BOOK 1 Classroom/Lab Work

Understanding Power Production

Steam Turbine Electrical Generation

Turbine Technologies, LTD.

Turbine Technologies, Ltd., 410 Phillips Street, Chetek, WI, 54728 USA.
Phone: 715-924-4876, **Fax:** 715-924-2436, **www.turbinetechnologies.com**

INTRODUCTION

Upon completion of this book, the student will have a solid understanding of how a majority of commercial electric power is generated. The lab work will give students a hands-on experience producing electrical power using the Rankine Power Cycle. The processes in the cycle are measured during operation and analyzed to better understand their performance characteristics. This knowledge transfers very well into the full-scale electric power generation industry.

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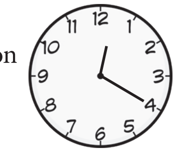
Duration: 20 min.



Lesson 1: Electric Power Generation

In this lesson, the student will learn what electric power generation is, different ways it is accomplished, and its importance to our lives on earth.

Focus 1: Introduction to Power

One of the most significant contributions to the development and continuation of our modern technological way of life has been the ability to obtain vast amounts of energy from natural resources. These energy sources allow us to control work, power and heat to meet the demands of societies around the world. Typical natural resources with energy use capabilities include oil, natural gas, coal, wood, water, wind, solar, and nuclear.

The science that explains and allows us to predict the amount of energy we may extract from these resources and how efficient we are at actually doing it is what thermodynamics is all about. It is the science that studies energy in its various forms or types and helps explain why some types of energy are better than others.

Electricity that we use to power countless aspects of our life is typically generated using these natural resources to fuel the processes.

Focus 2: Typical Types of Electrical Generation

Figure 1.1: Sherburne County (Sherco) coal-fired Electrical Generation Station, Becker Minnesota (2400 MW). Example of a Base Load Plant

You see large facilities called power plants, power dams, wind turbine farms, solar cell installations, waste to energy facilities, peaking stations and others as you travel. Each uses a natural resource as a fuel to power their electrical generation activity.

Since electricity can't be stored for later use, it has to be generated on demand. So, there are base load power plants that are sized to generate electricity to meet a majority of the typical demand. They have a constant fuel source and can run around the clock as needed. These base load plants are connected to and supply electricity to an electrical grid that gets this electricity to your home, school or business. Power companies monitor the grid to determine how much electricity is needed and where. The base load plants are sized and scheduled to serve the normal amount of electricity needs of the grid users in a reliable manner. They run at various output levels, in a balanced fashion to accomplish this goal.

Figure 1.2: Jet Engine Peaking Plant (8 units)
CPV Sentinel Plant, California
Example of a Jet Peaker Plant

In areas where load demand on the grid exceeds the ability of the base load plants to supply the need, supplemental plants are added to the mix. These are called peaking plants. They are typically powered by jet engines for quick start-up and operation and are used sparingly, because of cost, just to take care of the extra demand that was created that day. One example of extra demand could be a hot day causing much more air conditioning load than normal to be operating during some key afternoon hours.

Figure 1.3: Hoover Dam, Las Vegas, Nevada
Example of a hydro-electric generation station.

Hydro dams are a good natural electrical generation method. These use water backed up by dams to spin electric generation turbines to produce electricity. Hydro-electric power can be used as base load or peaking generation. Grid managers monitor water levels at these plants and can predict generation capacity for reasonably long periods of time, making them good for some base load activity (especially if a fossil-fueled base load plant is down for maintenance, etc.). Hydro can also be started up quickly and on the grid in the event some peaking is needed.

Figure 1.4: French Island Waste to Energy Plant, Lacrosse, WI

Waste to energy plants can typically be connected to the grid as a base load generator. These are specialty plants that typically use industrial and residential waste products such as wood and paper and generally garbage as fuel to power the plant. The fuel is used to boil water to create steam, and generate power the same way it is generated in a coal fired plant.

Figure 1.5: Rural Iowa Wind Turbine Farm

Renewable energy, such as wind turbines and solar farms can be connected to the grid and scheduled to supply electric energy when conditions are right for their use. They can relieve base load capacity, but cannot be counted on as a reliable base load supplier because the wind doesn't always blow, nor the sun shine. These sources are considered supplemental providers.

Figure 1.6: Solar Electric Generation Station
Nellis Air Force Base, Nevada

Solar energy plants are much harder to find. They are dependent on sunshine, so a majority of these plants are found in desert regions. This type of energy production is expensive to build. However, the amount of sunlight in desert regions and the lack of greenhouse emissions make an ideal choice for this region. There are two types of solar plants, solar cell and mirror. Solar cell plants convert the suns energy directly to power that can be distributed. Solar mirror plants used curved mirrors to focus the suns energy on a pipe filled with liquid. The liquid is then used to boil water to a steam, with electric power being produced just like in a coal fired plant.

Figure 1.7: Inactive Kewaunee Nuclear Power Station,
Carlton, WI

Nuclear energy plants are extremely efficient at generating electrical power. They can produce giga-watts (GW) of power using only a small amount of uranium or plutonium fuel. They are excellent base load systems because they can provide constant power for long periods of time. Fuel costs are estimated to be about 1/3 the cost for a typical coal fired power plant, and greenhouse emissions are extremely low. However, nuclear power production does have moderate risks. Disasters at Chernobyl in 1986 and Fukushima in 2011 made many countries reconsider their nuclear power production policies. As a result, plants reaching the end of their life cycle are being shut down versus renewed.

These are a majority of the ways electricity is generated.

Focus 3: So, how is the majority of electricity made?

Sometimes things in life become so reliable that they're taken for granted. Case in point, have you ever stopped to think about how much you depend on electricity?

Think about your last experience with even a brief power outage. Without electrical power, heat, air-conditioning and lighting cease to exist, so does the ability to charge your smart phone, watch T.V., or even cook a meal.

With electricity being such an important part of modern life, have you considered how it's made in those various ways we just discussed? Did you know that one of the first steps in producing a majority of the electricity we consume is to boil water? It may sound funny, but it's true!

Actually, a Scottish civil engineer by the name of William Rankine (pronounced "Rang-Keene") was one of the founding fathers of modern day thermodynamics. As we mentioned earlier, Thermodynamics is the study of energy and a major aspect of thermodynamics concerns itself with methods of converting heat into useful work, or power.

Figure 1.9: William Rankine

Rankine was born in 1820 and established a theoretical process that is still used today for the production of most of the world's electric power. That process was named in his honor and is known as the "Rankine Cycle".

The Rankine Cycle produces electrical power through four basic steps:

1. Water is pumped into a closed container called a boiler
2. The boiler is heated and the water changes into high pressure steam
3. The steam is shot out of a nozzle that's aimed at a paddle wheel. This paddle wheel is called a turbine. The expanding steam causes the turbine wheel to spin, which is connected to a generator that produces electricity
4. The steam coming out of the turbine condenses back into water, which is pumped back into the boiler to start the process or "cycle" all over again

This entire process occurs within a closed loop where the water or "working fluid" never escapes. It only changes phases from a liquid to a gaseous state and back. The Rankine Power Cycle is therefore known as a vapor power cycle. One interesting point is that over 90% of our electricity is generated this way.

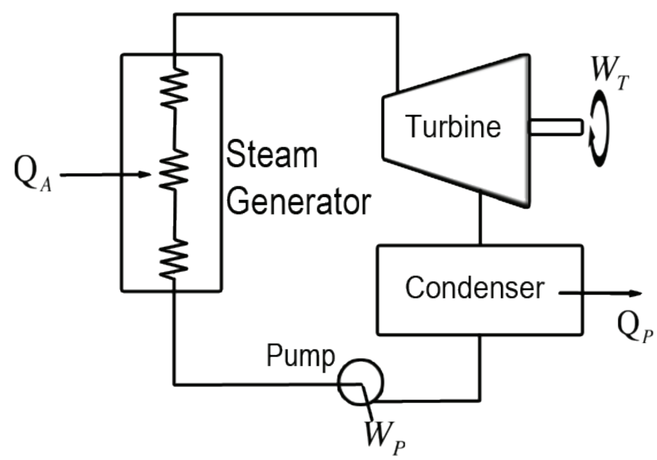


Figure 1.10: Typical schematic of the Rankine Cycle

The Rankine Cycle's major components and basic process are shown in Figure 1.10 above. The steam generator can be likened to a closed kettle of water being heated on a stove. In the case of an actual power plant, a fossil fuel such as coal, oil, or natural gas is burned creating heat. This heat source, Q_A, heats the water to a high temperature and pressure, creating high quality steam (going from a liquid to a vapor condition or state). This high quality steam in its high pressure and temperature state carries a great deal of energy. This high energy steam flows into a steam turbine, causing the steam turbine to spin (a steam turbine can be likened to a pin wheel being spun by wind blowing over it-in our case it's a steam turbine with high energy steam blowing over it). The steam turbine is connected to an electric generator, which generates electricity while spinning. As the steam passes through the turbine section, it transfers much of its built up energy to the turbine to do the work, W_T, of turning the generator. It loses much of its pressure and temperature. As it exits the turbine, the steam is now at too low of an energy value to be useful anymore so it is run through a condenser. A condenser literally reduces the temperature by rejecting heat, Q_R, and consequently the pressure of the steam further until it changes its state back to liquid water. This is done to reclaim and recycle the water by pumping it back into the boiler using a condensate return pump, W_P. Now, some of the waste steam is lost out of the condensers as the steam is converted back to liquid. Supplementary water must be added to the condensate return line to make up for this loss.

As a side note, a primary difference in today's modern power plants is the way in which the heat for water vaporization is generated (i.e. how the water is heated to make steam). In other words, the energy to fire the boiler may come from a nuclear reaction (fission), burning coal, oil, natural gas, or even from solar radiation. But, no matter how the boiler is brought up to temperature, it's all about boiling some water.

Knowledge Certification Quiz: Lesson 1

1. *In your own words, describe William Rankine's power cycle.*

2. *List the four major hardware components needed for the Rankine Cycle.*

   A.

   B.

   C.

   D.

3. *True or False: The Rankine Cycle consumes its' own working fluid.*

4. *Define the term Thermodynamics.*

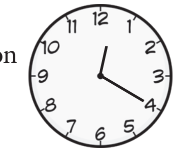
Extra Credit Question:

Would it be possible to use a different fluid, other than water, as the working fluid for the Rankine Cycle? Your answer should include some reasoning as to why water is used as the working fluid.

I certify that I have answered all certification quiz questions correctly and am ready for the next lesson.

Your Signature ______________________ Date ______________________

Approximate Lesson
Duration: 20 min.



Lesson 2: Idealized Rankine Cycle

In this lesson, the student will be introduced to some of the basic thermodynamics involved with the Rankine Cycle.

The Rankine Cycle is an idealized cycle that is defined and compared to the operation of the actual steam turbine cycle. As we have discussed briefly, the major components of this closed loop are the boiler or steam generator, steam turbine, condenser, and feedwater pump.

If you look at pressure/volume and temperature/entropy phase diagrams for water, you will see the characteristics of water converting from a liquid phase into a combination liquid/vapor region after crossing over the saturated liquid line. When it crosses the saturated vapor line, it is now in the pure vapor, or superheated steam region. This is important to know as it is the basis for the Rankine Cycle.

