



RankineCycler™

Steam Turbine Power System

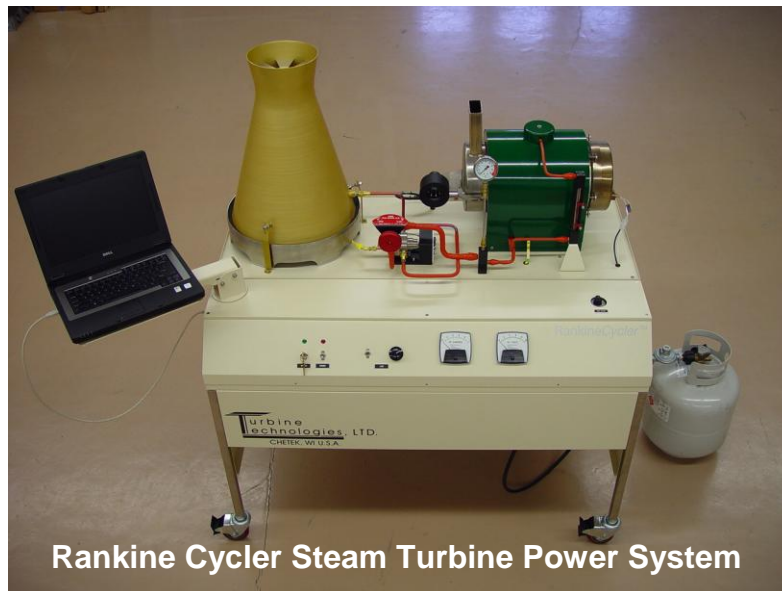
Sample Lab Experiment Procedure

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Rankine Cyclor™ Lab Experiment Manual

Lab Session #1: System Overview and Component Identification

Purpose: To gain an understanding of the Rankine Cyclor System as a whole and details of each component making up the system. This will prepare you for the next lab session in which you will operate the system.



Liquid Propane (L.P.) Cylinder
Fuel used to power boiler



Steam Generation Boiler
A dual-pass, flame tube system.
If system is cool, open boiler door to reveal boiler construction and flame tube layout. Also note burner fan and tube mounted in door.



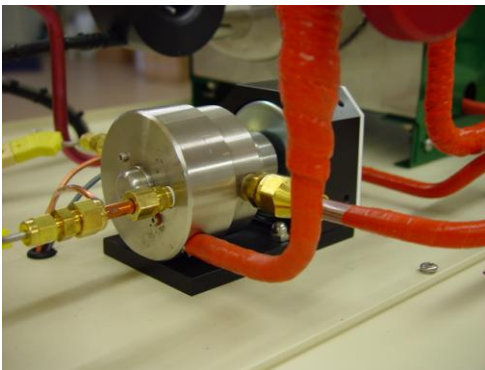
Boiler Sight Gage

Indicates Water Level in Boiler
Equipped with two adjustable
position bezels for marking boiler
water levels of interest during
operation.



Steam Admission Valve

Controls Steam Flow into Turbine

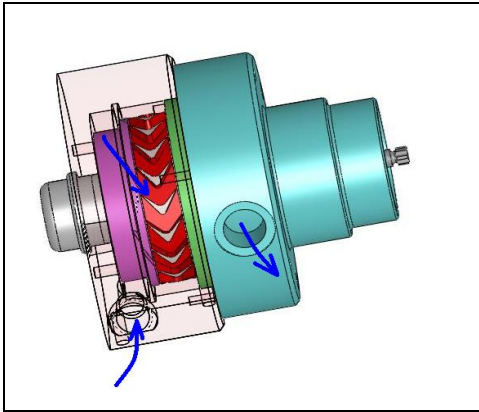


Steam Turbine

Impulse Micro Steam Turbine driven by
steam flow



**Impulse Steam Turbine Wheel / Housing
Detail View**



Steam Turbine CAD Cutaway

1. Steam enters inlet port.
2. Steam flow forced through slits in stator ring (purple), impinging on turbine blades, spinning turbine wheel (red).
3. Steam exits turbine to condenser.



Four Pole AC/DC Electrical Generator Driven by turbine to generate electricity.



Condenser Tower

Unit condenses turbine waste steam back to liquid. In a full-scale plant, condensate would be reclaimed and pumped back to boiler. Ultra small scale of Rankine Cycler makes returning condensate impractical.



