Lab Experiment 3: Campus Power Plant Operations

Section 23L

Jonathan Smith: Equipment, Graphs/Data Tables, Data/Uncertainty Analysis
Adam VanBuskirk: Team Leader, Summary, Design Objective
Brandon Golino: Theoretical/Procedure, Data Recorder, Design Objective
Jacob Klofta: Graphs/Data Tables, Discussion/Conclusion, Report Compilation
Kyle Rodriguez: Equipment, Data/Uncertainty Analysis

Experiment Performed: March 20, 2019
Report Submitted: April 10, 2019

Objectives:
To observe and measure the heat transfer processes and losses in large industrial equipment.

Summary:
Dear Plant Engineers,

While at the Plant, my group observed and recorded data from boiler six. From our collected data, we were able to compute the overall efficiency of the boiler six by comparing the energy content of the fuel being supplied to the net change in energy of the water to steam process. The efficiency of boiler six is 87.6%-92.2%. In addition, we were able to estimate the effectiveness of the Economizer to be 0.388. Lastly, after we observed the steam energy supplied to Spencer Lab, we were able to calculate the energy to be $3.70kW$ or $6.32(10^{-5})\frac{kW}{ft^2}$.
We are available to continue offering our consultation services should you choose to use them again. Thank you.

Sincerely,
Members of MEEG346-010 Team A1
Mechanical Engineering Dept.

Theoretical Background:

The Central Boiler for UD is located near Spencer Labs and provides steam for heating and hot water for all main campus buildings. The facility has six boilers that either use oil or natural gas and can alternate between them as needed. Most of the boilers are shell and tube heat exchangers. This means that one side of the boiler has the the products of fuel combustion and on the other side contains the water being boiled into steam. There are two main types of shell and tube exchangers: fire tube and water tube. This simply designates whether the fuel or the water is on the shell or tube side.

Each campus building, as well as pretty much any large building, contain equipment rooms where steam and chill water supplies are distributed. From here the correct temperature water or air is then supplied to their terminal units (i.e. air vents, water fountains, etc.). These systems employ many aspects of Mechanical Engineering, including fluids, heat transfer, control theory, materials, piping, and support structure.

Equipment:

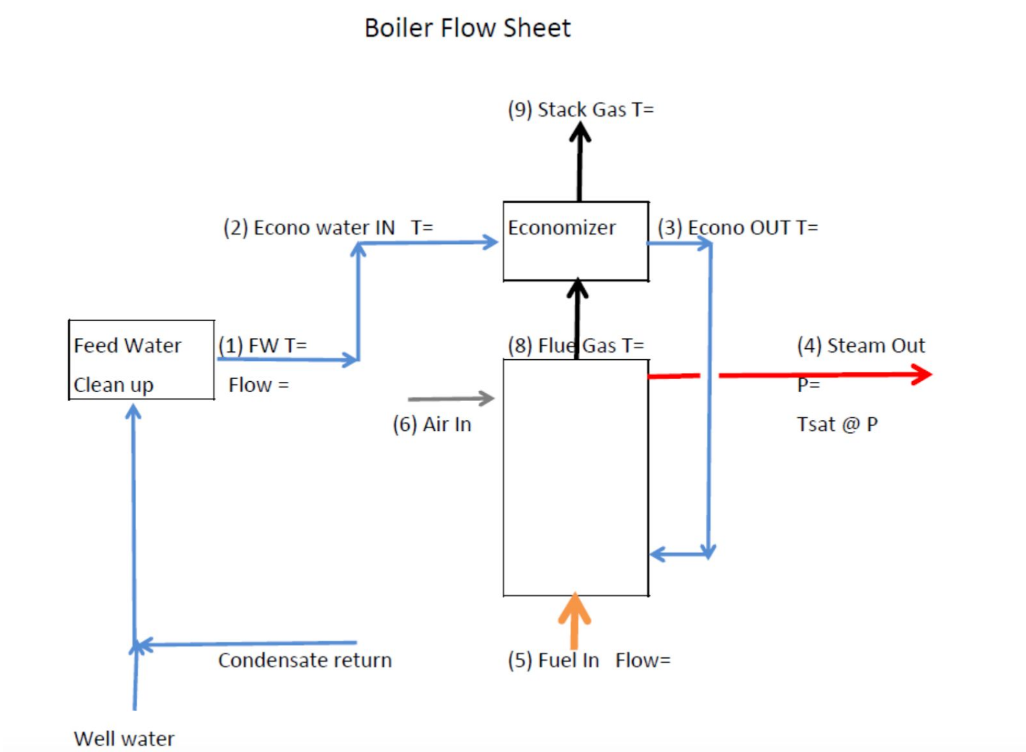


Figure 1. Diagram of the power plant which displays the flow of the water

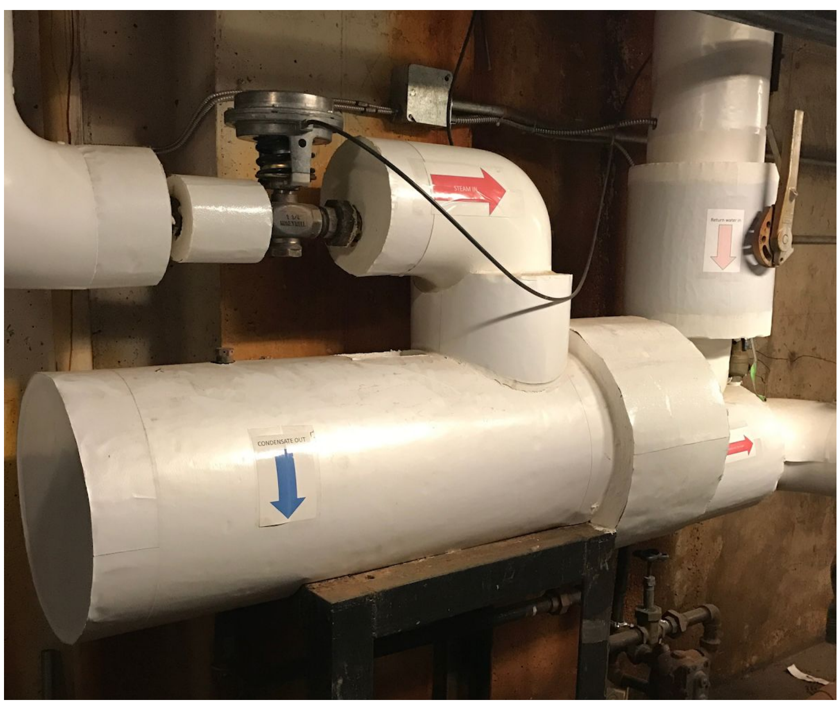


Figure 2. The system in the basement of Spencer lab that takes the steam in and water return in at the two red arrows on the top and then the condensate leaves at the blue arrow while the other red arrow leads out to the pump.

Procedure:

Part 1: Campus Power House
1. Meet in Spencer Lab, obtain safety glasses, walk to steam facility
2. Receive brief overview and orientation of facility
3. Record date, time, weather conditions, and ambient temp on data sheet
4. Observe key parts of boiler and label them on schematic
5. Record necessary temp, flow, and pressure data from control room

Part 2: Spencer Laboratory Terminal Heating System
1. Go to mechanical room in basement of Spencer Lab
2. Relate the schematic to the visible piping
3. Take necessary data from analog instruments, noting their scale

Results:
Part 1: Campus Power House

Date	3/20/2019	Flue Gas Temp	404 F
Time	8:55 AM	Steam Pressure	120 psig
Boiler #	6	Steam T_Sat*	350.055 F
Feed Water Temp	225 F	Fuel In	33758 SCFH
Feed Water Flow	33312 lbm/hr	Heating Value	1050 Btu/scf
Feed Water Pressure	205 psig	Total Steam Output	69.8 kilo lbm/hr
Economizer Temp In	225 F	Outside Temp	33.8 F
Economizer Temp Out	251 F	Boilers Operating	#1, #6, #4
Stack Gas Temp	329 F	Weather	Clear, sunny

Table 1: Data sheet values for Part 1, obtained from Appendix B.
*Using the observed pressure of the outward steam, T_Sat = 350.055 F from saturated steam tables.

Enthalpy:

Location	**Temperature (F)**	**Enthalpy (kJ/kG)**
Feed Water	225	449.609
Economizer in	225	449.609

Economizer out	251	510.872
Boiler out	350.055	2774.27

Total = 2774.27 kJ/kG - 510.872 kJ/kG = 2263.398 kJ/kG

Table 2. Calculated enthalpies of feed water in through the steam exiting the boiler. The enthalpies were calculated using known temperatures or pressures and a steam table.

Boiler Efficiency:

	X = 0.95	**X = 1**
Fuel Flow Rate (SCFH)	33,758	33,758
Steam Flow Rate (lbm/hr)	33,312	33,312
Δh (kJ/kG)	2151.136	2277.885
Energy Content of Fuel (C)	1050	1050
Efficiency	.876	.922

Table 3. Efficiency of the boiler. Energy in was calculated using energy input by the fuel.

