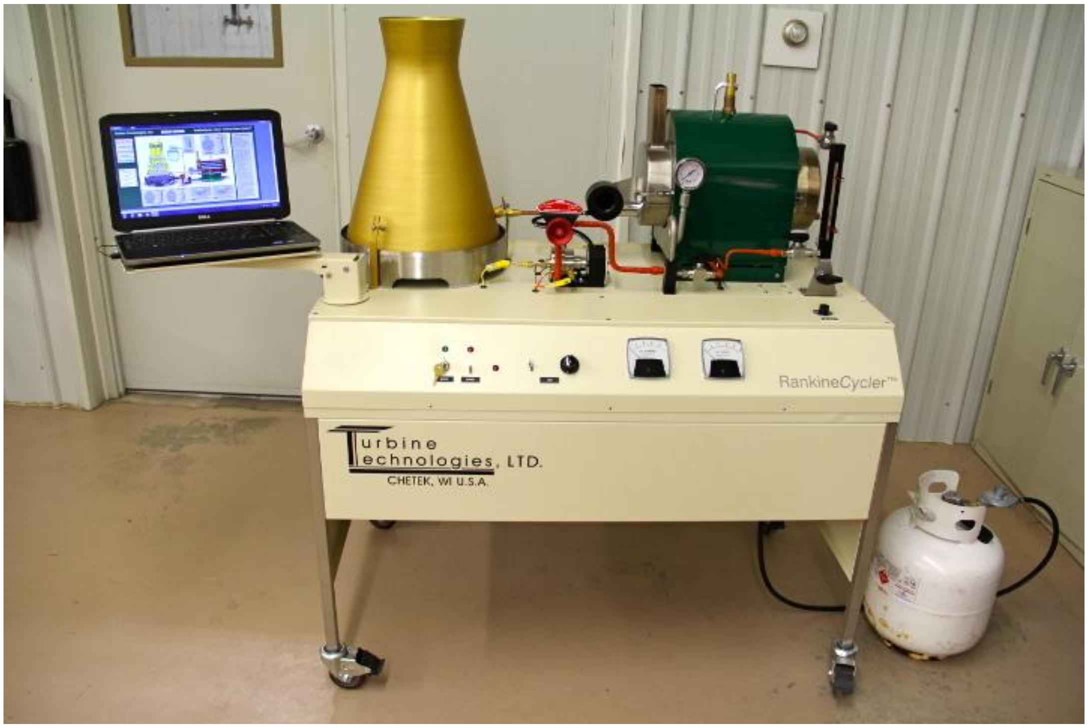


Rankine*Cycler*™

Steam Turbine Power System

Sample Lab Experiment Procedure

Rankine Cycler™ Lab Experiment Manual

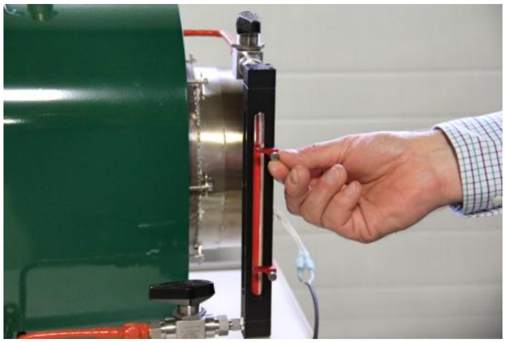
Lab Session #1: System Overview and Component Identification

Purpose: To gain an understanding of the Rankine Cycler 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.

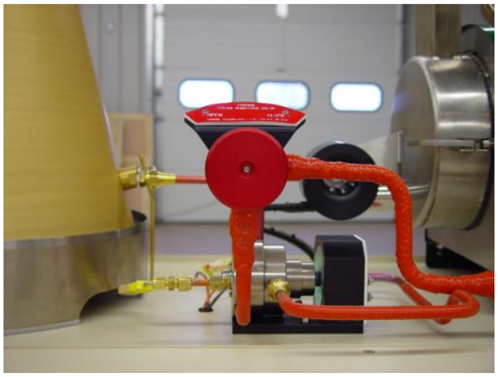
RankineCycler™ Steam Turbine Power System

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

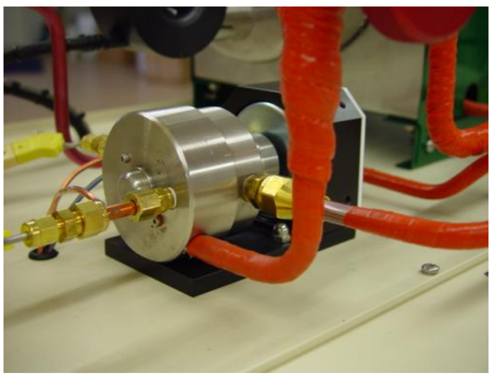
Steam Generation Boiler
A dual-pass, flame tube system.
If system is cool, open boiler door to reveal boiler construction and flame tube layout. Also note burner fan and tube mounted in door.



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

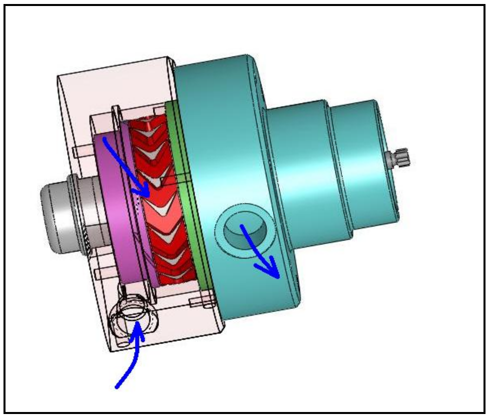


Steam Admission Valve
Controls Steam Flow into Turbine



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?

2,520 BTU/FT^3, 93,756 KJ/m^3

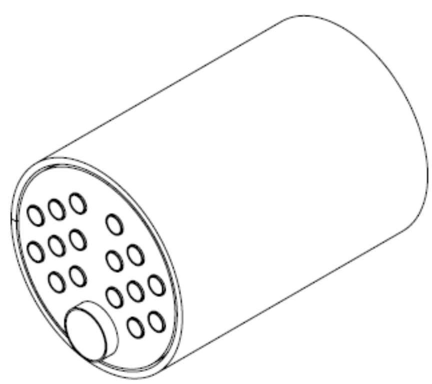
FROM PROPERTIES TABLE AT 60°F (15°C)

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

$$SI: \left(\frac{6\ell}{MIN}\right)\left(\frac{m^3}{1000\ell}\right)\left(\frac{93,756\ KJ}{m^3}\right)\left(\frac{60\ MIN}{HR}\right) = 33,752\ KJ/HR$$

$$US: \left(\frac{6\ell}{MIN}\right)\left(\frac{FT3}{28.32\ell}\right)\left(\frac{2,520\ BTU}{FT3}\right)\left(\frac{60\ MIN}{HR}\right) = 32,033\ BTU/HR$$

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 = 29.65 cm
Main Shell Wall Thickness = 0.64 cm
End Plate Outside Diameter = 20.70 cm
End Plate wall thickness = 0.64 cm
Main Flame Tube Outside Diameter = 5.08 cm
17 Return Pass Flame Tubes Outside Diameter = 1.90 cm

<u>GROSS INTERNAL VOLUME OF BOILER</u>

$$\pi r^2 L = \pi \left(\frac{20.70\,cm - 2(0.64\,cm)}{2}\right)^2 (29.65\,cm - 2(0.64\,cm)) = 8,403\ cm^3$$

<u>VOLUME OF FLAME TUBES</u>

$$LARGE: \pi r^2 L\ (1\ TUBE) = \pi\left(\frac{5.08}{2}\right)^2 (28.37)(1) = 575\ cm^3$$

$$SMALL: \pi r^2 L\ (17\ TUBES) = \pi\left(\frac{1.9}{2}\right)^2 (28.37)(17) = 1,367\ cm^3$$

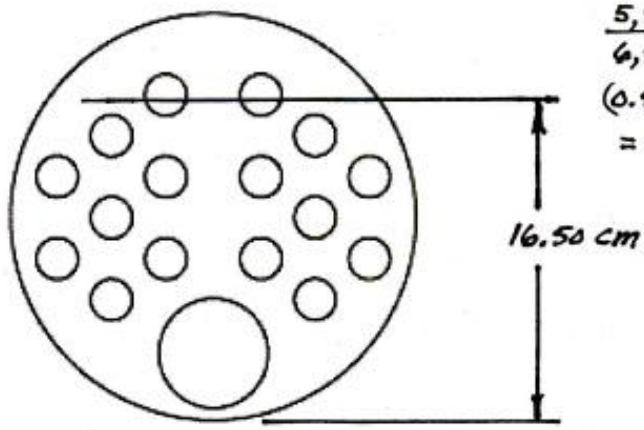
NET INTERNAL VOLUME: $8,403 - (575 + 1367) = 6,460\ cm^3 =$ <u>6,460 ml</u>

Locate the water level in the boiler if it is filled with 5,500 ml of water.
(Sketch location)

6,460 - 5,500 = 960 ml

$\frac{5,500}{6,460} = 0.85$

(0.85)(19.42 cm I.D.)
= 16.50 cm



Will there be space unoccupied by water? YES

If so, how much volume? 960 ml

Will any of the flame tubes not be covered by water? YES Number? 2
If so, what is the significance of this?