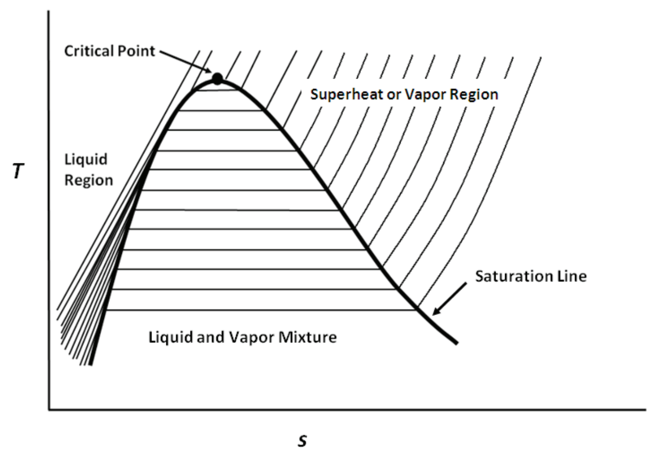


Figure 1.11: T-s diagram of steam-water phase change

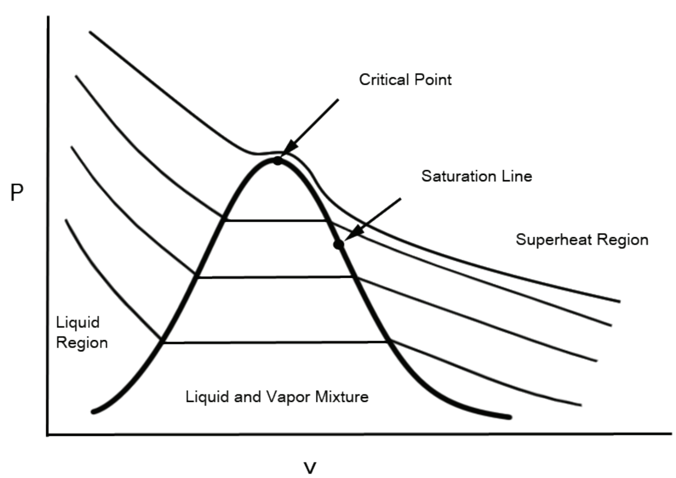


Figure 1.12: P-v diagram of steam-water phase change

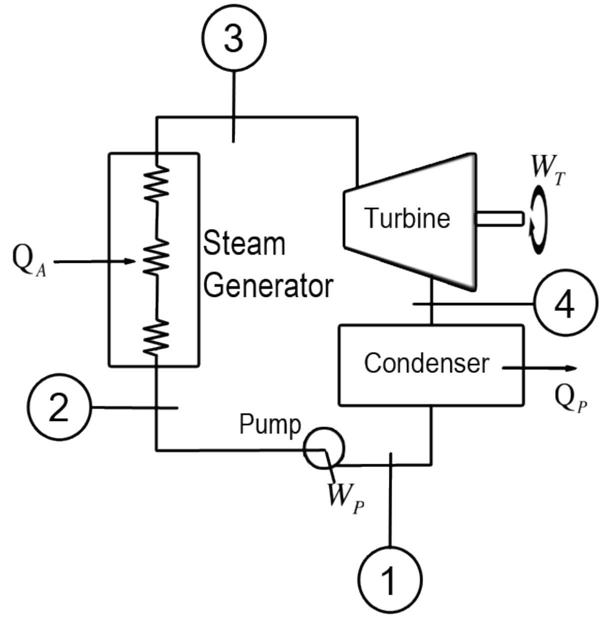


Figure 1.13: Typical schematic of the Rankine Cycle

All four components associated with the ideal Rankine Cycle are steady-flow devices, and thus all four processes that make up the Rankine Cycle can be analyzed as steady-flow process. The kinetic and potential energy changes of the system flow are small relative to the heat and work items, so they are not addressed. The energy analysis of the four components is as follows:

Pump (process 1-2): Pump pressurizes the liquid water coming from the condenser prior to it going back into the boiler. The energy balance in the pump is:

$W_p = h_2 - h_1$ (Work into the pump = enthalpy* at position 2 – enthalpy at 1).

Boiler (process 2-3): Liquid water enters the boiler and is heated to superheated state while in the boiler. The energy balance in the boiler is:

$q_{in} = h_3 - h_2$ (Heat energy added to boiler = enthalpy at position 3 – enthalpy at 2).

Turbine (process 3-4): Steam from the boiler, which has an elevated temperature and pressure, expands through the turbine to produce work and then is discharged to the condenser with relatively low pressure. The energy balance in the turbine is:

$W_t = h_3 - h_4$ (work output of turbine = enthalpy of position 3 – enthalpy at 4).

Condenser (process 4-1): The low pressure steam coming out of the turbine is condensed back to liquid water in the condenser. The energy balance in the condenser is:

$q_{out} = h_4 - h_1$ (heat rejected by the condenser = enthalpy at position 4 – enthalpy at 1).

*Note: If you have not studied enthalpy yet, it is the measure of total energy of a thermodynamic system. It is accomplished by finding the energy state (enthalpy) of high-interest points in the system. Measured temperature/pressure values from those points are applied to a steam table, which provides the enthalpy values for those specific points. All points are then added up to yield the total energy of the system. Further study should be undertaken to become knowledgeable about this topic.

If we interlay these ideal processes on P-v and T-s diagrams, we see how they transition the water/steam saturation line.

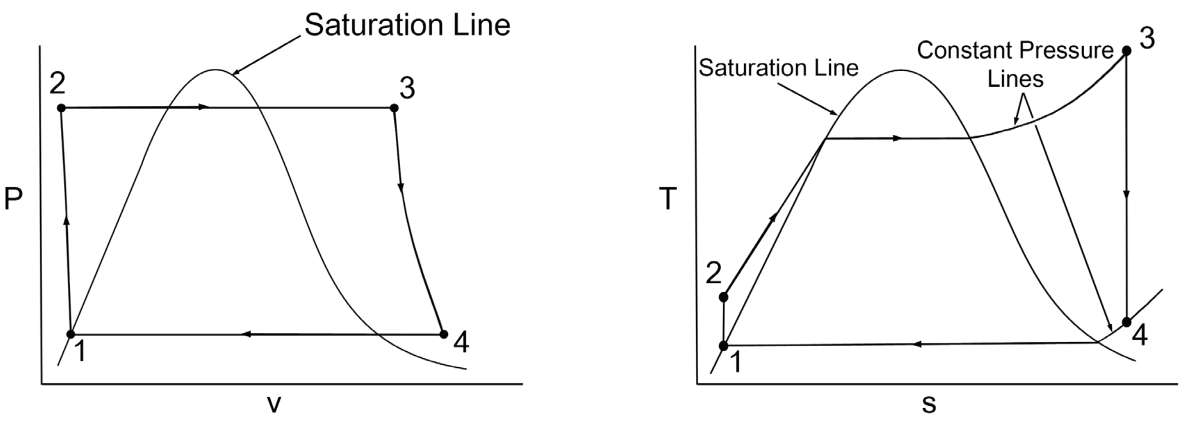


Figure 1.14: Property Diagrams of the Rankine Cycle

For the whole cycle: The ideal energy balance can be obtained by summing up the 4 energy equations, we just looked at, into the following:

$(q_{in} - q_{out}) - (W_t - W_p) = 0$ ((Heat input into boiler –heat rejected by the condenser) – (Work the turbine does – work that condensate return pump does)).

Thermal Efficiency: This is the ratio of work done in the cycle to the heat added to the cycle.

$$\eta_T = \frac{W_{cycle}}{q_{add}} \times 100 = \frac{h_3 - h_4 + h_1 - h_2}{h_3 - h_2}$$

Note: In practice, we do not have an ideal cycle, due to irreversibilities in various components, namely friction and heat loss.

Fluid friction causes pressure drops in the boiler, condenser, and connecting pipes. To compensate, the water needs to be pumped to a higher pressure.

Heat loss from the steam to the surroundings takes place when steam flows through various connecting pipes and components. To maintain the same work output, more heat must be transferred to the steam in the boiler.

So, you will see ideal cycle layouts on a property diagram when learning about this in the classroom. Keep in mind that the layouts will be slightly different when using real data rather than ideal calculations.

Because we are using real equipment and a real cycle, we use steam tables to identify the properties of the steam at the different states throughout the cycle.

Knowledge Certification Quiz: Lesson 2

1. Looking at a T-s or P-v diagram for water phase change, you see water going through three phase changes as it is heated. What are they?

2. As the process crosses the saturation line into the vapor region, what condition is ultimately desired to yield the best quality of steam?

3. In an ideal Rankine Cycle, there are 4 processes that are analyzed. What are they?

4. Analysis relies on knowing enthalpy states at different positions in the system. From your classroom work, what is enthalpy?

5. What can you use to identify the properties of steam, including enthalpy values, at different states throughout the cycle?

I certify that I have answered all certification quiz questions correctly and am ready for the next lesson.

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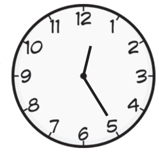
Your Signature Date

Approximate Lesson
Duration: 25 min.



Lesson 3: Understanding the RankineCycler™

Upon completion of this lesson, the student will have solid, hands-on experience running a steam turbine electrical generation station called RankineCycler™. The RankineCycler™ will be thoroughly introduced, including all components that make up the actual system, its integrated data acquisition system and virtual instrument panel. From there, operating the steam turbine power system will allow the student to experience and study the important performance parameters such as; fuel energy density, boiler heat flow, energy conversion efficiency, system mass flow rate, turbine work rate, generator output/efficiency, condenser efficiency, total system efficiency.

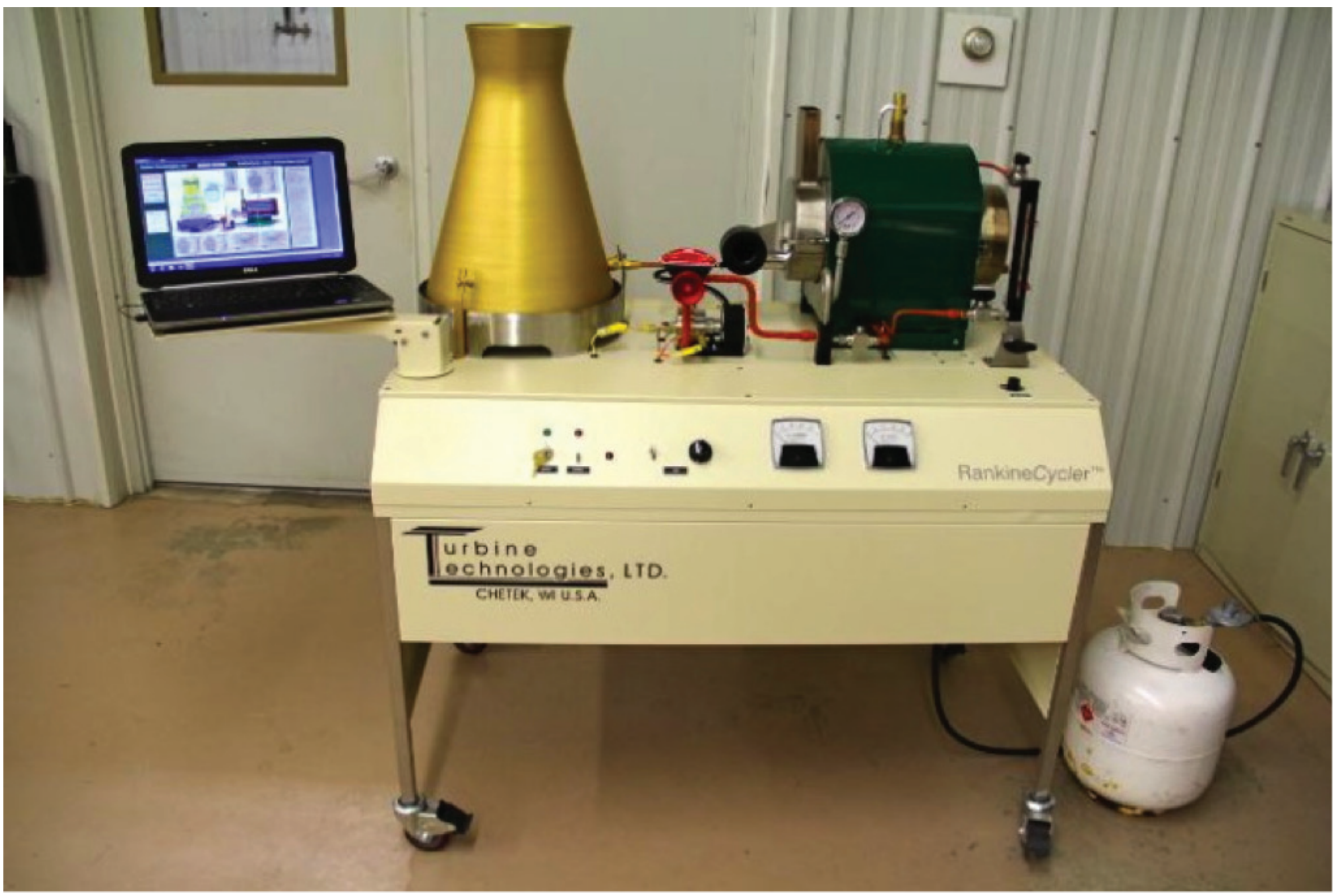


Figure 2.1: RankineCycler™ *System Features*

Focus 1: Introducing the RankineCycler™ Steam Turbine Power System in Detail

Imagine taking a full-size steam turbine electrical generation plant and shrinking it down to fit on a desk-top. Now you have a better idea of what this system is all about. All of the major components that make up a full-scale unit are replicated to this small scale that still allows the system to be operable.

System Item Descriptions:

Locate each item on the RankineCycler™ System and perform the action indicated. Be sure you understand how each individual function works before moving on to the next.

Figure 2.2: 20 lb. Propane Cylinder with Regulator

Liquid Propane (L.P.) Cylinder: Liquid Propane is the desired fuel source as it is readily available, convenient to use, portable, and has 2.5 times the energy density of natural gas.

Action: Locate L.P. tank. Notice it is connected to the RankineCycler™ through a hose setup which feeds boiler system burner. It features and on-off valve and a pressure reduction regulator. Since the pressure inside the L.P. tank is higher than what is required by the system burner, the regulator reduces the tank feed pressure to a factor the burner can handle.