Heat Exchanger Effectiveness:

M_c (lbm/hr)	33,312
T_c,in (F)	225
T_c,out (F)	251
C_p,c (BTU/lbm)	1
C (BTU/lbm)	33,312
T_h,in (F)	404
T_h,out (F)	329
C_p,h (BTU,lbm)	6860
Q (MBTU/hr)	.698

Q_max (MBTU/hr)	1.8
Effectiveness	.388

Table 4: This table illustrates the values used to calculate our effectiveness.

Quality of Steam:

Enthalpy Entering	2263.398 kJ/kG
Enthalpy Exiting	510.872 kJ/kG
Enthalpy of a Liquid (@ 120 PSI)	2774.27 kJ/kG
Quality	.8158

Table 5: This table shows how we calculated the quality of our steam

Part 2: Spencer Laboratory Terminal Heating System

Using the conversion factor h_fg provided in Appendix B and the steam supply rate from Table 2, the rate was converted to be 2647.1 lbm/hr.

To find the heat transfer Q, the specific heat value Cp = 0.4767 Btu/lbm*F for steam was used in calculations. All other values were provided in the table above.

$$Q = mC_p\Delta T = 2647.1 * 0.4767 * 10 = 12618.7\frac{Btu}{hr} = 3.69818kW$$

The value for the total occupied area of Spencer Laboratory was given as 58,000 sq. ft. This metric is then used to determine the energy per square foot.

$$\frac{Q}{A} = \frac{3.69818\ kW}{5388.376\ m^2} = 6.86(10^{-4})\frac{kW}{m^2}$$

Uncertainty Analysis:

Using Propagation of Uncertainty, it was found that the uncertainty of the boiler efficiency calculation was approximately 4.53%. The energy content of the fuel was assumed to vary by 50 Btu/SCF, the digital readouts in the control room were observed to fluctuate while they were being read, and since the quality of the steam is unknown, the difference in Δh for 100% and 95% quality was about 126 Btu/lbm. This method was used as it takes the uncertainties of all variables into account and measures the effect they have on the result. Knowing a more exact value of the energy content of the fuel and having a method of measuring the the exit steam quality would reduce the uncertainty of our final result.

$$\frac{\delta\eta}{\eta} = \sqrt{(\frac{\delta E}{E})^2 + (\frac{\delta SCFH}{SCFH})^2 + (\frac{\delta \Delta h}{\Delta h})^2 + (\frac{\delta steamflow}{steamflow})^2}$$

$$\Rightarrow \frac{\delta\eta}{\eta} = \sqrt{(\frac{50}{1050})^2 + (\frac{100}{33758})^2 + (\frac{50}{2277.89})^2 + (\frac{100}{33312})^2} = 0.0526$$

Discussion & Conclusion:

From lab calculations, the obtained values for boiler efficiency were determined to be within reason at 87-92%. We do not believe that a higher efficiency should be expected, due to uncertainty in both our calculations and the fluctuations in recording the data in both parts. In addition, it cannot be expected that the boiler is perfectly efficient, as we know this is impossible in real world situations.

The energy loss between the power plant and Spencer Lab can be attributed to a few factors. Minor head loss due to the length and bends in the pipe will account for some loss. In addition, we expect that the steam begins to condense in the pipes before reaching Spencer Lab. We know this to be true, as the system within Spencer Lab shows us that the noticeable condensation must be removed from the pipes to help increase efficiency. As the quality of the steam decreases, the efficiency also decreases, a statement that can be reinforced through our calculations. None of our observed or calculated values appear to be out of the ordinary, even when considering our uncertainty.

Design Objective Analysis:

The three parts to the Design Objective are found above in the Results. The first objective is found in results: part 1, section 2. The second objective is found in results: part 1, section 3. The third objective is found in results: part 2, section 1.

The efficiency range of boiler six is 87.6%-92.2%.

The effectiveness of the Economizer is 0.388.

The steam energy supplied to Spencer Lab is 3.70kW.