Data Acquisition Computer

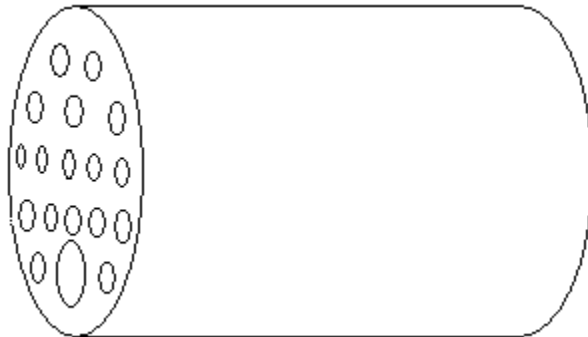
Connects to unit's data acquisition system via USB port. Displays and captures data for operation and analysis.

In preparation for system operation and data analysis, answer the following questions:

- 1.) Liquid Propane (LP) is vaporized and used as boiler burner fuel. What is the energy content per unit volume of gaseous LP?

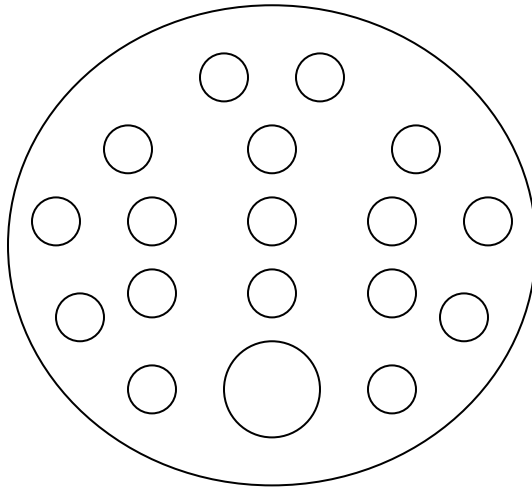
- 2.) If system flow meter measures gaseous LP flow at 6 liters/min to boiler burner, what is steady state energy consumption per hour?

- 3.) The boiler is shell and tube style construction. Calculate the available volume for water in the boiler given the basic construction dimensions.



Main Shell External Length = 29.85 cm
Main Shell Wall Thickness = 0.198 cm
End Plate Outside Diameter = 20.32 cm
End Plate wall thickness = 0.318 cm
Main Flame Tube Outside Diameter = 5.08 cm
17 Return Pass Flame Tubes Outside Diameter = 1.90 cm

Locate the water level in the boiler if it is filled with 6000 ml of water.
(Sketch location)



Will there be space unoccupied by water?

If so, how much volume?

Will any of the flame tubes not be covered by water?
If so, what is the significance of this?

Number?

Barometric Pressure

What is the present barometric pressure in your area?

Why would barometric pressure be important when planning to operate the Rankine Cyclor?

What will be your reliable source for accurate barometric pressure readings?

Rankine Cyclor™ Lab Experiment Manual

Lab Session #2: System Operation

Purpose: Conduct start-up, operation, data gathering and shut down of Rankine Cyclor Steam Turbine Power System.

Procedure:

Utilize Rankine Cyclor™ Operators Manual and follow **Section 4.2 Expanded Normal Procedures** to perform system start-up, operation, data acquisition and shut down.

Utilize the data acquisition system to capture the operational values from startup to shut down (covered in Section 4.2.3 Data Collection).

Be sure to record the following data during the run:

Steady State Start Time: _____

Steady State Stop Time: _____

Initial Boiler Fill Amount: _____

Amount of Steady State Run Boiler Water Replaced: _____

Amount of Condensate Collected from Condenser: _____

Rankine Cyclers™ Lab Experiment Manual

Lab Session #3: Rankine Cyclers Data Run Plots

Purpose: Graphically plot Rankine Cyclers Run Data in preparation for system analysis and performance calculations to be conducted in Lab #4.

Procedure: Follow the instructions starting on page 2 of this lab procedure to plot system run data.

Plot the following, utilizing MS-Excel Spreadsheet Program:

- 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

Print out plots and order them as listed.

Mark the steady state start and stop window on each plot.

Choose and mark an analysis point at a specific time somewhere within the steady state window. This will be the basis for your steady state, steady flow system performance analysis calculations.

