California State University, Long Beach

College of Engineering
Department of Mechanical Engineering

EXPERIMENT 5: Simple Steam Power Plant

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Course: MAE 337-Thermal Engineering Lab

Section 9

Group 5
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Abstract:

The purpose of this experiment is to gain a better understanding of the Rankine cycle and understand the importance of the thermodynamic cycle used in steam power plants to generate power.The steam power plant used in this experiment is manufactured by Turbine Technologies. The system consists of a turbine, a boiler, a and generator, a condenser, and instrumentations including a Flowmeter, thermocouples, pressure transducers, and a PC data-acquisition system.For the energy a tank of propane was attached to supply the experimental runs. The data is recorded by the lab instructor using a data acquisition program. The purpose of the lab process is to replicate a Rankine cycle in order for students to have an in-depth understanding of the simple steam power plant. The contrast and comparison of the Ideal Rankine cycle with the actual cycle will provide the students the perspectives on why the data are not usually ideal for the actual cycles and also where the potential errors are coming from. In the end, the variation in turbine speed, fuel flown, boiler temperature and pressure were analyzed and furthermore the efficiency of the boiler, condenser, and generator were also calculated to determine which combination will be the most efficiency.

Table of Content **page #**

Objective

The main objective of this experiment is to determine the characteristics of a steam power plant and gain an understanding of the Rankine Cycler System as a whole and details of each component making up the system.

Introduction

The Rankine cycle was long introduced and revolutionized how humans optimize energy. The demand for ways to obtain vast amounts of energy from natural resources has been crucial to our modern technological way of life throughout history. This cycle involves the process of pumping water into a closed metal container called a boiler. After that, the boiler was heated to a certain temperature to produce high-pressure steam, shooting the steam out of a nozzle to spin a turbine wheel (paddle wheel), which is connected to a generator that produces electricity. On the other hand, condensing the steam transfers back into water to start the process again. The main components of a simple steam power plant mainly consists of a pump, boiler, turbine, and condenser.

The ideal, efficient, and also simplest steam cycle is the Rankine cycle. All of the components of the cycle are steady flow devices.In the beginning (stage 1), water is inserted into the pump as a saturated liquid and is compressed isentropically therefore, the boiler reaches saturated condition. As a result, the water temperature increases slightly due to a reduction in its specific volume. At state 2, compressed liquid water enters the boiler where it is heated at a constant pressure. The process takes place in the heat exchanger chamber with the push of combustion liquid propane. The steam generator compliments the boiler and the superheating section. At state 3, superheated vapor enters the turbine, which expands isentropically, producing work that rotates the shaft connected to a paddlewheel in an electric generator. As the steam passes through the turbine, the temperature and pressure are escaped. In the final stage, the cooled steam returns to the condenser, where it is condensed and entered as liquid water. The cycle is now completed and it keeps repeating to keep generating electricity.

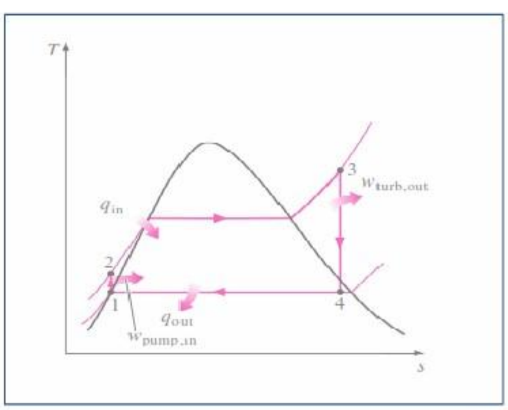


Figure 1: T-s diagram of Rankine Cycle

List of Apparatus

Figure 2: The Turbine Technologies Steam Power Plant.

