHVBtu/Ft³	1019	HHV Btu/lb Oil		Rate Units	600,000 (Btu/hr or kW)	Idling Test	
Test ID #		Sp. Gravity		HHV Btu/Gal Oil		Test Rate	3,016		
Technician	Ben Taylor	Wobbe		API Gravity Oil		% to Max Inout		Midpoint Setting	°F / °C
Rel Hum %	40	Gas T °F	55.4	C Oil		CO2 %		Control Differential	°F / °C
Design CO2 %		Meter P "W.C.	6.2	H Oil					
		Baro P "Hg	29.9	Oil Nozzle Size					
		Man P "W.C.	50	Pump Press Oil					
		Corr. Fact Gas							

Room air (every 15 min) and Outlet Water Temperature (every minute) to be recorded per section 9.3 separately and Summaried on this Data Sheet

row

	Boiler Stabilization Cycle 1	Boiler Stabilization Cycle 2	Boiler Stabilization Cycle 3	Boiler Stabilization Cycle 4	Boiler Stabilization Cycle 5	Boiler Stabilization Cycle 6
Burner On Min's						1
Burner On Sec's						0
Total Cycle Min's						41
Total Cycle Sec's						0
Max Water Out (°F)						123.9
Min Water Out (°F)						117.7
Midpoint (°F)						120.8
Room Temp (°F)						65.3

	Boiler Idling Cycle 1	Boiler Idling Cycle 2	Boiler Idling Cycle 3	Boiler Idling Cycle 4	Boiler Idling Cycle 5	Boiler Idling Cycle 6
Burner On Min's	1	1	0	0	1	0
Burner On Sec's	0	0	30	30	0	30
Total Cycle Min's	41	42	41	46	41	48
Total Cycle Sec's	30	30	30	30	30	0
		#	#	#	#	#
Max Water Out (°F)	123.9	123.9	123.7	124.0	124.0	124.0
Min Water Out (°F)	117.7	117.8	117.9	117.8	117.8	117.8
Midpoint (°F)	120.8	120.8	120.8	120.9	120.9	120.9
Room Temp (°F)	66.3	65.8	67.1	67.6	68.9	69.2

	Hr	Min	Sec
Total Test Duration		259	150
Total Time Burner On		3	90
Avg. Cycle Length	0	43.17	25
Avg. Burner On Time		0.5	15

Total Thermal Energy Fed Thru 6 Cycles	15	Ft³, Gal, or KW
Total Elec. Equip. Energy Used Thru 6 Cycles	0.001	KW
Avg. Max Outlet Water Temp	123.9	°F
Avg. Minimum Outlet Water Temp	117.8	°F
Avg. Midpoint Water Temp	120.9	°F

Avg. Thermal Energy Fed, Btu/hr	3,016
Avg. Thermal Energy Fed, % to Max	0.5%
Water flow rate (gpm)	24.0
Full Fire Water flow rate (gpm)	24.0

Appendix B – Sensor Specs and Calibration Information

Temperature Sensors

Table 20. Temperature, Pressure, and Flow Calibration Data

Channel	STD	IUT	STD	IUT	
RTD1	32	31.8	199.9	199.46	Hart 1502A
RTD2	32	32	199.9	199.66	Ser# 5626
RTD3	32	31.7	199.9	199.25	
RTD4	32	31.8	199.9	199.48	
TC12	32	32	200.067	200.41	Hart 1502A
TC13	32	32.1	200.067	200.31	Ser# 5626
TC14	32	32	200.067	200.55	
TC15	32	32	200.067	200.43	
TC0	32	32.13	120.08	120.28	Hart 1502A
TC1	32	32.18	120.08	120.2	Ser# 5626
TC2	32	32.18	120.08	120.3	
P1	0	1	100	5	Consolidated Controls UPC5100
Flow Meter	0	0.997			
	4.63	1.174			Coriolis Flow Standard
	16.75	1.61			CMF 100
	25.77	1.95			
	34.96	2.27			
	42.91	2.55			
	51.24	2.86			
	98.57	4.54			

TABLE 21. ADDITIONAL TEMPERATURE CALIBRATION DATA

TEMPERATURE SENSOR CALIBRATION DATA SHEET

Description of Test ______

Reference Temp. Instrument (1): Ice Bath S/N N/A Cal Date N/A
Reference Temp. Instrument (2): Fluke 1502A S/N ______ Cal Date 12/20/11
Calibration Bath Make/Model Hart 9105 Serial Number ______
Data Logger Make/Model cRIO Serial Number ______
Calibration Date 10/13/11
Calibration Performed By Rodriguez - Taylor

Calibration Data:

Chan Num	Channel Description	Cal Date	Std Temp 1	Meas Temp 1	Std Temp 2	Meas Temp 2	Slope	Offset	Notes
0		10/13/11	32.0	32.2	119.66	120.0			
1			32.0	32.2	119.66	120.1			
2			32.0	32.3	214.94	215.4			
3				32.4	214.98	215.0			
4				32.4	214.95	215.2			
5				32.4	214.96	215.3			
6				32.4	214.94	215.4			
7				32.4	214.95	215.3			
8				32.4	214.94	215.3			
9									
10			32.0	32.3	214.95	215.2			
11			32.0	32.3	214.96	215.2			

Post-Calibration Uncertainty Results

Measurement Location	LabView Mod Location	32F	80F	120F	190F	250F	Minimum Accuracy +/- F	Original Cal Point 1	Original Cal Point 2
Ambient	Mod 6 TC 0	0.191	0.465	1.088	0.419	0.919	1	32	120
Boiler Intake	Mod 6 TC 1	0.211	0.104	0.238	0.655	0.046	1	32	120
TC Grid Flue	Mod 6 TC 2	0.191	0.061	0.148	0.453	0.283	2	32	215
TC Grid Flue	Mod 6 TC 3	0.191	0.039	0.040	0.236	0.694	2	32	215
TC Grid Flue	Mod 6 TC 4	0.201	0.495	1.069	0.609	0.695	2	32	215
TC Grid Flue	Mod 6 TC 5	0.181	1.213	0.199	0.637	0.036	2	32	215
TC Grid Flue	Mod 6 TC 6	0.161	0.127	0.110	0.256	0.585	2	32	215
TC Grid Flue	Mod 6 TC 7	0.191	0.132	0.187	0.480	0.245	2	32	215
TC Grid Flue	Mod 6 TC 8	0.191	0.084	0.105	0.127	0.719	2	32	215
-	Mod 6 TC 9	-	-	-	-	-	-	-	-
TC Grid Flue	Mod 6 TC 10	0.161	0.118	0.161	0.697	0.074	2	32	215
TC Grid Flue	Mod 6 TC 11	0.074	1.014	0.052	0.170	0.722	2	32	215
-	Mod 6 TC 12	-	-	-	-	-	-	-	-
-	Mod 6 TC 13	-	-	-	-	-	-	-	-
-	Mod 6 TC 14	-	-	-	-	-	-	-	-
-	Mod 6 TC 15	-	-	-	-	-	-	-	-
Boiler Outlet RTD Grid	Mod 4 RTD 0	0.056	0.059	0.139	0.076	0.950	0.2	80	190
Boiler inlet	Mod 4 RTD 1	0.029	0.115	0.204	0.403	0.323	0.2	80	190
Boiler Oultet RTD Grid	Mod 4 RTD 2	0.203	0.222	0.254	0.436	0.407	0.2	80	190
Downstream Boiler Outlet	Mod 4 RTD 3	0.034	0.082	0.119	0.230	0.533	0.2	no record	no record
-		-	-	-	-	-	-	-	-
Boiler Outlet RTD Grid		0.047	0.019	0.154	0.465	0.231	0.2	no record	no record
Boiler Outlet RTD Grid		0.093	0.022	0.095	0.304	0.424	0.2	no record	no record
-		-	-	-	-	-	-	-	-

RTD's were not calibrated to 250F, nor saw these temperatures during the test.

Pacific Gas and Electric Company®

PRESSURE SENSORS

TABLE 22. FLUE PRESSURE CALIBRATION DATA FOR UNIT 2

Cal Date		10/19/2011
Std Mfg	DHI	
Std Model	RMP4 Reference Pressure Monitor	
Cal Due		3/24/2012
Voltage	in H2O	
2.986		0
4.026		0.54
3.47		0.251
2.025		-0.5
2.507		-0.248

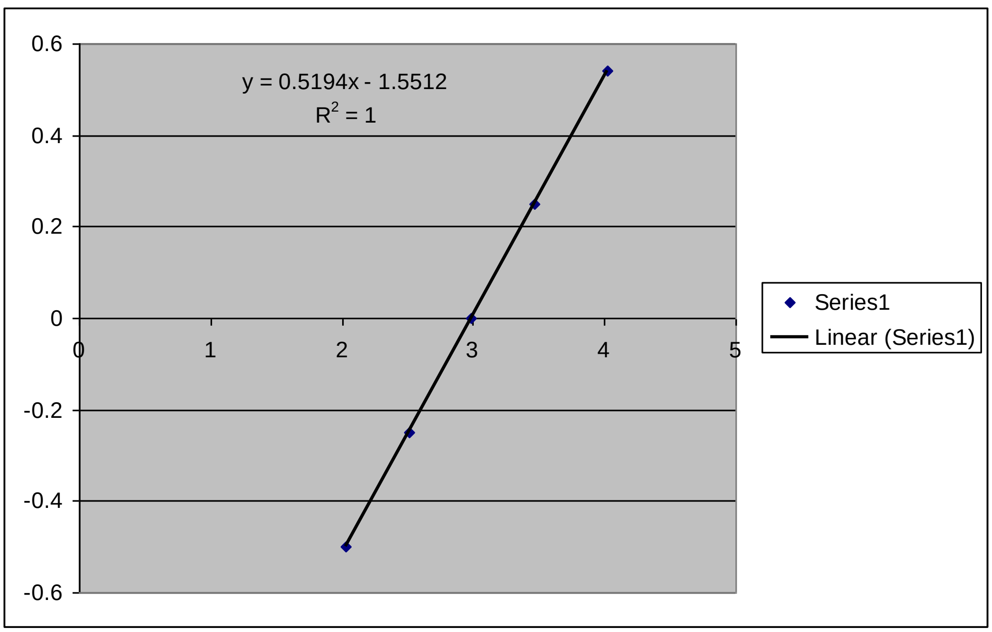


TABLE 23. PRESSURE TRANSMITTER CALIBRATION DATA

Values are based on voltage drop across precision resistor.

	Cal pt,	Reading	voltage
Gas	0		1.02
	7		1.52
	10		1.74
	20		2.48
	30		3.19
	40		3.393
	50		4.68
	55		5.02
Atm	0	14.37	3.87
Diff	-5		na
	-3		na
	0		2.997
	3		4.22
	5		5.02
H20	note	0	
	note	60	3.4

GAS METER

AL-1400 Diaphragm Meter

Remanufactured Meter

Elster American Meter's aluminumcase meters are designed to provide positive displacement accuracy for industrial or commercial loads

Features

- Die-cast aluminumcase
- Oil-impregnated, self-lubricating bushings
- Molded, convoluted diaphragms for smooth operation and long life
- Rigid, reinforced flag rods for positive alignment and sustained accuracy
- Graphite-filled phenolic valves to minimize wear
- Long-life, low friction, grommet seals
- Security seals that indicate tampering

Advantages

- Temperature compensation available from -30°F to 140°F (-34°C to 60°C)
- 1400 SCFH (39.6 m^3/h) (0.60 specific gravity gas) at 1/2-inch W.C. differential
- AMR/AMI compatibility
- Meets ANSI B109.2 specifications

Applications

The AL-1400 is ideally suited for commercial and industrial installations. It is unequaled for accuracy retention and for life cycle maintenance economies.