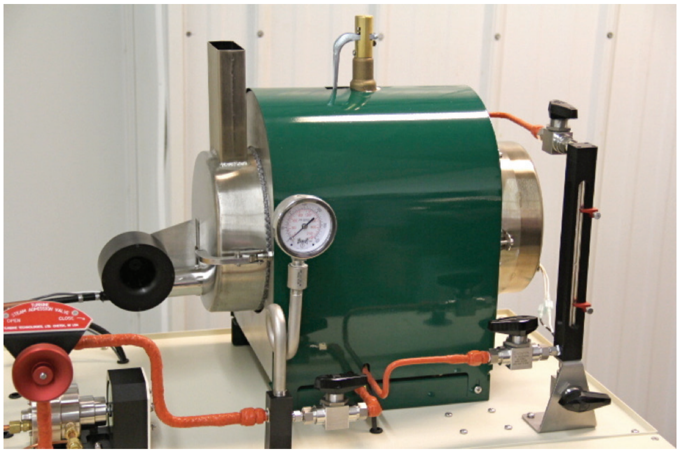


Figure 2.3: ASME Flame Tube Water Boiler

Steam Generation Boiler : ASME Certified dual pass, flame tube water boiler system. This boiler heats water, converting it to high quality steam for driving the steam turbine (discussed later). Shell and tube configuration with operable front inspection opening, fire tube blower

Action: If the system is not in operation (OFF) and is COOL, open the boiler door to reveal the boiler construction and flame tube layout. Notice the burner fan and tube mounted in the door, as well as the exhaust pipe. Right on top of the unit, you'll notice a gold-colored device; this is a pressure blow-down valve. It automatically relieves pressure in the boiler if the pressure goes beyond the normal operational setpoint. On the front left, you will see a pressure gauge.

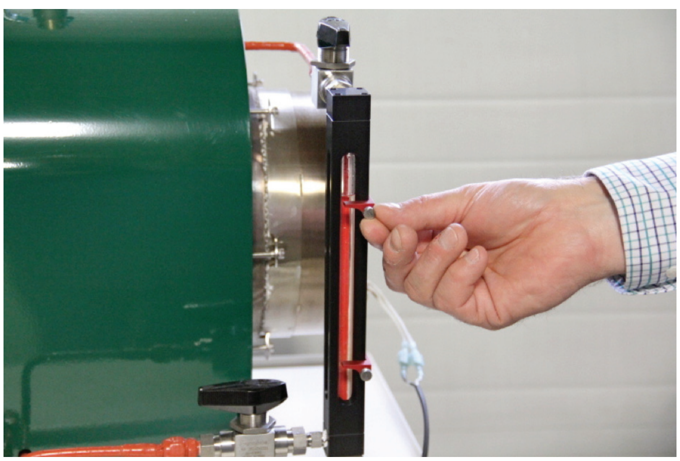


Figure 2.4: Boiler Site Gauge

Boiler Site Gauge : Visibly indicates the water level in boiler. It is equipped with two adjustable position bezels for marking boiler water levels of interest during operation.

Action: Notice each position bezel on the front of the site gauge. Each has a knob that you can adjust by turning it one way or another to loosen or tighten in place. Adjust the top bezel by unscrewing the knob just enough to allow the bezel to slide up and down in the site glass window. Position it where you want and then tighten the knob to secure the bezel to that position. You will be repositioning both of these during operation to signify the water levels (start and finish) when you operate the system.

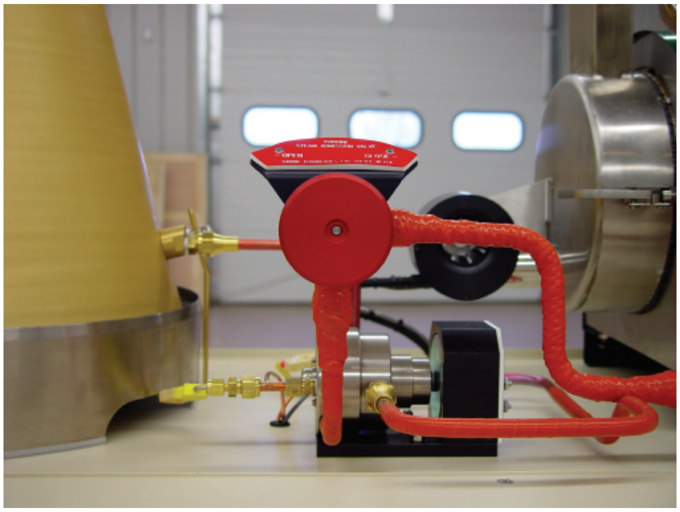


Figure 2.5 Steam Admission Valve

Steam Admission Valve : The Steam Admission Valve controls the steam flow into the turbine.

Action: Locate the steam admission valve. The red hand wheel will be slowly opened during the operation of the system to allow steam to flow in a controlled manner into the steam turbine. Grasp the wheel with your hand and turn it counter-clockwise. This is opening the valve. Turn it until it is fully opened. Then turn it clockwise until it is fully closed.

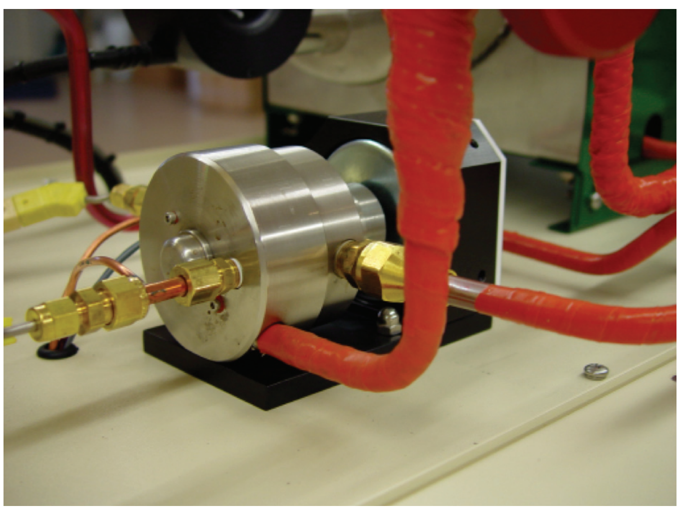


Figure 2.6: Steam Turbine

Steam Turbine : Impulse Micro Steam Turbine driven by steam flow.

Action: Locate the steam turbine and trace the steam line coming into it from the steam admission valve.

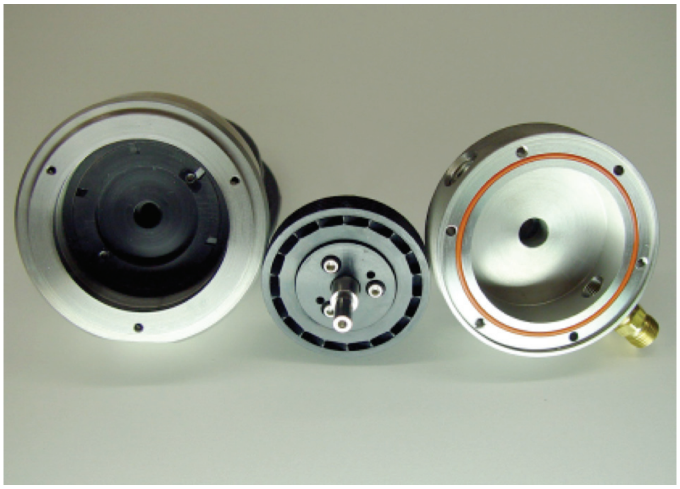


Figure 2.7: Impulse Steam Turbine Wheel

Impulse Steam Turbine Wheel : Detail views are shown.

Action: Since you cannot see into the actual turbine, these pictures show you the turbine wheel as it is situated in the housing. The CAD model shows how steam enters into the housing and impinges on the turbine wheel, causing it to spin. The turbine wheel is connected to and spins a shaft which ultimately drives the electric generator (next slide).

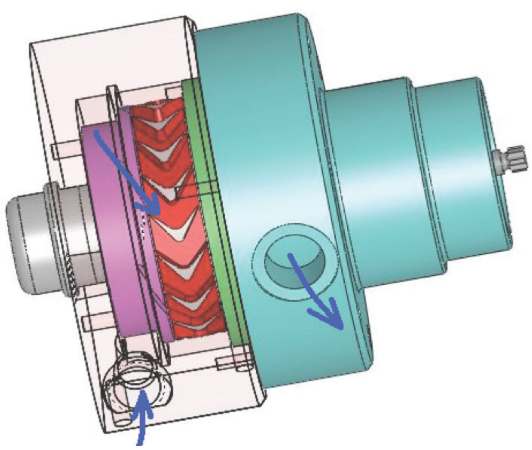


Figure 2.8: Steam Turbine CAD Cutaway

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.

Figure 2.9: AC/DC Electric Generator

Four Pole AC/DC Electric Generator : As mentioned above, this is driven by the steam turbine to generate electricity. It is set up for single phase electrical power output. It has 4 magnetic poles in its rotational assembly.

Action: Locate the generator and notice the drive shaft connection between the steam turbine and generator. On the generator face, notice the two connection points that can be used to power something with a small power requirement (5 to 10 watts). You will find that one connection point will output alternating current, the other direct current.

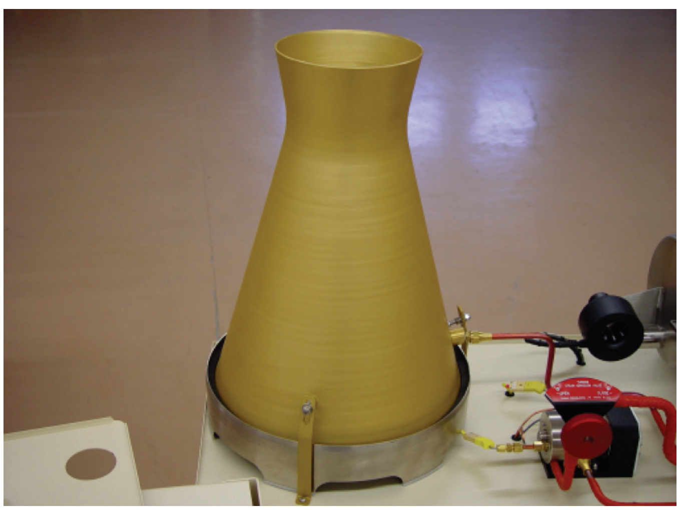


Figure 2.10: Condenser Tower

Condenser Tower : The condenser tower provides cooling to the waste steam so that it will change phase back to a liquid. In a full-scale plant, this reclaimed condensate would be pumped back into the boiler. The ultra-small scale of RankineCycler™ makes returning the condensate to the boiler impractical.

Action: Look into the top of the condenser. You will see a series of baffle plates in the unit. These plates direct the waste steam along the outer skin of the condenser. This large skin surface provides a heat exchange capability with the cooler outside air. This is considered an air-cooled condenser. On the lower backside of the condenser, a drain hose is placed to drain off condensate that is collected during system operation.

Data Acquisition Computer : Connects to the unit's data acquisition system via the built in USB port. Displays and captures operational data for real-time display and analysis.

Action: If unit is not on, turn it on and then open the RankineCycler™ Virtual Instrument Panel. Review the screen and familiarize yourself with the elements that are displayed on the screen. These will be the real time pressure, temperatures, flows and outputs the data acquisition system will be recording.

Figure 2.11: Laptop for Data Acquisition

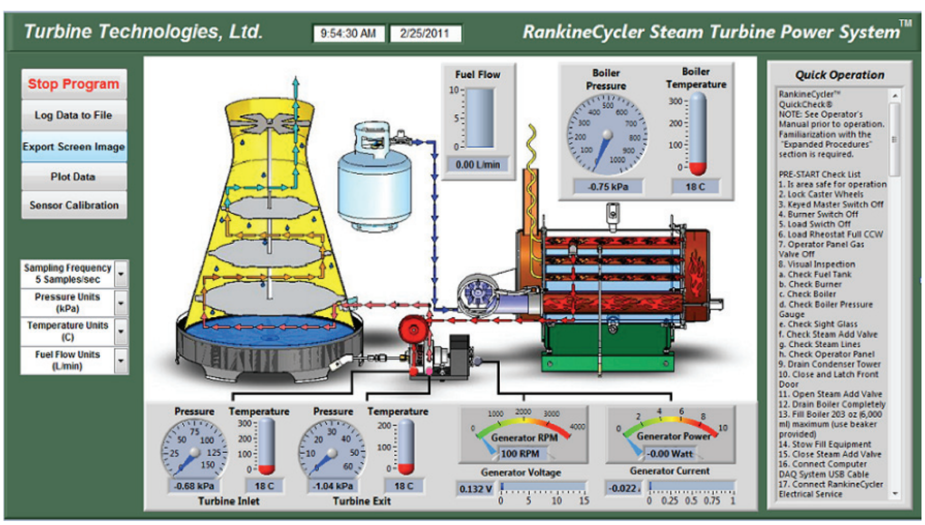


Figure 2.12: Virtual Instrument Panel

Focus 2: Pre-Operation Data Gathering

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

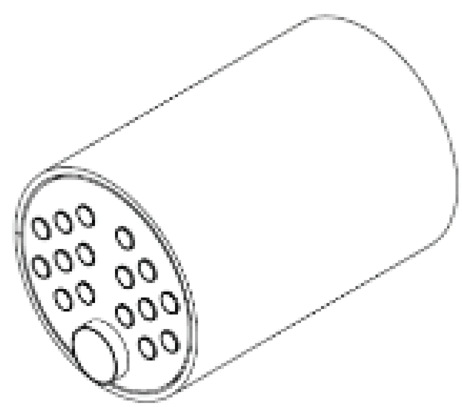
Main Shell Wall Thickness = 0.198 cm

End Plate Outside Diameter = 20.32 cm

End Plate wall thickness = 0.318 cm

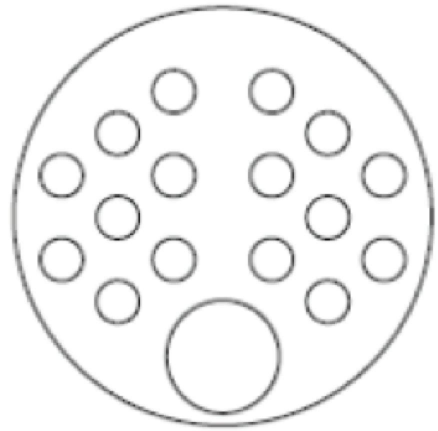
Main Flame Tube Outside Diameter = 5.08 cm

16 Return Pass Flame Tubes Outside Diameter = 1.90 cm



Locate the water level in the boiler if it is filled with 5,500 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?