From your plots (specific time mark) and data collected from system run, please record the following:

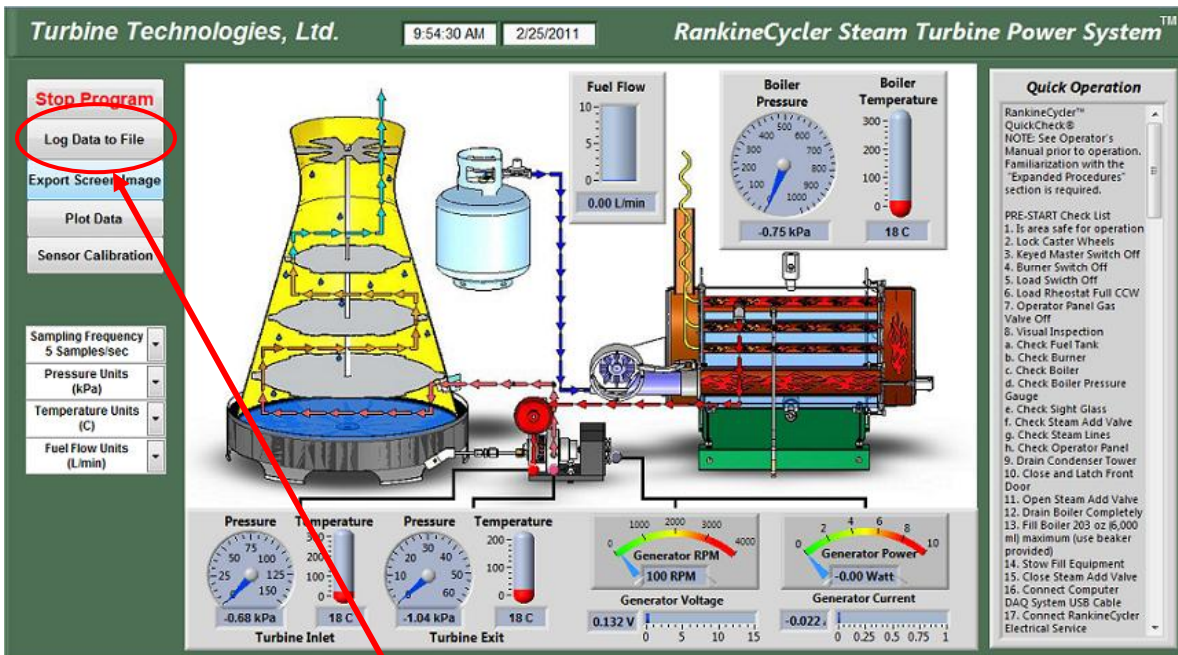
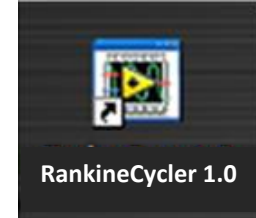
Atmospheric Pressure _____
Initial Boiler Fill Amount _____
Fuel Flow _____
Boiler Pressure _____
Boiler Temperature _____
Turbine Inlet Pressure _____
Turbine Inlet Temperature _____
Turbine Outlet Pressure _____
Turbine Outlet Temperature _____
Steady State Condensate Amount _____
Steady State Boiler Water Use _____

DATA ACQUISITION (See Operators Manual, Section 4.2.5 for more details).

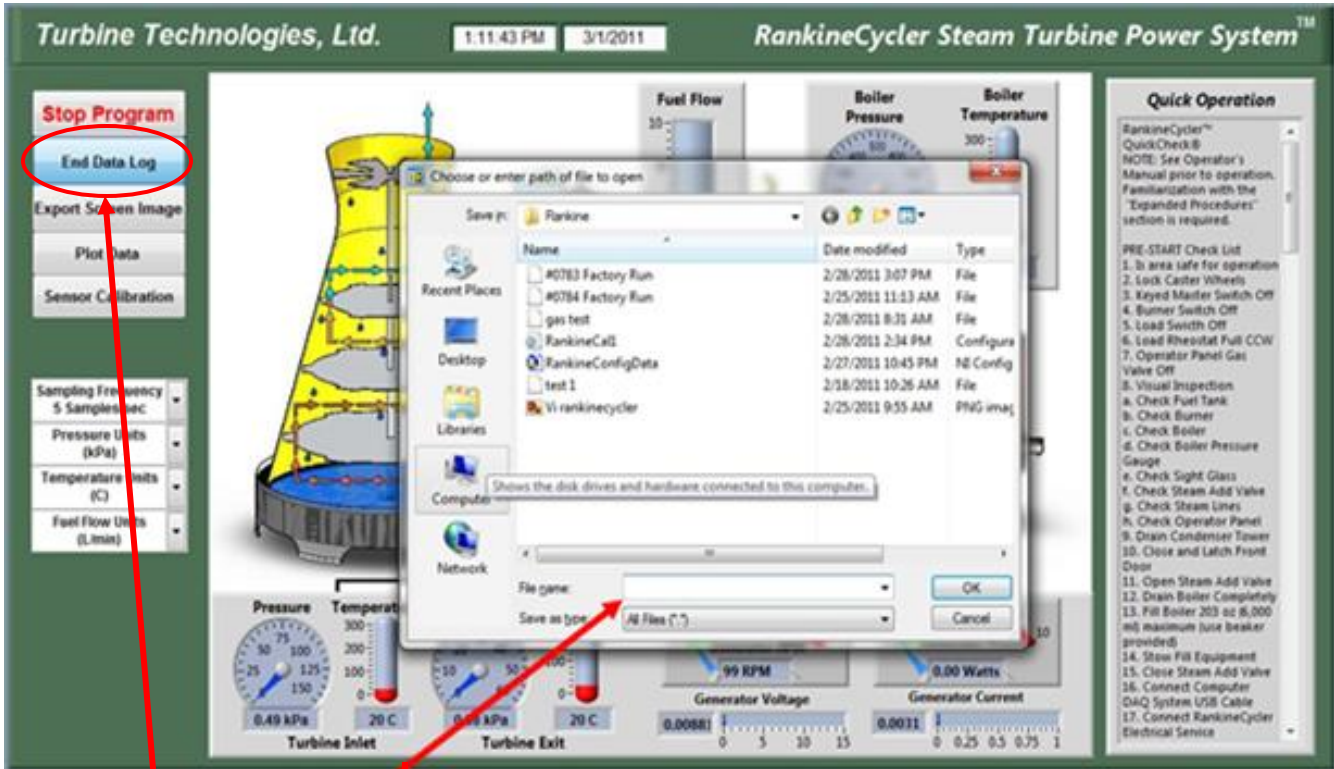
Recording and using your data properly is an important part of successfully completing the lab.