THESE TUBES SUPPLY HEAT DIRECTLY TO STEAM ACCUMULATION IN THE SPACE, RAISING THE STEAM QUALITY INTO THE SUPERHEAT REGION.

Barometric Pressure

What is the present barometric pressure in your area?
TODAY IT IS 30.02 IN HG = 0.101373 MPa = 14.7 PSI

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

ALL PRESSURE READINGS ARE GAGE PRESSURE. THERMODYNAMIC PROPERTY TABLE INFORMATION IS BASED ON ABSOLUTE PRESSURE: $P_{ABS} = P_{ATM} + P_{GAGE}$

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

ONE SOURCE IS: WWW. WUNDERGROUND. com
CHECK UNDER "CURRENT CONDITIONS"

Rankine Cycler™ Lab Experiment Manual

Lab Session #2: System Operation

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

Procedure:
Utilize Rankine Cycler™ 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: 9:06 AM

Steady State Stop Time: 9:16 AM

Initial Boiler Fill Amount: 5,500 ml

Amount of Steady State Run Boiler Water Replaced: 2,115 ml

Amount of Condensate Collected from Condenser: 400 ml

Rankine Cycler[TM] Lab Experiment Manual

Lab Session #3: Rankine Cycler Data Run Plots

Purpose: Graphically plot Rankine Cycler 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:

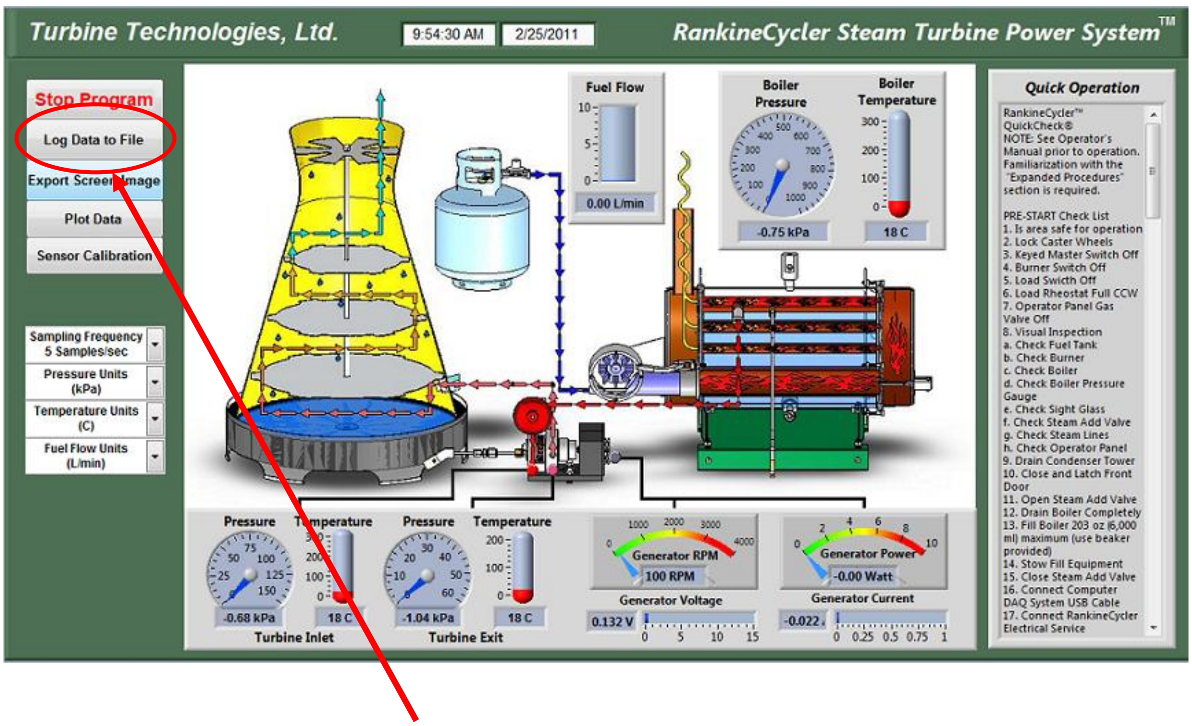
Atmospheric Pressure 14.7 PSI
Initial Boiler Fill Amount 5,500 ml
Fuel Flow 6.25 ℓ/min
Boiler Pressure 126.7 PSIA
Boiler Temperature 175 °C
Turbine Inlet Pressure 24.7 PSIA
Turbine Inlet Temperature 157 °C
Turbine Outlet Pressure 19 PSIA
Turbine Outlet Temperature 133 °C
Steady State Condensate Amount 400 ml
Steady State Boiler Water Use 2115 ml

<u>DATA ACQUISITION</u> (See Operators Manual, Section 4.2.5 for more details).

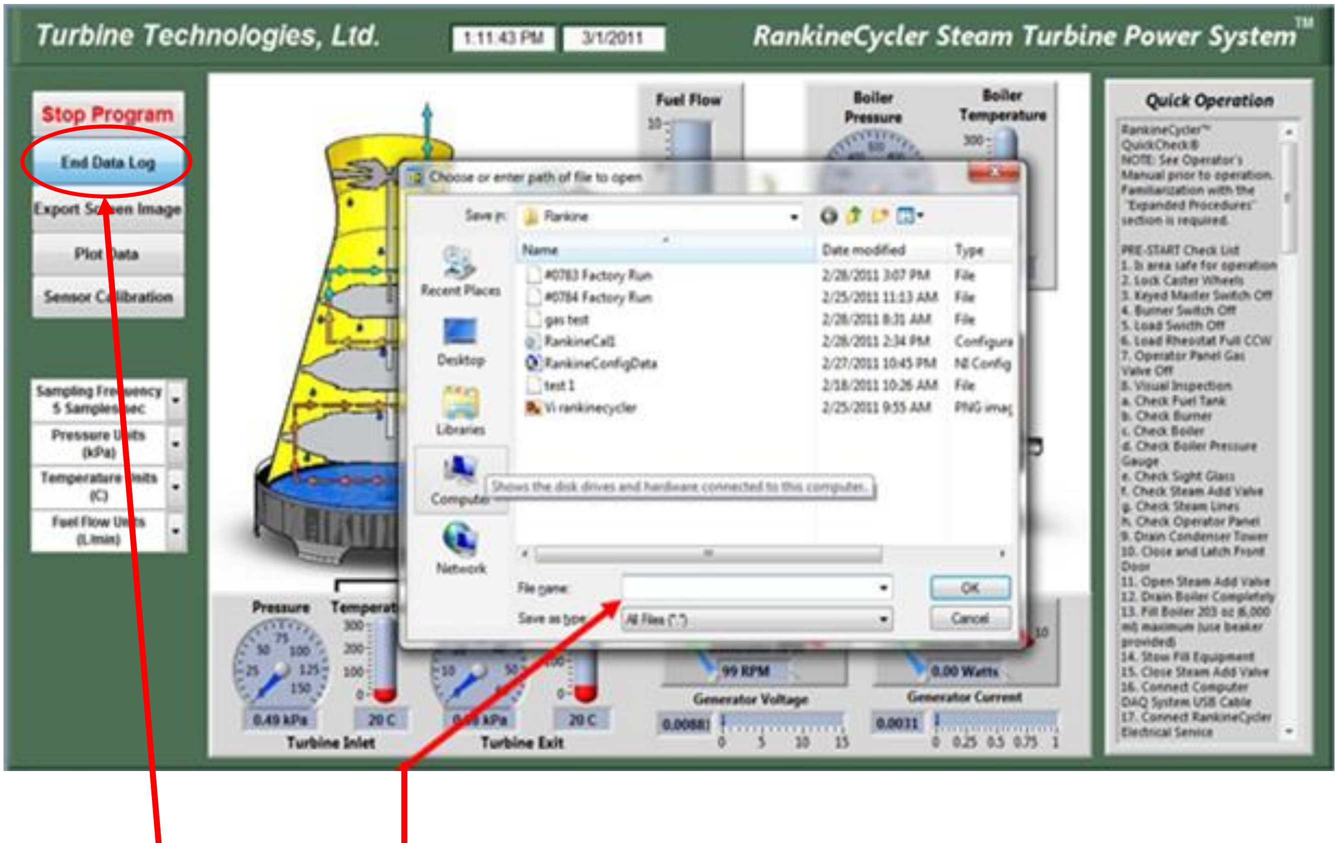
Recording and using your data properly is an important part of successfully completing the lab.