Number?

If so, what is the significance of this?

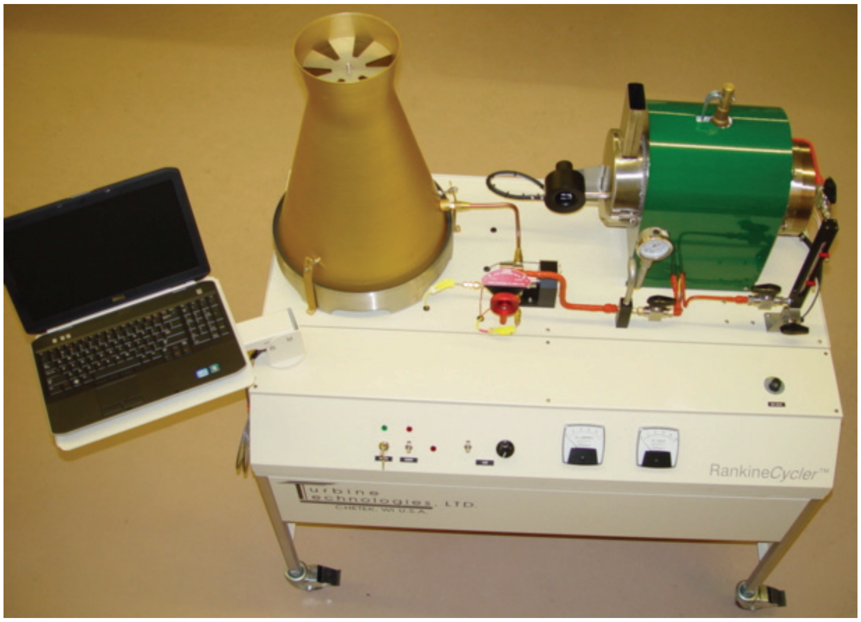
Barometric Pressure

What is the present barometric pressure in your area?

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

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

Knowledge Certification Quiz: Lesson 3



1. *Locate the Components without looking back at your notes:*

A) Boiler System

B) Boiler Water Level Sight Glass

C) Steam Admission Valve

D) Turbine Genset

E) Cooling Tower.

F) DAQ Computer

2. What is the boiler fuel for powering the RankineCycler™?

3. If boiler is filled with 5500mL of water (assuming empty boiler to start with), will there be space unoccupied by water? If so, how much volume?

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

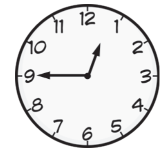
5. How can current atmospheric pressure be easily obtained?

I certify that I have answered all certification quiz questions correctly and am ready for the next lesson.

______________________________ ________________________

Your Signature Date

Approximate
Lesson Duration:
45 min.



Lab Session 1: System Operation

Purpose:

Conduct start-up, operation, data gathering and shut down of RankineCycler™ Steam Turbine Power System.

Procedure:

Utilize RankineCycler™ 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 which is covered on pages 27 and 28 (also covered in Section 4.2.3 Data Collection of the operators manual).

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: ___________________

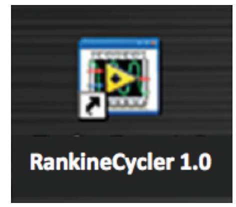
Amount of Condensate Collected from Condenser: ___________________

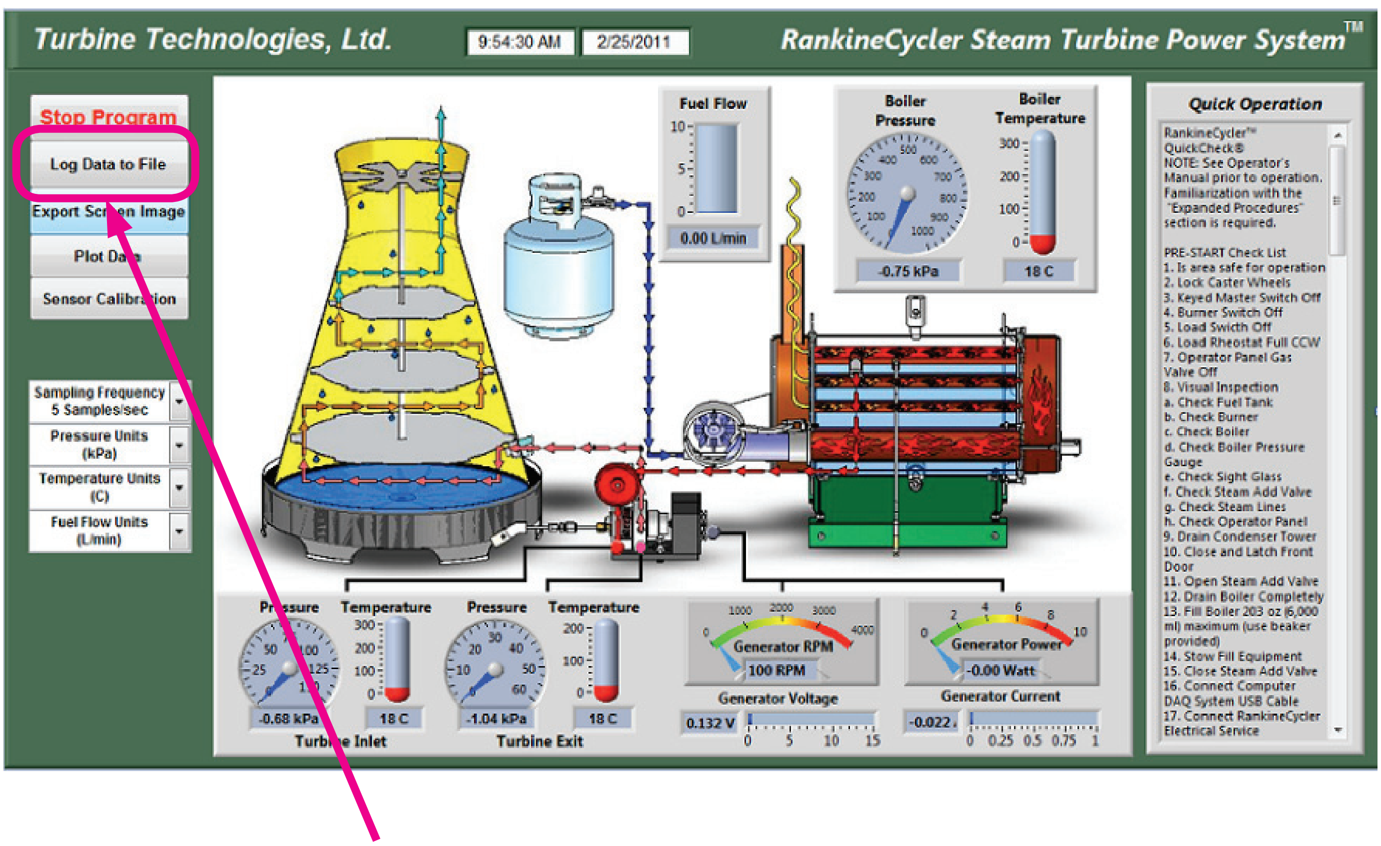
Data Acquisition:

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

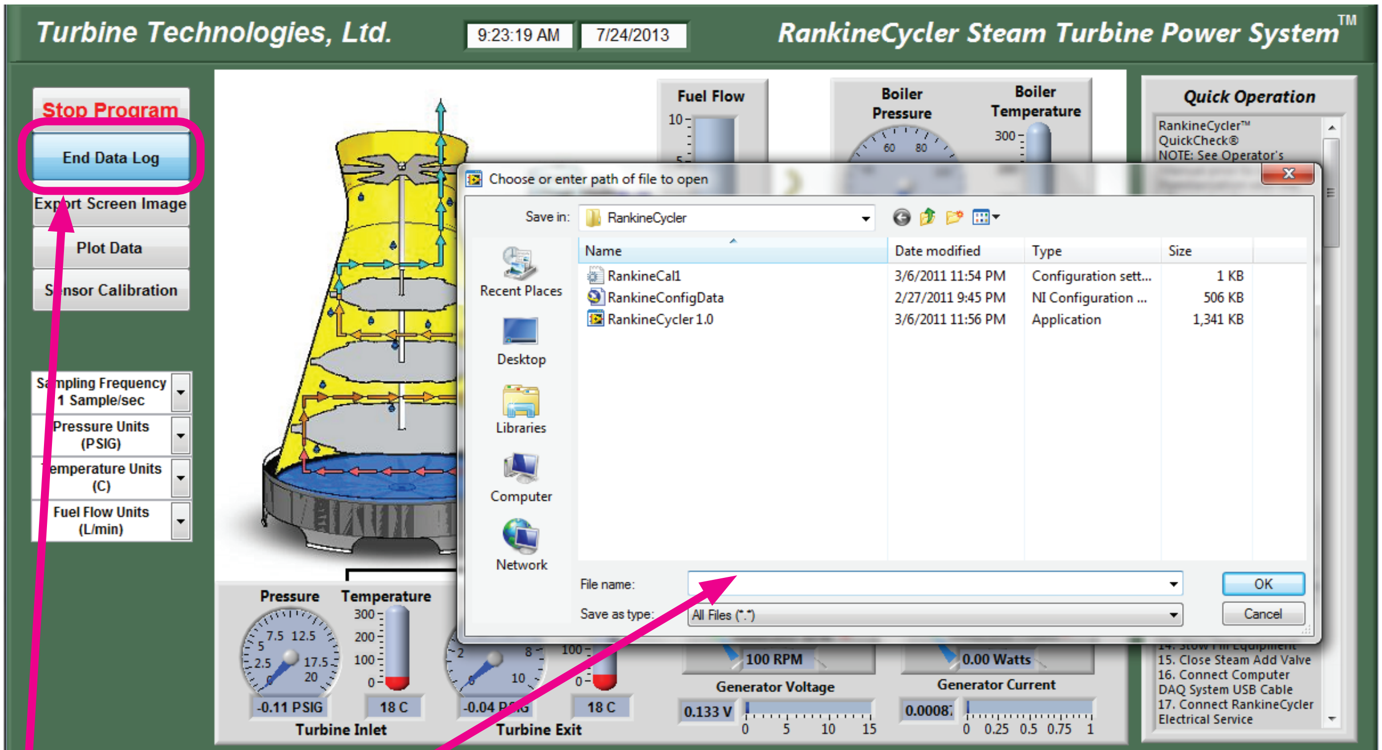
Operation of Lab Unit

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.



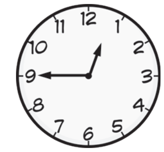


To start logging data, press **Log Data to File** Button



- 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**.

Approximate
Lesson Duration:
45 min.



Lab Session 2: RankineCycler™ Data Run Plots

Purpose:

Graphically plot RankineCycler™ Run Data in preparation for system analysis and performance calculations to be conducted in Lab Session 3.