Options

- Regular or Temperature Compensated
- Pointer or odometer index
- 5ft^3, 10ft^3, or 0.1m^3 drive
- 2" NPT, 3" NPT and 3" flanged connection sizes
- 100 PSIG (6895 mbar) Maximum Allowable Operating Pressure (MAOP)
- Pressure compensating indexes
- Standard or UV protected index covers
- Remote Volume Pulsers

elster
American Meter

Pacific Gas and Electric Company®

TABLE 24. GAS METER CALIBRATION DATA

Sep. 26 11 07:26a PG&E Utility User 510-659-2648 p.2

Search Results for Meter Number: 25965676 Server: GEMP

Userid:	SWC8	Cnts per Cubic Foot:	877.81
Transaction Code:	O	Test Result:	
Transaction Date:	10/18/2007 09:50:11	Num of Tests:	4
Bank Num:	9	Repair Code:	B
Prover Num:	2	Retire Code:	
Meter Type:	5	Remove Reason:	
Meter Num:	25965676	Max Differential:	0
Model Code:	245	Index Registration:	24374
Opn Pr Result:	0.05	Mtr Sampled Type:	
Opn Pr Temp:	0.06	Mtr Attribute:	F
Opn Pr EOR:	4387	QA Type:	
Check Pr Result:	0.01	QA Sampled Type:	
Check Pr Temp:	0.01	PO Group Num:	
Check Pr EOR:	4389	Special Code:	

Userid:	SWC8	Cnts per Cubic Foot:	877.81
Transaction Code:	O	Test Result:	
Transaction Date:	2/23/2011 11:50:55	Num of Tests:	2
Bank Num:	9	Repair Code:	B
Prover Num:	2	Retire Code:	
Meter Type:		Remove Reason:	
Meter Num:	25965676	Max Differential:	0
Model Code:	245	Index Registration:	62418
Opn Pr Result:	0.08	Mtr Sampled Type:	
Opn Pr Temp:	-1.07	Mtr Attribute:	F
Opn Pr EOR:	4395	QA Type:	
Check Pr Result:	0	QA Sampled Type:	
Check Pr Temp:	-1.13	PO Group Num:	
Check Pr EOR:	4399	Special Code:	

LAST TEST RESULTS TO GO BY

Received Time Sep. 26. 2011 7:27AM No. 6753

TABLE 25. RTD BOILER OUT ARRAY CALIBRATION DATA

TEMPERATURE CALIBRATION PROCEDURE

COPY Exp 12/23/11

Attachment 7.1.3
Number: WI-PTA-3.1
Revision: 1
Page: 1 of 1

TEMPERATURE SENSOR CALIBRATION INITIAL PROGRAMMING DATA SHEET

Description of Test ______

Reference Temp. Instrument (1): HART 1502A S/N A59096 Cal Date 6/17/12
Reference Temp. Instrument (2): ______ S/N ______ Cal Date ______
Low Primary Temp Std Description: Hot block S/N: ______ Temp (Deg F): 80
High Primary Temp Std Description: Hot block S/N: ______ Temp (Deg F): 200
Calibration Bath Make/Model HART 9105 Serial Number A3B078
Data Logger Make/Model ______ Serial Number ______
Calibration Date 12/19/11
Calibration Performed By B. TAYLOR

Transfer Standard Ice Point Checks

Transfer Standard	Cal Check Date	Ice Point Temp	Standard Reading

Transfer Standard Calibration Temperatures

Transfer Standard	Pre-Test Cal Date	Temp 1	Temp 2	Temp 3
Std 1 Reading				
Std 1 Corrected Reading				
Std 2 Reading				
Std 2 Corrected Reading				
Average Temperature				

Calibration Data:

	Chan Num	Channel Description	Cal Date	Corr Std Temp 1	Meas Temp 1	Corr Std Temp 2	Meas Temp 2	Slope	Offset	Notes
Wire 5	0	RTD #5 3:00	12/19	80.003	79.862	189.951	189.659			
wire 7	1	RTD #6 6:00	↓	80.001	79.813	189.728	189.732			
wire 8	2	RTD #7 9:00	↓	80.000	79.556	189.714	189.363			

Note:
[1] Use of this data sheet is not required. A different sheet may be used provided all required information is included on the substitute data sheet.

[2] Record n/a for any information not applicable on this datasheet.

PTA-3_1 R1 Cal Temp.doc

TABLE 26. DETERMINATION OF HHV AND STATISTICAL REVIEW OF SOURCE DATA

Gas Quality Information for BTU Area B01

from 01/06/2011 *to* 12/06/2010

Date	Btu Content per std cf	Specific Gravity density, air=1.0	N2 mole %	CO2 mole %
01/06/2011	1,011.30	0.577	0.28	1.29
01/05/2011	1,011.40	0.577	0.28	1.28
01/04/2011	1,011.90	0.577	0.29	1.26
01/03/2011	1,012.10	0.577	0.29	1.27
01/02/2011	1,012.20	0.577	0.29	1.27
01/01/2011	1,012.30	0.577	0.29	1.27
12/31/2010	1,012.30	0.577	0.29	1.26
12/30/2010	1,012.40	0.577	0.29	1.26
12/29/2010	1,013.10	0.576	0.30	1.19
12/28/2010	1,014.10	0.576	0.30	1.13
12/27/2010	1,014.20	0.576	0.30	1.13
12/26/2010	1,014.20	0.576	0.30	1.13
12/25/2010	1,014.10	0.576	0.30	1.13
12/24/2010	1,014.50	0.576	0.31	1.12
12/23/2010	1,013.30	0.576	0.30	1.16
12/22/2010	1,012.10	0.575	0.29	1.18
12/21/2010	1,012.10	0.575	0.29	1.18
12/20/2010	1,012.30	0.576	0.29	1.18
12/19/2010	1,014.10	0.576	0.29	1.15
12/18/2010	1,015.50	0.577	0.29	1.13
12/17/2010	1,015.50	0.577	0.30	1.13
12/16/2010	1,016.50	0.577	0.31	1.12
12/15/2010	1,018.00	0.578	0.32	1.12
12/14/2010	1,018.00	0.578	0.32	1.12
12/13/2010	1,018.00	0.578	0.32	1.11
12/12/2010	1,018.10	0.578	0.32	1.11
12/11/2010	1,018.10	0.578	0.32	1.11
12/10/2010	1,018.10	0.578	0.32	1.11
12/09/2010	1,018.10	0.578	0.32	1.11
12/08/2010	1,018.10	0.578	0.32	1.11
12/07/2010	1,017.90	0.578	0.32	1.11
12/06/2010	1,016.60	0.577	0.30	1.08

Disclaimer: The data on these pages is a representative sample of gas quality information only. It is raw, unreviewed, real-time data provided solely for informational purposes, and not for billing purposes. PG&E makes no claim or representation that the data provided is accurate. No party should rely on such data, including, but not limited to, for billing purposes. Data may be subject to adjustments and corrections prior to being used for billing or record keeping.

This table is data for "BTU Area B01" which happens to have daily measurements. The standard deviation of this data is 2.5 BTU/ft^3 which is 0.25% of the average. Standard 155 calls for ±1% accuracy. Four standard deviations is 1% accuracy (within the bounds) and encompasses 99.99% of the data. Data is available at this website: http://www.pge.com/pipeline/operations/gas_quality/index.shtml.

Here are the weekly averages for Area B01:

BTU Area	Weekly Heating Values for the Week Starting:						
	01/03/2011	12/27/2010	12/20/2010	12/13/2010	12/06/2010	11/29/2010	11/22/2010
B01	1,013	1,015	1,016	1,013	1,011	1,011	1,013

ATS is part of BTU Area J11, which unfortunately does not have the daily values. Weekly averages are readily available for more areas, and can be found at this website: http://www.pge.com/pipeline/operations/therms/heat_value.shtml. The same table provides weekly averages for many areas. You can scroll down to area J11 to see the weekly averages at ATS.

J11	1,020	1,020	1,019	1,020	1,021	1,016	1,017

WATER METER

Badger Meter

M-Series® Mag Meter
M-2000 Detector

GENERAL

The Badger Meter M-Series® mag meter model M-2000 detector is the result of years of research and field use in electromagnetic flow meters. Based on Faraday's law of induction, these meters can measure almost any liquid, slurry or paste that has minimum electrical conductivity.

Designed, developed and manufactured under strict quality standards, the M-Series meter features sophisticated, processor-based signal conversion with accuracies of ±0.25 percent. The wide selection of liner and electrode materials helps ensure maximum compatibility and minimum maintenance over a long operating period.

OPERATION

The flow meter is a stainless steel tube lined with a nonconductive material. Outside the tube, two DC powered electromagnetic coils are positioned diametrically opposing each other. Perpendicular to these coils, two electrodes are inserted into the flow tube. Energized coils create a magnetic field across the whole diameter of the pipe.

As a conductive fluid flows through the magnetic field, a voltage is induced across the electrodes. This voltage is proportional to the average flow velocity of the fluid and is measured by the two electrodes. This induced voltage is then amplified and processed digitally by the converter to produce an accurate analog or digital signal. The signal can then be used to indicate flow rate and totalization or to communicate to remote sensors and controllers.

This technology provides many advantages. With no parts in the flow stream, there is no pressure loss. Also, accuracy is not affected by temperature, pressure, viscosity, density or flow profile. Finally, with no moving parts, there is practically no maintenance required.

APPLICATION

Because of its inherent advantages over other more conventional technologies, this meter can be used in the majority of industrial flow applications. Whether the fluid is water or highly corrosive, very viscous, contains a moderate amount of solids or requires special handling, this meter can accurately measure fluid flow. Today, magnetic meters are successfully used in industries including food and beverage, pharmaceutical, water and wastewater and chemical.

ELECTRODES

When looking from the end of the meter into the inside bore, the two measuring electrodes are positioned at three o'clock and nine o'clock. M-2000 mag meters have an "empty pipe detection" feature. This is accomplished with a third electrode positioned in the meter between twelve o'clock and one o'clock.

M-2000 Detector

If this electrode is not covered by fluid for a minimum five-second duration, the meter will display an "empty pipe detection" condition, send out an error message if desired, and stop measuring to maintain accuracy. When the electrode again becomes covered with fluid, the error message will disappear and the meter will continue measuring.

As an option to using grounding rings, a grounding electrode (fourth electrode) can be built into the meter during manufacturing to assure proper grounding. The position of this electrode is at five o'clock.

FEATURES

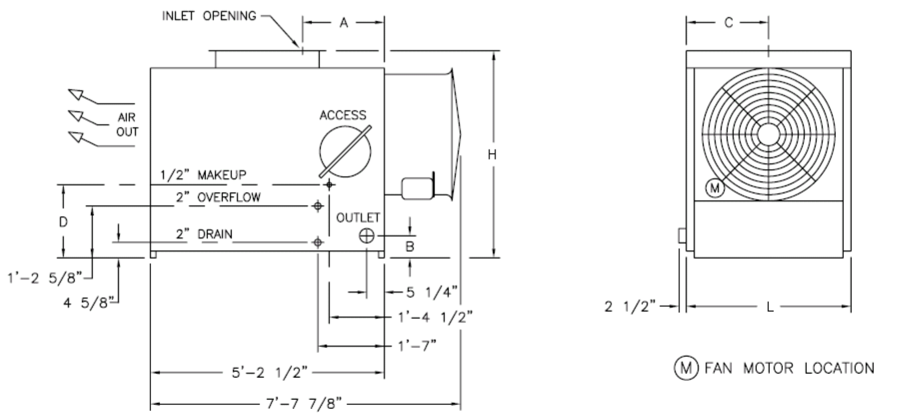
- ±0.25 percent accuracy independent of fluid viscosity, density and temperature
- Unaffected by most solids contained in fluids
- Pulsed DC magnetic field for zero point stability
- No pressure loss for low operational costs
- Corrosion resistant liners for long life
- Calibrated in state-of-the art facilities
- Integral and remote signal converter availability
- Optional grounding rings or grounding electrode
- Measurement largely independent of flow profile
- NSF listed

ITB-186-01 (4-11)

Technical Brief

APPENDIX C – COOLING TOWER SPEC SHEET

 BAC–8832 A



MODEL NO.	DIMENSIONS						WEIGHT (LB.)		CONNECTION SIZES	
	L	H	A	B	C	D	APPROXIMATE OPERATING	APPROXIMATE SHIPPING	INLET	OUTLET
FXT–26	4'–6 1/8"	5'–11 1/4"	1'–7 3/4"	6 7/8	2'–3"	1'–8"	2080	940	4"	4"
FXT–30	4'–6 1/8"	5'–11 1/4"	1'–7 3/4"	6 7/8	2'–3"	1'–8"	2090	950	4"	4"
FXT–33	4'–6 1/8"	5'–11 1/4"	1'–7 3/4"	6 7/8	2'–3"	1'–8"	2090	950	4"	4"
FXT–38	4'–6 1/8"	7'–3 1/4"	1'–4 7/8"	7 7/8	2'–3"	1'–10 1/2"	2420	1000	6"	6"
FXT–42	4'–6 1/8"	7'–3 1/4"	1'–4 7/8"	7 7/8	2'–3"	1'–10 1/2"	2420	1000	6"	6"
FXT–47	4'–6 1/8"	7'–3 1/4"	1'–4 7/8"	7 7/8	2'–3"	1'–10 1/2"	2440	1020	6"	6"
FXT–58	6'–0 1/8"	7'–3 1/4"	1'–4 7/8"	7 7/8	3'–0"	1'–10 1/2"	3140	1220	6"	6"
FXT–68	6'–0 1/8"	7'–3 1/4"	1'–4 7/8"	7 7/8	3'–0"	1'–10 1/2"	3150	1230	6"	6"

NOTES:
1. ALL DIMENSIONS ARE IN FEET AND INCHES. WEIGHTS ARE IN POUNDS.
2. UNLESS OTHERWISE INDICATED, ALL CONNECTIONS 4 INCHES AND SMALLER ARE MPT AND CONNECTIONS 6 INCHES AND LARGER ARE BEVELLED FOR WELDING.
3. FIELD PIPING SHOULD BE FABRICATED AT THE TIME OF UNIT INSTALLATION. PRE–FABRICATION OF PIPE WORK IS NOT RECOMMENDED.

B.A.C. ORDER NO:	BALTIMORE AIRCOIL COMPANY	MODEL: FXT COOLING TOWER	
DATE:		DRAWING NUMBER: BAC–8832 A	C

FIGURE 10. COOLING TOWER SCHEMATIC. MODEL FXT-68 WAS SELECTED FOR THE TEST APPARATUS

APPENDIX D – HEAT EXCHANGER INFORMATION

JOSEPH H. SCHAUF CO., INC.
Manufacturers' Representative
REFRIGERATION • AIR CONDITIONING • INDUSTRIAL HEAT TRANSFER
P.O. BOX 110069 • CAMPBELL, CALIFORNIA 95011-0069 • (408) 866-0723
FAX: (408) 866-5899

July 26, 2010

Attention: BIDDING CONTRACTORS

Subject: PG&E Test Center – San Ramon, California
GEA Plate & Frame Heat Exchanger

Mr. Beliso:

We are pleased to submit our quotation for equipment manufactured by GEA PHE North America:

Heat Exchanger

One (1) GEA Model NAO2X CYFL-150 plate & frame heat exchanger. Unit is selected for the following thermal performance:

HS: 75 GPM water, 120°F to 80°F with a 3.19 **psi** pressure loss
CS: 75 GPM water, 70°F to 110°F with a 3.25 **psi** pressure loss

Unit would be furnished with: (65) AISI 304 stainless steel plates with NBR clip-on rubber gaskets, 2" NPT threaded nipple connections, ASME construction and epoxy painted carbon steel frame.