Procedure

In the beginning, the lab instructor filled the boiler with 5500 ml of distilled water.The DAQ system was also turned on with the purpose of adequate the system for data acquisition. The pressure valve was opened for 5 seconds to balance the inside pressure with the atmospheric pressure and the propane tank valve was opened. The switch is moved clockwise to turn on the main power and the burner was set to ready. When the pressure got to 125 psi, the preheating process started and lasted for 7 to 10 minutes. The instructor opened the steam admission valve to allow steam to flow throughout the system, observing the boiler pressure, analyzing the load on and adjusting the corresponding turbine speed, closing the steam admission valve to stop steam flow, and allowing boiler pressure to regenerate. The steam admission valve needed to slowly open until the voltmeter showed an approximate 9.0 volts. The load rheostat was adjusted to maintain 0.3A and 9V. Steady-state conditions are achieved when the amp meter indicated approximately 0.3 Amps, the voltmeter indicated approximately 9 Volts, and the boiler pressure displayed approximately 125 psi. In the end, experimental runs can begin once a reasonable steady state is achieved. The data acquisition software was utilized by the instructor in order to gather the data for students to analyze. After 10 minutes, the steam boiler and valves were closed and the pressure valve was closed after 45 minutes. Also, the condensing liquid was measured using a 3L cylinder.

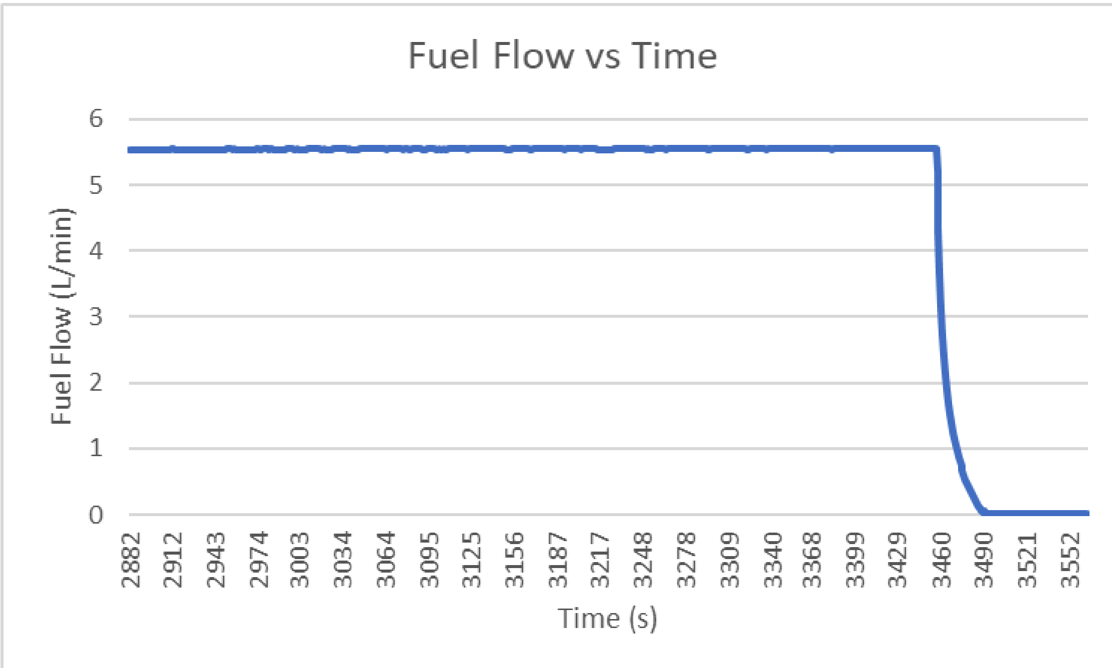
Table of Data and Results

Point	$T(^{\circ}F)$	P(psia)	state	$h(btu/lb_m)$	$S(Btu/lb_m R)$
1 (using table A-6)	352.56	132.2	Superheated Vapor	1196.5	NR
1(using NIST website)	352.6	132.2	Superheated Vapor	1195.7	NR
2	248.5	29.6	liquid	217.25	0.322
3 & 4	206.3	18.8	liquid	189.92	NR
3s	NR	18.8	liquid	189.92	NR
5	201.8	14.7	liquid	180.16	NR