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:

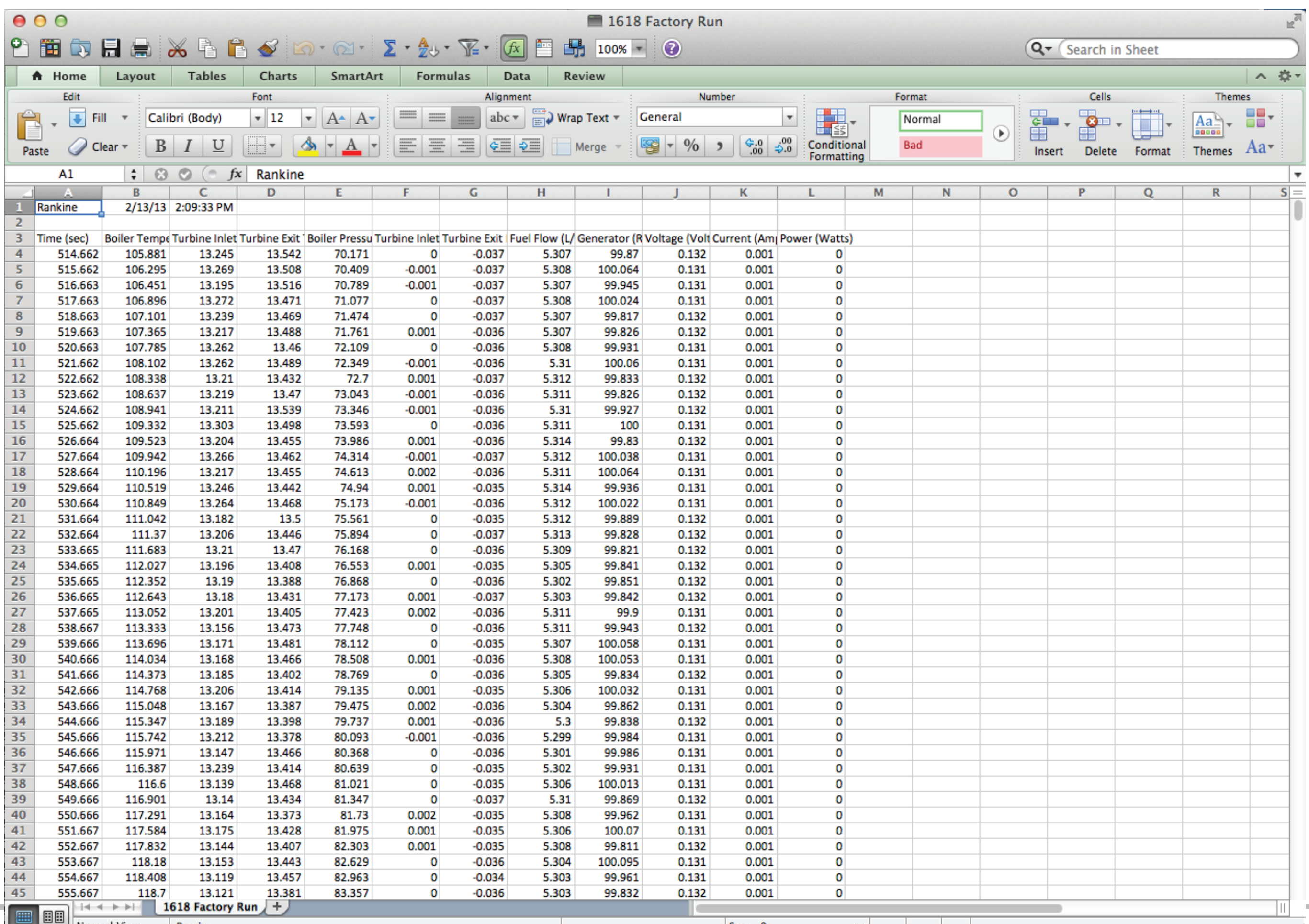
Atmospheric Pressure __________________
Initial Boiler Fill Amount __________________
Fuel Flow_____________
Boiler Pressure _________________
Boiler Temperature __________________
Turbine Inlet Pressure _________________
Turbine Inlet Temperature __________________
Turbine Outlet Pressure ___________________
Turbine Outlet Temperature ___________________
Steady State Condensate Amount _________________
Steady State Boiler Water Use _________________

Importing: Getting Data Into Microsoft Excel

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.

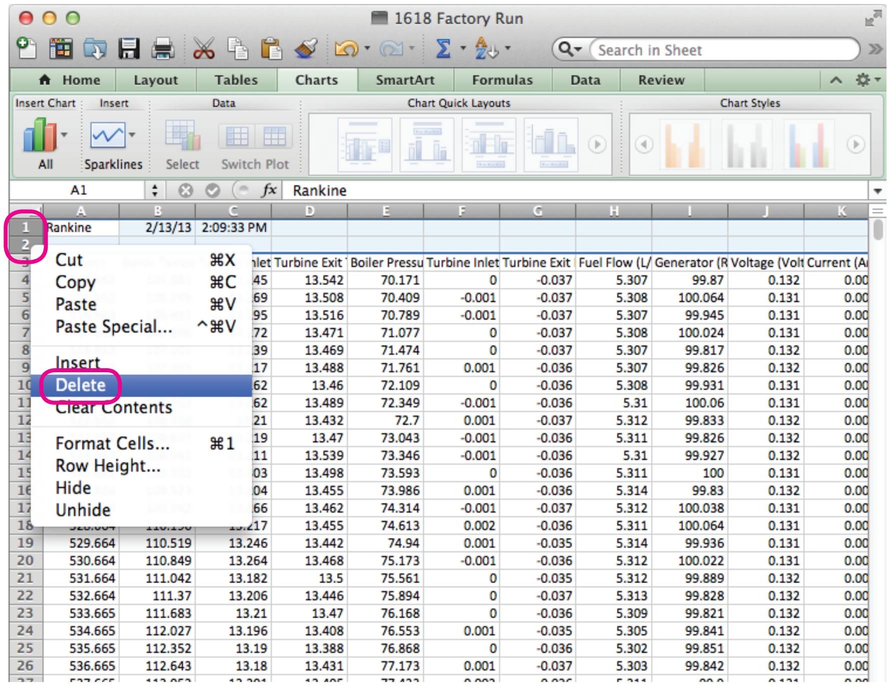
1. Open: MS-Excel on computer desktop
2. Click: **File**
3. Click: **Open**
4. Click: **C-Drive**
5. Click: **Users\Public\Public Documents\Rankine**
6. Click: "**All Files**" under "Files of Type"
7. Select: The **File Name** You Assigned in "Log Data to File"
8. Click: Next (In Text Import Window, Step 1 of 3)
9. Click: Next (In Text Import Window, Step 2 of 3)
10. 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	Rankine	2/13/13	2:09:33 PM									
2												
3	Time (sec)	Boiler Tempe	Turbine Inlet	Turbine Exit	Boiler Pressu	Turbine Inlet	Turbine Exit	Fuel Flow (L/	Generator (R	Voltage (Volt	Current (Am	Power (Watts)
4	514.662	105.881	13.245	13.542	70.171	0	-0.037	5.307	99.87	0.132	0.001	0
5	515.662	106.295	13.269	13.508	70.409	-0.001	-0.037	5.308	100.064	0.131	0.001	0
6	516.663	106.451	13.195	13.516	70.789	-0.001	-0.037	5.307	99.945	0.131	0.001	0
7	517.663	106.896	13.272	13.471	71.077	0	-0.037	5.308	100.024	0.131	0.001	0
8	518.663	107.101	13.239	13.469	71.474	0	-0.037	5.307	99.817	0.132	0.001	0
9	519.663	107.365	13.217	13.488	71.761	0.001	-0.036	5.307	99.826	0.132	0.001	0
10	520.663	107.785	13.262	13.46	72.109	0	-0.036	5.308	99.931	0.131	0.001	0
11	521.662	108.102	13.262	13.489	72.349	-0.001	-0.036	5.31	100.06	0.131	0.001	0
12	522.662	108.338	13.21	13.432	72.7	0.001	-0.037	5.312	99.833	0.132	0.001	0
13	523.662	108.637	13.219	13.47	73.043	-0.001	-0.036	5.311	99.826	0.132	0.001	0
14	524.662	108.941	13.211	13.539	73.346	-0.001	-0.036	5.31	99.927	0.132	0.001	0
15	525.662	109.332	13.303	13.498	73.593	0	-0.036	5.311	100	0.131	0.001	0
16	526.664	109.523	13.204	13.455	73.986	0.001	-0.036	5.314	99.83	0.132	0.001	0
17	527.664	109.942	13.266	13.462	74.314	-0.001	-0.037	5.312	100.038	0.131	0.001	0
18	528.664	110.196	13.217	13.455	74.613	0.002	-0.036	5.311	100.064	0.131	0.001	0
19	529.664	110.519	13.246	13.442	74.94	0.001	-0.035	5.314	99.936	0.131	0.001	0
20	530.664	110.849	13.264	13.468	75.173	-0.001	-0.036	5.312	100.022	0.131	0.001	0
21	531.664	111.042	13.182	13.5	75.561	0	-0.035	5.312	99.889	0.132	0.001	0
22	532.664	111.37	13.206	13.446	75.894	0	-0.037	5.313	99.828	0.132	0.001	0
23	533.665	111.683	13.21	13.47	76.168	0	-0.036	5.309	99.821	0.132	0.001	0
24	534.665	112.027	13.196	13.408	76.553	0.001	-0.035	5.305	99.841	0.132	0.001	0
25	535.665	112.352	13.19	13.388	76.868	0	-0.036	5.302	99.851	0.132	0.001	0
26	536.665	112.643	13.18	13.431	77.173	0.001	-0.037	5.303	99.842	0.132	0.001	0
27	537.665	113.052	13.201	13.405	77.423	0.002	-0.036	5.311	99.9	0.131	0.001	0
28	538.667	113.333	13.156	13.473	77.748	0	-0.036	5.311	99.943	0.132	0.001	0
29	539.666	113.696	13.171	13.481	78.112	0	-0.035	5.307	100.058	0.131	0.001	0
30	540.666	114.034	13.168	13.466	78.508	0.001	-0.036	5.308	100.053	0.131	0.001	0
31	541.666	114.373	13.185	13.402	78.769	0	-0.036	5.305	99.834	0.132	0.001	0
32	542.666	114.768	13.206	13.414	79.135	0.001	-0.035	5.306	100.032	0.131	0.001	0
33	543.666	115.048	13.167	13.387	79.475	0.002	-0.036	5.304	99.862	0.131	0.001	0
34	544.666	115.347	13.189	13.398	79.737	0.001	-0.036	5.3	99.838	0.132	0.001	0
35	545.666	115.742	13.212	13.378	80.093	-0.001	-0.036	5.299	99.984	0.131	0.001	0
36	546.666	115.971	13.147	13.466	80.368	0	-0.036	5.301	99.986	0.131	0.001	0
37	547.666	116.387	13.239	13.414	80.639	0	-0.035	5.302	99.931	0.131	0.001	0
38	548.666	116.6	13.139	13.468	81.021	0	-0.035	5.306	100.013	0.131	0.001	0
39	549.666	116.901	13.14	13.434	81.347	0	-0.037	5.31	99.869	0.132	0.001	0
40	550.666	117.291	13.164	13.373	81.73	0.002	-0.035	5.308	99.962	0.131	0.001	0
41	551.667	117.584	13.175	13.428	81.975	0.001	-0.035	5.306	100.07	0.131	0.001	0
42	552.667	117.832	13.144	13.407	82.303	0.001	-0.035	5.308	99.811	0.132	0.001	0
43	553.667	118.18	13.153	13.443	82.629	0	-0.036	5.304	100.095	0.131	0.001	0
44	554.667	118.408	13.119	13.457	82.963	0	-0.034	5.303	99.961	0.131	0.001	0
45	555.667	118.7	13.121	13.381	83.357	0	-0.036	5.303	99.832	0.132	0.001	0

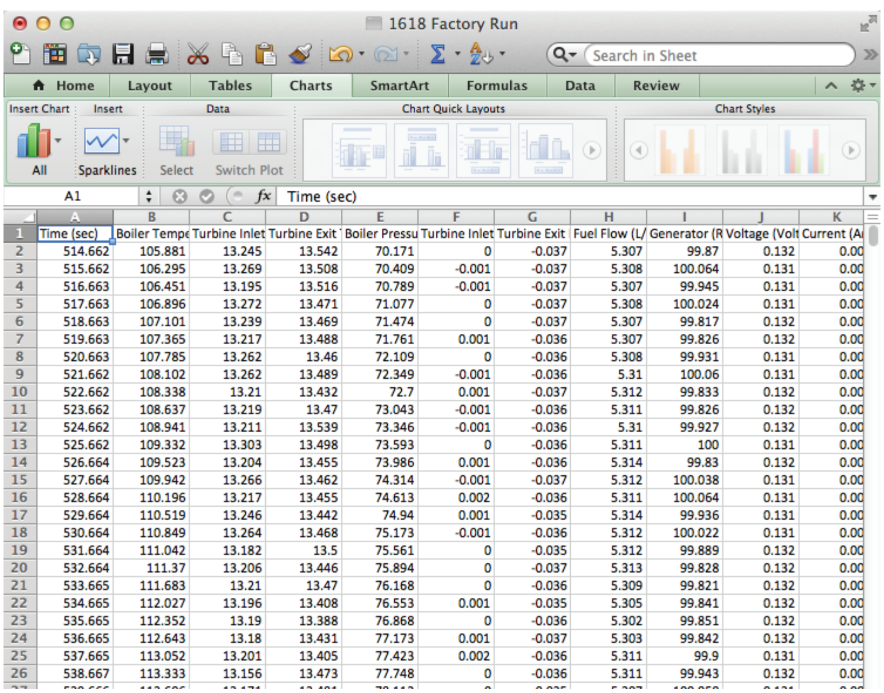
Graphing: Using Microsoft Excel to graph data



First we need to remove rows 1 and 2 from the data import. This will make graphing the data much easier.