The Model NAO2X CYFL-150 would ship assembled in one (1) piece with a total approximate shipping weight of 775 pounds. Approximate operating weight will be 825 pounds.

Total net price, FOB Factory with freight allowed to the Bay Area . . . **$4,400.00.**

The current production lead-time for this equipment is 5 to 6 weeks ARO.

FIGURE 11. HEAT EXCHANGER DESIGN CRITERIA

Offer 2004818212 Customer: JOSEPH H SCHAUF CO INC

Customer:	JOSEPH H SCHAUF CO INC				
Quotation-No.:	2004818212	**Inquiry-No.:**	PG&E Test Center		
Contact:	Allen		**Item:** 10	**Alternative:**	0
Customer Item:			**Date:**	05/24/2010	

GEA ECOFLEX Plate Heat Exchanger: NA02X CYFL-150

Thermal data for 1 unit(s) in parallel and 1 unit(s) in series

	hot side	cold side	
Media:	Hot Water	Cold Water	
Heat exchanged:	1491411		Btu/h
Mass flow:	37291	37363	lb/h
Volume flow:	75.0	75.0	US gpm
Temperature inlet:	120.00	70.00	°F
Temperature outlet:	80.00	110.00	°F
Pressure drop:	3.19	3.25	PSI
Working pressure inlet:	45.00	45.00	PSIg

Product properties

Density:	61.99	62.11	lb/ft³
Heat capacity:	0.99795	0.99794	Btu/lb°F
Thermal conductivity:	0.36132	0.35675	Btu/fth°F
Dyn. viscosity inlet:	0.557	0.975	cP
Dyn. viscosity outlet:	0.858	0.614	cP

Unit Data

Plate Type:	NA02X H		
Heat transfer area (total / per unit):	169.53	169.53	ft²
Number of plates (total / per unit):	65	65	
Plate thickness:	0.020		in
LMTD:	10.00		R
Surface margin:	0.3		%
Plate material:	AISI304		
Gasket material / Gasket type:	NBR	glueless	
Internal flow (passes x channels):	1 x 32	1 x 32	
No. of frames (par. / ser. / total):	1	1	1
Frame material and surface:	SA516GR70	painted	RAL5002

The connection types and positions are defined in the attached dimension sheet.

Design temperature:	**Min.:** 32.00 / 32.00		**Max.:**	230.00 / 230.00	°F
Design pressure:	**Min.:** 0.00 / 0.00		**Max.:**	150.00 / 150.00	PSIg
Test pressure:	195.00 / 195.00	PSIg	**Design code:**	ASME	

Remarks:

Page 3

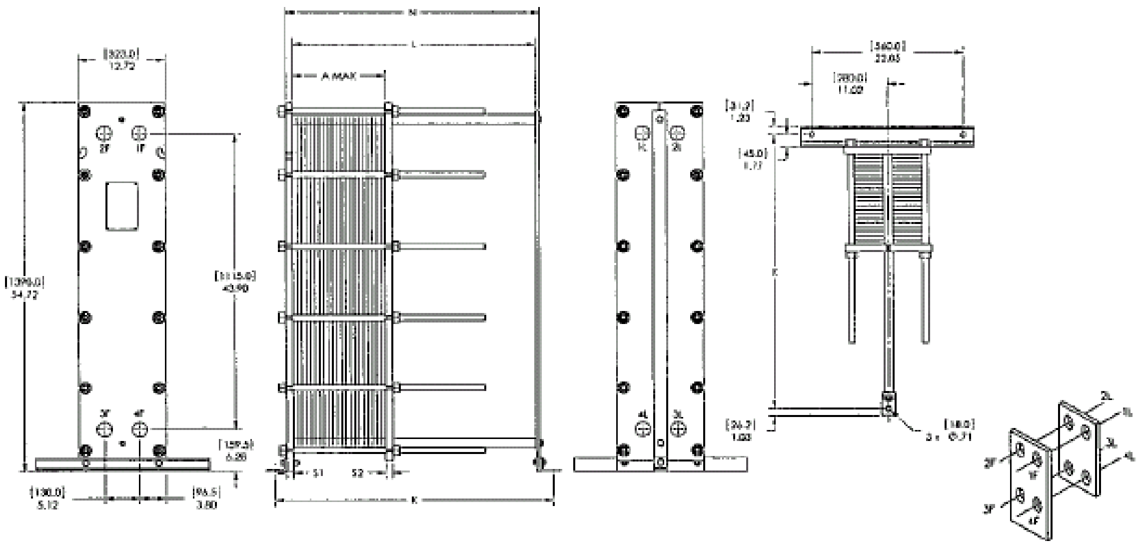
FIGURE 12. HEAT EXCHANGER SPECIFICATIONS

Offer 2004818212 Customer: JOSEPH H SCHAUF CO INC

Dimension Sheet Plate Heat Exchanger

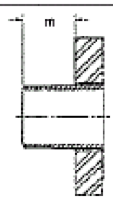
Customer:	JOSEPH H SCHAUF CO INC		
Quotation:	**2004818212**	**Item No.: 10**	**Alternative No.: 0**
Customer item:			

Type: NA02X CYFL-150 Dimensions of drawing in [mm] NA02X CYFL-150.tif



N:	37.323 in	S_1:	0.984 in	a-max frame:	13.358 in	empty weight:	734.93 lbs
K:	40.827 in	S_2:	0.984 in	a-max actual:	8.395 in	max. total weight:	823.71 lbs
L:	35.433 in						

Pos	DN	Type	Media	In	Out	Add.	m
1F	2"	AISI316L Male NPT Nipple	Hot Water	x	-	-	1.938 in
2F	2"	AISI316L Male NPT Nipple	Cold Water	-	x	-	1.938 in
3F	2"	AISI316L Male NPT Nipple	Cold Water	x	-	-	1.938 in
4F	2"	AISI316L Male NPT Nipple	Hot Water	-	x	-	1.938 in

 m			
nipple			
ANSI-B16.3			
1F;2F;3F;4F			

Technical Revisions reserved. Layer thickness of painted frames according to ISO 12944-5. Frame plate surface quality according to ISO 8501-1 SA 2½. The design details are valid for PHE's manufactured by GEA PHE Systems North America.

FIGURE 13. HEAT EXCHANGER SCHEMATIC

APPENDIX E – ELECTRIC HEATER INFO (FOR THROUGHFLOW TEST)

Model B-40U-FFB is installed in this Test Apparatus

TABLE 27. SUPPLEMENTAL ELECTRIC HEATER SPECIFICATIONS

Standard Model Specifications @ 3ph (U.S.A.)					
Dual-Energy Models	B-18U-FFB	B-24U-FFB	B-30U-FFB	B-35U-FFB	B-40U-FFB
kW	18	24	30	35	40
BTU / H	61,416	81,888	102,360	119,420	136,480
Amps @ 208V / 3ph	48.00	66.69	83.37	96.00	n/a
No. Of Power Supplies (Breaker Size)	1 x 60A	2 x 50A	2 x 60A	2 x 60A	
Amps @ 480V / 3ph	21.68	28.90	36.13	42.15	48.00
Disconnect Switch	30A	30A	60A	60A	60A

Appendix F – LabVIEW Reference

Table 28. LabView Channel List

Channel	Description	Input/Output	Signal Type	Parameter Units
A1	Boiler W	Input	Analog	W
A2	VFD Power W	Input	Analog	W
A3	Recirc Pump W	Input	Analog	W
A4	Water Heater W	Input	Analog	W
A5	Fuel Fed	Input	Pulse	cfm
A6	3-Way Mixing Valve	Input	Analog	% open
A7	Flue Condensate Weight	Input	Analog	lbm
A8	Flow Meter	Input	Analog	gpm
A9	Pump VFD Speed	Input	Analog	%
A10	3-Way Mixing Valve	Output	Analog	% open
A11	Pump VFD Speed	Output	Analog	gpm
A12	CO2%	Input	Analog	%
A13	CO%	Input	Analog	%
A14	O2%	Input	Analog	%
A15	Boiler Firing Rate	Input	Analog	%
A16	HWST	Input	Analog	°F
A17	HWRT	Input	Analog	°F
A18	Exhaust Temp	Input	Analog	°F
A19	FFWD Temp	Input	Analog	°F
A20	O2 level	Input	Analog	%
A21	CO level	Input	Analog	%
A22	Flame strength %	Input	Analog	%
D1	VFD	Input	Digital	On/Off
D2	Recirc Pump	Input	Digital	On/Off
D3	Water Heater	Input	Digital	On/Off
D4	Cooling Tower Fan	Input	Digital	On/Off
D5	Cooling Tower Pump	Input	Digital	On/Off
D6	Boiler Firing Status	Input	Digital	On/Off
D7	Boiler Firing Rate	Input	Digital	On/Off
T1	Boiler Inlet Upstream	Input	Analog	°F
T2	Boiler Inlet	Input	Analog	°F
T3	Boiler Outlet	Input	Analog	°F
T4	Boiler Outlet Downstream	Input	Analog	°F
T5	HX Boiler Supply	Input	Analog	°F
T6	HX Boiler Return	Input	Analog	°F
T7	HX CT Supply	Input	Analog	°F

T8	HX CT Return	Input	Analog	°F
T9	Grid TC1	Input	Analog	°F
T10	Grid TC2	Input	Analog	°F
T11	Grid TC3	Input	Analog	°F
T12	Grid TC4	Input	Analog	°F
T13	Grid TC5	Input	Analog	°F
T14	Grid TC6	Input	Analog	°F
T15	Grid TC7	Input	Analog	°F
T16	Grid TC8	Input	Analog	°F
T17	Grid TC9	Input	Analog	°F
T18	Room Air	Input	Analog	°F
T19	Chamber Air	Input	Analog	°F
T20	Boiler Inlet Air	Input	Analog	°F
P1	Boiler Loop	Input	Analog	psi
P2	Chamber dP	Input	Analog	psi
P3	Vent	Input	Analog	psi
P4	Gas	Input	Analog	psi
P5	Fire Box	Input	Analog	psi
P6	Flue	Input	Analog	psi
P7	%RH	Input	Analog	psi
P8	Spare 2	Input	Analog	n/a