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



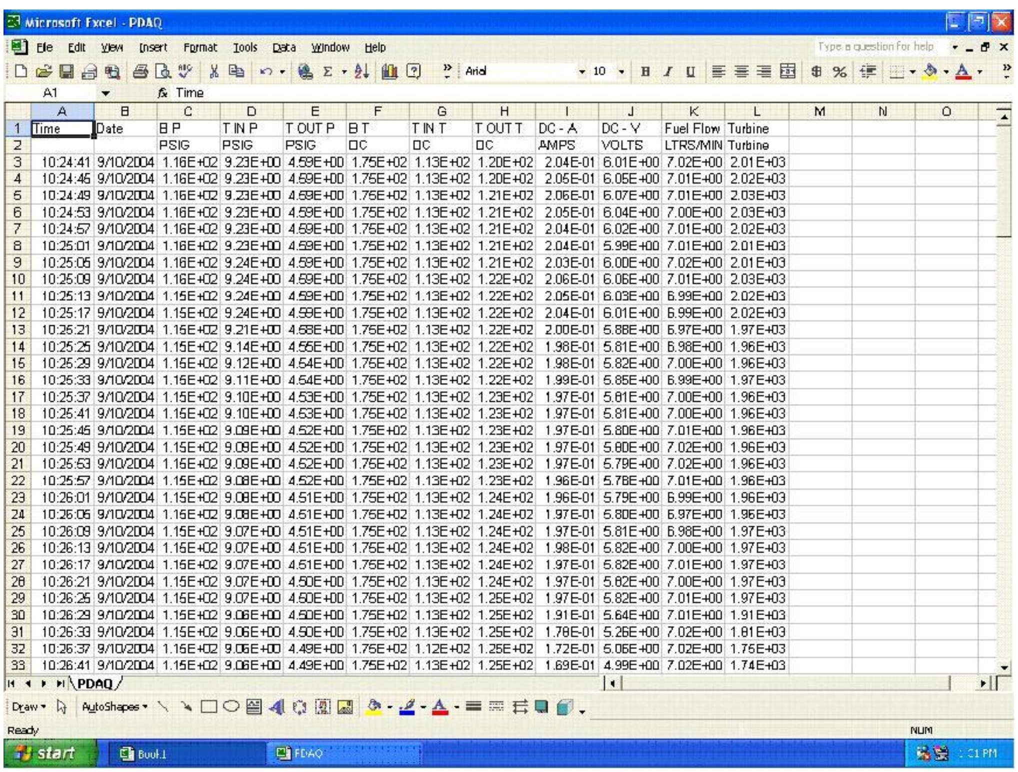
- Enter a **File Name** where indicated, then click OK and the dialogue box will close. The program will send data to this file.
- To stop saving data, click **End Data Log** button.
- To retrieve the data file;
  1. click on **My Computer**
  2. select the **C Drive**
  3. select **Users** folder
  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.

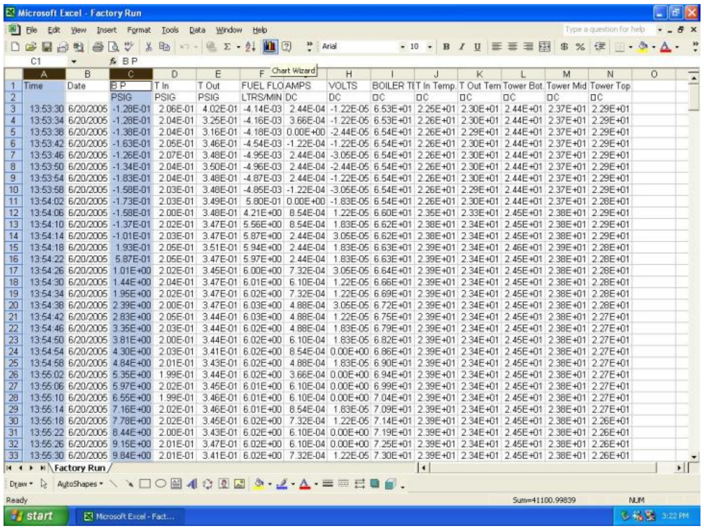
Open: MS-Excel on computer desktop
Click: File
Click: Open
Click: C-Drive
Click: Users\Public\Public Documents\Rankine
Click: “All Files” under “Files of Type”
Select: The File Name You Assigned in “Log Data to File”
Click: Next (In Text Import Window, Step 1 of 3)
Click: Next (In Text Import Window, 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
1	Time	Date	B P	T IN P	T OUT P	B T	T IN T	T OUT T	DC - A	DC - V	Fuel Flow	Turbine
2			PSIG	PSIG	PSIG	DC	DC	DC	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	10:24:45	9/10/2004	1.16E+02	9.23E+00	4.59E+00	1.75E+02	1.13E+02	1.20E+02	2.05E-01	6.05E+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	10:25:05	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	6.03E+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	1.15E+02	9.21E+00	4.58E+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	6.98E+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	5.78E+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	10:26:05	9/10/2004	1.16E+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	10:26:25	9/10/2004	1.16E+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.