Operation of Lab Unit

From Windows, OPEN the RankineCycler Software by double-clicking on the RankineCycler 1.0 shortcut icon located on the Windows Desktop. RankineCycler 1.0 will start with the *Main Display/Control* and *Channel Configuration Window* displayed.



To start logging data, press **Log Data to File** Button



- Enter a **File Name** where indicated, then click OK and the dialogue box will close. The program will send data to this file.
- To stop saving data, click **End Data Log** button.
- To retrieve the data file;
 1. click on **My Computer**
 2. select the **C Drive**
 3. select **Users** folder
 4. select **Public Documents**
 5. select **Rankine**
 6. select **File Name** you had chosen.
- When importing the file into a spreadsheet program for analysis, you may have to look under **All Files**.

Importing Acquisition Data into MS-Excel Spreadsheet

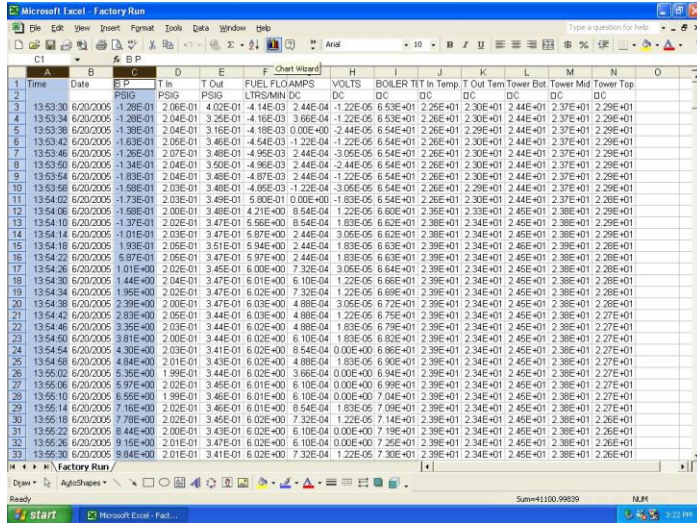
A convenient way to analyze RankineCycler performance data is to graph the data points using MS-Excel Spreadsheet. To do this, the ASCII data captured during the lab data acquisition must be imported into Excel.

- Open: MS-Excel on computer desktop**
- Click: File**
- Click: Open**
- Click: C-Drive**
- Click: Users\Public\Public Documents\Rankine**
- Click: "All Files" under "Files of Type"**
- Select: The File Name You Assigned in "Log Data to File"**
- Click: Next (In Text Import Window, Step 1 of 3)**
- Click: Next (In Text Import Window, Step 2 of 3)**
- Click: Finish (In Text Import Window, Step 3 of 3)**