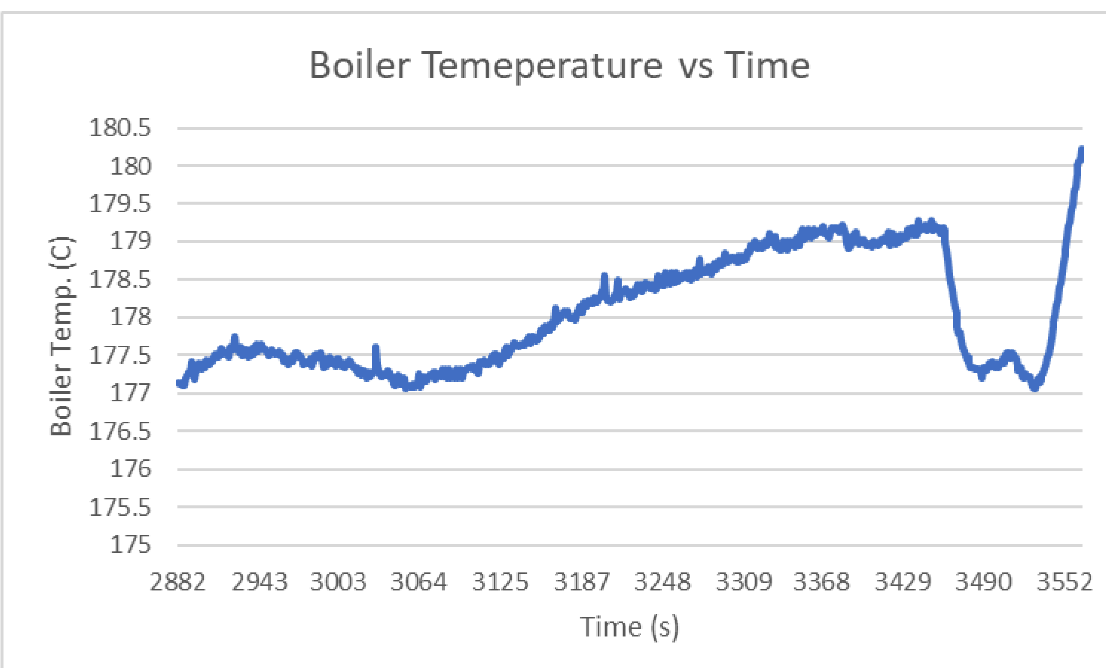
	Run 1
Boiler’s Max Capacity (cm3)	6538
% of boiler filled with water initially	84.1
mass flow rate of steam (lbm/hr)	76
Heat of steam leaving the boiler (Btu/hr)	90873
Heat supplied to the Boiler by Propane gas (Btu/hr)	12986
Work of the turbine (Btu/hr)	2077.1
Turbine efficiency (%)	NR
Rankine cycle thermal efficiency (%)	14.85
Generator efficiency (%)	0.41
Condenser efficiency (%)	9.56
Heat removed from the condenser (Btu/hr)	742
Overall efficiency of the system	0.06
Heat rate (Btu)	5654052

Part 1:

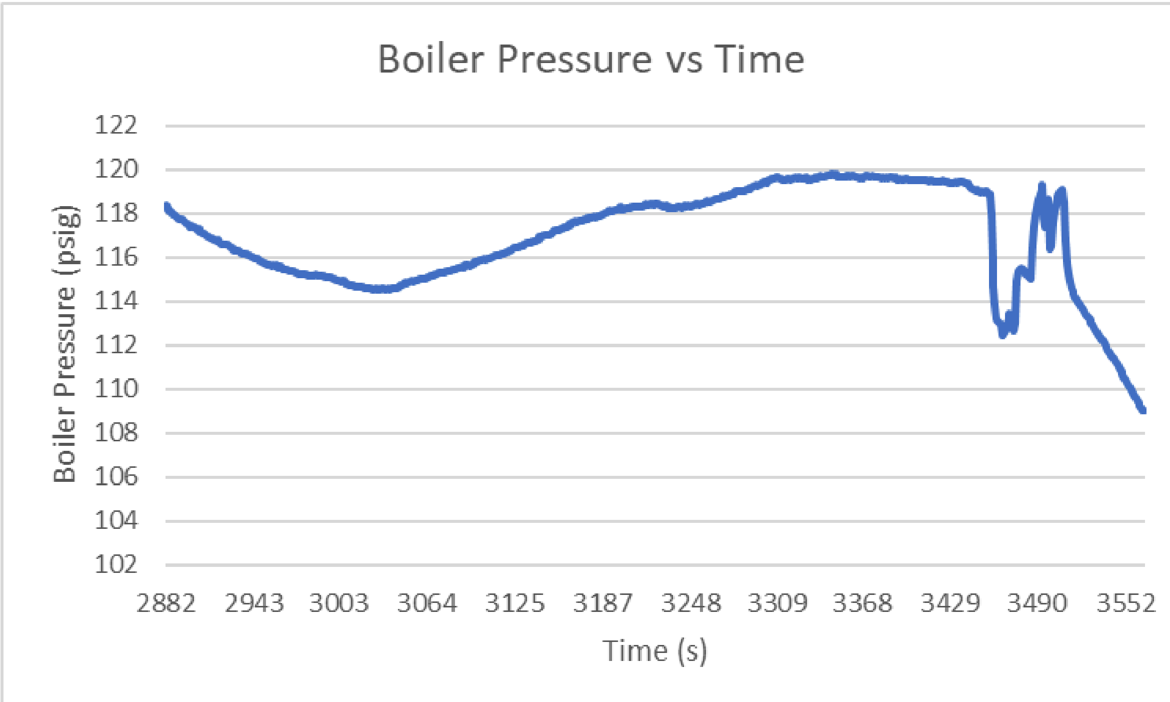
Fuel Flow vs Time



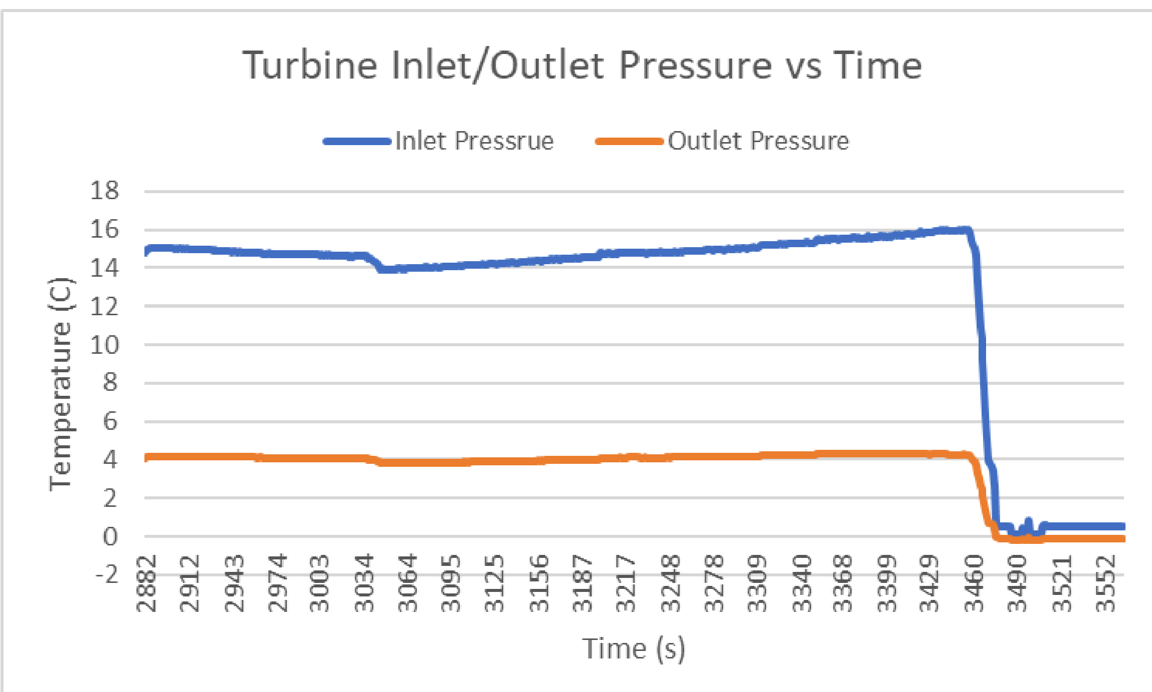
Boiler Temperature vs. Time