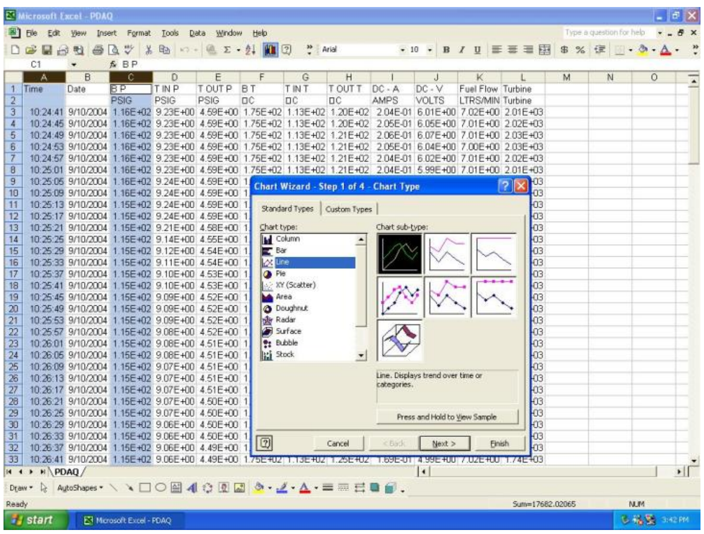
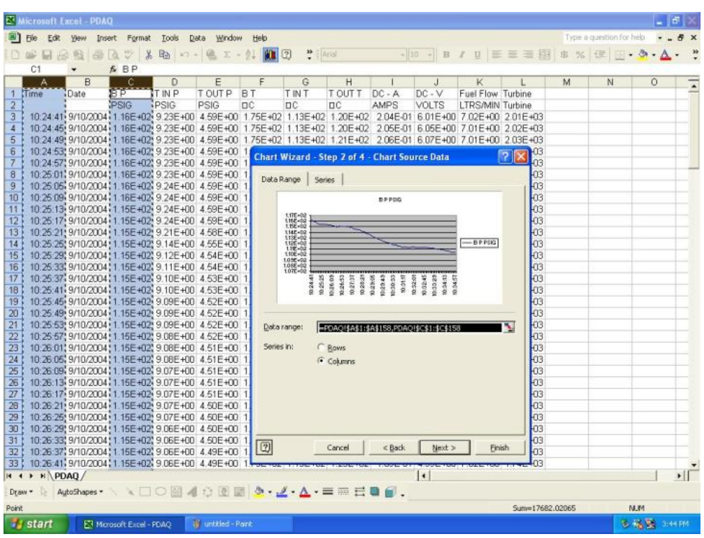
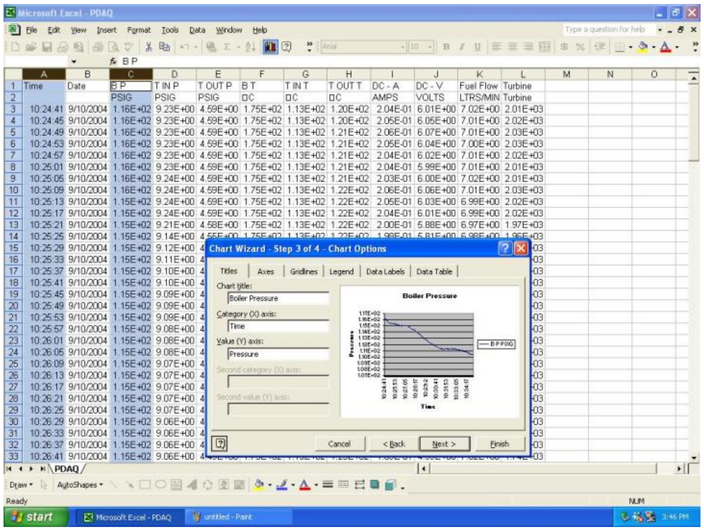


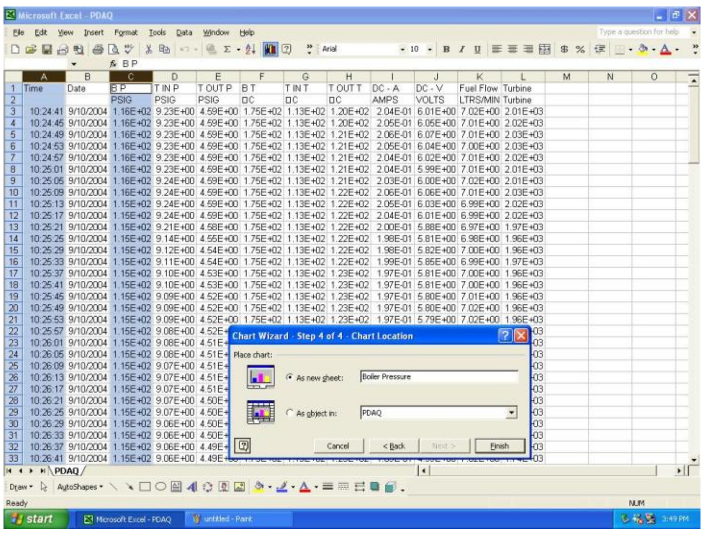
Chart Type: Line
Chart Sub Type: Line (first one)
Next



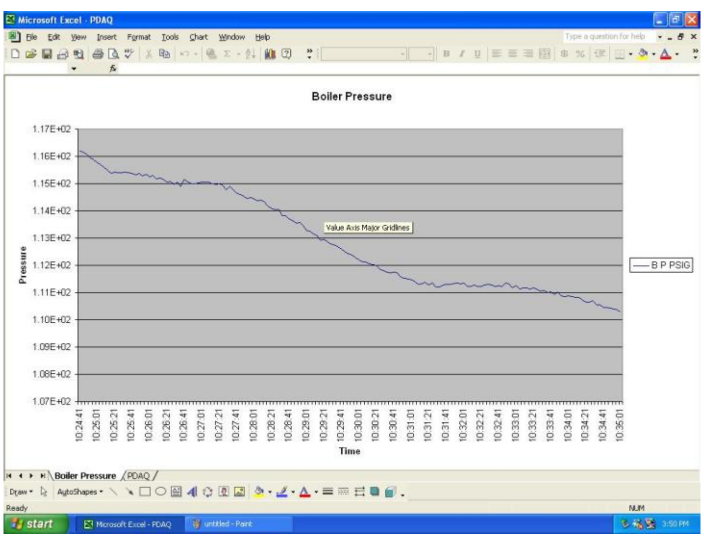
Accept data range listed by choosing: Next



Choose Graph Options and Labels



Name Graph, Click as New Sheet, Finish



Completed Boiler Pressure Graph

Rankine Cycler[TM] 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.*

$$\dot{Q}_{BOILER} + \dot{m}_{IN}^{\,0}\left(h_{IN} + KE_{IN} + PE_{IN}\right) = \dot{m}_{OUT}\left(h_{OUT} + KE_{OUT}^{\,0} + PE_{OUT}^{\,0}\right) + \dot{W}_{OUT}^{\,0}$$

NO CONDENSATE RETURN PUMP, $\therefore \dot{m}_{IN} = 0$

$$\boxed{\dot{Q}_{BOILER} = \dot{m}_{OUT}\,h_{OUT} = \left(28\ \frac{lb}{hr}\right)\left(1193\ \frac{btu}{lb}\right) = 33{,}404\ \frac{btu}{hr}}$$

COMPARE TO MEASURED PROPANE GAS FLOW TO BURNER

$$\left(6.25\ \frac{l}{min}\right)\left(\frac{ft^3}{28.3\,l}\right)\left(2500\ \frac{btu}{ft^3}\right)\left(60\ \frac{min}{hr}\right) = \underline{33{,}127}\ \frac{btu}{hr}$$

Turbine / Generator (SSSF)

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

$$\dot{Q}_{turb}^{\,0} + \dot{m}_{IN}\left(h_{IN} + KE_{IN}^{\,0} + PE_{IN}^{\,0}\right) = \dot{m}_{OUT}\left(h_{OUT} + KE_{OUT}^{\,0} + PE_{OUT}^{\,0}\right) + \dot{W}_{TURB}$$

- NO HEAT FLOW INTO TURBINE
- $\dot{m}_{IN} = \dot{m}_{OUT}$, Δ KE AND Δ PE ARE NEGLIGIBLE

$$\dot{W}_{TURB} = \dot{m}\left(h_{IN} - h_{OUT}\right) = \left(28\ \frac{lb}{hr}\right)\left(1198\ \frac{btu}{lb} - 1178\ \frac{btu}{lb}\right) = 560\ \frac{btu}{hr}$$

POWER GENERATION $= (0.21A)(6.3V) = 1.32\ W$

$$\boxed{\eta_{GENERATOR} = \frac{\text{POWER OUTPUT}}{\text{POWER INPUT}} = \frac{1.32\ W}{164\ W} = 0.008 = \underline{0.8\%}}$$

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.

$$\dot{Q}_{COND} + \dot{m}_{IN}(h_{IN} + KE_{IN}^{\nearrow 0} + PE_{IN}^{\nearrow 0}) = \dot{m}_{OUT}(h_{OUT} + KE_{OUT}^{\nearrow 0} + PE_{OUT}^{\nearrow 0}) + \dot{W}_{COND}^{\nearrow 0}$$

- WORK IS NOT DONE BY WORKING FLUID IN CONDENSER
- $\dot{m}_{IN} = \dot{m}_{OUT}$

$$\dot{Q}_{COND} = \dot{m}(h_{IN} - h_{OUT}) = \left(28\,\frac{lb}{hr}\right)\left(1178\,\frac{btu}{lb} - 36.46\,\frac{btu}{lb}\right) = \underline{-31,963}\ \frac{btu}{hr}$$

(HEAT FLOW OUT OF SYSTEM)

What is the Condenser Efficiency during SSSF?

