MMET 370

THERMODYNAMICS FOR TECHNOLOGISTS

LAB MANUAL

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About the Author

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Preface:

This laboratory will serve three purposes. The first is to provide the students with a practical and basic hands-on knowledge on thermodynamics. The student will learn how to use the laboratory equipment and to measure experimentally the main variables encountered in thermodynamics and heat transfer applications. In addition, the student will have the opportunity to experimentally prove the validity of the laws of thermodynamics and run experiments that deals with thermodynamics cycles.

The second objective of this lab manual is to provide the students with the tools to build computer models of thermodynamic systems. In order to achieve this goal, they will be exposed to EES (Engineering Equation Solver), and will learn how to use it. The students will learn how to deal with thermodynamics properties, unit systems, the use of tables and graphs in EES.

Finally, this laboratory will give students a practical experience on how to record and present experimental data and draw appropriate conclusions.

This lab manual contains experiments that can be classified into three broad categories:

1. Computer experiments, which involve computer modeling using EES or built-in computer simulations on EES.
2. Basic thermodynamics experiments, which will provide a foundation on basic concepts learned in class, such as temperature measurement, power measurement, specific heat of elements and basic mass and energy balance.
3. Thermodynamics Cycles, which involve working with real thermodynamics cycles such as the refrigeration cycle. The students will have the opportunity to use a refrigeration trainer and a mini power plant.

Lab Report Format and Grading Rubric: As mentioned in a separate handout posted on Canvas

Each laboratory experiment will require a group lab report. Please consult the lab report format and rubric handout.

Each computer experiment will require an individual report that should contain the following:

- Discussion: State the problem in your own words.
- Equation: Summary of the equations used in the experiment with explanation.
- Findings: Summary of the experimental data, you could use tables, figures or graphs.
- Conclusions: Interpretation of the findings.

For both computer and laboratory experiments, the emphasis will be on the results and meaningful conclusions.

Grading Policy: Grading Rubric: As mentioned in a separate handout posted on Canvas

Report writing is a group effort. The group members are expected to meet and discuss the results and questions for every lab. If the group feels that a particular member did not contribute towards the report they should not include his/her name on it. If a student is absent for the lab, but contributes towards writing the report, he/she will not be assigned a grade for the lab. A make-up lab could be arranged for a legitimate leave of absence (such as medical or university excused absence), but this is totally up to the discretion of the lab instructor.

EES Tutorial

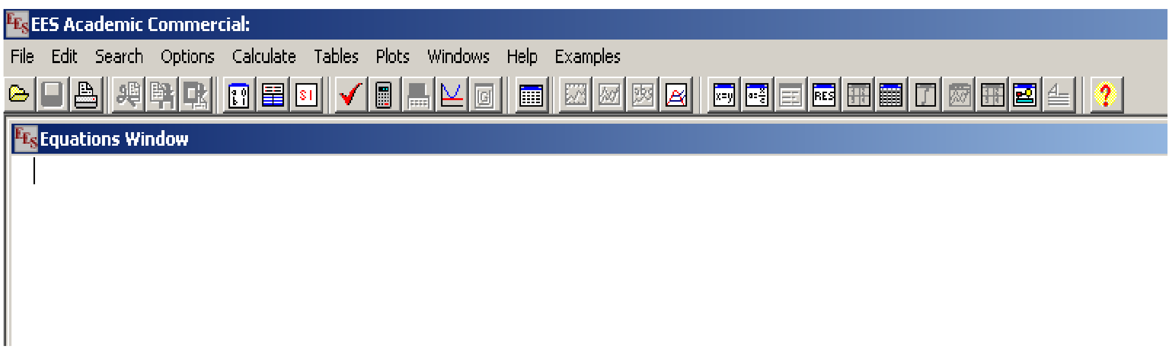
Introduction

EES stands for Engineering Equation Solver. EES allows entering the equations to be solved in any order; it is not necessary to write the equations with the unknown in an explicit way. Also EES has many built in functions that are particularly suitable to solve engineering thermodynamics problems, among them are system units checking and a comprehensive thermo physical properties database.

In addition, EES provides tools to work with parametric, dynamic tables and a variety of graph capabilities that can be used in design and analysis task. Finally, EES allows us to add functions, procedures and sub-programs in a structured language similar to FORTRAN and link it with programs developed in C++, FORTRAN, etc.