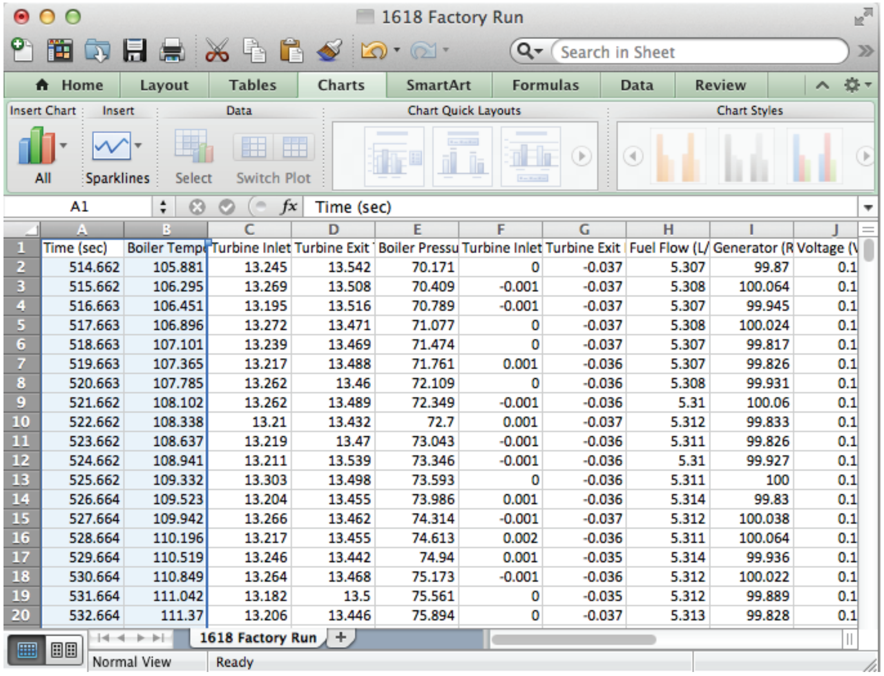
Select the 1 to highlight all of row 1, and hold the **shift key** and select row 2.

This will highlight the entire contents of row 1 and row 2. Right click on the selection and hit delete



You should now have a spreadsheet that looks like this.

We are now ready to begin graphing

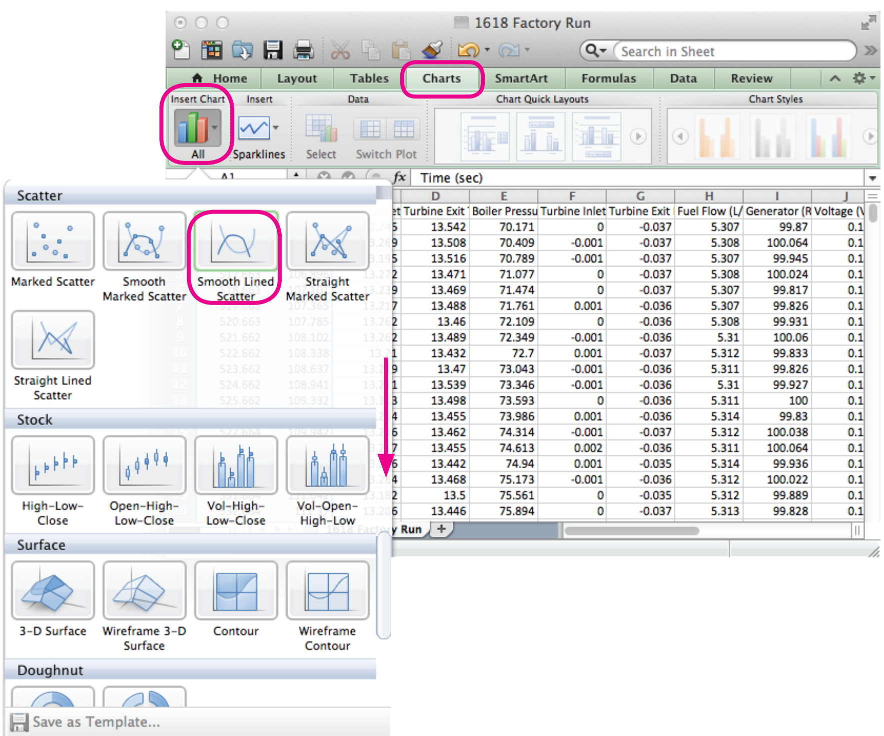


For this example, the Time and Boiler Temperature column data will be plotted.

Highlight the columns of data desired for the graph.

Select the A at the top of column A, and hold the **shift key** and select the B at the top of column B

This will highlight the entire contents of column A and column B. Don't worry about the words in the columns, excel will deselect those automatically and use them for labeling.

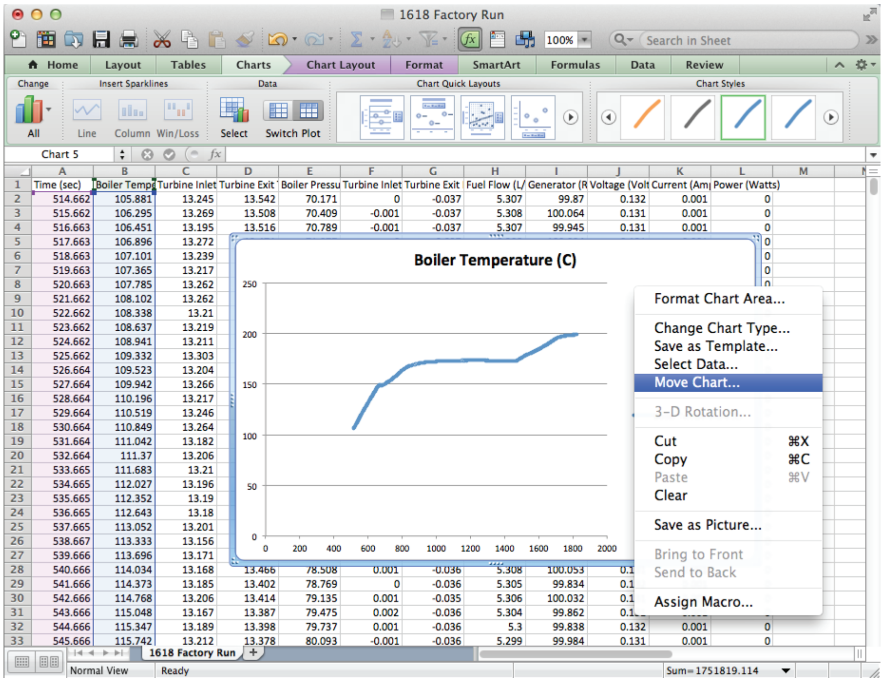


Click **Charts** in the menu bar.

Click the **Insert Chart** icon.

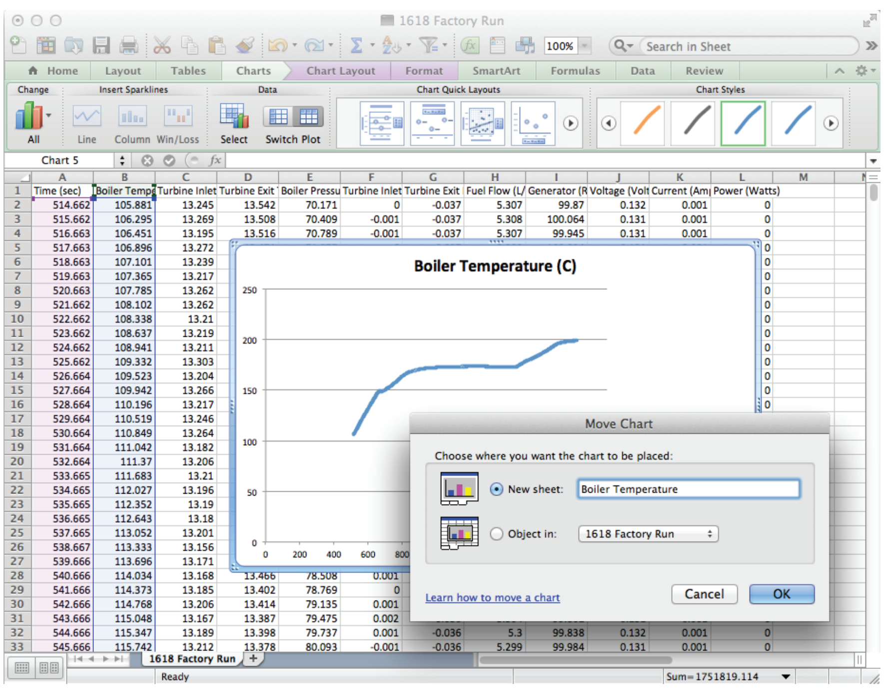
Scroll down to the **Scatter** section.

Select the **Smooth Lined Scatter.**



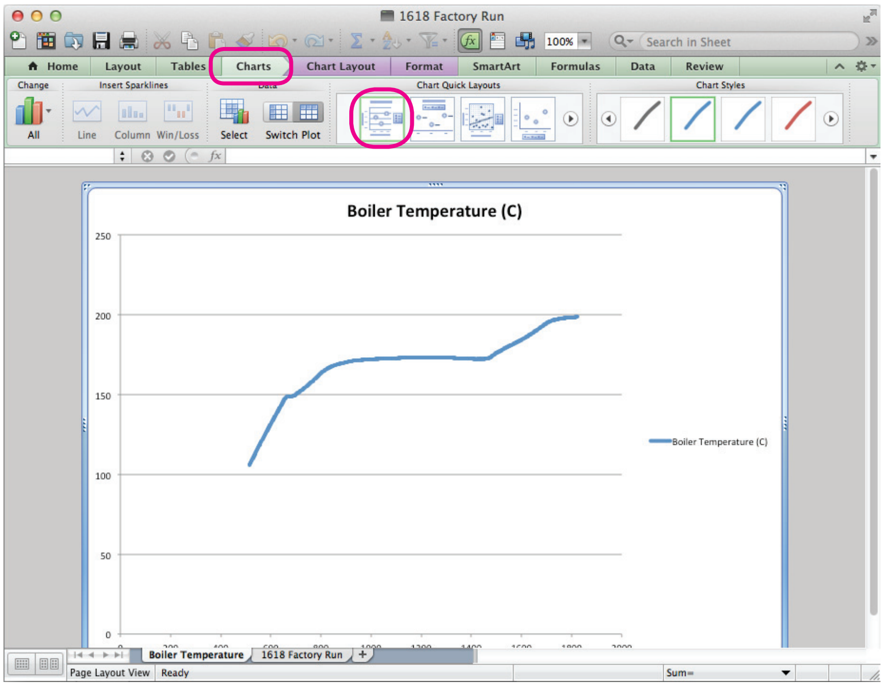
The graph will be placed over the top of your existing spreadsheet.

Right click on the chart and select **Move Chart.**



Within the Move Chart window select **New Sheet.**

Label the new sheet the same as the chart title, **Boiler Temperature.**

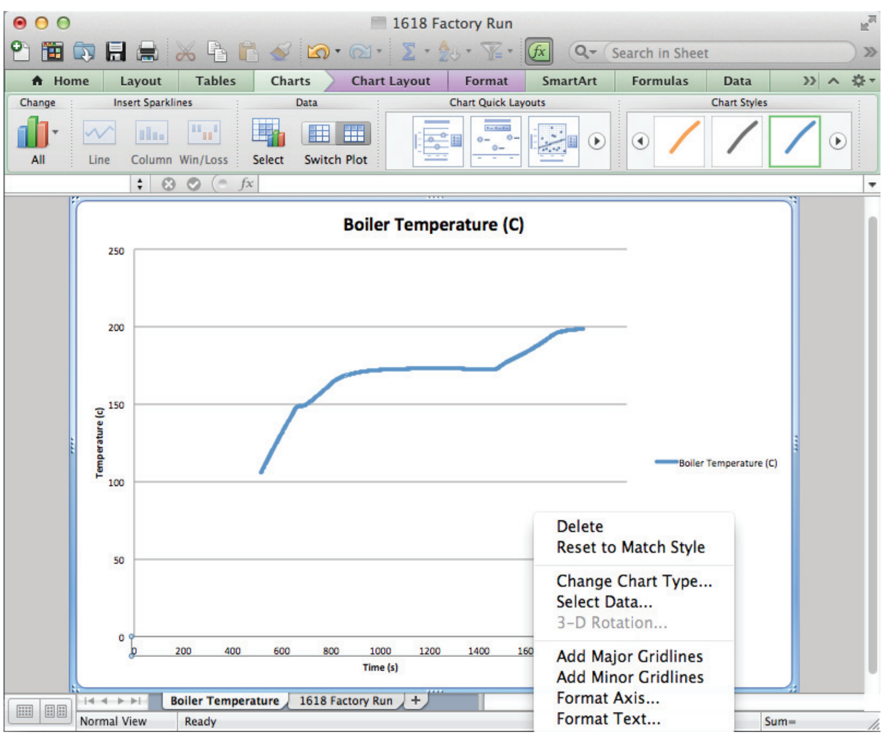


The graph will now be open in a new spreadsheet window.

Click **Charts** from the top menu bar again.