Your data will now be in spreadsheet form.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Time	Date	BP	T IN P	T OUT P	BT	T IN T	T OUT T	DC - A	DC - Y	Fuel Flow	Turbine		
2			PSIG	PSIG	PSIG	OC	OC	OC	AMPS	VOLTS	LTRS/MIN	Turbine		
3	10:24:41	9/10/2004	1.16E+02	9.23E+00	4.59E+00	1.75E+02	1.13E+02	1.20E+02	2.04E-01	6.01E+00	7.02E+00	2.01E+03		
4	10:24:46	9/10/2004	1.16E+02	9.23E+00	4.59E+00	1.75E+02	1.13E+02	1.20E+02	2.06E-01	6.06E+00	7.01E+00	2.02E+03		
5	10:24:49	9/10/2004	1.16E+02	9.23E+00	4.59E+00	1.75E+02	1.13E+02	1.21E+02	2.06E-01	6.07E+00	7.01E+00	2.03E+03		
6	10:24:53	9/10/2004	1.16E+02	9.23E+00	4.59E+00	1.75E+02	1.13E+02	1.21E+02	2.05E-01	6.04E+00	7.00E+00	2.03E+03		
7	10:24:57	9/10/2004	1.16E+02	9.23E+00	4.59E+00	1.75E+02	1.13E+02	1.21E+02	2.04E-01	6.02E+00	7.01E+00	2.02E+03		
8	10:25:01	9/10/2004	1.16E+02	9.23E+00	4.59E+00	1.75E+02	1.13E+02	1.21E+02	2.04E-01	5.99E+00	7.01E+00	2.01E+03		
9	10:25:06	9/10/2004	1.16E+02	9.24E+00	4.59E+00	1.75E+02	1.13E+02	1.21E+02	2.03E-01	6.00E+00	7.02E+00	2.01E+03		
10	10:25:09	9/10/2004	1.16E+02	9.24E+00	4.59E+00	1.75E+02	1.13E+02	1.22E+02	2.06E-01	6.06E+00	7.01E+00	2.03E+03		
11	10:25:13	9/10/2004	1.15E+02	9.24E+00	4.59E+00	1.75E+02	1.13E+02	1.22E+02	2.05E-01	6.05E+00	6.99E+00	2.02E+03		
12	10:25:17	9/10/2004	1.15E+02	9.24E+00	4.59E+00	1.75E+02	1.13E+02	1.22E+02	2.04E-01	6.01E+00	6.99E+00	2.02E+03		
13	10:25:21	9/10/2004	1.16E+02	9.21E+00	4.59E+00	1.75E+02	1.13E+02	1.22E+02	2.00E-01	5.88E+00	6.97E+00	1.97E+03		
14	10:25:25	9/10/2004	1.15E+02	9.14E+00	4.55E+00	1.75E+02	1.13E+02	1.22E+02	1.98E-01	5.81E+00	6.96E+00	1.96E+03		
15	10:25:29	9/10/2004	1.15E+02	9.12E+00	4.54E+00	1.75E+02	1.13E+02	1.22E+02	1.98E-01	5.82E+00	7.00E+00	1.96E+03		
16	10:25:33	9/10/2004	1.15E+02	9.11E+00	4.54E+00	1.75E+02	1.13E+02	1.22E+02	1.99E-01	5.85E+00	6.99E+00	1.97E+03		
17	10:25:37	9/10/2004	1.15E+02	9.10E+00	4.53E+00	1.75E+02	1.13E+02	1.23E+02	1.97E-01	5.81E+00	7.00E+00	1.96E+03		
18	10:25:41	9/10/2004	1.15E+02	9.10E+00	4.53E+00	1.75E+02	1.13E+02	1.23E+02	1.97E-01	5.81E+00	7.00E+00	1.96E+03		
19	10:25:45	9/10/2004	1.15E+02	9.09E+00	4.52E+00	1.75E+02	1.13E+02	1.23E+02	1.97E-01	5.80E+00	7.01E+00	1.96E+03		
20	10:25:49	9/10/2004	1.15E+02	9.09E+00	4.52E+00	1.75E+02	1.13E+02	1.23E+02	1.97E-01	5.80E+00	7.02E+00	1.96E+03		
21	10:25:53	9/10/2004	1.15E+02	9.09E+00	4.52E+00	1.75E+02	1.13E+02	1.23E+02	1.97E-01	5.79E+00	7.02E+00	1.96E+03		
22	10:25:57	9/10/2004	1.15E+02	9.08E+00	4.52E+00	1.75E+02	1.13E+02	1.23E+02	1.96E-01	5.76E+00	7.01E+00	1.96E+03		
23	10:26:01	9/10/2004	1.15E+02	9.08E+00	4.51E+00	1.75E+02	1.13E+02	1.24E+02	1.96E-01	5.79E+00	6.99E+00	1.96E+03		
24	10:26:06	9/10/2004	1.15E+02	9.08E+00	4.51E+00	1.75E+02	1.13E+02	1.24E+02	1.97E-01	5.80E+00	6.97E+00	1.96E+03		
25	10:26:09	9/10/2004	1.15E+02	9.07E+00	4.51E+00	1.75E+02	1.13E+02	1.24E+02	1.97E-01	5.81E+00	6.98E+00	1.97E+03		
26	10:26:13	9/10/2004	1.15E+02	9.07E+00	4.51E+00	1.75E+02	1.13E+02	1.24E+02	1.98E-01	5.82E+00	7.00E+00	1.97E+03		
27	10:26:17	9/10/2004	1.15E+02	9.07E+00	4.51E+00	1.75E+02	1.13E+02	1.24E+02	1.97E-01	5.82E+00	7.01E+00	1.97E+03		
28	10:26:21	9/10/2004	1.15E+02	9.07E+00	4.50E+00	1.75E+02	1.13E+02	1.24E+02	1.97E-01	5.82E+00	7.00E+00	1.97E+03		
29	10:26:26	9/10/2004	1.15E+02	9.07E+00	4.50E+00	1.75E+02	1.13E+02	1.25E+02	1.97E-01	5.82E+00	7.01E+00	1.97E+03		
30	10:26:29	9/10/2004	1.15E+02	9.06E+00	4.50E+00	1.75E+02	1.13E+02	1.25E+02	1.91E-01	5.64E+00	7.01E+00	1.91E+03		
31	10:26:33	9/10/2004	1.15E+02	9.06E+00	4.50E+00	1.75E+02	1.13E+02	1.25E+02	1.78E-01	5.26E+00	7.02E+00	1.81E+03		
32	10:26:37	9/10/2004	1.16E+02	9.06E+00	4.49E+00	1.75E+02	1.12E+02	1.25E+02	1.72E-01	5.06E+00	7.02E+00	1.75E+03		
33	10:26:41	9/10/2004	1.15E+02	9.06E+00	4.49E+00	1.75E+02	1.13E+02	1.25E+02	1.69E-01	4.99E+00	7.02E+00	1.74E+03		