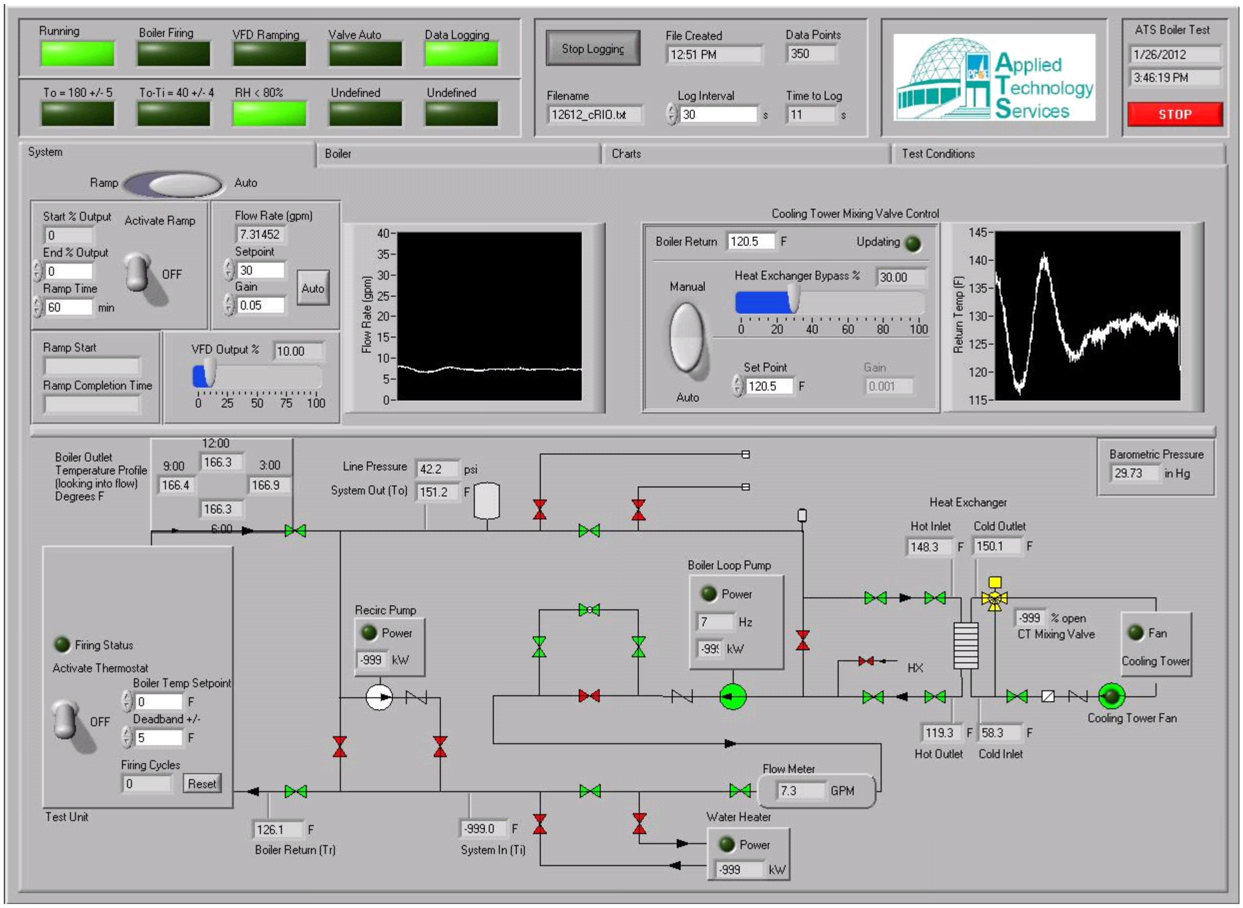


FIGURE 14. LABVIEW SYSTEM SCREEN

FIGURE 15. LABVIEW BOILER SCREEN

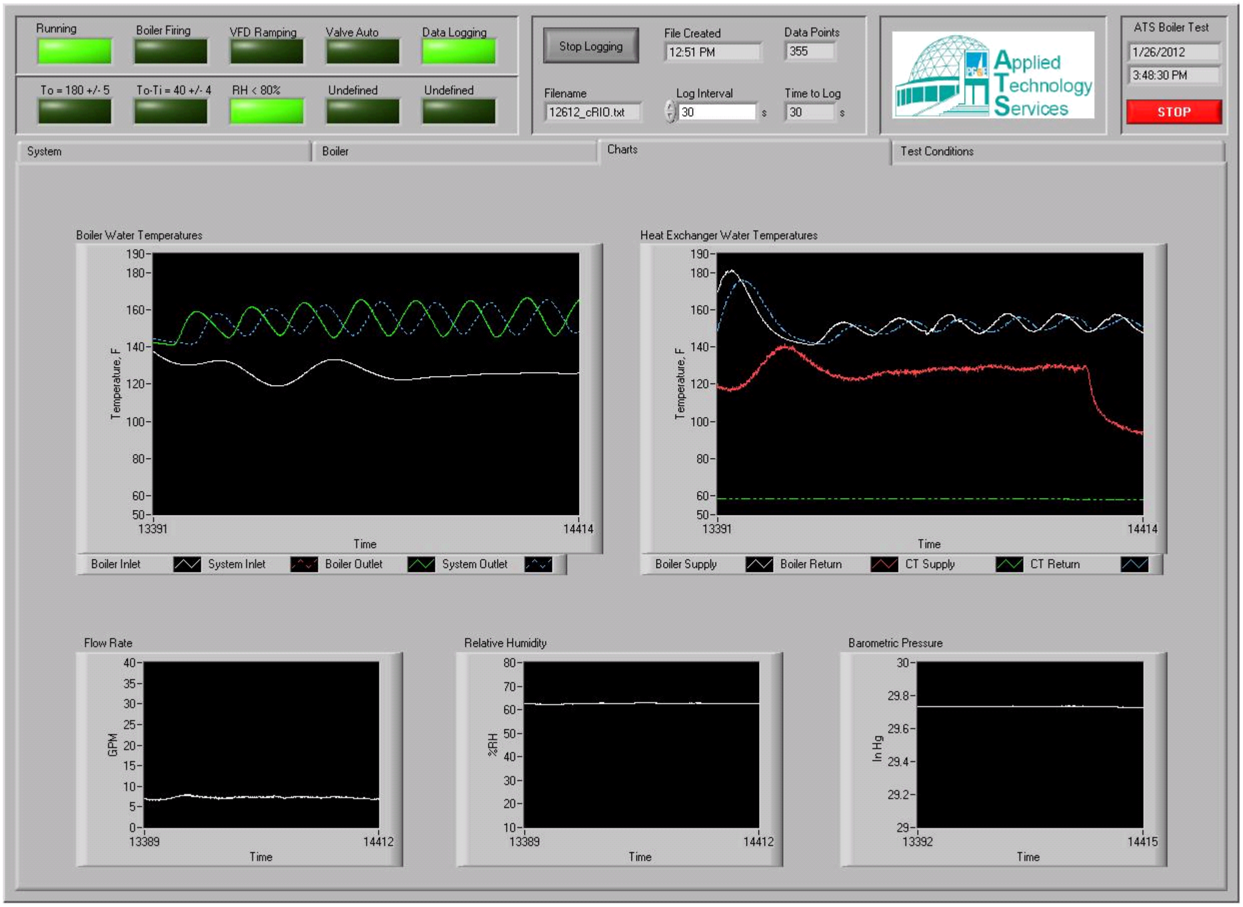


FIGURE 16. LABVIEW CHARTS SCREEN

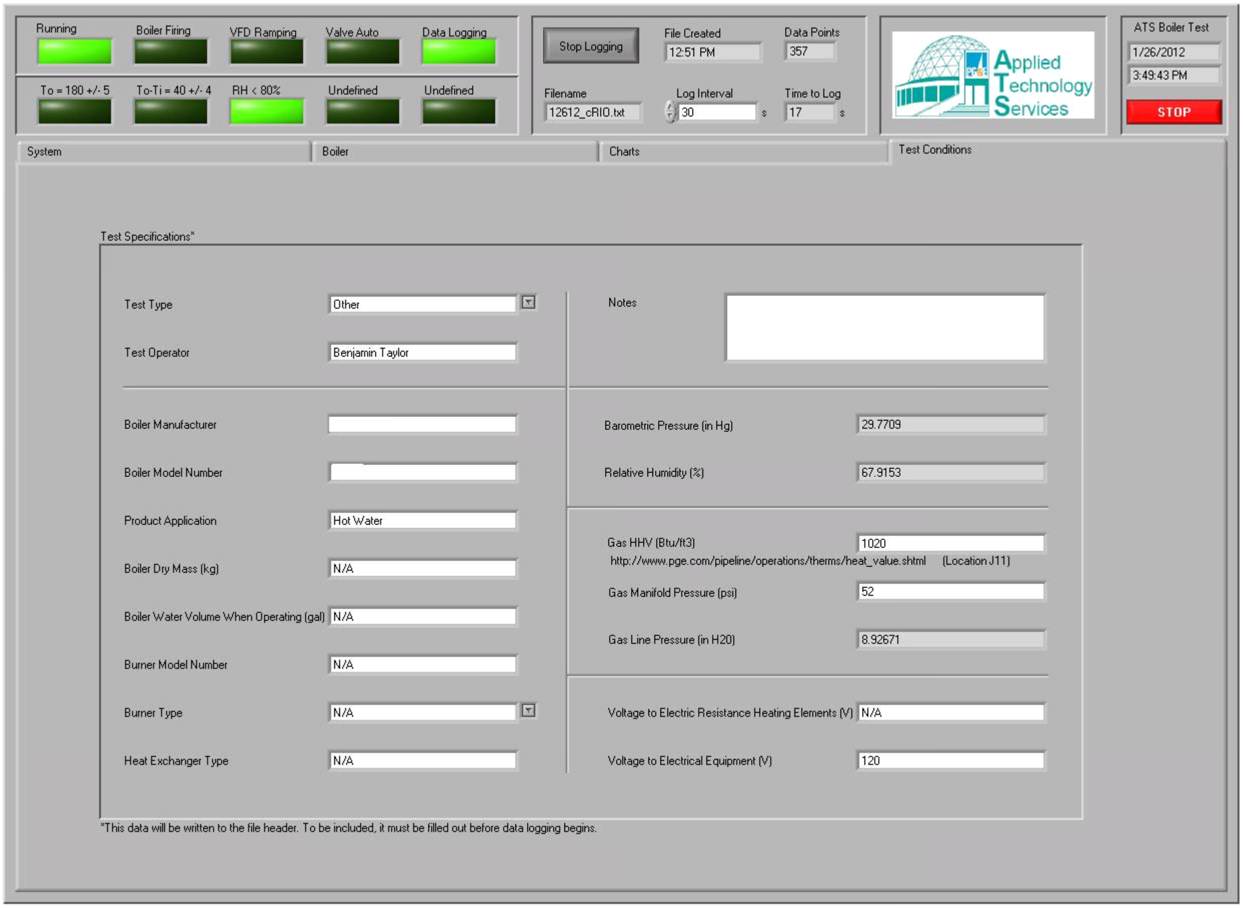


FIGURE 17. LABVIEW TEST CONDITIONS SCREEN

APPENDIX G – TUNING RESULTS

10/11/11
Hi Fire

testo 330-2LL
V1.61 01786396/USA

SITE

Start: 10/11/11 13:51:51

207.4	°F	T stack
9.47	%	CO2
87.7	%	EFF
21.0	%	ExAir
4.0	%	Oxygen
40	ppm	CO
29	ppm	NO
49	ppm	Undiluted CO
30	ppm	NOx
-----	inH2O	Draft
73.2	°F	Ambient temp
80.2	°F	Instr. temp.
-----	°F	Diff. temp.
-----	mbar	Diff. Press.
-----	ppm	CO2amb
-----	ppm	aCo
0.56	l/min	Pump flow

Fuel: Natural gas
O2ref.: 3.0%
CO2max: 11.7%
Heat transf.°F: ----- °F

10/11/11
Low Fire

testo 330-2LL
V1.61 01786396/USA

SITE

Start: 10/11/11 13:43:24

98.3	°F	T stack
8.41	%	CO2
97.0	%	EFF
35.0	%	ExAir
5.9	%	Oxygen
6	ppm	CO
13	ppm	NO
8	ppm	Undiluted CO
14	ppm	NOx
-----	inH2O	Draft
72.1	°F	Ambient temp
80.1	°F	Instr. temp.
-----	°F	Diff. temp.
-----	mbar	Diff. Press.
-----	ppm	CO2amb
-----	ppm	aCo
0.57	l/min	Pump flow

Fuel: Natural gas
O2ref.: 3.0%
CO2max: 11.7%
Heat transf.°F: ----- °F

FIGURE 18. INITIAL START UP OF UNIT 2 ON OCTOBER 11, 2011

testo 330-2 LL
V1.08 02184837/USA

12/01/2011 11:27:12

Location
SITE
Combustion Type
2nd combustion type
FOLDER

Fuel: Natural Gas
CO2 Max: 11.7 %

Combustion test

99.3	°F	Temp. stack
5.6	%	Oxygen
8.57	%	CO2
6	ppm	CO
12	ppm	NO
13	ppm	NOx
5.0	%	NO2 addition
96.6	%	Eff. gross
89.6	%	Eff. net
32.5	%	Excess air
6	ppm	CO Ambient
67.5	°F	Ambient temp

Pacific Gas & Electric
Applied Technology Serv.
3400 Crow Canyon Road
San Ramon, CA 94583

SN: 13603673

Version No.: V1.10

Type of fuel:
Natural Gas
Dry analysis
O2 normalisation: off

Date: 01.12.11

Time: 12:28:04

T ambient:	62	F
T gas :	102	F
Tg - Ta :	39	F
CO :	6.0	ppm
O2 :	5.77	%
NO2 :	5.2	ppm
NO :	11.8	ppm
CxHy:	1810.4	ppm
CO2 :	8.28	%
NOx :	17.0	ppm
efficiency :	88.6	%
loss :	11.4	%
excess air :	34.2	%
water :	0.0	%
O2 norm :	0.0	%

(925) 820-2000

FIGURE 19. UNIT 2 TUNING RESULTS AFTER BURNER REINSTALLATION ON DECEMBER 1, 2011

Ambient combustion air temperature during calibration 60 °F

Gas Pressure downstream of the SSOV at 100% valve position 2.95 inches W.C.