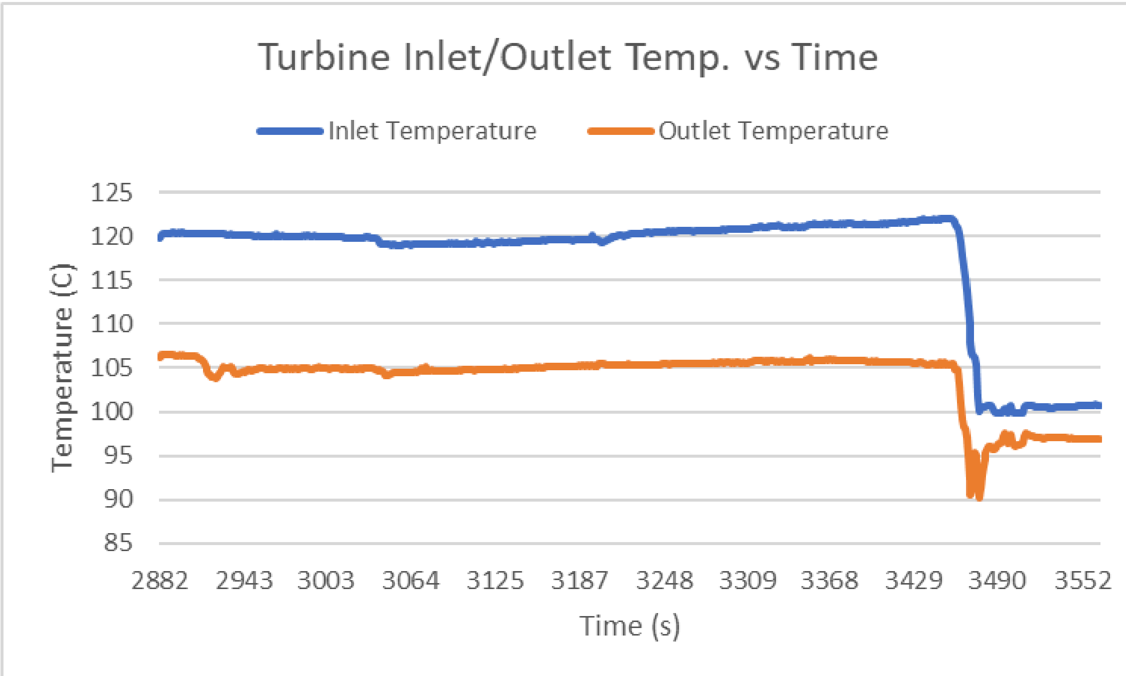
Boiler Pressure vs. Time



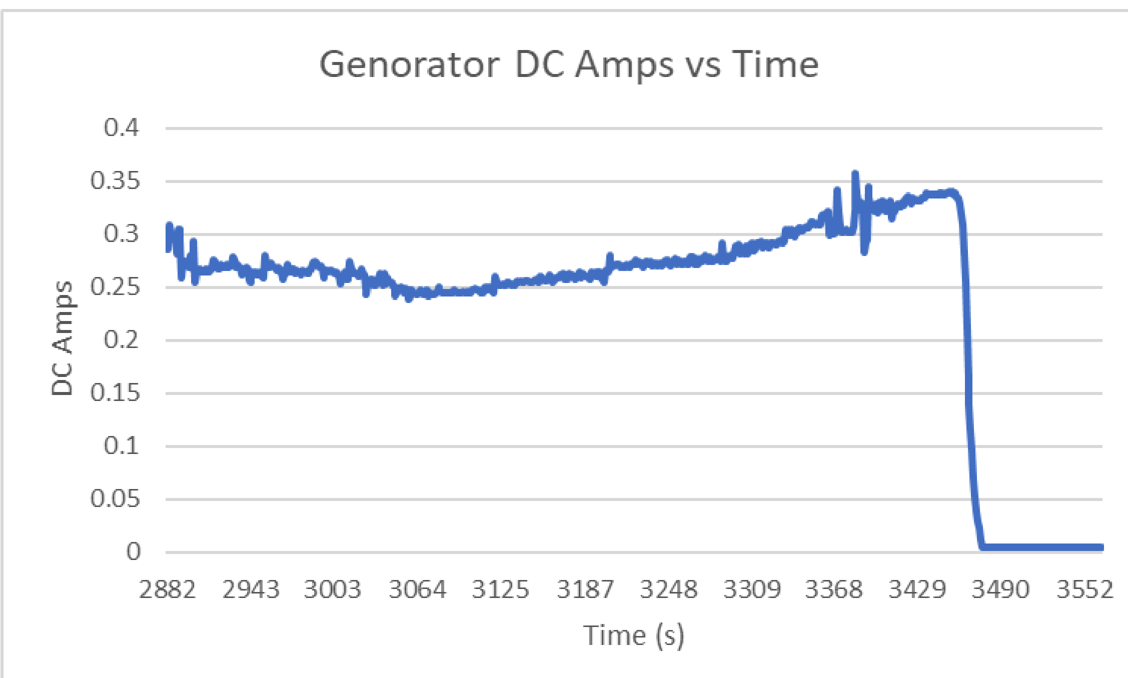