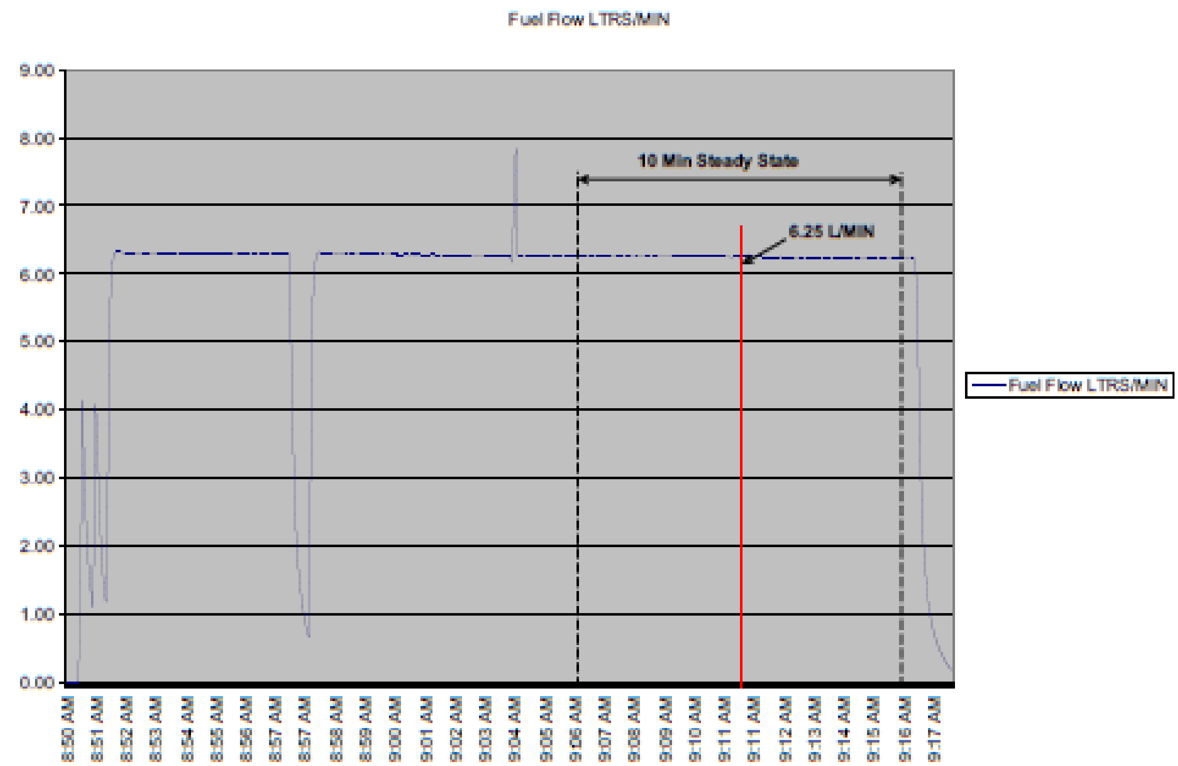
DURING SSSF RUN, WE WERE ABLE TO CONDENSE 400 ml WATER

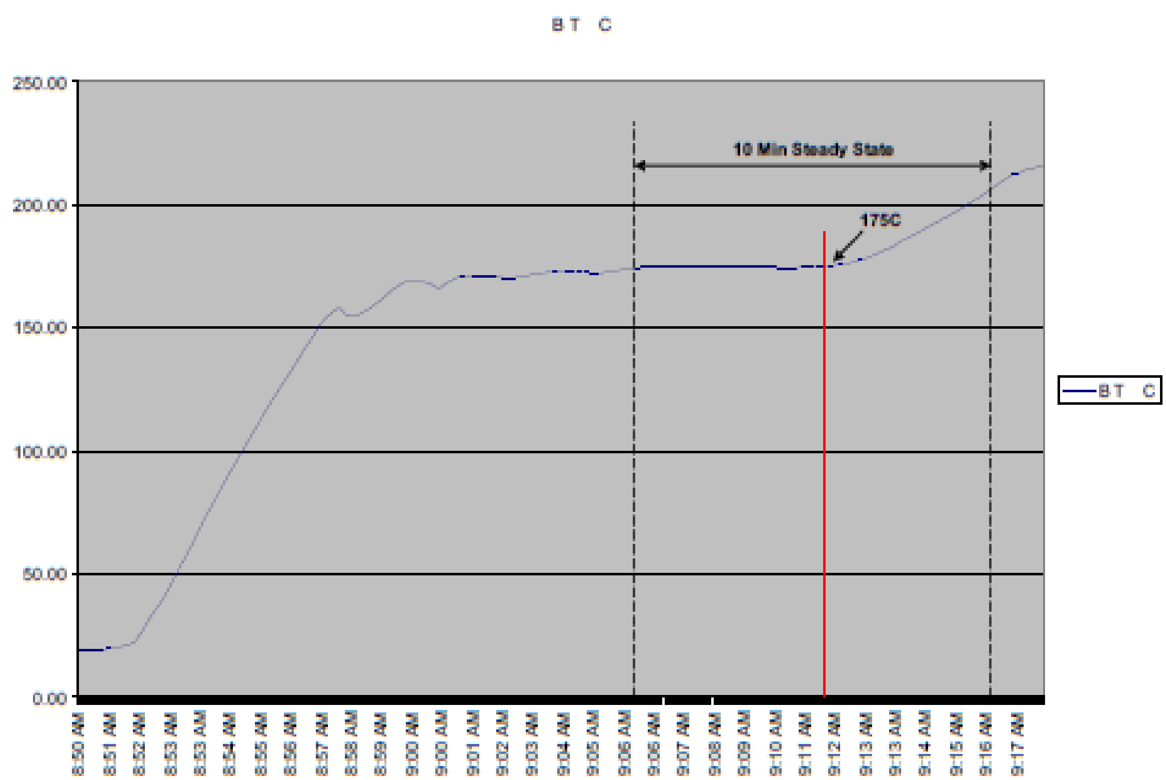
$$\eta_{COND} = \frac{400\ ml\ \text{CONDENSATE}}{2115\ ml\ \text{MASS FLOW}} \times 100 = \underline{19\%}$$

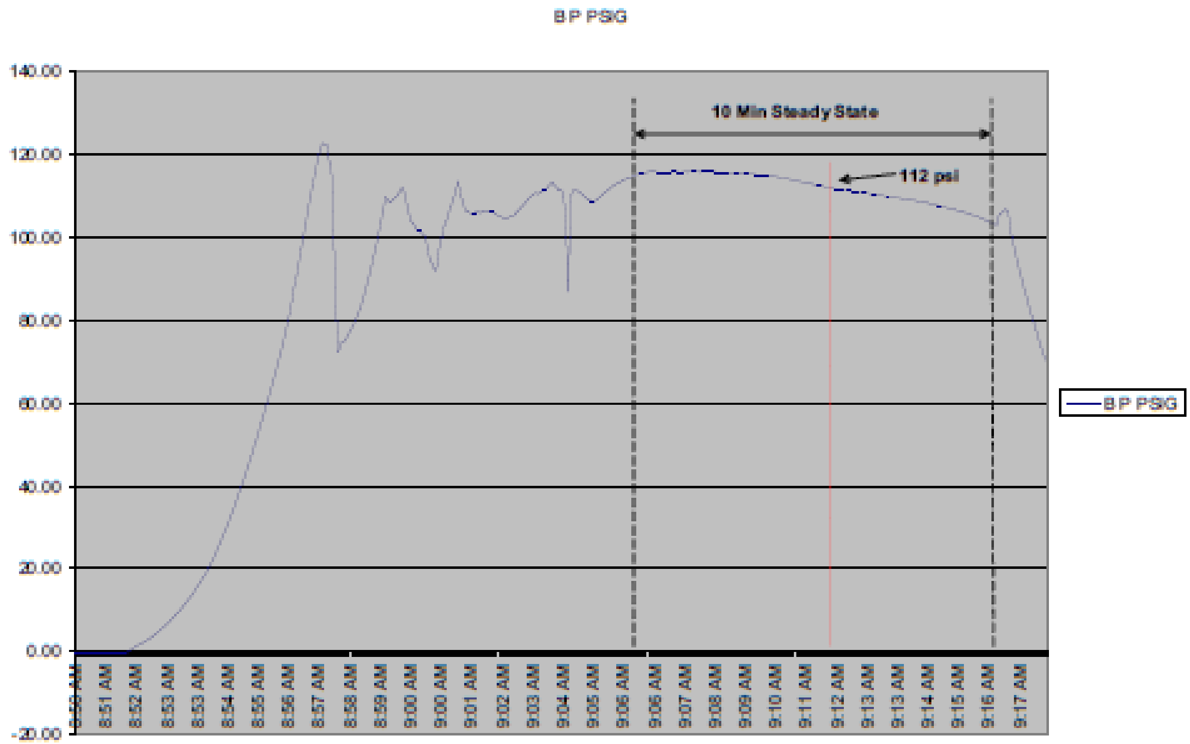
Total System Efficiency (SSSF)
What is the electrical power output verses the fossil-fuel energy input?