Starting EES

To start the program select start, programs and click the EES icon. Also, you can go to windows explorer, program files, EES and start EES. You should have a screen similar to the following



EES has a menu bar with the following menus: **File, Edit, Search, Options, Tables, Plots, Windows, Help, and Examples**. Below the menu bar is the tool bar with icons of the commonly used functions. In the **Equations Window**, we type the equations to be solved

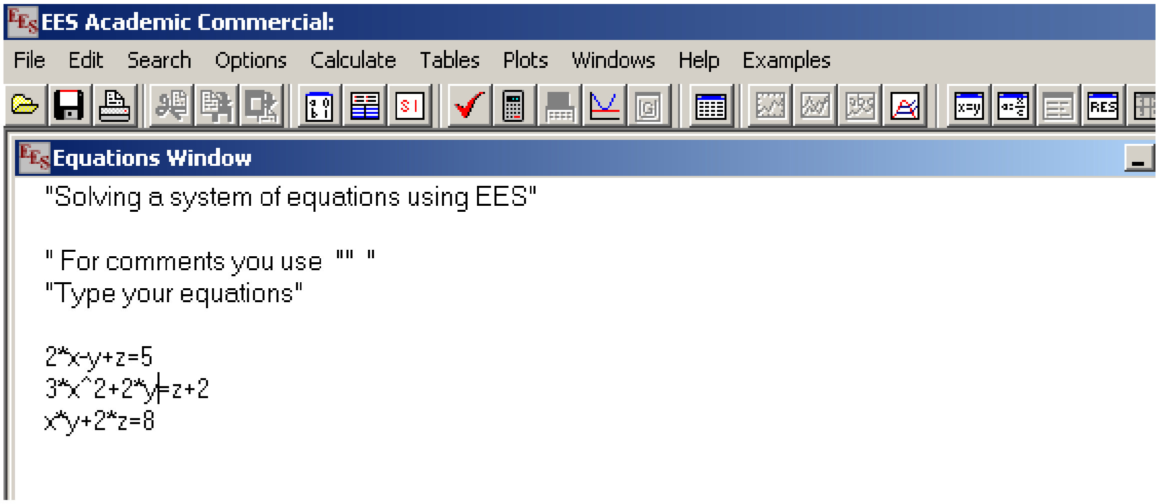
Example

- Solve the following system of equations in EES:

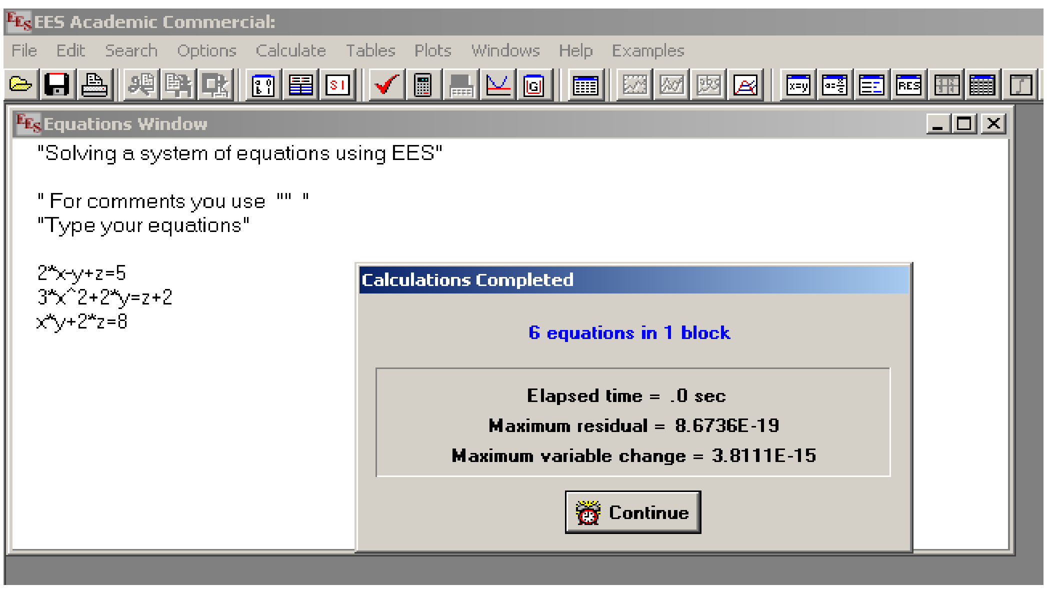
$$2x - y + z = 5$$
$$3x^2 + 2y = z + 2$$
$$xy + 2z = 8$$

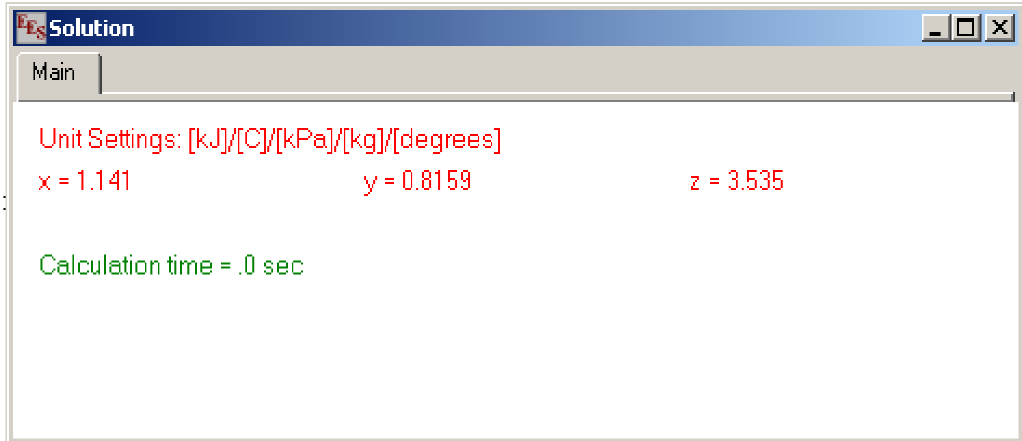
Solution

- Type the equations in the **Equations Window**.