Iris Air Damper position 4.5

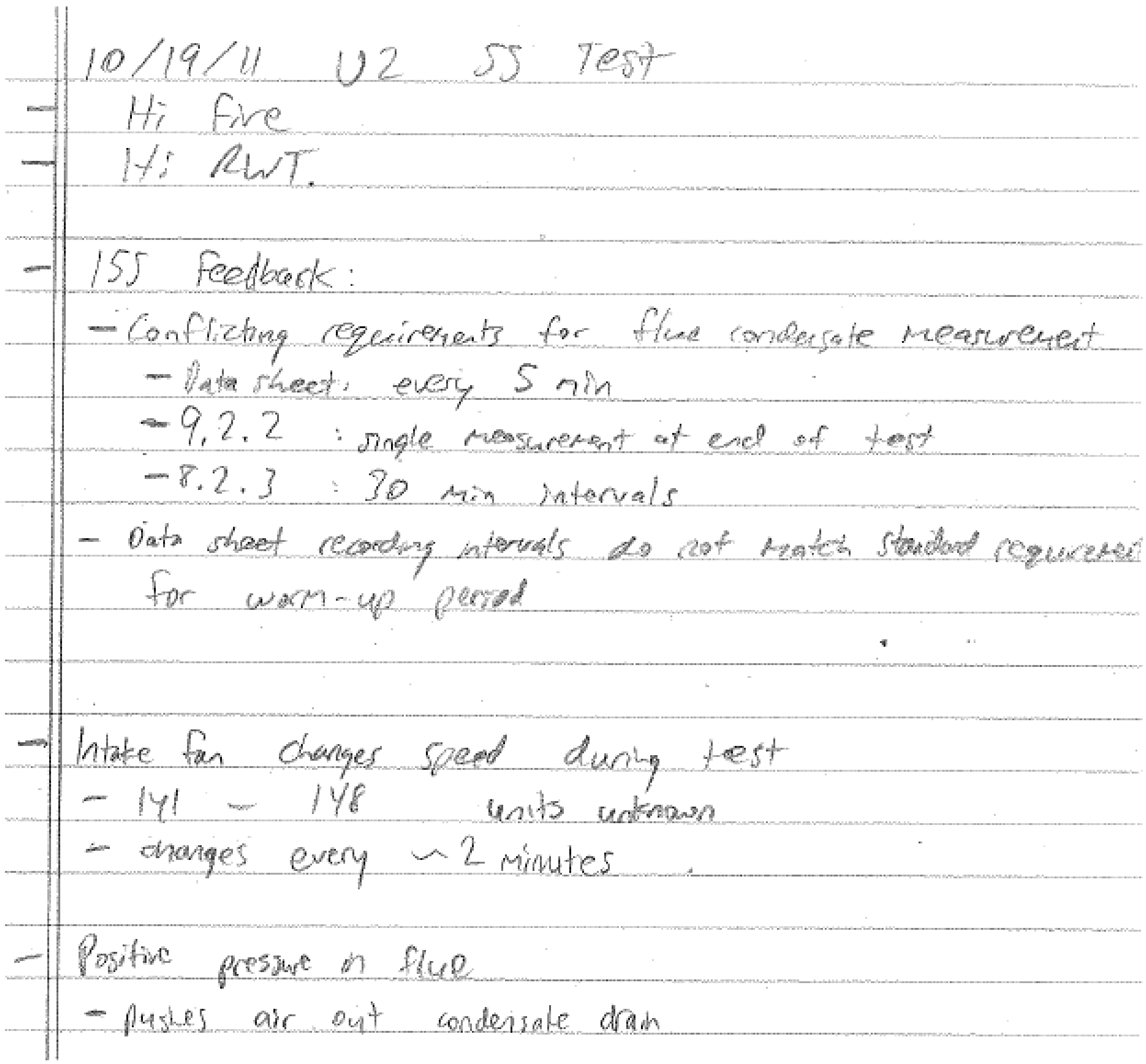
Valve Position	O_2	CO	NOx	Drive Voltage to Blower (CAL-VDC)	Supply Gas Pressure	Manifold Gas Pressure
@100%	5.3 %	68 ppm	18 ppm	6.0 Vdc	4.0 "wc	2.95 "wc
@80%	6.0 %	27 ppm	10 ppm	4.35 Vdc	}	2.9 "
@60%	6.3 %	18 ppm	8 ppm	3.90 Vdc	}	2.95 "
@45%	7.0 %	8 ppm	6 ppm	3.60 Vdc	}	2.95 "
@30%	7.0 %	3 ppm	6 ppm	3.15 Vdc	}	3.0 "
@16%	8.0 %	0 ppm	2 ppm	2.65 vdc	9.0 "wc	3.0 "

Vacuum at Blower Proof Switch at 16% valve position: −1.4 "wc.

−1.0 "wc

FIGURE 20. UNIT 3 TUNING DATA AT INITIAL STARTUP

APPENDIX H – TEST HAND NOTES



10/19/11 U2 SS Test

- Hi Fire
- Hi RWT.

- ISS Feedback:
  - Conflicting requirements for flue condensate measurement
    - Data sheet: every 5 min
    - 9.2.2 : single measurement at end of test
    - 8.2.3 : 30 min intervals
  - Data sheet recording intervals do not match standard requirement for warm-up period

- Intake fan changes speed during test
  - 141 – 148 units unknown
  - changes every ~2 minutes

- Positive pressure in flue
  - pushes air out condensate drain

FIGURE 21. UNIT 2 HIGH TEMP / HIGH FIRE NOTES

11/10/11 U2 Hi Temp ~~Max Temp~~ Lo fire
HHV: 1018
Gas P: 52

ΔT ~40F (42-82F) @ 10.5% VFD output

Flue pressure reading slightly negative
- how can this affect the results?
- should installer be required to tune it in both modes? + pressure hi fire, - pressure lo fire

Heavy propane heating required
- how much does propane exhaust affect the boiler's combustion?

9.5% 86.5% -A note on CT bypass %, coming from below (increasing) is different than coming from above (decreasing)
86.9% - This was done by increasing
87.5, 87.4

11/14/11 Controller tuning / test
P .0002
I .0075
D Ø

Manual value @ 87.03% after stabilization
Test start 13:00 (warm up 13:00 - 13:30)

Tare weight = 217.5 g

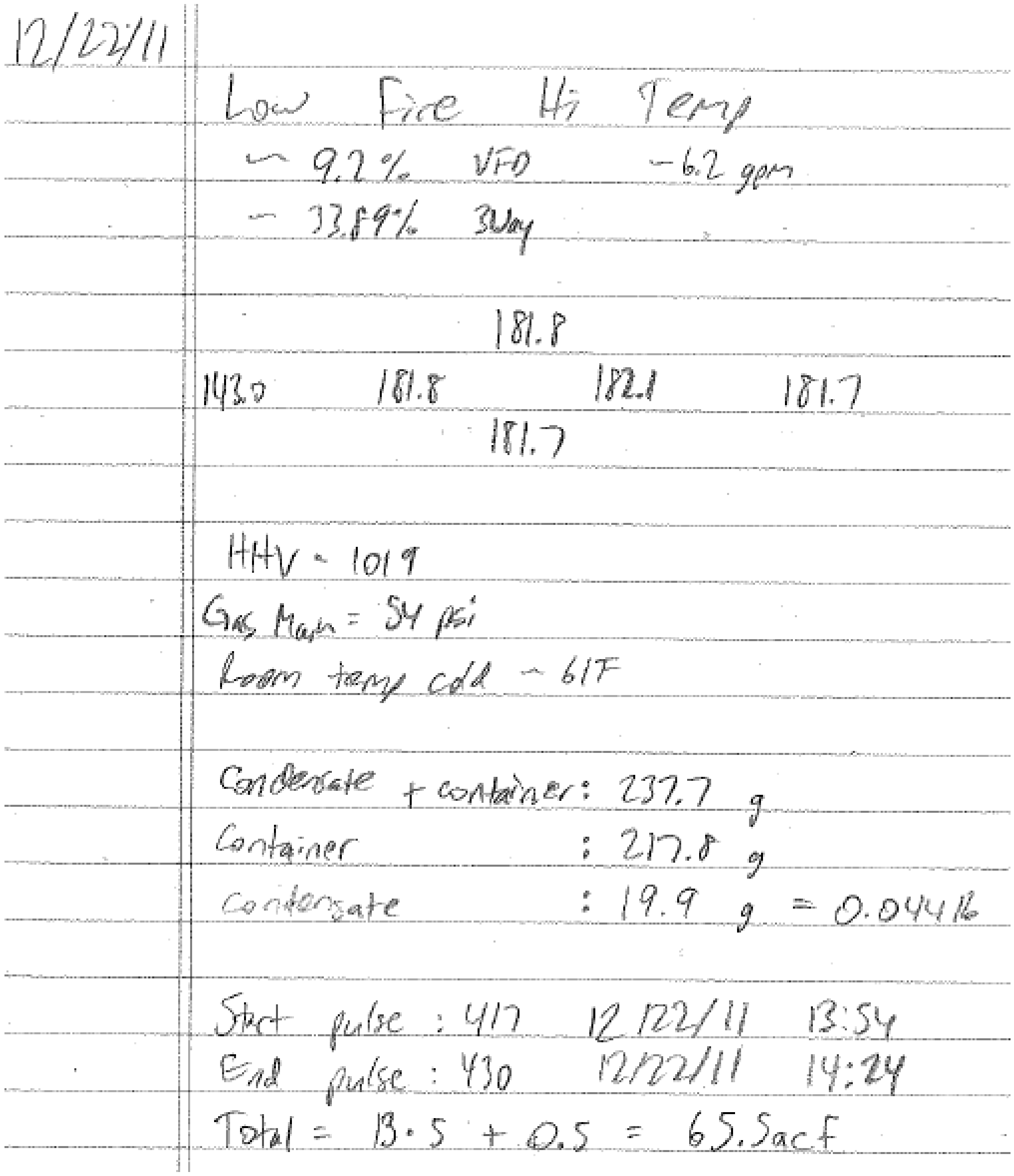
Tare	Time	Water Ø
217.8	13:30	102.5
217.7	14:00	97.9
217.2	14:30	
	~~15:00~~	
	15:30	