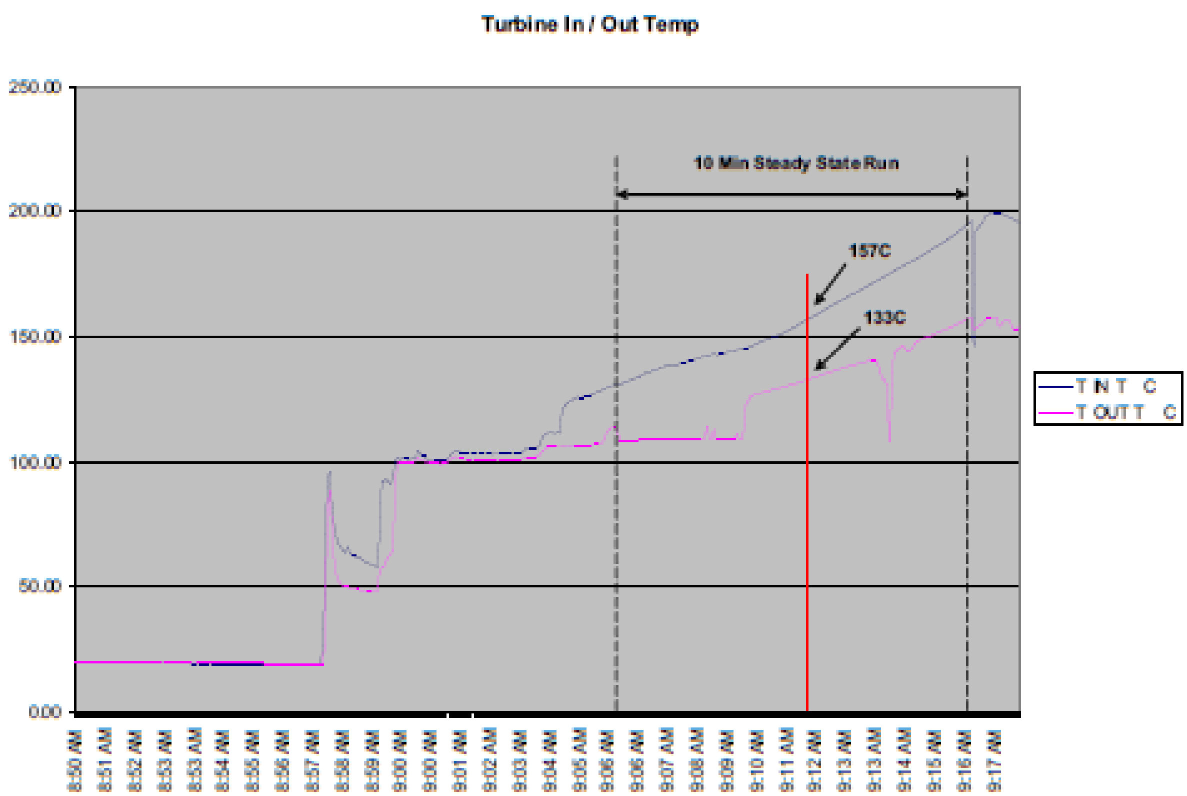
$$\frac{\text{ELECTRICAL GENERATOR OUTPUT}}{\text{ENERGY INPUT (PROPANE)}} = \frac{1.32\ W}{\left(33,127\,\frac{btu}{hr}\right)\left(\frac{W \cdot hr}{3.414\,btu}\right)} \times 100$$