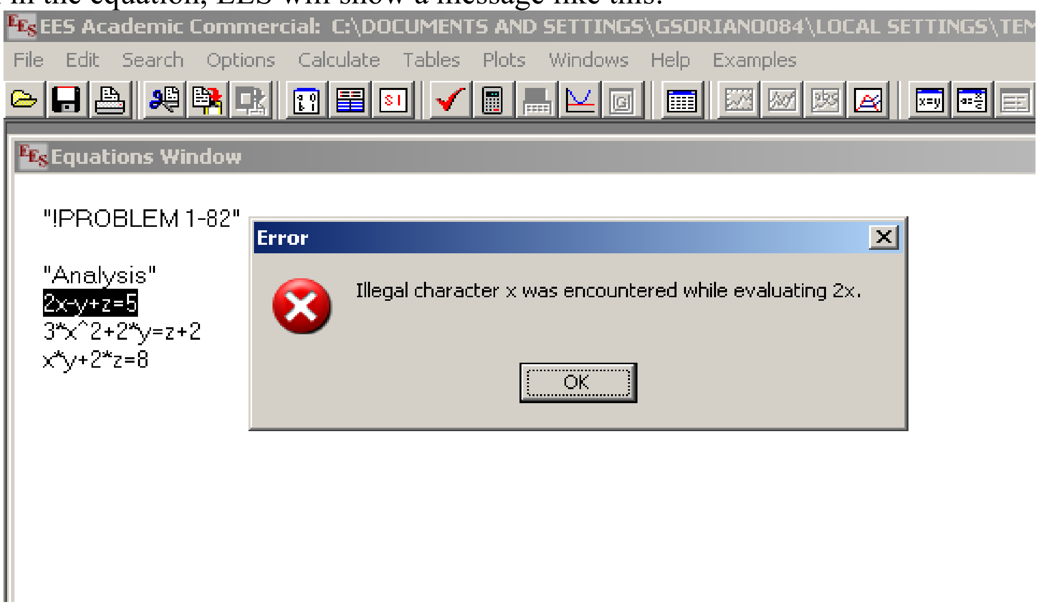


To obtain the solution, we just press **F2**:

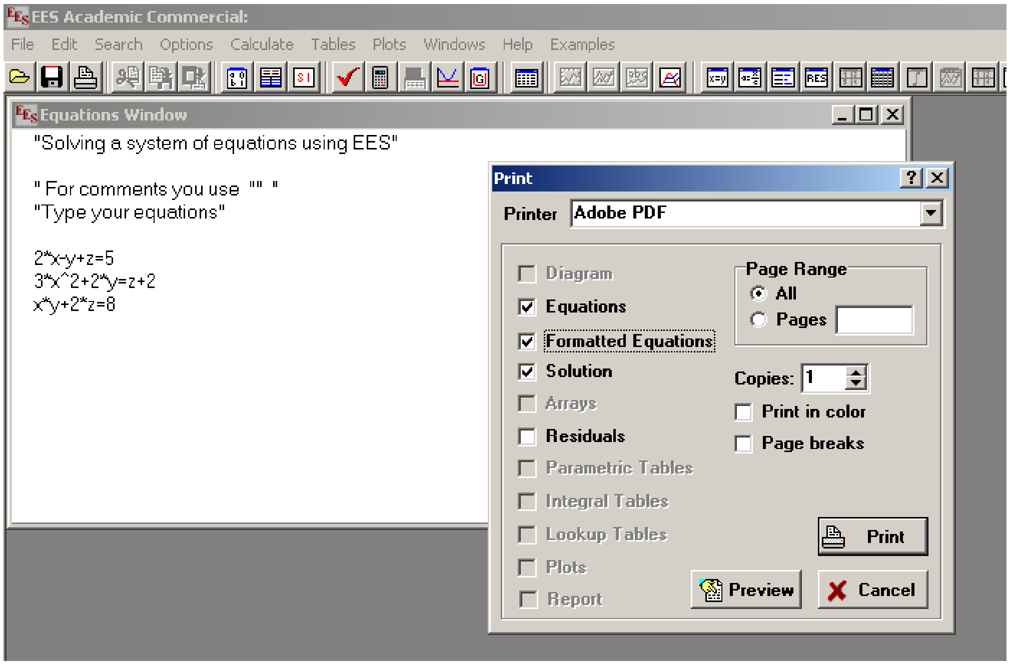




If we make a syntax error while typing the equations such as forgetting to include the multiplication symbol in the equation, EES will show a message like this:

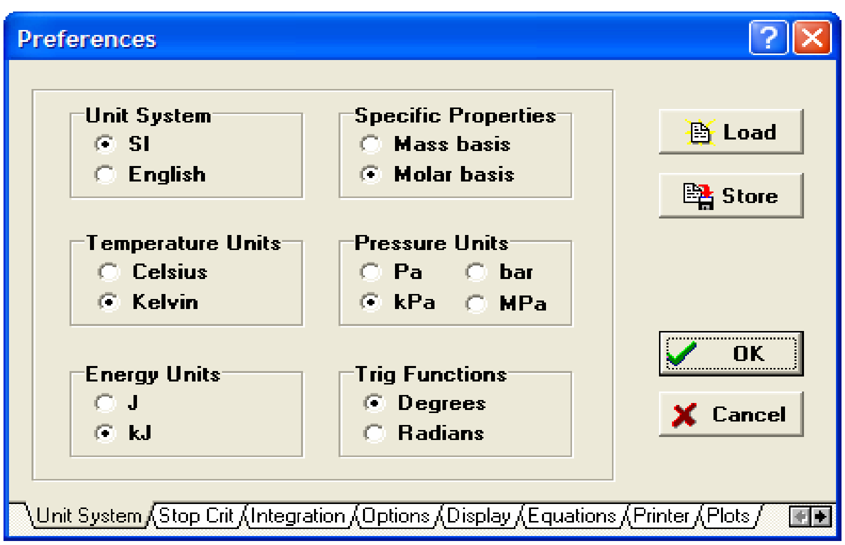


In order to print the equations and solutions, select the menu **File**, **Print** and select what you want to print. EES gives you the choice to print the equations, solutions, tables and graphs that you have created.

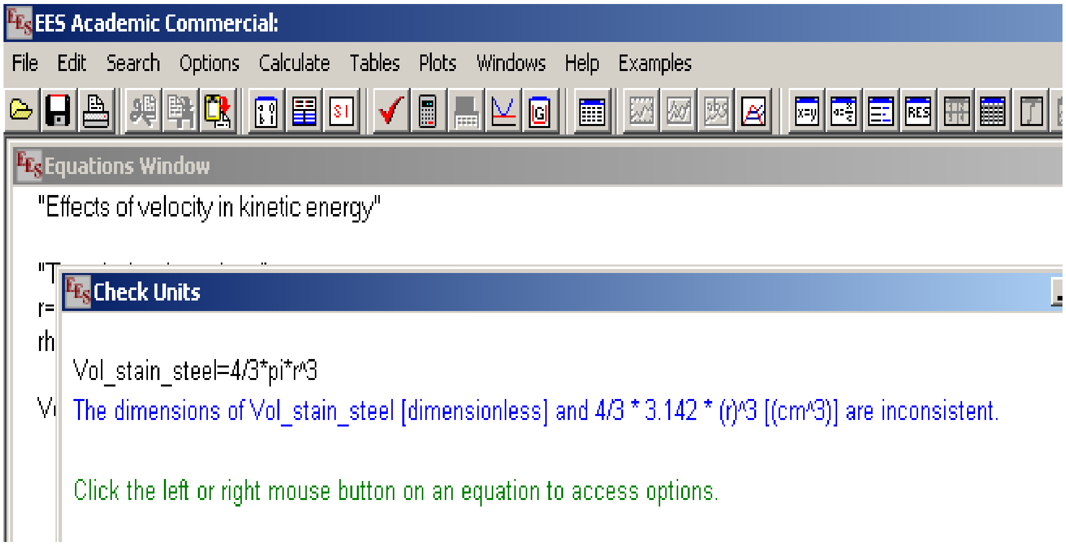


Working with units:

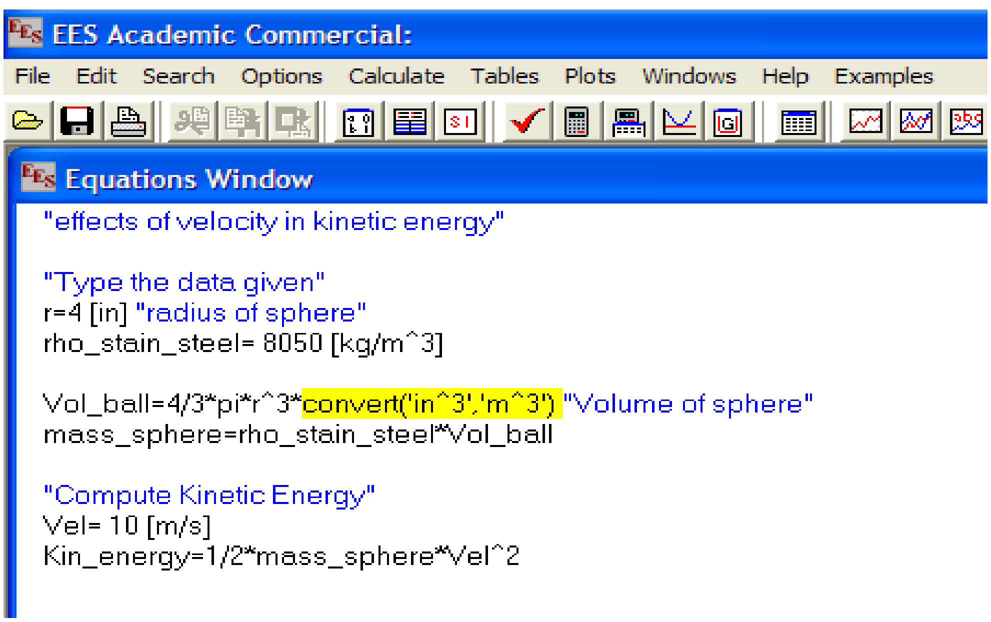
EES gives you the option to select the system of units of your choice. Simply go to the **Options** menu and select Unit system of your choice:



We can check the consistency of units by pressing **F8** or the menu **Calculate**, check units. EES will tell us of any inconsistency in the use of units, we just have to specify the units in the screen **Check Units** by right clicking on the equation and selecting variable units:



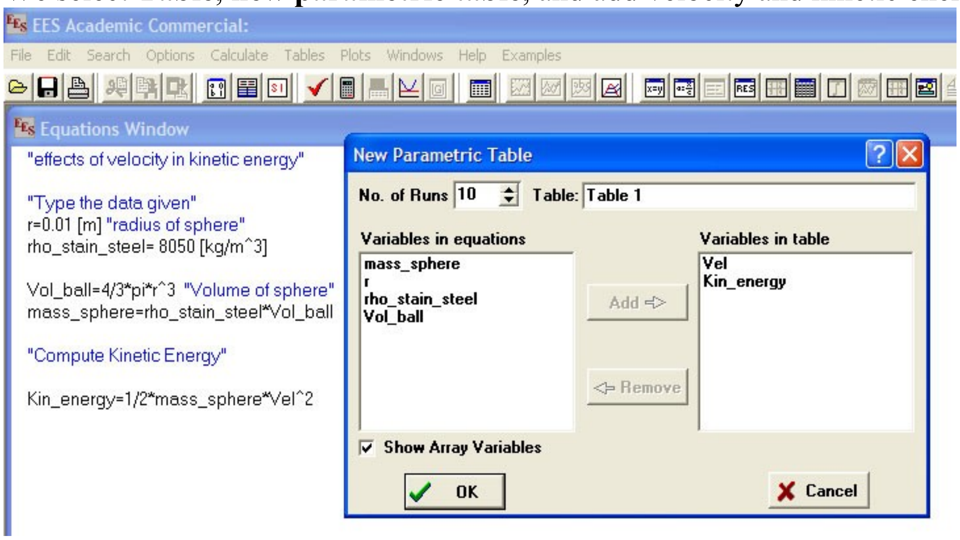
In case our data is given in different unit system, we can use the command convert with the following format: **Convert ('units given', 'units desired')**



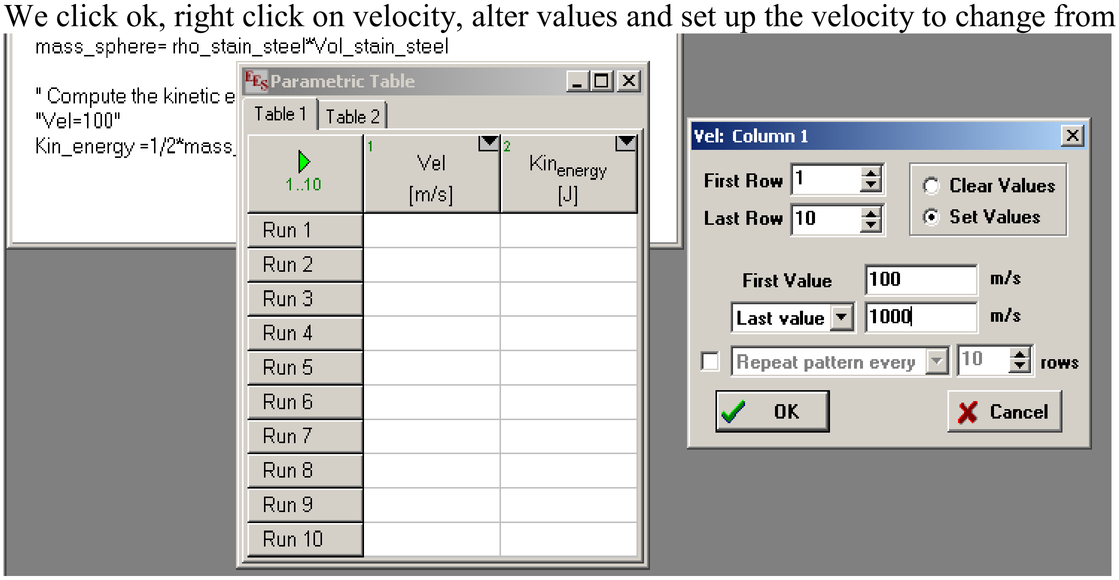
Parametric Tables and Graphs:

The use of parametric tables and graphs is better presented with an example:

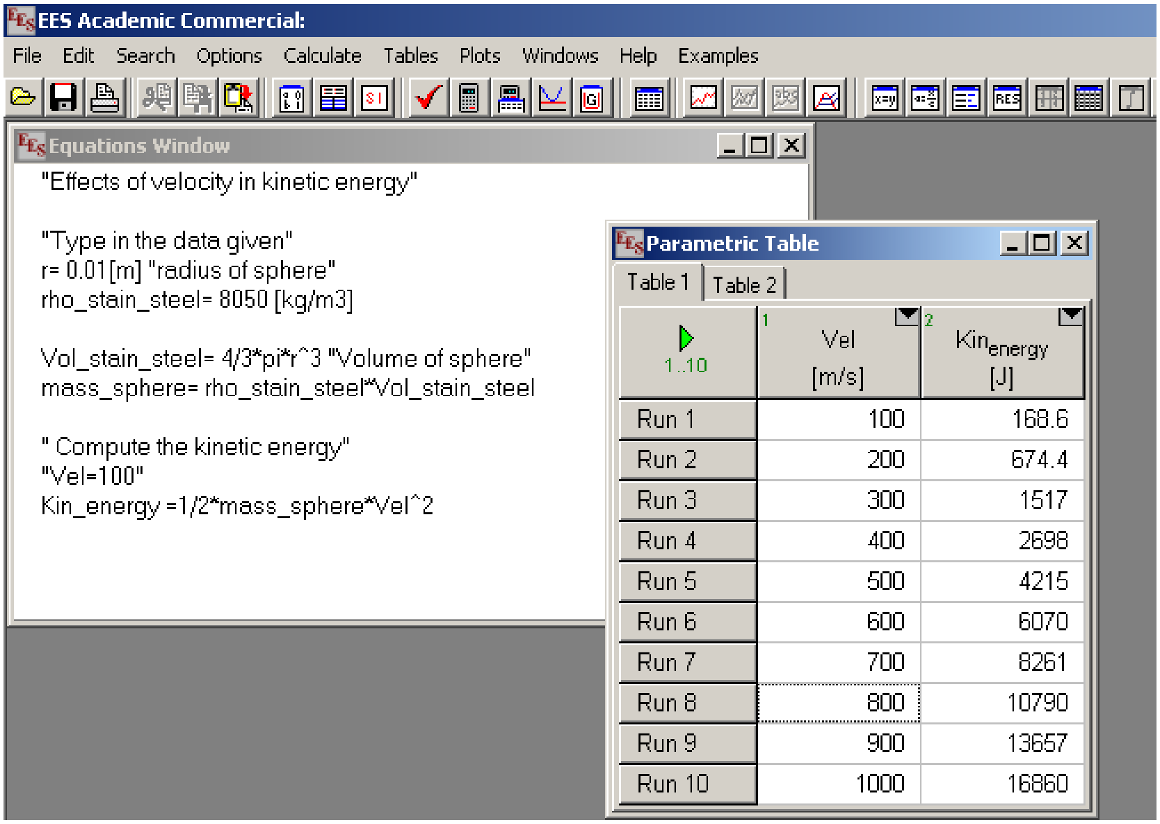
Suppose we would like to investigate the effect of change in velocity from 100 m/s to 1000 m/s, on the kinetic energy of a ball made of stainless steel with a diameter of 10 cm.
Since it is impractical to manually change the value of velocity from 100 to 1000 m/s, we are going to use a parametric table.
First, we type the equations but leave the velocity unspecified.
We select **Table**, **new parametric table**, and add velocity and kinetic energy as the variables in the table:



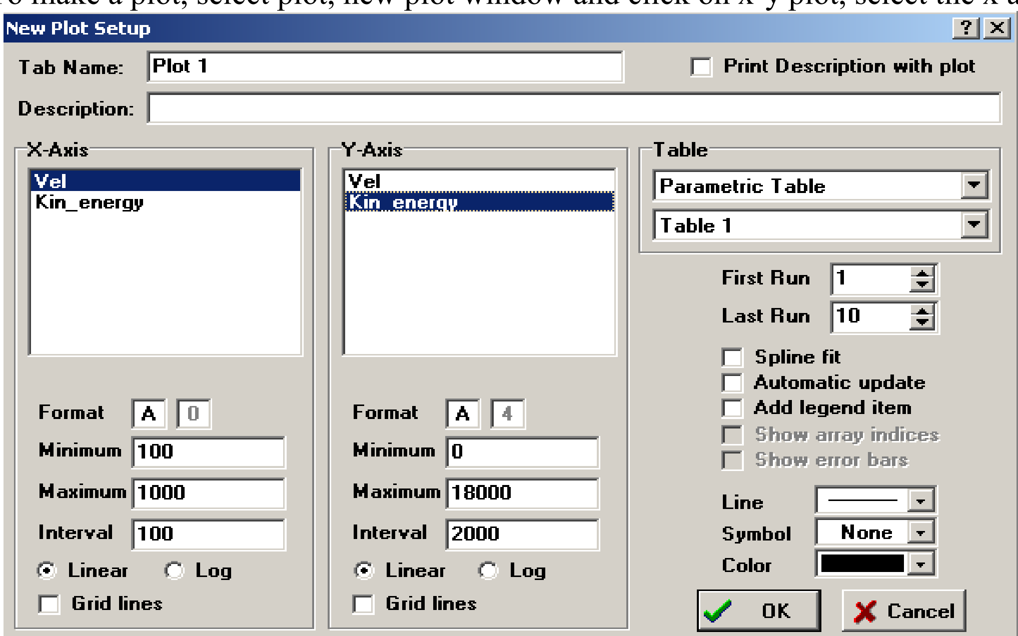
We click ok, right click on velocity, alter values and set up the velocity to change from 100 to 1000 m/s