Turbine Inlet/Outlet Pressure vs. Time



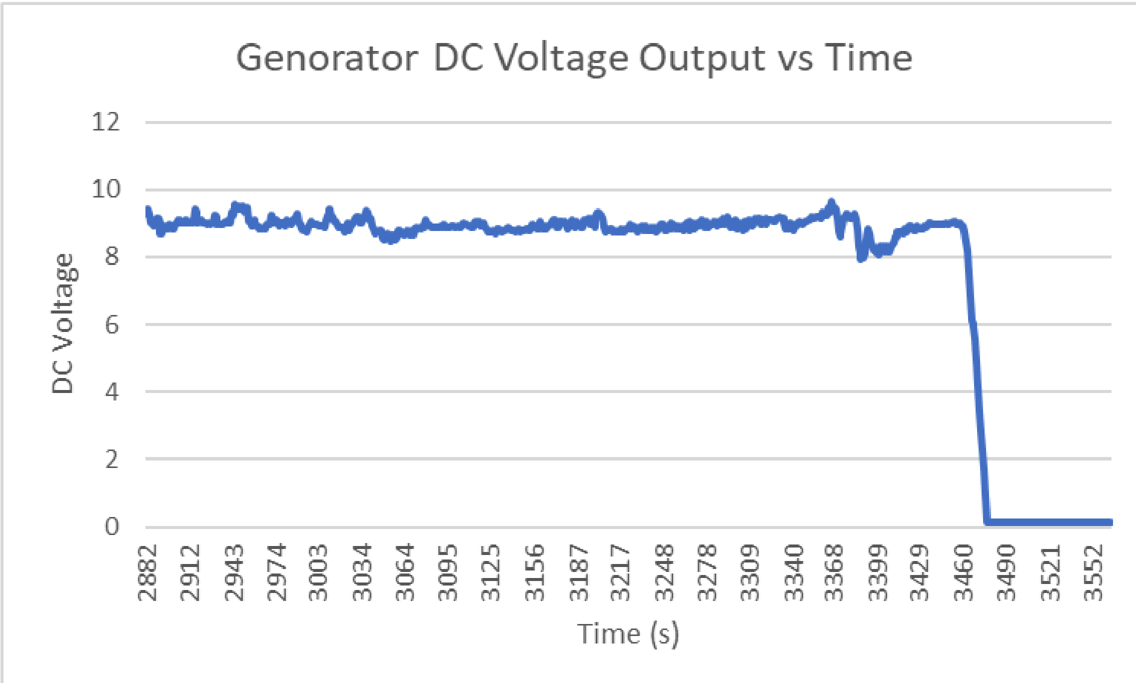
Turbine Inlet/Outlet Temperature vs. Time