Graphing Data using MS-Excel Spreadsheet Graphing Function



Highlight columns of data desired for graph. For this example, the Time and BP column data will be plotted.

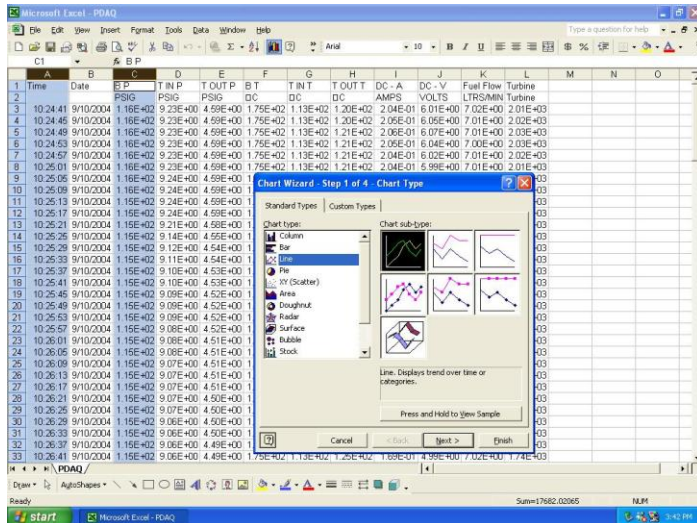
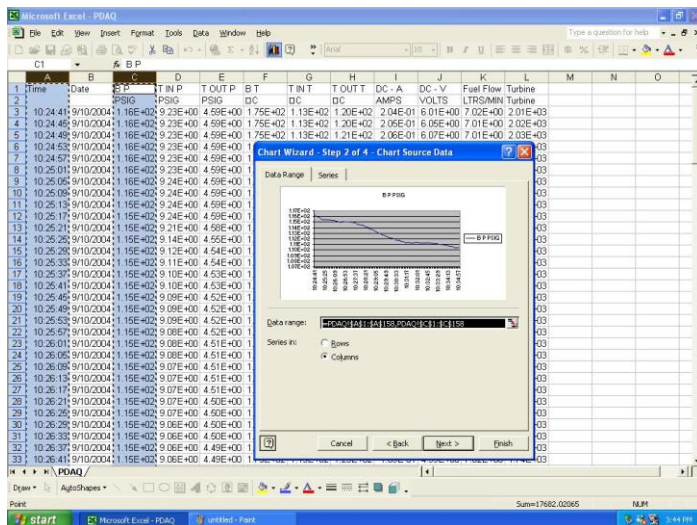
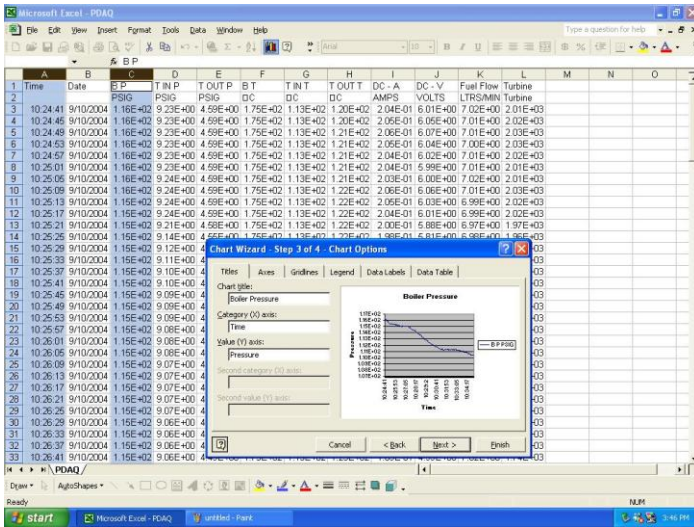