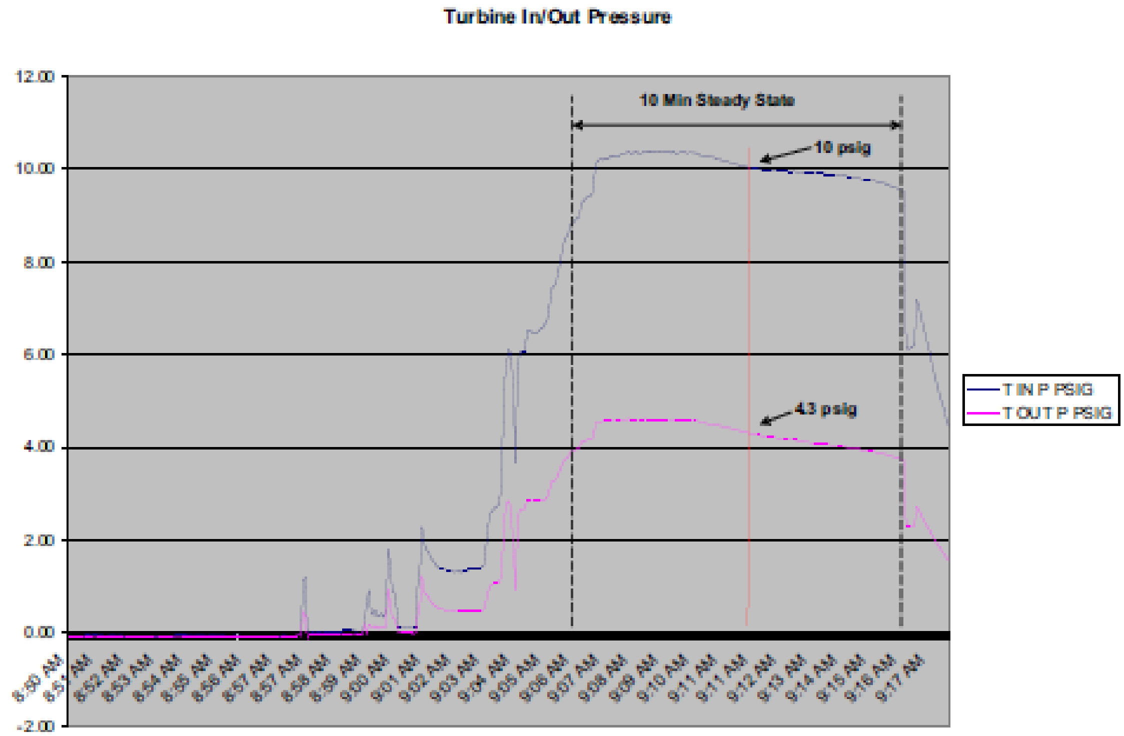
$$\eta_{SYSTEM} = 0.013\%$$

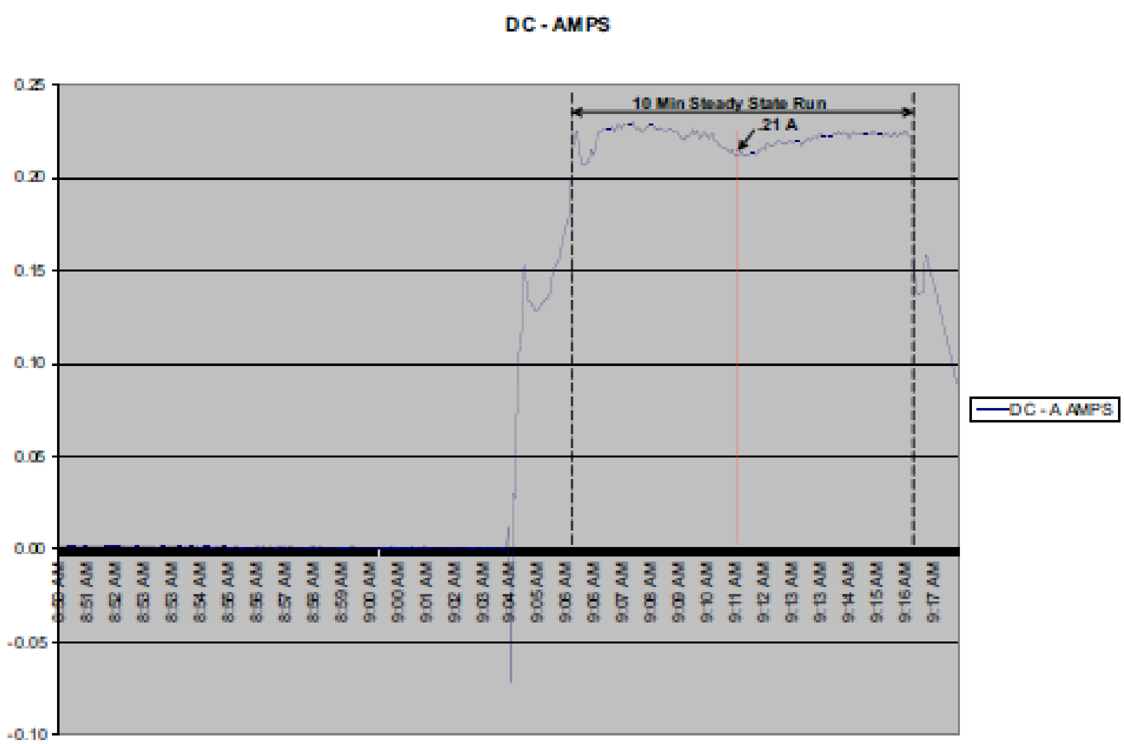

Fuel Flow LTRS/MIN
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
10 Min Steady State
6.25 L/MIN
Fuel Flow LTRS/MIN
8:50 AM
8:51 AM
8:52 AM
8:53 AM
8:54 AM
8:55 AM
8:56 AM
8:57 AM
8:57 AM
8:58 AM
8:59 AM
9:00 AM
9:01 AM
9:02 AM
9:03 AM
9:04 AM
9:05 AM
9:06 AM
9:07 AM
9:08 AM
9:09 AM
9:10 AM
9:11 AM
9:11 AM
9:12 AM
9:13 AM
9:14 AM
9:15 AM
9:16 AM
9:17 AM

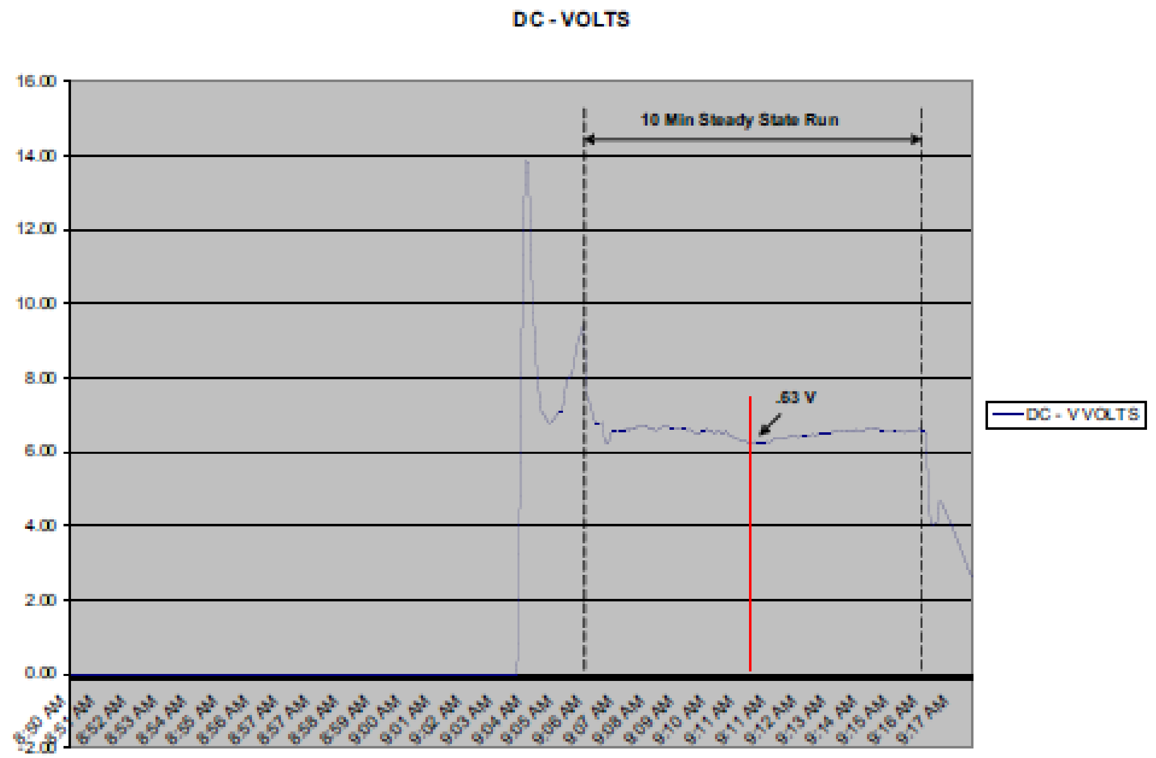

B T C
250.00
200.00
150.00
100.00
50.00
0.00
10 Min Steady State
175C
B T C
8:50 AM
8:51 AM
8:52 AM
8:53 AM
8:53 AM
8:54 AM
8:55 AM
8:56 AM
8:57 AM
8:58 AM
8:59 AM
9:00 AM
9:00 AM
9:01 AM
9:02 AM
9:03 AM
9:04 AM
9:05 AM
9:06 AM
9:06 AM
9:07 AM
9:08 AM
9:09 AM
9:10 AM
9:11 AM
9:12 AM
9:13 AM
9:13 AM
9:14 AM
9:15 AM
9:16 AM
9:17 AM

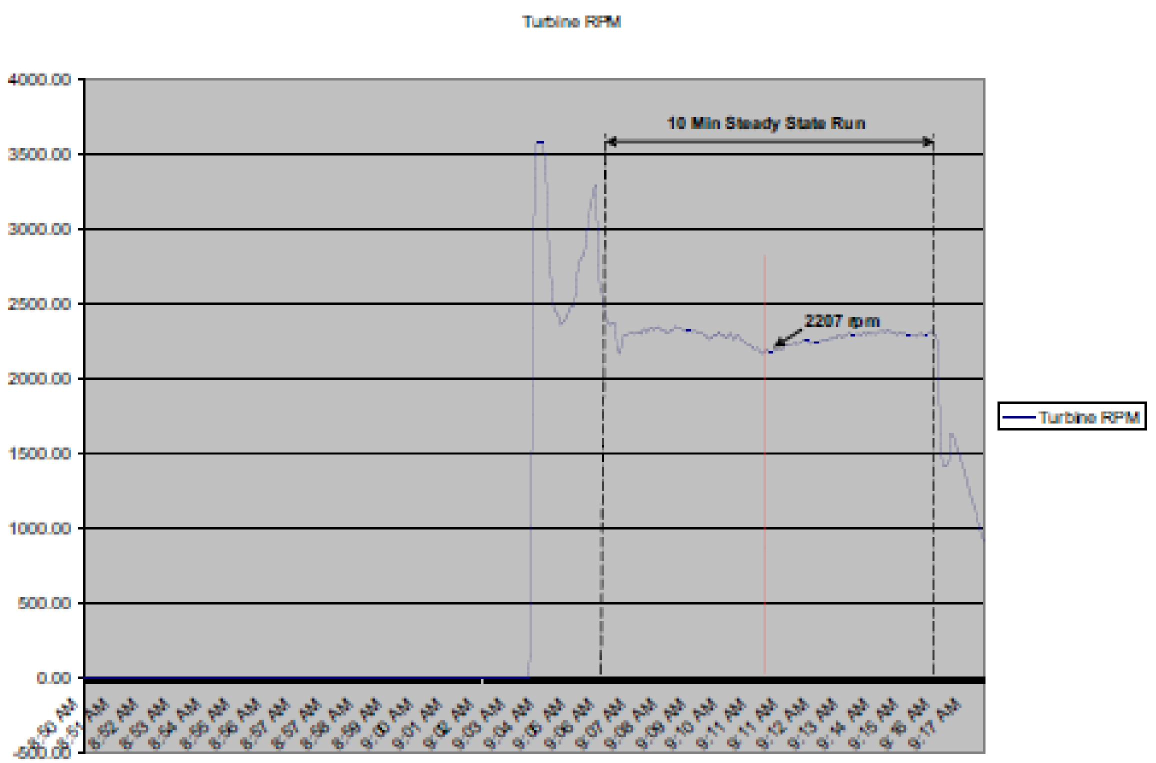

B P PSIG
10 Min Steady State
112 psi
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
B P PSIG
8:50 AM
8:51 AM
8:52 AM
8:53 AM
8:53 AM
8:54 AM
8:55 AM
8:56 AM
8:57 AM
8:58 AM
8:59 AM
9:00 AM
9:00 AM
9:01 AM
9:02 AM
9:03 AM
9:04 AM
9:05 AM
9:06 AM
9:06 AM
9:07 AM
9:08 AM
9:09 AM
9:10 AM
9:11 AM
9:12 AM
9:13 AM
9:13 AM
9:14 AM
9:15 AM
9:16 AM
9:17 AM