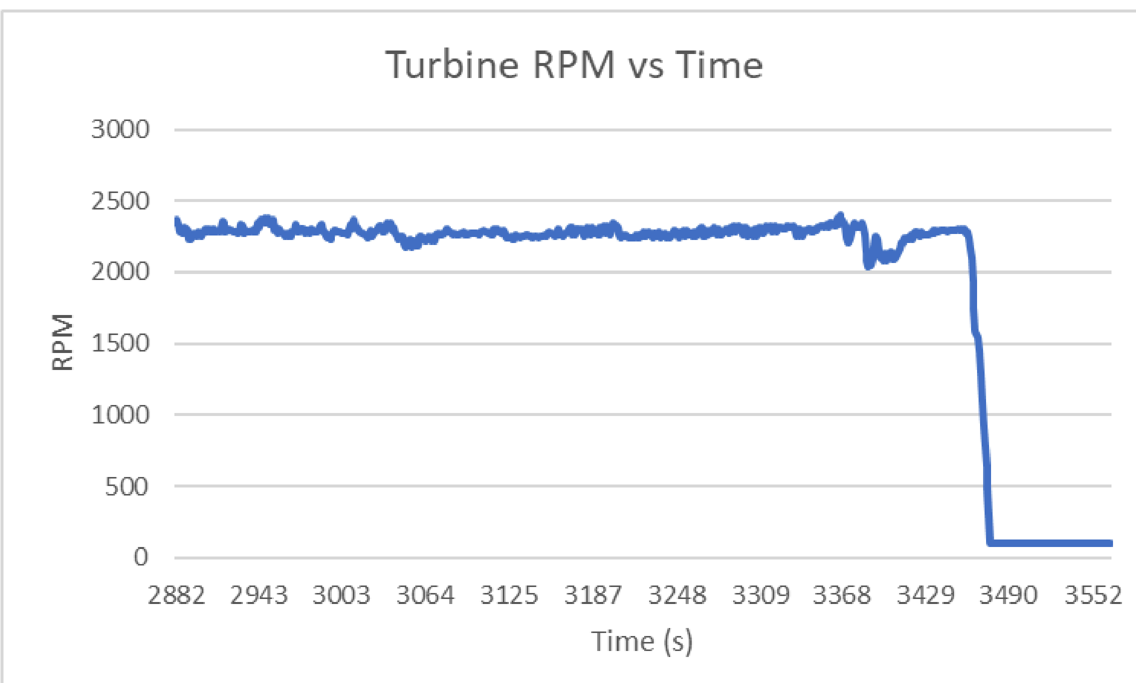
Generator DC Amps Output vs. Time



Generator DC Voltage Output vs. Time



Turbine RPM vs. Time



	State	Enthalpy
Boiler	Superheated Vapor	1195.7
Turbine Inlet	liquid	217.25
Turbine Outlet	liquid	189.92
Condenser Inlet	liquid	189.92
Condenser Outlet	liquid	180.16

Sample Calculations

Part 1:

Determining the state

$T_{1,avg} = 178^{\circ}C = 352.5^{\circ}F$

$P_{1,avg} = 117\,psig + 14.7psi = 132\,psia$

Using Table A-5E

$T_{sat@132psia} \approx 350^{\circ}F < T_{1,avg}$ Therefore state on is a superheated vapor

$$h_{@352.5^{\circ}F,\,120\,psia} = 1190.8\frac{Btu}{lbm} + (352.5^{\circ}F - 341.25^{\circ}F)\frac{(1202.1\frac{Btu}{lbm} - 1190.8\frac{Btu}{lbm})}{(360^{\circ}F - 341.25^{\circ}F)} = 1197.58\frac{Btu}{lbm}$$

$$h_{@352.5^{\circ}F,\,140\,psia} = 1193.4\frac{Btu}{lbm} + (352.5^{\circ}F - 353.03^{\circ}F)\frac{(1197.8\frac{Btu}{lbm} - 1193.4\frac{Btu}{lbm})}{(360^{\circ}F - 353.03^{\circ}F)} = 1193.07\frac{Btu}{lbm}$$

$$h_1 = 1197.58\frac{Btu}{lbm} + (132\,psia - 120\,psia)\frac{(1193.07\frac{Btu}{lbm} - 1197.58\frac{Btu}{lbm})}{(140\,psia - 120\,psia)} = 1195.7\frac{Btu}{lbm}$$

Part 2

a)

$$V_{max,\,Boiler} = V_{Main\,shell,\,internal} - V_{Flame\,tubes} = 8403cm^3 - 1865cm^3 = 6538cm^3$$

$$V_{main\ shell,\ internal} = \frac{\pi D_i^2}{4} \times L_i = \frac{\pi(19.42cm)^2}{4} \times 28.37cm = 8403cm^3$$

$$V_{Flame\ tubes} = \frac{\pi L_i}{4}(d_{o,main}^2 + 16d_{o,return}^2) = \frac{\pi 28.42cm}{4}((5.08cm)^2 + 16(1.90cm)^2) = 1865cm^3$$

$$D_i = D_o - 2W = 20.70cm - 2(0.64cm) = 19.42cm$$

$$L_i = L_e - 2W = 29.65cm + 2(0.64cm) = 28.37cm$$

$$\%\ of\ volume\ initially\ filled\ with\ water = \frac{5500}{V_{max}} \times 100 = \frac{5500}{6538cm^3} \times 100 = 84.1\%$$

b) Mass flow rate of steam in lbm/hr:

$$\mathring{m}_{steam} = \frac{mass\ of\ water\ used\ in\ run\ (lbm)}{time\ of\ run\ (hr)} = \frac{12.1254lbm}{0.16hr} = 76\frac{lbm}{hr}$$

c) Heat flow rate of steam leaving the boiler in Btu/hr

$$\mathring{Q}_{Boiler} = \mathring{m}_{steam} \times h_1 = 76\frac{lbm}{hr} \times 1195.7\frac{Btu}{lbm} = 90873\frac{Btu}{hr}$$