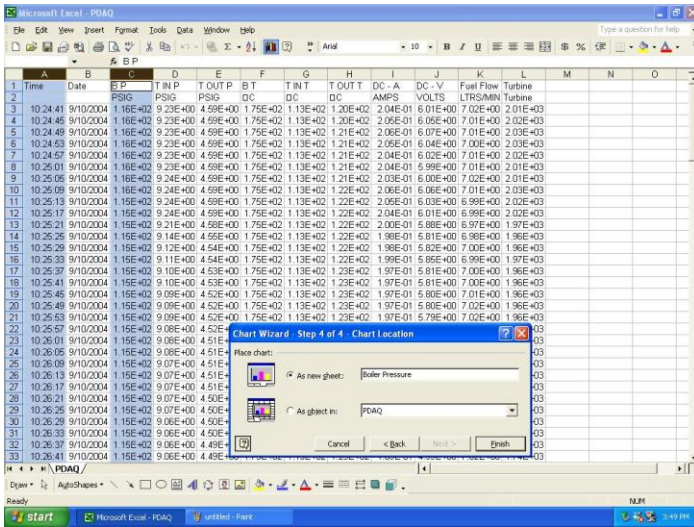
Chart Type: Line
Chart Sub Type: Line (first one)
Next



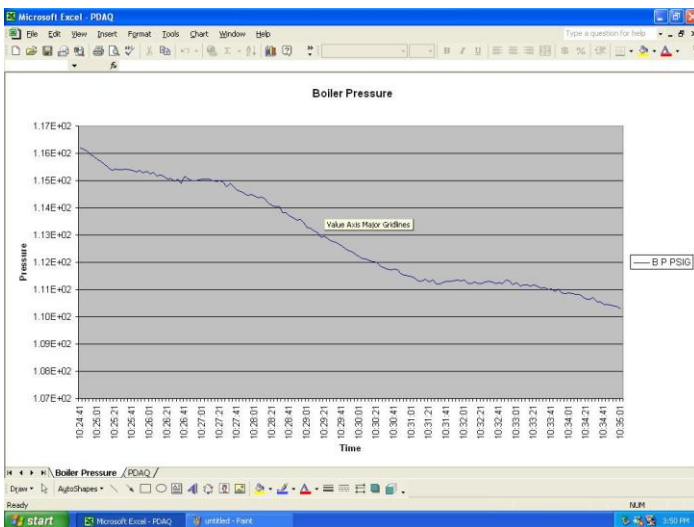
Accept data range listed by choosing: Next



Choose Graph Options and Labels



Name Graph, Click as New Sheet, Finish



Completed Boiler Pressure Graph

Rankine Cyclers™ Lab Experiment Manual

Lab Session #4: System Analysis

Purpose: To perform system performance calculations using First Law Energy Conservation Equation for Steady State, Steady Flow Conditions (**SSSF**). The data for these calculations come from the information plotted and recorded in Lab #3.

Procedure: Analyze each component listed and perform the calculation requested.