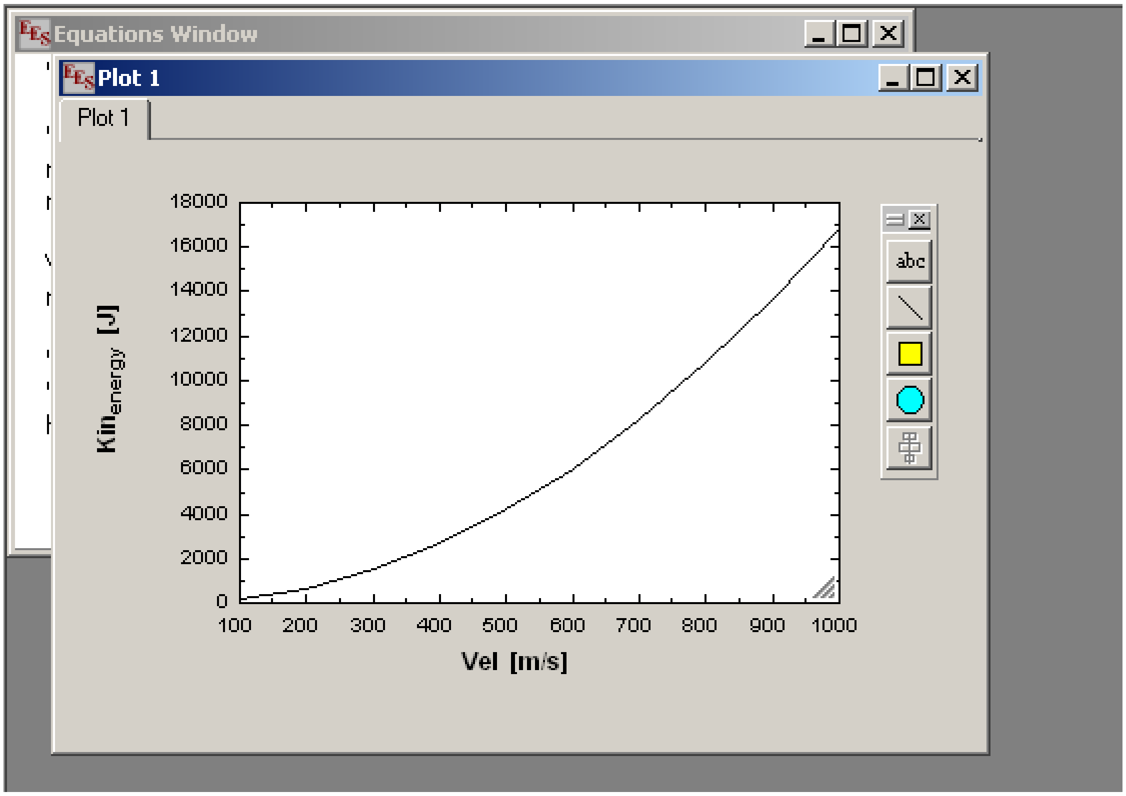
Next, press the green arrow and EES will automatically fill the values of kinetic energy:



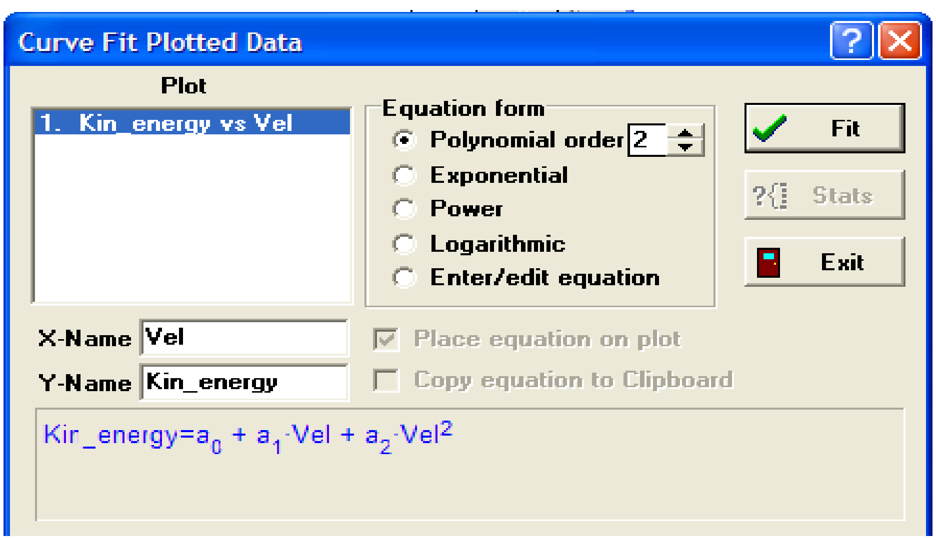
To make a plot, select plot, new plot window and click on x-y plot, select the x and y axis.