Start 15:30, 82 pulses, P=.0002, I=.001, D=.0001

217.6	16:00	124.3
217.6	16:30	129.7
	17:00	129.1
	17:30	135.5

FIGURE 22. UNIT 2 HIGH TEMP / LOW FIRE NOTES NOVEMBER 2011

Pacific Gas and Electric Company®



12/22/11

Low Fire Hi Temp

~ 9.2% VFD ~6.2 gpm

~ 33.89% 3Way

181.8

143.0 181.8 182.1 181.7

181.7

HHV ≈ 1019

Gas Main = 54 psi

Room temp cold ~ 61F

Condensate + container: 237.7 g

Container : 217.8 g

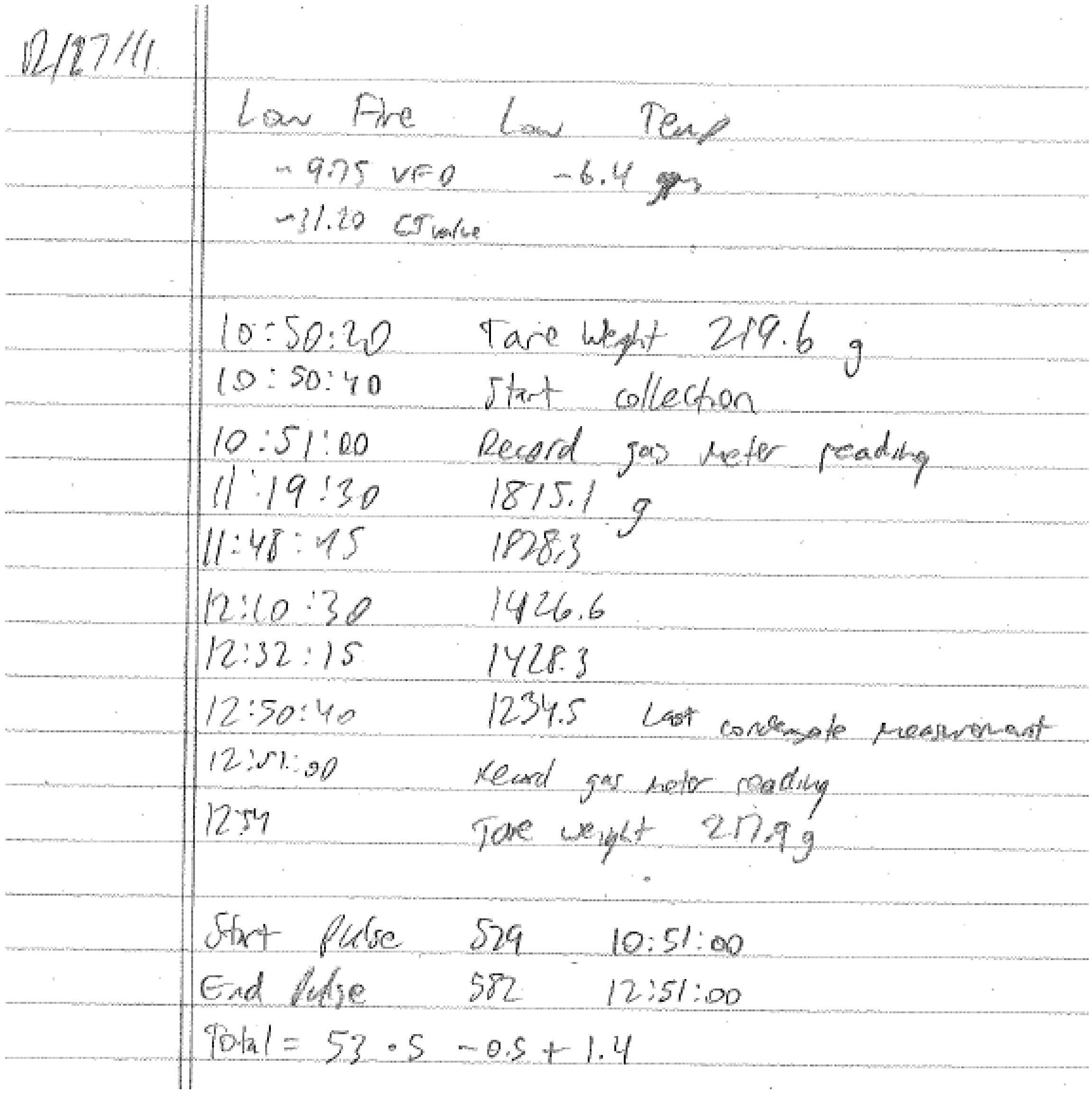
Condensate : 19.9 g = 0.044 lb

Start pulse : 417 12/22/11 13:54

End pulse : 430 12/22/11 14:24

Total = 13.5 + 0.5 = 65.5acf

FIGURE 23. UNIT 2 HIGH TEMP / LOW FIRE NOTES DECEMBER 2011



12/27/11

Low Fire Low Temp

~9.75 VFD ~6.4 gpm

~31.20 CT valve

10:50:20 Tare Weight 219.6 g

10:50:40 Start collection

10:51:00 Record gas meter reading

11:19:30 1815.1 g

11:48:45 1878.3

12:10:30 1426.6

12:32:15 1428.3

12:50:40 1234.5 Last condensate measurement

12:51:00 Record gas meter reading

12:54 Tare weight 217.9 g

Start Pulse 529 10:51:00

End Pulse 582 12:51:00

Total = 53 • 5 ~0.5 + 1.4

FIGURE 24. UNIT 2 LOW TEMP / LOW FIRE NOTES DECEMBER 2011

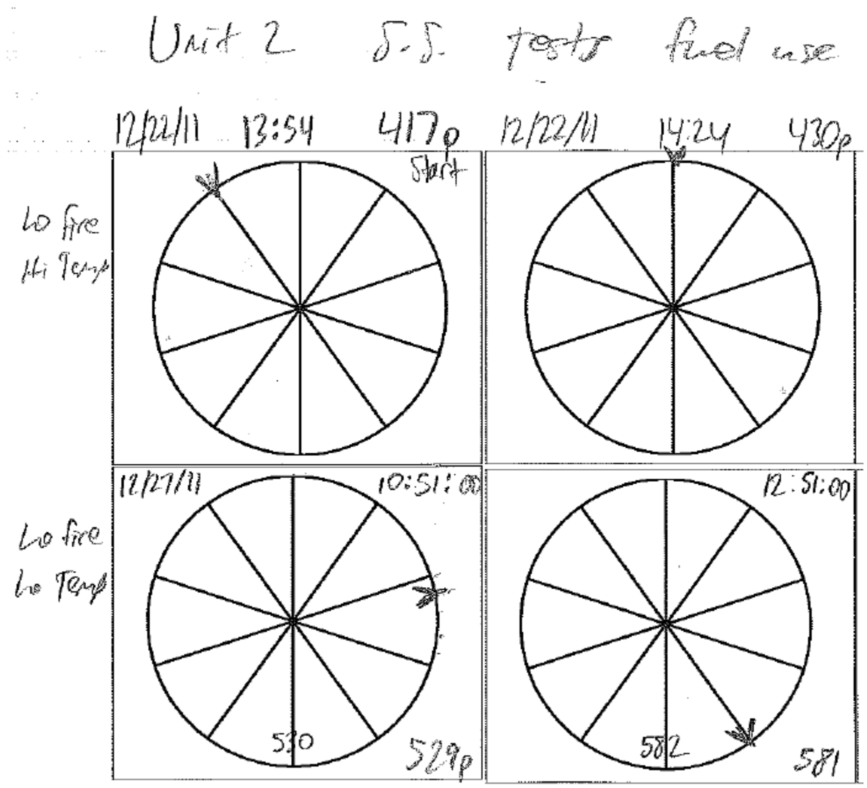


FIGURE 25. UNIT 2 STEADY STATE TESTS FUEL USE NOTES

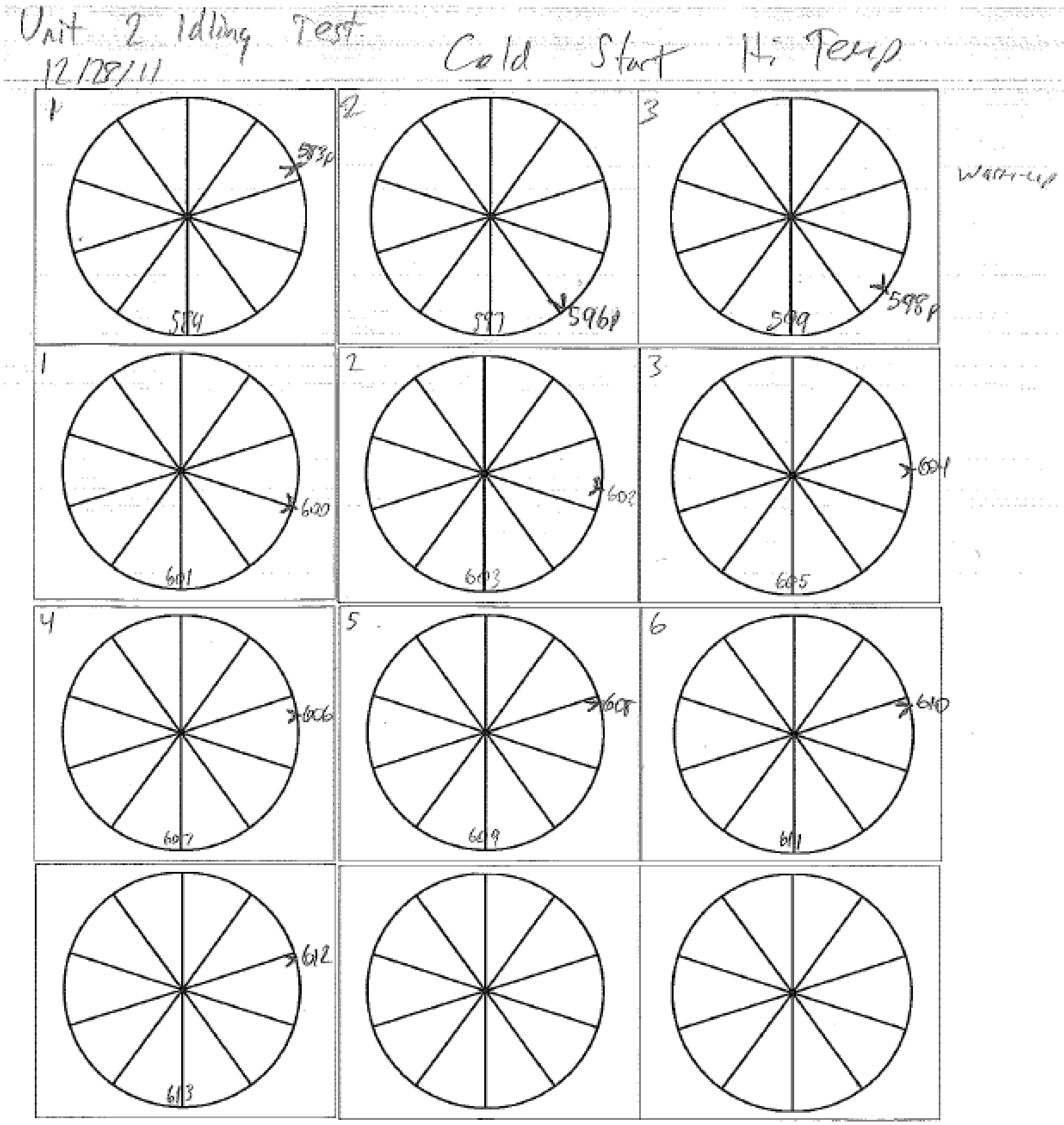


FIGURE 26. UNIT 2 HIGH TEMP IDLING TEST FUEL CONSUMPTION RECORDINGS

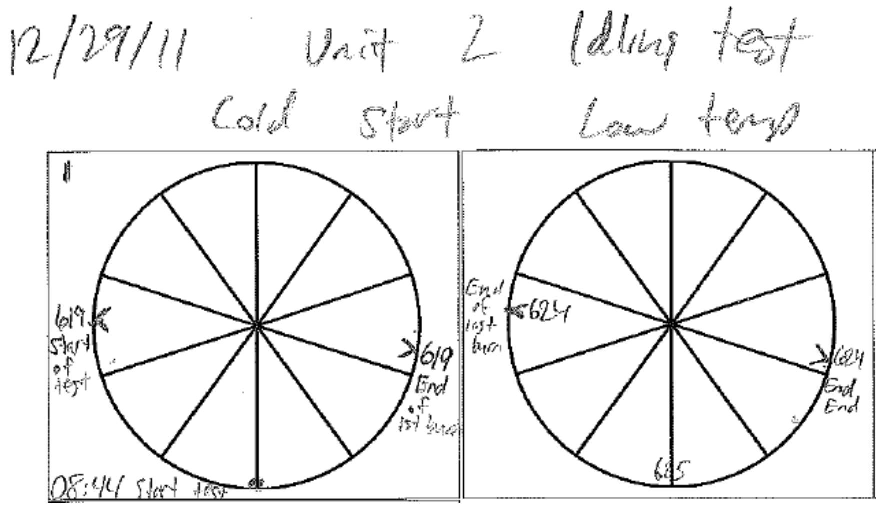
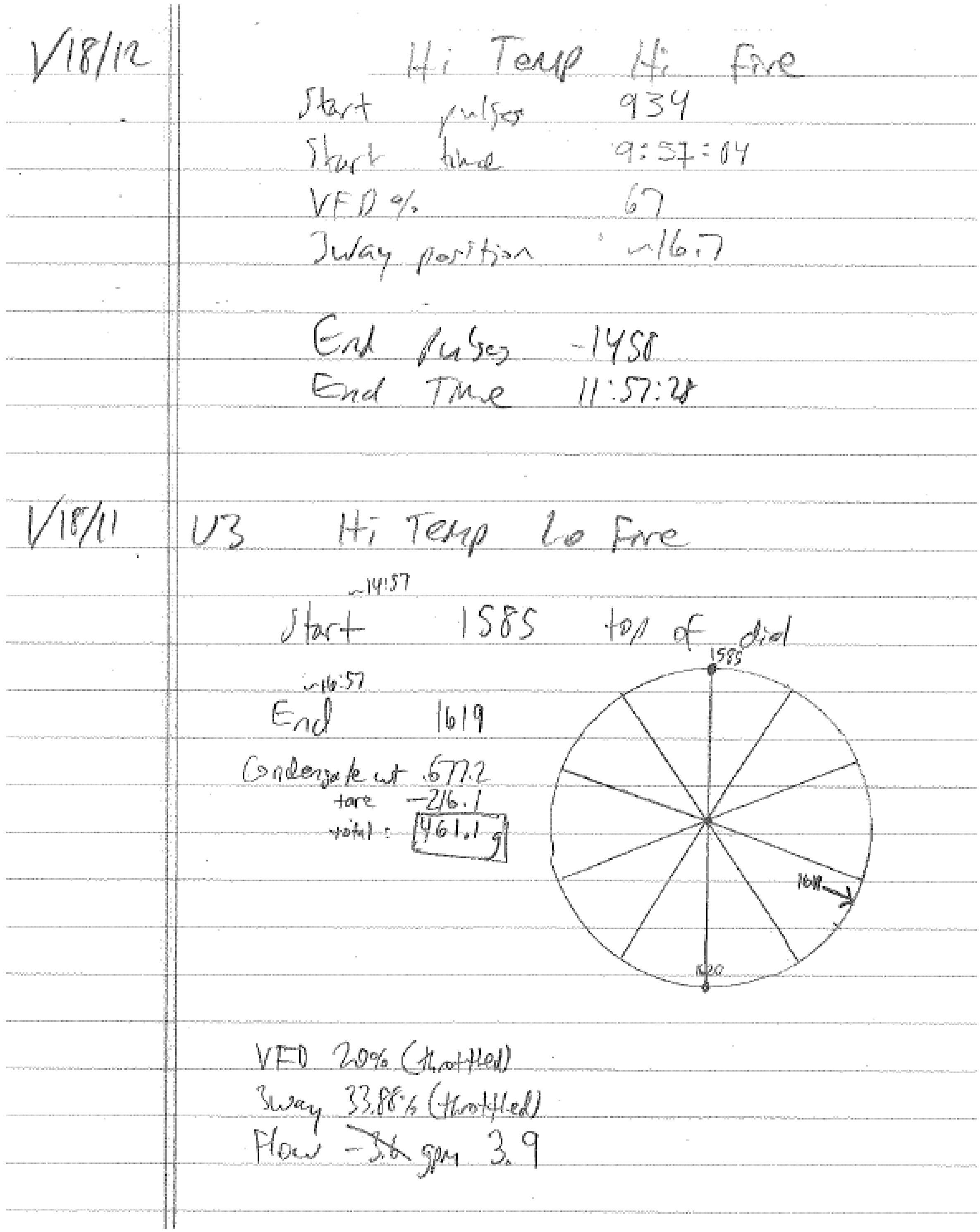


FIGURE 27. UNIT 2 LOW TEMP IDLING TEST FUEL CONSUMPTION RECORDINGS


1/18/12 Hi Temp Hi Fire

Start pulses 934

Start time 9:57:04

VFD % 67

3way position ~16.7

End pulses ~1458

End Time 11:57:28

1/18/11 U3 Hi Temp Lo Fire

~14:57

Start 1585 top of dial

~16:57

End 1619

Condensate wt 677.2

tare −216.1

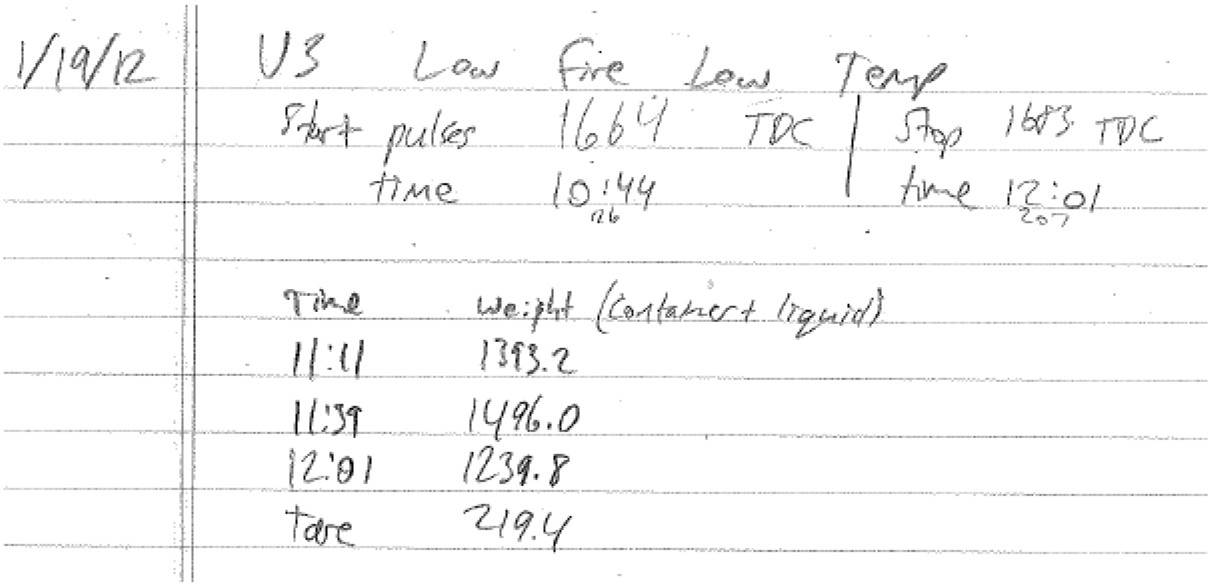
total = 461.1 g

VFD 20% (throttled)