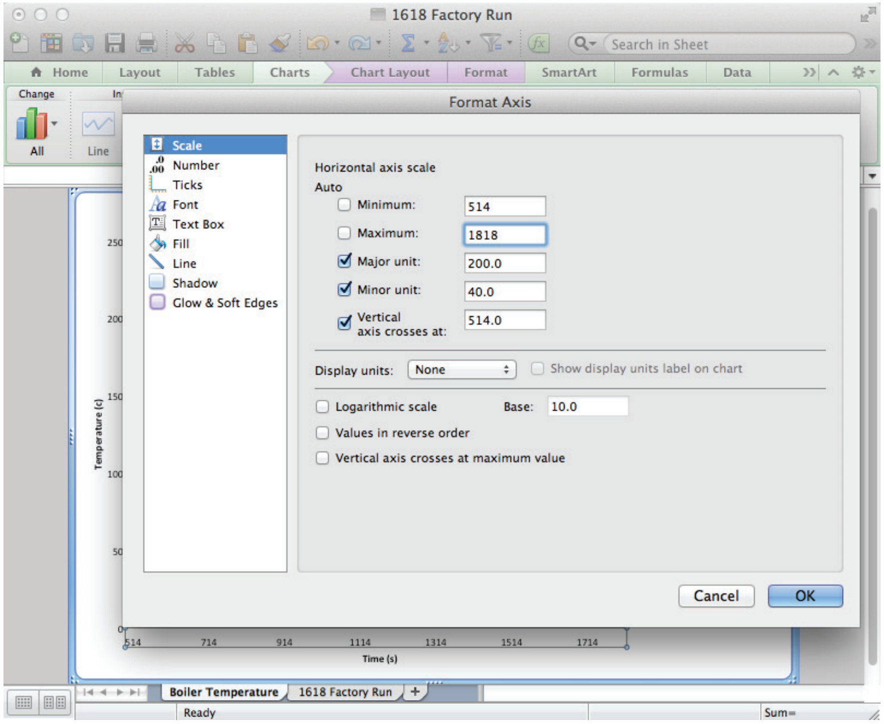
Click **Layout 1** in Chart Quick Layouts section. This will add Axis Titles to your chart.

Click and label the x-axis as Time (s) and the y-axis as Temperature (C)



For this data, the time does not start until 514 s, and ends at 1818 s.

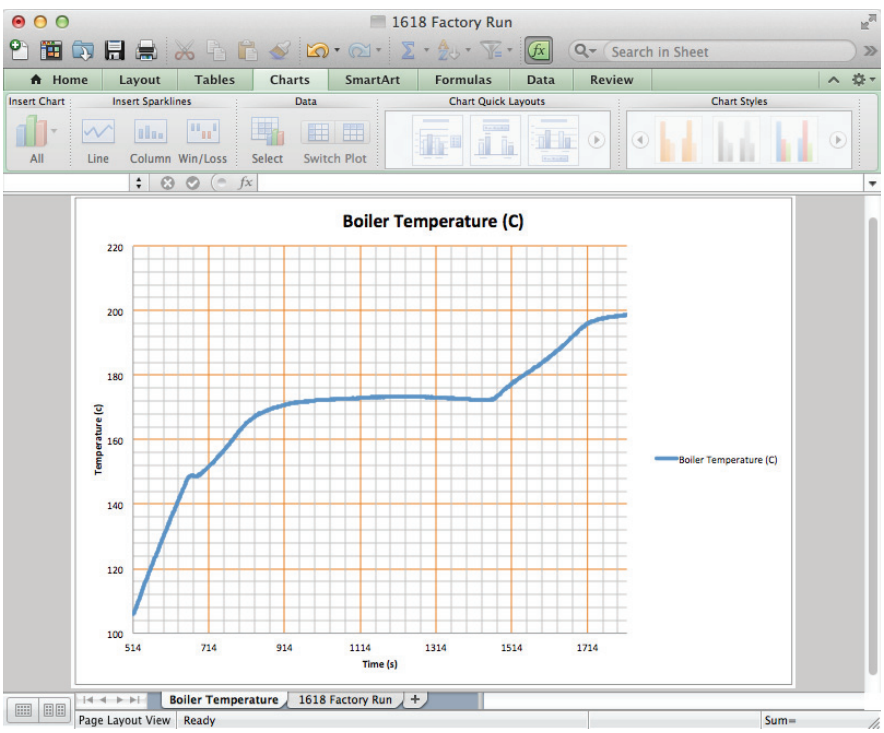
Right click on the x-axis and select **Format Axis.**



We need to set the x-axis minimum and maximum values to 514 and 1818.

Click **OK** and the axis should be formatted correctly

This same process can be done to the y-axis if needed.

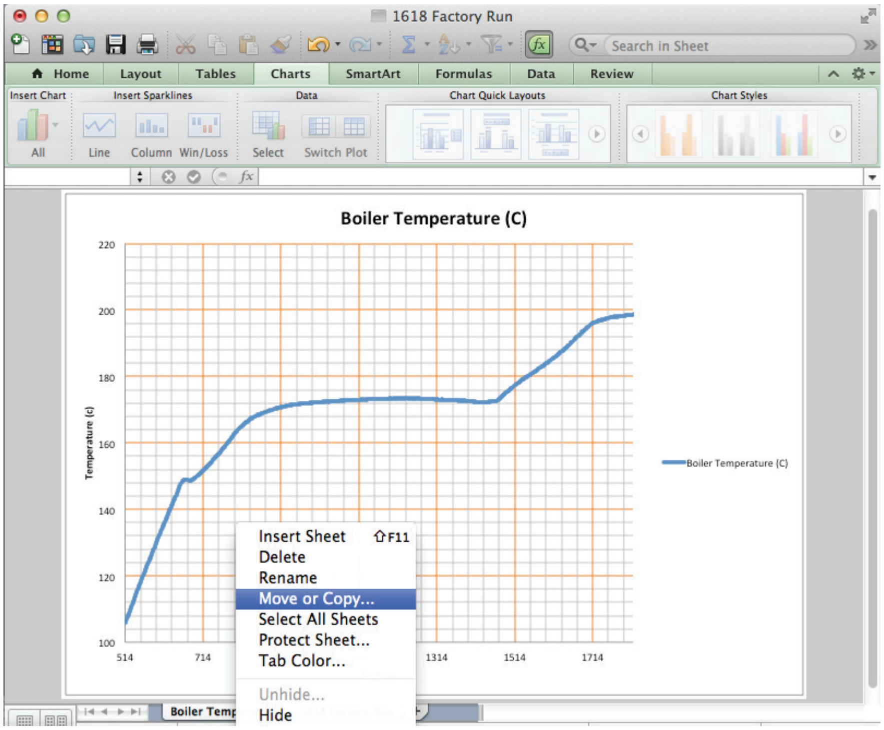


Add gridlines to the data to make it easier for reading datapoint values.

Right click on either axis and add **major gridlines**, **minor gridlines**, or both.

Do this the same for both axes.

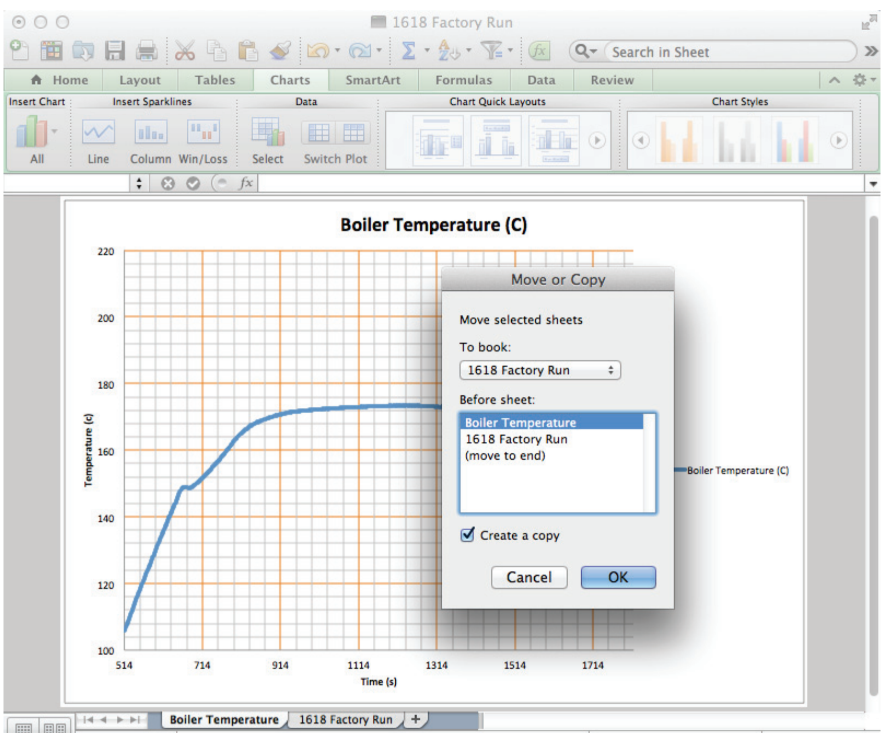
If both gridlines are being used, it is sometimes nice to have the major gridlines a different color.



Now, we need to repeat the previous process over and over until all the data has been graphed. Fortunately, there is a shortcut to finish the remaining graphs.

We have 10 more columns of data for this example, so we will need to make 10 more graphs. Since all of our graphs will be using Time (s) for the x-axis, we can make a copy of the Boiler Temperature graph and update the y-axis accordingly. By making copies, we ensure that all of the graphs will be in a similar format.

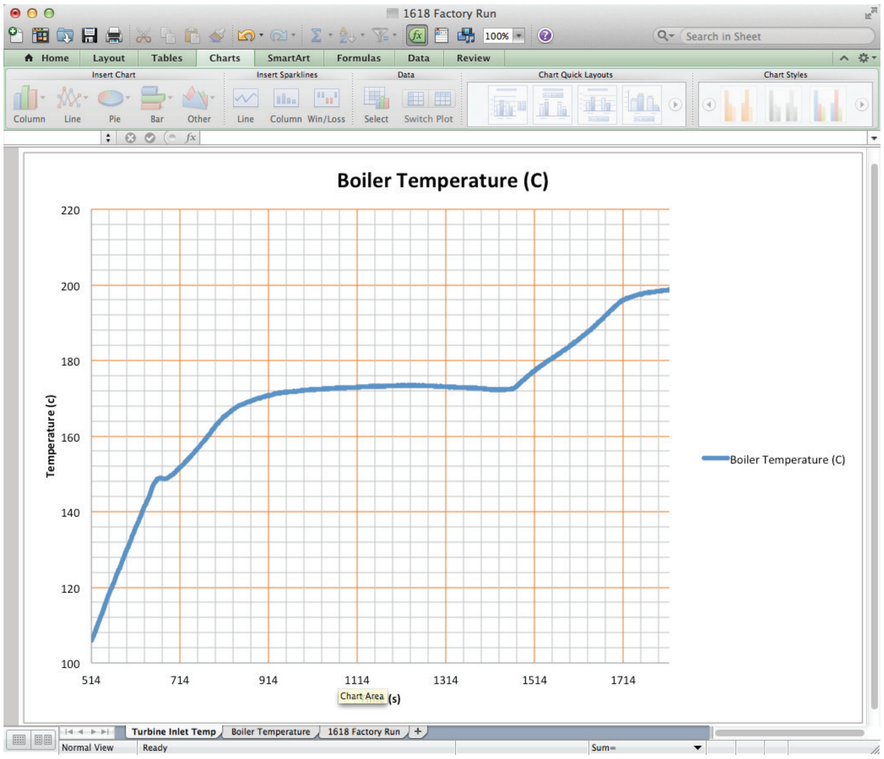
Right click on the Boiler Temperature tab at the bottom of the screen and select **Move or Copy.**



Click the **Create a copy** checkbox.

Click **OK.**

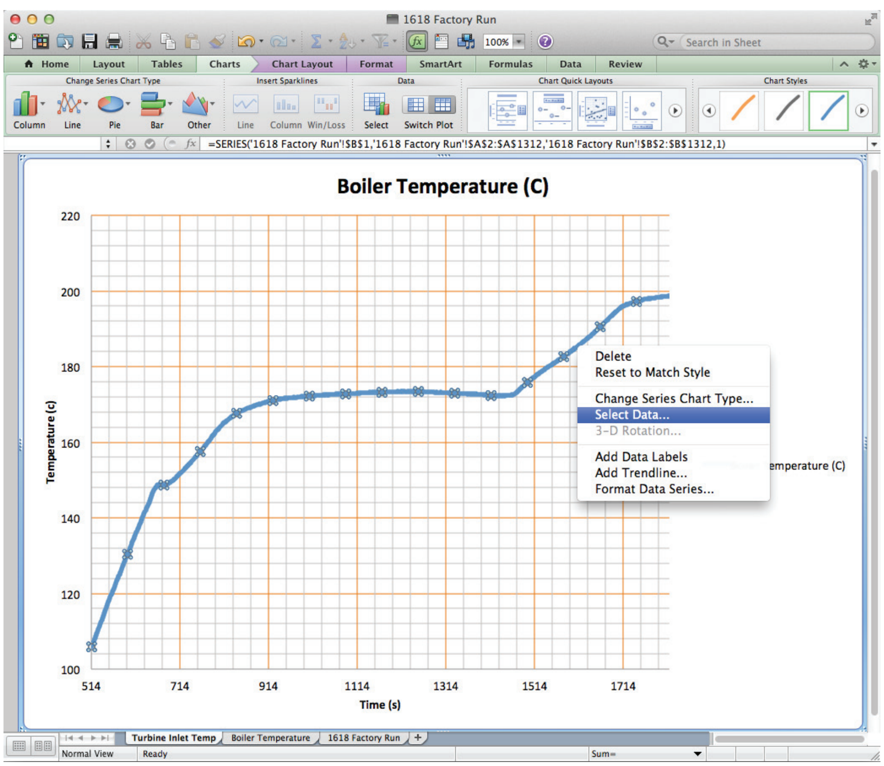
A second copy of our Boiler Temperature graph has been made.