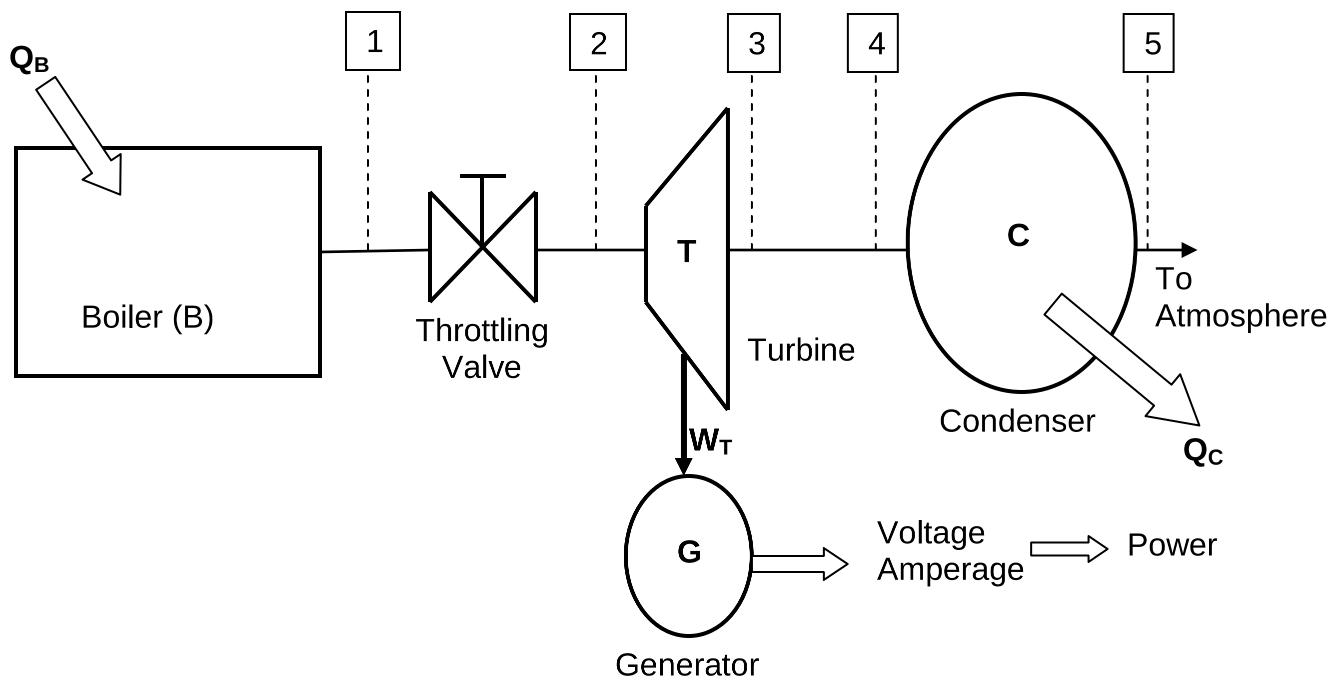

Turbine In / Out Temp
10 Min Steady State Run
157C
133C
250.00
200.00
150.00
100.00
50.00
0.00
T IN T C
T OUT T C
8:50 AM
8:51 AM
8:52 AM
8:53 AM
8:53 AM
8:54 AM
8:55 AM
8:56 AM
8:57 AM
8:58 AM
8:59 AM
9:00 AM
9:00 AM
9:01 AM
9:02 AM
9:03 AM
9:04 AM
9:05 AM
9:06 AM
9:06 AM
9:07 AM
9:08 AM
9:09 AM
9:10 AM
9:11 AM
9:12 AM
9:13 AM
9:13 AM
9:14 AM
9:15 AM
9:16 AM
9:17 AM


Turbine In/Out Pressure
10 Min Steady State
10 psig
4.3 psig
T IN P PSIG
T OUT P PSIG
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00


DC - AMPS
10 Min Steady State Run
.21 A
DC - A AMPS
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10


DC - VOLTS
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
10 Min Steady State Run
.63 V
DC - VVOLTS


Turbine RPM
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
-500.00
10 Min Steady State Run
2207 rpm
Turbine RPM



System Mass Flow Rate ($\dot{m}$)

$$\dot{m} = \left(\frac{2115\ ml}{10\ min}\right)\left(\frac{1\ liter}{1000\ ml}\right)\left(\frac{0.03531\ ft^3}{liter}\right)\left(\frac{62.4\ lb}{ft^3}\right)\left(\frac{60\ min}{hr}\right) = 28\ \frac{lb}{hr}$$

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

1. **Boiler**

Measured	P_b =	126.7 PSIA = 0.873 mPa
Measured	T_b =	175°C = 448°K = 347°F = 807°R
Table	v_b =	3.554 ft³/lb = 0.2218 m³/kg
Table	h_b =	1193 btu/lb = 2775 KJ/kg
Table	u_b =	1110 btu/lb = 2581 KJ/kg
Table	s_b =	1.586 btu/lb°R = 6.638 KJ/kg °K

2. **Turbine Inlet**

Measured	P_{Tin} =	24.7 PSIA = 0.170 MPa
Measured	T_{Tin} =	157°C = 430°K = 314°F = 775°R
Table	v_{Tin} =	18.42 ft³/lb = 1.15 m³/kg
Table	h_{Tin} =	1198 btu/lb = 2785 KJ/kg
Table	u_{Tin} =	1114 btu/lb = 2590 KJ/kg
Table	s_{Tin} =	1.767 btu/lb°R = 7.395 KJ/kg °K

3. **Turbine Outlet**

Measured	P_{Tout} =	19 PSIA = 0.131 KPa
Measured	T_{Tout} =	133°C = 406°K = 271°F = 731°R
Table	v_{Tout} =	22.58 ft³/lb = 1.409 m³/kg
Table	h_{Tout} =	1178 btu/lb = 2740 kJ/kg
Table	u_{Tout} =	1099 btu/lb = 2555 KJ/kg
Table	s_{Tout} =	1.77 btu/lb°R = 7.4 KJ/kg °K

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

Measured	P_{Cin} =	19 PSIA = 0.131 MPa
Measured	T_{Cin} =	133°C = 406°K = 271°F = 731°R
Table	v_{Cin} =	22.58 ft³/lb = 1.409 m³/kg
Table	h_{Cin} =	1178 btu/lb = 2740 kJ/kg
Table	u_{Cin} =	1099 btu/lb = 2555 kJ/kg
Table	s_{Cin} =	1.77 btu/lb°R = 7.4 kJ/kg °K

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

Measured	P_{Cout} =	14.7 PSIA = 0.101 MPa
Measured	T_{Cout} =	20°C = 293°K = 68°F = 528°R
Table	v_{Cout} =	0.01605 ft³/lb = 0.001 m³/kg
Table	h_{Cout} =	36.46 btu/lb = 83.4 kJ/kg
Table	u_{Cout} =	36.41 btu/lb = 83.3 kJ/kg
Table	s_{Cout} =	0.07144 btu/lb°R = 0.294 kJ/kg °K