Heat supplied by the LP gas:

$$\mathring{Q}_{supplied\ by\ propane} = \mathring{V}_{fuel} \times LHV = 5.55\frac{ft^3}{hr} \times 2520\frac{Btu}{ft^3} = 13986\frac{Btu}{hr}$$

a) Turbine work output in Btu/hr:

$$\mathring{W}_{Turbine} = \mathring{m}_{steam}(h_2 - h_3) = 76\frac{Btu}{hr} \times (217.25\frac{Btu}{hr} - 189.92\frac{Btu}{hr}) = 2077.1\frac{Btu}{hr}$$

b) Turbine efficiency

$$\eta_{turbine} = \frac{w_{actual}}{W_{ideal}} \times 100 = (\frac{h_2 - h_3}{h_2 - h_{3s}}) \times 100$$

c) Rankine Cycle efficiency

$$\eta_{th,Rankine} = \frac{\mathring{W}_{Turbine}}{\mathring{Q}_{supplied}} \times 100 = \frac{2077.1\frac{Btu}{hr}}{13986\frac{Btu}{hr}}(100) = 14.85\%$$

d) Efficiency of electric generator

$$\eta_{Generator} = \frac{W^{\circ}_{Generator}}{W^{\circ}_{Turbine}} \times 100 = \frac{8.44\frac{Btu}{hr}}{2077.1\frac{Btu}{hr}} \times 100 = 0.41\%$$

Condenser:

Condenser's efficiency:

$$\eta_{condenser} = \frac{mass\ of\ condensate}{total\ mass\ of\ water\ used\ in\ experiment} \times 100 = \frac{526g}{5500g} \times 100 = 9.56\%$$

Rate of heat removed from the condenser:

$$Q^{\circ}_{Removed,condenser} = m^{\circ}_{steam}(h_4 - h_5) = 76\frac{lbm}{hr}(189.92\frac{Btu}{hr} - 180.16\frac{Btu}{hr}) = 742\frac{Btu}{hr}$$

Rankine Cycler:

$$\eta_{overall} = \frac{w^{\circ}_{Generator}}{Q^{\circ}_{supplied\ by\ propane}} \times 100 = \frac{8.44\frac{Btu}{hr}}{13986\frac{Btu}{hr}} \times 100 = 0.06\%$$

$$Hate\ Rate = \frac{3412}{\eta_{overall}} = \frac{3412}{0.0006} = 5654052Btu$$

Discussion and Analysis of Results

For this experiment, we gathered data from a working Rankine cycle steam turbine power system. Data was measured for the pressure in the boiler, turbine inlet, and turbine exit, also temperature of the boiler, turbine inlet, and exit. The thermal efficiency of this cycle was 14.85% which is a bit low but not too bad. The efficiency of the condenser wasn't too bad either at 9.56% and the turbine efficiency is not able to be found. This experiment was conducted only one time, which doesn't allow for a separation between human and mechanical errors. This experiment was also conducted in an open cycle instead of a closed loop. The system is open since there is no inlet flow into the boiler and there is also no pump to send the condensed liquid from the condenser back to the boiler.

Conclusion and Recommendations

In conclusion, this is a fairly successful experiment considering that the overall result yields a realistic efficiency of the components and the whole Rankine cycle in general.The combination of experimental procedures and in-depth calculation/analysis of the acquired data provide clear demonstration of the steam power plant operation.Furthermore, the students can acquire more knowledge on the difference between the ideal and actual Rankine cycle. Moreover, the calculated heat transfer,heat flow rate, heat loss in components also assisted the overall theory. However, the system has some underlying issues and minor errors involving heat loss, the energy is escape/ not condense enough, incomplete vaporization, and the potential of the uncertainty of the overall model. In overall, it is important to carefully operate, conducting precise measurement, and having proper maintenance for the steam power plant components(boiling chamber, condenser, turbines, and generator). There is still room for improvement including implementing good lab protocols and proper maintenance.

References

Çengel, Yunus A. Thermodynamics : an Engineering Approach. Boston :McGraw-Hill Higher Education, 2008.

Member's Contribution

Hung Ngo: Abstract, Introduction, Procedures, Conclusion and Recommendations

Paul Yousefian: Data and results, Sample Calculations

Ricardo Jimenez: Discussion and Analysis of Results