Right click on the new tab Boiler Temperature (2) and select **Rename.**

Change the name of the copy to match the title of column C in the spreadsheet.

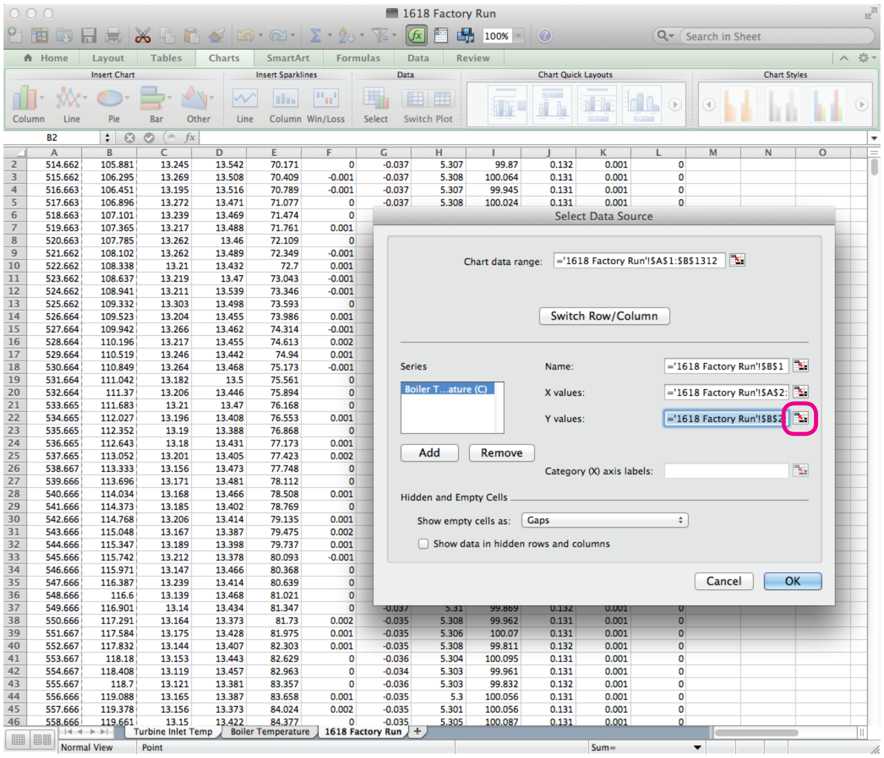
In this case the name was changed to **Turbine Inlet Temp.**



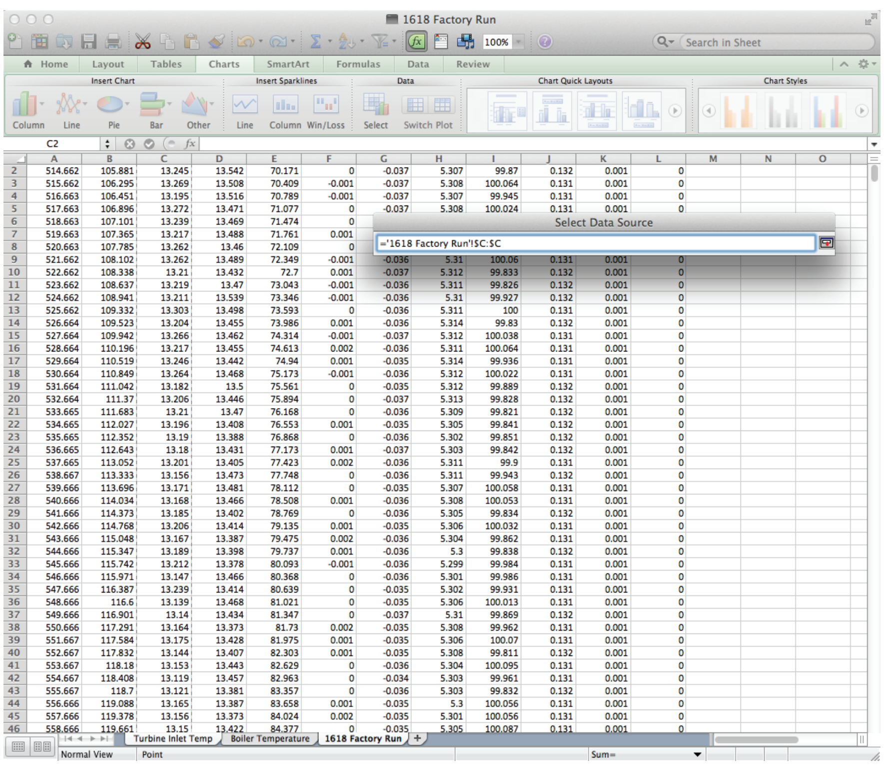
Now all that is left is to change the source data for the graph.

We need to make our new graph plot the correct y-axis values that correspond with Turbine Inlet Temp.

Right Click on the blue line and click **Select Data.**

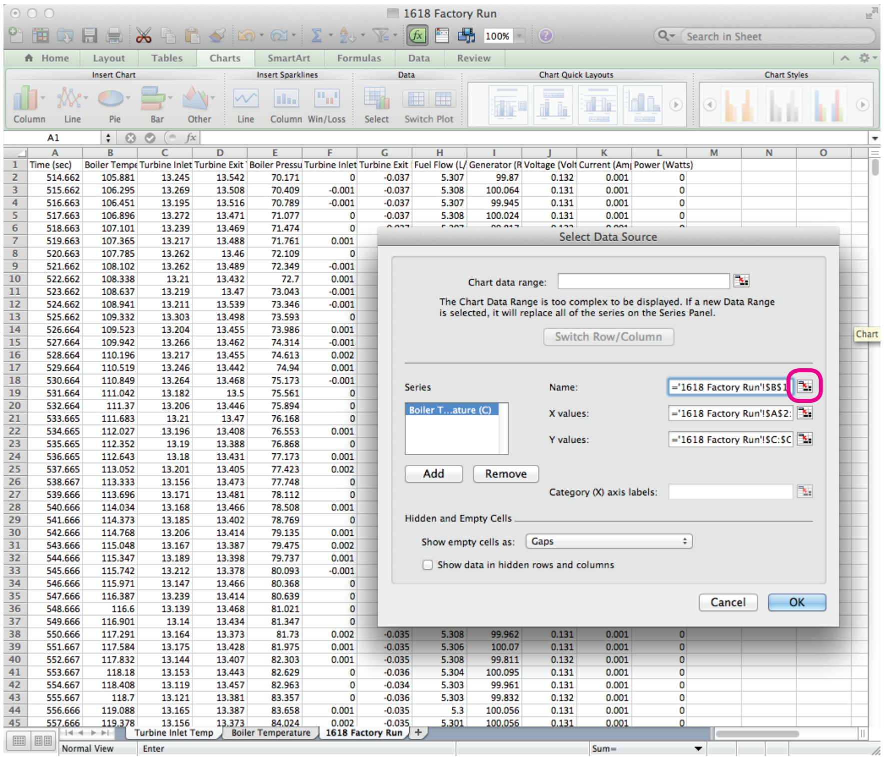


Click on the y-axis **icon** to select new data for the y-axis.



Click on column C to select that data for the y-axis.

Once the desired data is selected, hit **enter.**



Before closing the source data window, we need to update the Name of the chart so that it correctly displays the title from column C.

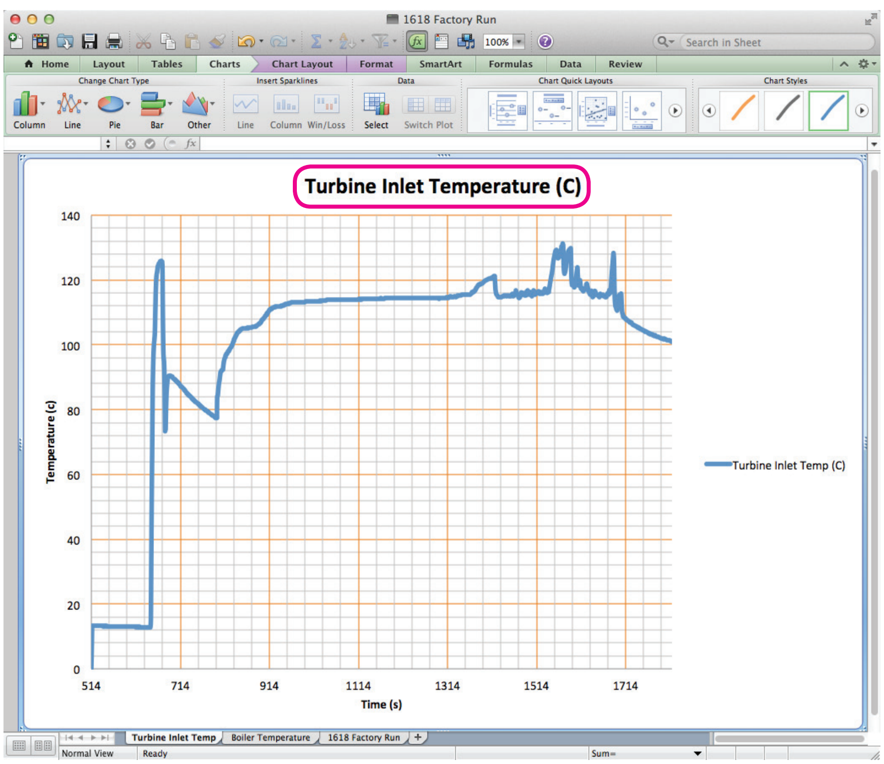
Click on the **Name icon** to select the proper cell from column C that contains the name of the column.

In this case we need to click on cell **C1.**

Hit **enter** to confirm the source and it will take you back to the Select Source Data window.

In this case, we want to keep Time (s) for the x-values so that source does not need to be updated.

Hit **OK** to apply the source changes that we have made.



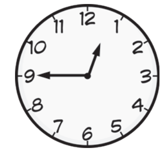
The data and chart key should now be updated to show the Turbine Inlet Temperature graph.

The last step of the copy process is to change the chart Title to **Turbine Inlet Temperature (C).**

We now have a graph for the Turbin Inlet Temperature data.

This copy process can be repeated to produce graphs for all columns of data. You may need to re-adjust the x and y-axis minimums/maximums to correspond with the new data points.

Approximate
Lesson Duration:
45 min.



Lab Session 3: 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.

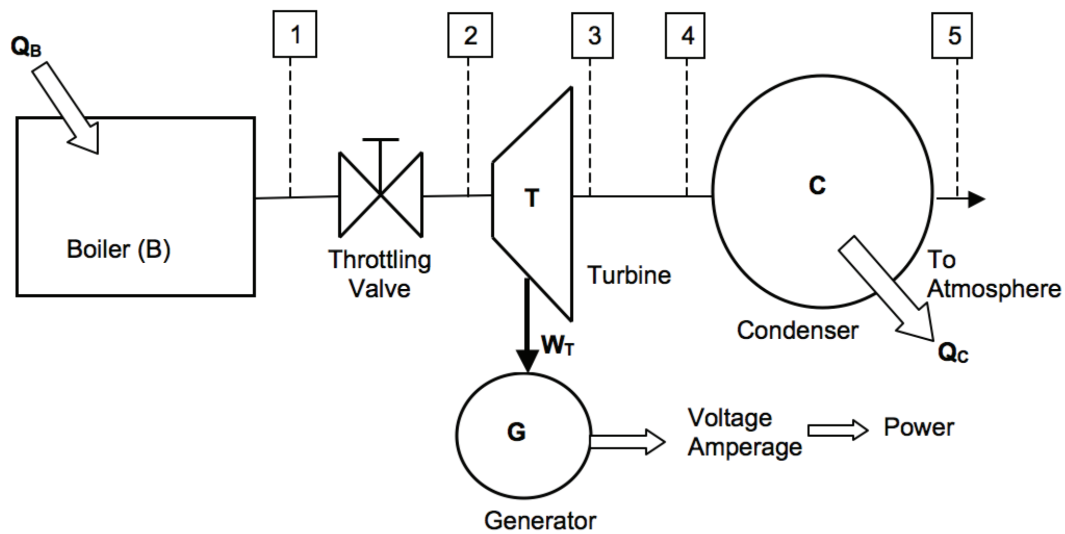
Turbine / Generator (SSSF)

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?



System Mass Flow Rate (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	$P_{Tin} =$
Measured	$T_{Tin} =$
Table	$v_{Tin} =$
Table	$h_{Tin} =$
Table	$u_{Tin} =$
Table	$s_{Tin} =$

3. Turbine Outlet

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

4. Condenser Inlet (Use Tout Data)

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

5. Condenser Outlet (to atmosphere)

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

Turbine Technologies, Ltd., 410 Phillips Street, Chetek, WI, 54728
USA.