Appendix A: Lab Roles

Lab Section 23-LA1 Experiment # 3 Date 3/20/19

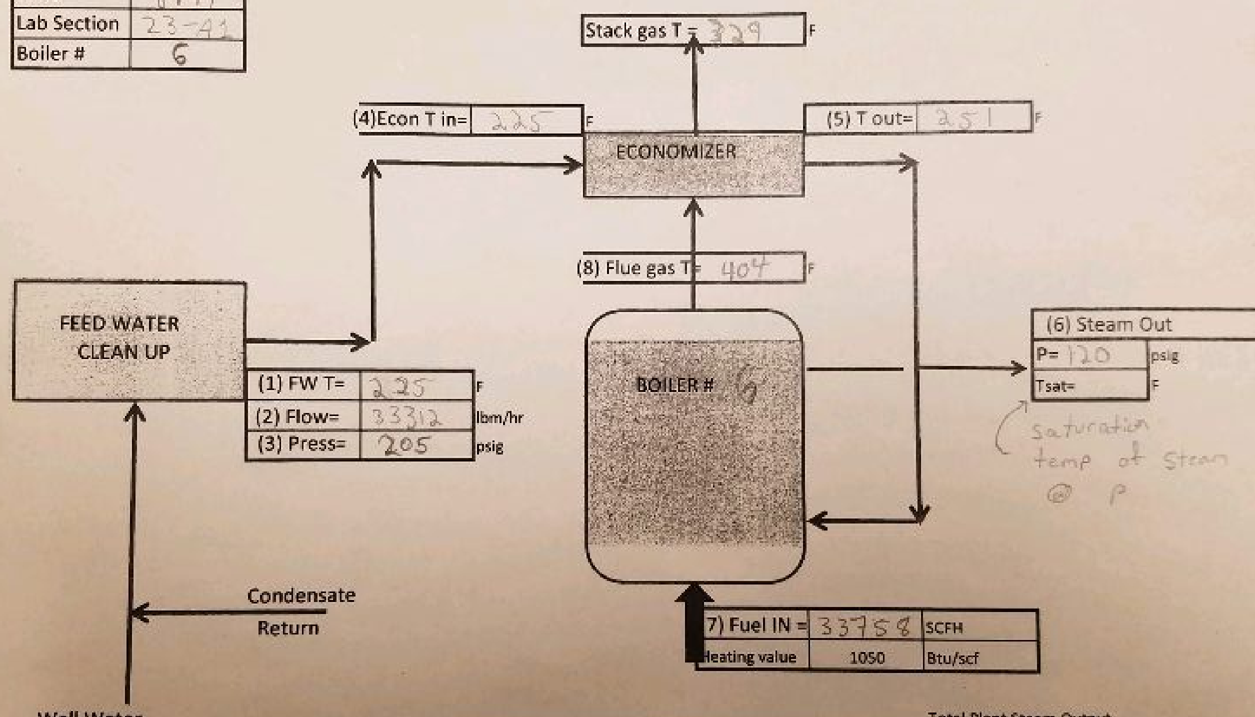
Note: Roles must be agreed on before work starts. Every team member must be represented. It is a commitment. The roles should be rotated for each experiment. Each role in principle has a specific contribution (page or paragraph) to create for the report.

	Name
Team Leader/ Coordinator	AV
Theoretical and Procedure write up	BG
Equipment operation (1 or more)	JDS / KR
Data recorder	BG
Equipment diagram (sketch or photo. Include instrumentation)	KR
Graphs, data tables for report (2 people)	JDS / JK
Data & Uncertainty analysis for report (2 people)	JDS / AV
Discussion and Conclusion	JK
Summary Letter	KR
Report typing and compilation	JK
Design Objective Analysis (2 people)	AV / BG

TA initial__________

Appendix B: Data Sheets

Date	3/20/19
Time	8:44
Lab Section	23-41
Boiler #	6



					Total Plant Steam Output	
Boilers operating	# 6	# 1	# 4	#	69.8	lbm/hr
Outside Temp	33.8				Kilo lb/hr	
Weather obs	Clear day, sunny					

SDH

X-3 | Date 3/20/2019

Data sheet for Spencer Lab

Steam Supply to Building (digital gage) | 1.8 | Mbtu/hr

Calc | 2647.1 | lbm/hr | (Btu/hr/h_{fg})

hfg= 860

Steam Supply splits:
(1) Heat water that circulates to terminal units (offices)
(2) Heat outside air for labs, halls, interior spaces

(1) U-tube heat exchanger (steam on shell side, water in tubes:

Water out	161	F	
Water retrn	151	F	
Pump flow	180 gpm		lbm/hr
Water ΔT	10	F	

Q= m c ΔT	12618.7	Btu/hr
	.012618	Mbtu/hr

(2) Balance of steam supplied heats outside air
(3-story intakes on bldg near Academy St entrance)

An energy conservation metric is Energy/ft^2

Spencer occupied space (3 stories + basement):

Total square ft = 58,000 ft^2 = 5388.376 m^2

Energy/ft^2 | .21756 | Btu/ft^2 or | 6.86×10^{-4} | kw/m^2

(This metric obviously depends on condtions. Smaller is better)

<DH

Appendix C: Analysis Calculations