Boiler (SSSF)

Calculate heat flow out of boiler. How does this compare with measured LP gas flow to burner? *Assume: No condensate pumped back into boiler, Changes in Kinetic and Potential Energy are negligible.*

Turbine / Generator (SSSF)

Find the Work rate of the Turbine and Efficiency of Electric Generator

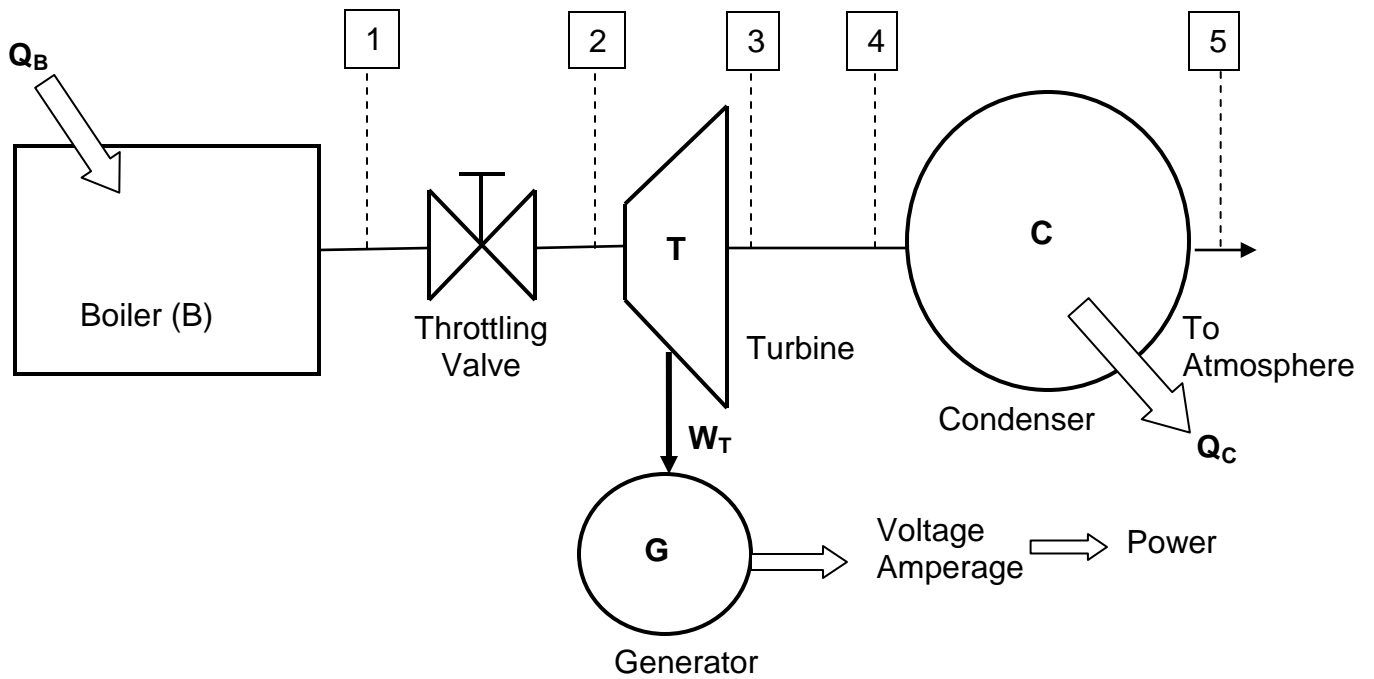
Condenser (SSSF)

What is the total heat flow rate out of the system at the condenser?
Assume changes in Potential and Kinetic Energy are negligible.

What is the Condenser Efficiency during SSSF?

Total System Efficiency (SSSF)

What is the electrical power output verses the fossil-fuel energy input?



System Mass Flow Rate (\dot{m})

Using Steam Tables, gather state data for each point of interest in the system:

1. **Boiler**

Measured $P_b =$
 Measured $T_b =$
 Table $v_b =$
 Table $h_b =$
 Table $u_b =$
 Table $s_b =$

2. **Turbine Inlet**

Measured $P_{T_{in}} =$
 Measured $T_{T_{in}} =$
 Table $v_{T_{in}} =$
 Table $h_{T_{in}} =$
 Table $u_{T_{in}} =$
 Table $s_{T_{in}} =$

3. **Turbine Outlet**

Measured $P_{T_{out}} =$
 Measured $T_{T_{out}} =$
 Table $v_{T_{out}} =$
 Table $h_{T_{out}} =$
 Table $u_{T_{out}} =$
 Table $s_{T_{out}} =$

4. **Condenser Inlet** (Use T_{out} Data)

Measured $P_{C_{in}} =$
 Measured $T_{C_{in}} =$
 Table $v_{C_{in}} =$
 Table $h_{C_{in}} =$
 Table $u_{C_{in}} =$
 Table $s_{C_{in}} =$

5. **Condenser Outlet** (to atmosphere)

Measured $P_{C_{out}} =$
 Measured $T_{C_{out}} =$
 Table $v_{C_{out}} =$
 Table $h_{C_{out}} =$
 Table $u_{C_{out}} =$
 Table $s_{C_{out}} =$