3way 33.88% (throttled)

Flow ~~3.6~~ gpm 3.9

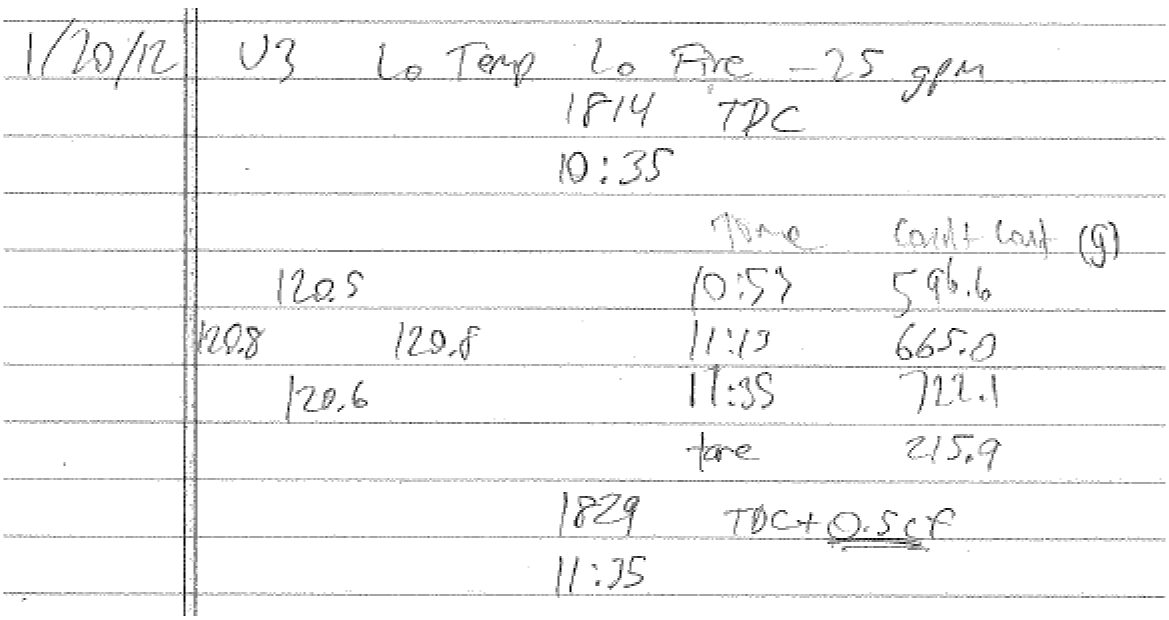
FIGURE 28. UNIT 3 HIGH TEMP STEADY STATE TEST NOTES



1/19/12 U3 Low Fire Low Temp
Start pulses 1664 TDC | Stop 1683 TDC
time 10:44 | time 12:01
126 207

Time	weight (container + liquid)
11:11	1393.2
11:39	1496.0
12:01	1239.8
tare	219.4

FIGURE 29. UNIT 3 LOW FIRE / LOW TEMP HAND NOTES – AT FLOW REQUIRED FOR 40°F ΔT

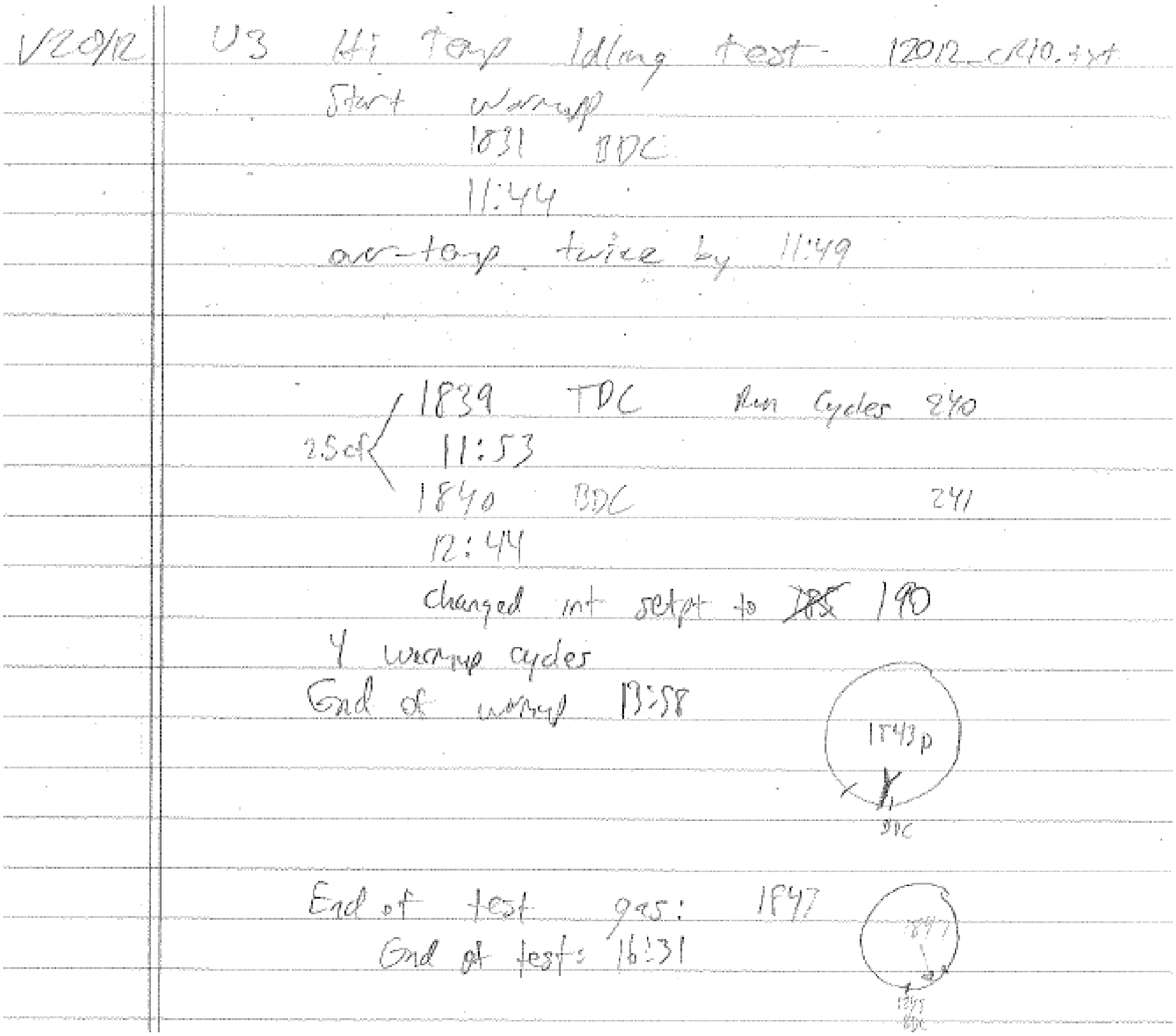


1/20/12 U3 Lo Temp Lo Fire ~2.5 gpm
1814 TDC
10:35

		Time	Cont + Liq (g)
120.5		10:57	596.6
120.8	129.8	11:13	665.0
120.6		11:35	722.1
		tare	215.9

1829 TDC + 0.5 cf
11:35

FIGURE 30. UNIT 3 LOW FIRE / LOW TEMP HAND NOTES – AT MINIMUM RECOMMENDED FLOW



1/20/12 U3 Hi Temp Idling test - 12012_c?10.txt
Start warmup
1831 BDC
11:44
air-temp twice by 11:49

1839 TDC Run Cycles 240
25 cd
11:53
1840 BDC 241
12:44
changed int setpt to ~~185~~ 190
4 warmup cycles
End of warmup 13:58
1843p
BDC

End of test gas: 1847
End of test: 16:31
1847
BDC

FIGURE 31. UNIT 3 HIGH TEMP IDLING TEST – DEFAULT DIFFERENTIAL OF 4°F

APPENDIX I - SUPPLEMENTAL EVALUATIONS

TEMPERATURE STRATIFICATION STUDY

BACKGROUND

The Test Apparatus contains redundant system temperature sensors in order to adhere to Section 6.5.8.1 of the Standard. This section describes requirements for water temperature measurement locations:

"The inlet temperature measurement device (T_{in}) is to be located approximately 12 inches before the recirculation loop, or approximately 12 inches from the boiler when there is no recirculation loop. The outlet temperature measurement device (T_{out}) is to be located approximately 12 pipe diameters after the recirculation loop or approximately 12 pipe diameters from the boiler when there is no recirculation loop.'

In order to keep the test apparatus as flexible as possible, measurement devices were located upstream and downstream of the recirculation loop on both sides of the boiler (see Figure 1). This way, no significant modifications would be required regardless of whether or not the boiler required a recirculation loop. The sensors on the boiler side of the recirculation loop are "Boiler In" and "Boiler Out". The sensors on the heat exchanger side of the recirculation loop are called "System In" and "System Out".

During initial low fire tests of Unit 2, a significant discrepancy was noticed between the Boiler Out measurement and System Out measurement (on the order of several degrees). Clearly the flow through the boiler is not turbulent at low flow and the water temperature is not uniform in the boiler outlet pipe. An error of a few degrees has a significant impact on the boiler's output, so finding a solution to the stratification issue was critical.

INITIAL TESTS

First, the possibility of a failed RTD was examined by varying the flow rate through the system. Doing so revealed that both Boiler Out and System Out probes measured the same temperature at flow rates above 10 gallons per minute (gpm). This confirmed that the RTDs were in fact functioning properly. However, at lower flow rates, there was a discrepancy in readings which led to the hypothesis that stratification may be occurring in the pipes at flow rates below 10 gpm. The loop flow rate is only about 6 gpm for Unit 2's low fire tests, so data collected during this low fire test were likely inaccurate.In order to confirm that the temperature in the pipe was indeed stratified, measurements were recorded while traversing the pipe diameter with the RTD. A maximum difference of over 10 degrees was measured.

POSSIBLE SOLUTIONS

Two main solutions were discussed to mitigate the stratification issue.

The first was to insert additional valves upstream of the temperature sensor. These valves could be partially closed to increase turbulence and mix the flow. Several arrangements were discussed, with varying numbers and orientations of the valves.

The second was to add a small recirculation loop to mix the flow, with the suction side downstream of the temperature sensor and the discharge side upstream of the temperature sensor, or vice versa. Initial discussions revolved around the System Out measurement location, but it was later decided that the Boiler Out location was more important because mixed flow would carry through the system, so any mixing needed to be done upstream of the first temperature measurement location.

Options for circulating the flow around the RTD can be seen in Figure 32 and Figure 33. In Figure 32, an additional pump would be added (along with plumbing). The expansion tank would be shifted up. Mixing valves could be added upstream of the loop to increase turbulence. The option in Figure 33 is less costly because it utilizes the existing recirculation loop's pump. However, this would only work for boilers that did not require a recirculation loop.

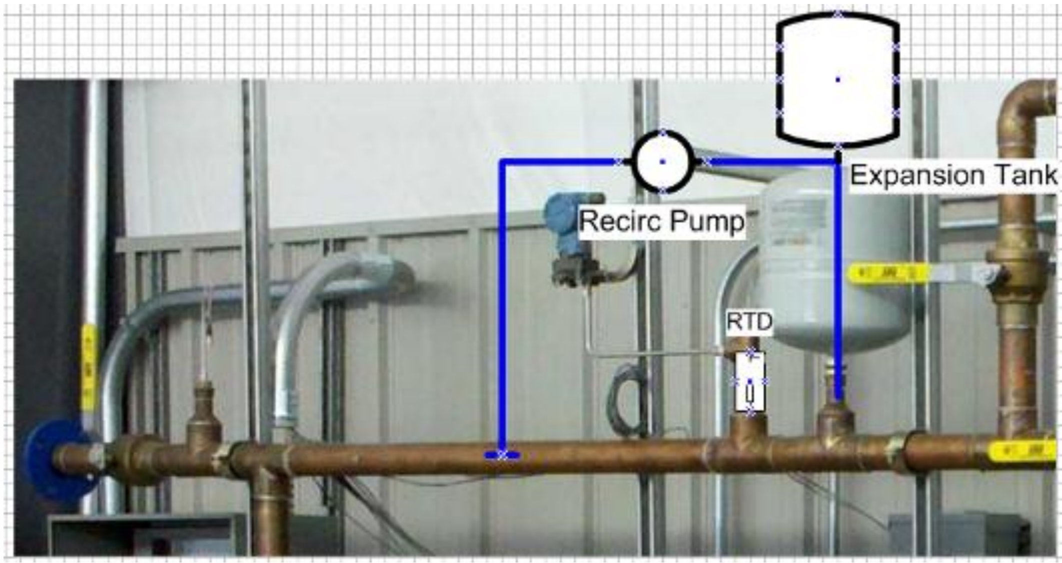


FIGURE 32: STRATIFICATION MITIGATION – ADD RECIRC LOOP AROUND RTD

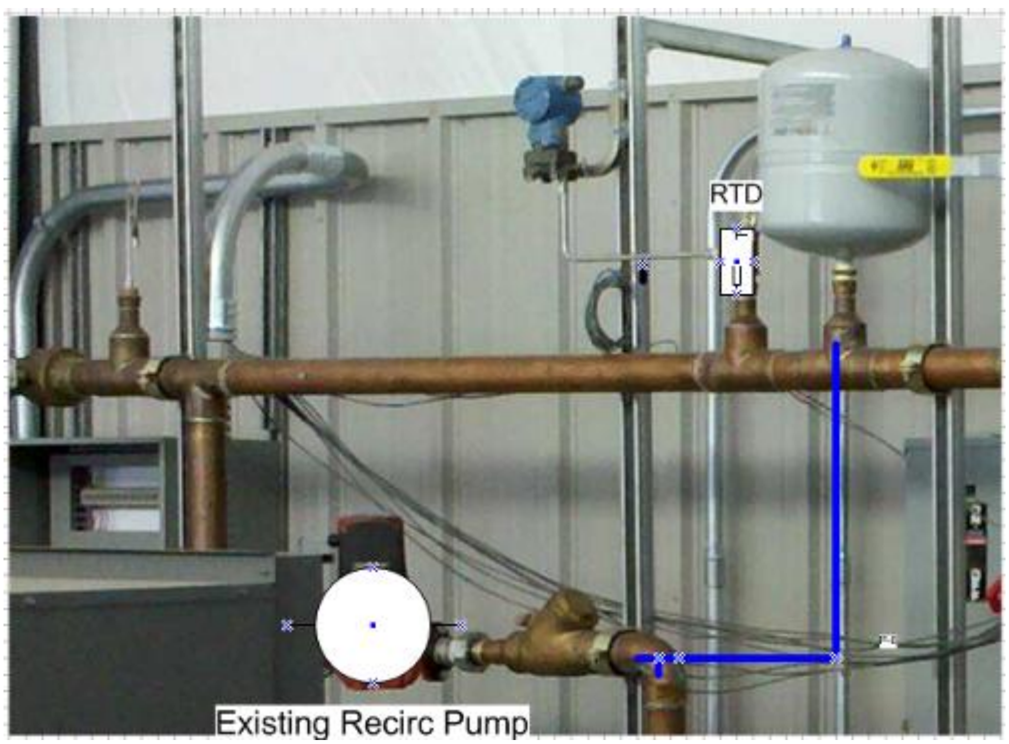


FIGURE 33: STRATIFICATION MITIGATION – USE EXISTING RECIRC LOOP

FINAL SOLUTION

After shifting the focus to the Boiler Out RTD location, a method was devised to combine all possible mixing options. In between the Boiler and Boiler Out RTD, a mixing loop was added containing valves and a mixing pump. The arrangement allows the mixing pump to be run in parallel or in series with the main loop, and the valves can be used without the pump to test their effectiveness in mixing the flow. The solution is shown schematically in Figure 34

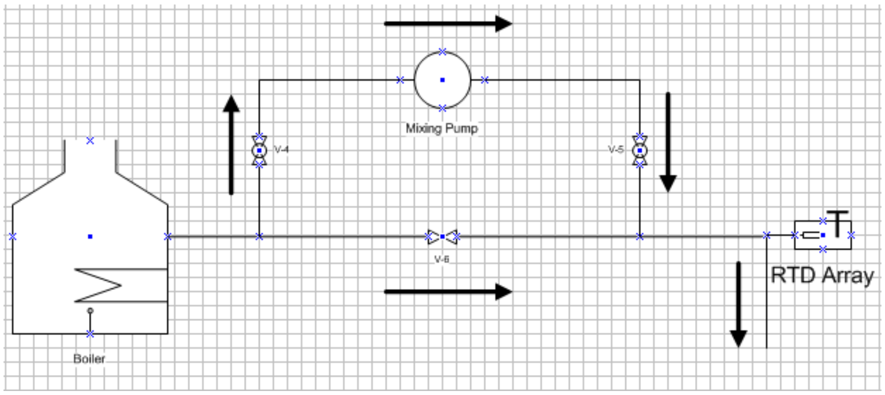


FIGURE 34: STRATIFICATION MITIGATION - SCHEMATIC OF FINAL MIXING SOLUTION

In addition to the mixing loop, an RTD array was added to capture a temperature profile of the flow. RTD's were located in the endcap of a T fitting, at the 12:00, 3:00, 6:00, and 9:00 positions, shown in Figure 35.

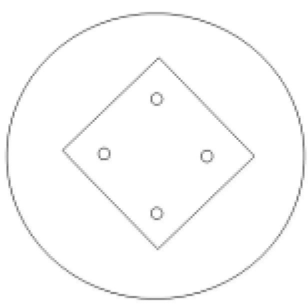


FIGURE 35: STRATIFICATION MITIGATION – RTD ARRAY

A photo of the installed mixing loop is included in Figure 36 below. A 1/6 HP pump is installed as the mixing pump. System heat gain due to this pump is approximately 0.14°F. The Standard committee should evaluate whether or not to include the energy input to this mixing pump in the thermal efficiency analysis. Currently, it is not included.

FIGURE 36: STRATIFICATION MITIGATION – INSTALLED SOLUTION

RESULTS

On December 21, 2011, installation of the mixing loop was completed and stratification testing continued. Readings of the RTD array were recorded before firing up the boiler to verify that all were reading the same temperature. Then the system was brought to steady state condition with the mixing pump off, and a 6°F difference was noted in the RTD array. Next, the mixing pump was turned on in parallel with the flow, and with the gate valve 100% open. After the system settled, it was evident that the solution was successful and brought all temperatures to within 0.5°F. Lastly, the mixing pump was turned off, and the stratification problem returned. A summary of the measurements is in Table 29 below.

TABLE 29: STRATIFICATION MITIGATION – TEST RESULTS

21-Dec	Stratification test							
	Boiler In	12:00	3:00	6:00	9:00	System Out	System Flow	Max Difference
0 Flow		52.0	52.2	52.2	52.2		6.3	0.2
0 Flow		52.4	52.6	52.6	52.6		6.3	0.2
Mixing Off	140.4	**181.0**	**180.7**	**175.0**	**175.3**	177.3	6.2	**6.0**
Mixing On	136.9	**177.2**	**177.6**	**177.2**	**177.2**	177.2	6.0	**0.4**
Mixing Off	137.9	**180.4**	**179.4**	**174.3**	**174.9**	176.4	6.0	**6.1**

STRATIFICATION STUDY CONCLUSION

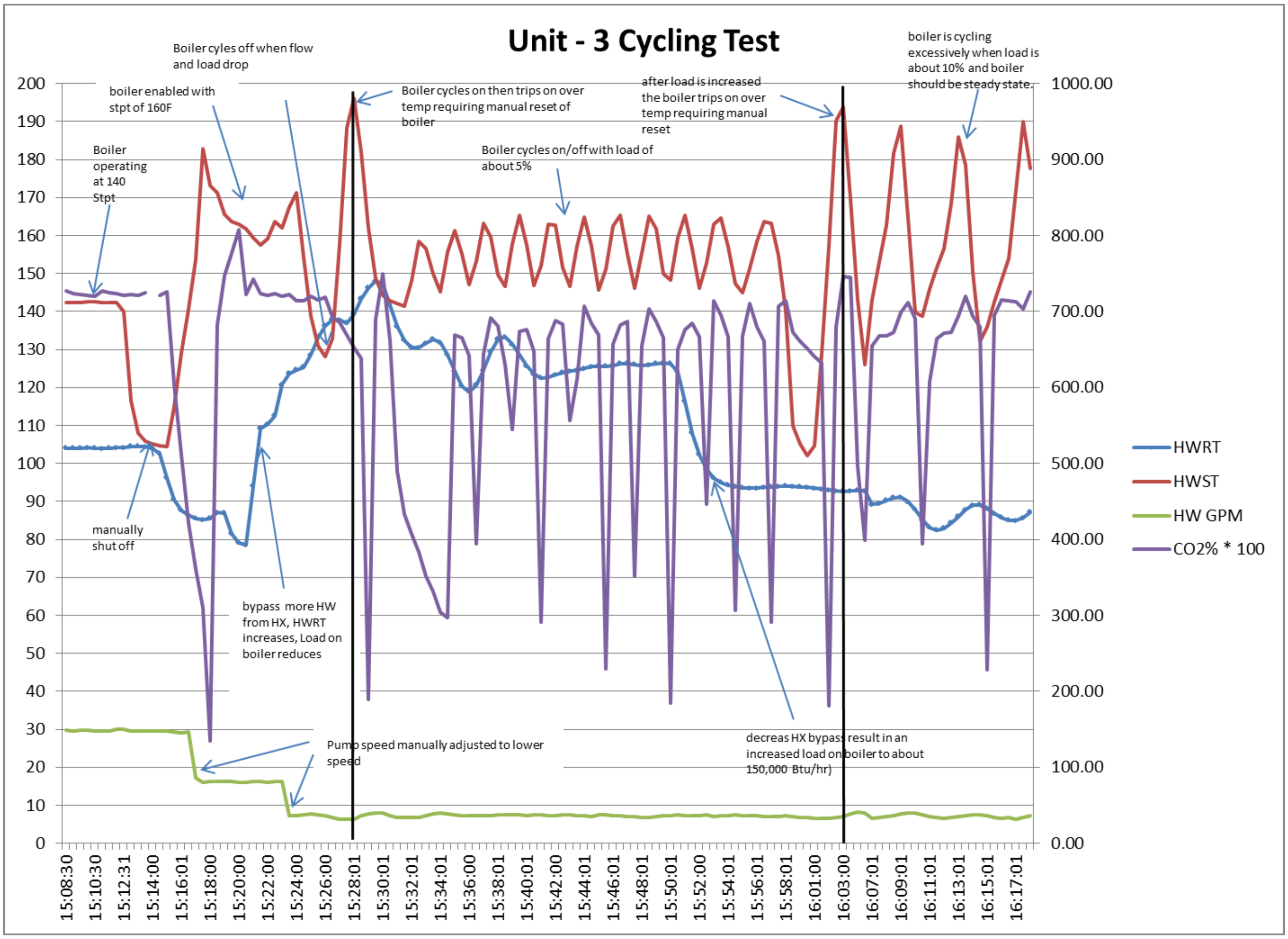
Detailed testing of the best method to mitigate the stratification issue is beyond the scope of this project. While the small mixing pump in series appears to be a good solution for Unit 2 on this Test Apparatus, other labs will have varying pipe sizes and flow rates will change for other boilers. Labs should have the flexibility to use whatever mixing devices are most appropriate for them (e.g. valves, pumps, pipe size reductions, etc.). In order to insure fully mixed flow we have recommended that Standard 155P require an array of sensors on the outlet and that any power consumed by mixing devices be included in the calculations (See Recommendations).

CYCLIC TESTING OF UNIT 3

Standard 155P does not require any testing where the boiler serves a non-zero load using its own internal control algorithms. In order to evaluate the stability of a boiler under its own internal controls, Unit 3 was presented with a varying load profile over a one hour test period. The figure below shows the results.

At 15:08 the unit was operating under its own control at steady state with a load of about 30%, a setpoint of 140F, and a flow rate of about 30 gpm (the manufacturer's required minimum flow). At 15:15 the boiler was manually shut off and the flow rate was reduced to about 15 gpm. The boiler was then reenabled with a higher setpoint (160F) and controlled relatively stably. At 15:24 the flow rate was further reduced to about 8 gpm in order to achieve a load of about 5%. The boiler cycled off. Then at about 15:26 the boiler cycled back on and tripped on over temperature requiring manual reset of the boiler. This was unexpected. We would have expected the boiler to react quickly enough to the low load not to result in a hard reset. The boiler was then reset and it cycled relatively stably to meet the 5% load. At about 15:25 the load was increased on the boiler to about 10% of design capacity by lowering the boiler entering water temperature. This caused the boiler leaving water temperature to drop significantly. This in turn caused the boiler to over fire and hard trip at about 16:03. Again this was unexpected. We would have expected the boilers controls to be able to stably meet the increased load. After being manually reset at about 16:07, the boiler cycled excessively. Again this was unexpected. We would have expected the boiler to achieve steady state given the load was well above the boiler minimum load and relatively stable.

It is important not to read too much into these test results because the flow rates are considerably lower than the manufacturers required minimum flow rates. The main conclusion of this testing is that that internal controls can have a significant effect on boiler efficiency and stability and that the assumptions in the Standard about boiler stability at all conditions may not be warranted.


Unit - 3 Cycling Test
Boiler cyles off when flow and load drop
boiler enabled with stpt of 160F
Boiler operating at 140 Stpt
Boiler cycles on then trips on over temp requiring manual reset of boiler
after load is increased the boiler trips on over temp requiring manual reset
boiler is cycling excessively when load is about 10% and boiler should be steady state.
Boiler cycles on/off with load of about 5%
manually shut off
bypass more HW from HX, HWRT increases, Load on boiler reduces
Pump speed manually adjusted to lower speed
decreas HX bypass result in an increased load on boiler to about 150,000 Btu/hr)
HWRT
HWST
HW GPM
CO2% * 100

REFERENCES

ASHRAE Standard 155P 2010 07 06 Working Draft, "Method of Testing for Rating Commercial Space Heating Boiler Systems." July 6, 2010

Leni-Konig, Katrina. "Cee Boiler Test Plan Rev 100110-JS." December 29, 2010.

Pacific Gas and Electric Company California Gas Transmision Pipe Ranger Heating Values, http://www.pge.com/pipeline/operations/therms/heat_value.shtml