And we obtain the desired plot:

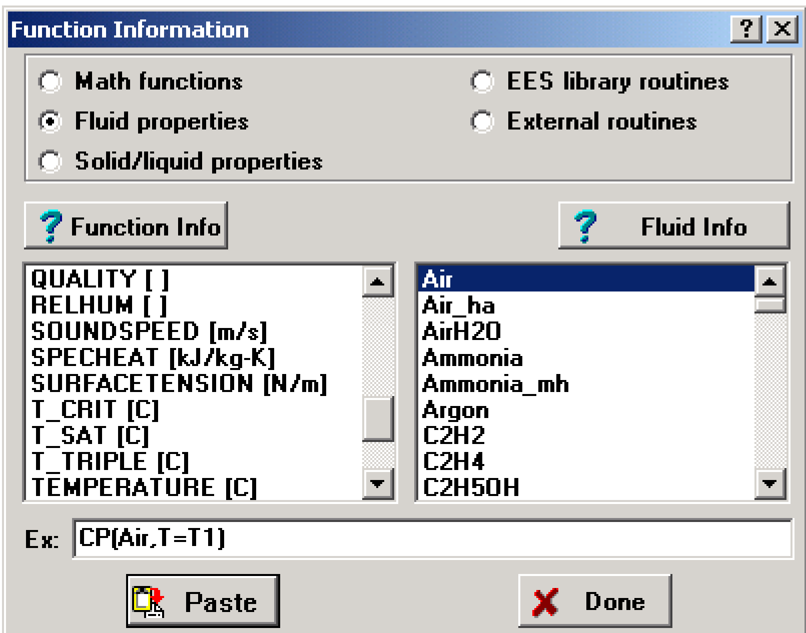


EES also gives us the capability to make a curve fit simply by going on **Plots** and **curve fit**. We can get the fit and the statistical parameters of the fit with the button **Stats**. Also we can place the equation on the plot:



Thermophysical Properties in EES

EES provides thermophysical properties of a wide variety of fluids that are found in engineering applications. In order to access the properties database, in the menu **Options**, select **Function Info** and the following window will appear.



Select the fluid and property of interest, and paste it to the equation window.

Experiment 1: Data Fitting Techniques (Least Square Method)

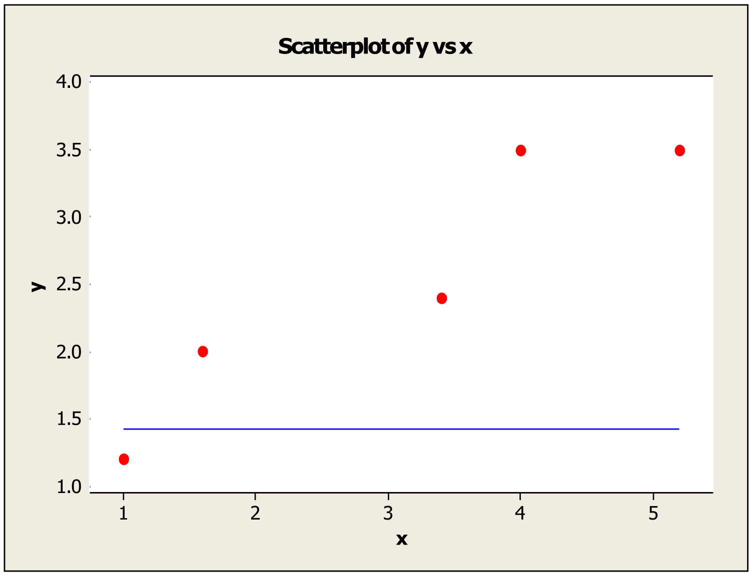
EES Activity

Objective:

- To understand the basics of data fitting techniques, specifically the least square method.
- To obtain a mathematical model for the given data sets.

Theory:

Suppose that we measured two variables over a range of values and seek an equation of the form: y=a•x +b



y	x
1.2	1.0
2.0	1.6
2.4	3.4
3.5	4.0
3.5	5.2

We look to minimize the following quantity S, which is the squared difference of measured and calculated data:

$$S = \sum_{i=1}^{n} \left[y_i - (ax_i - b) \right]^2$$

In order to find the coefficients a and b that best represent the data, we minimize the squared difference by setting its derivative with respect to a and b to zero:

$$\frac{dS}{da} = 0 \,, \quad \frac{dS}{db} = 0$$

Performing the corresponding algebra, we obtain the following equations:

$$a = \frac{n\sum x_i y_i - \left(\sum x_i\right)\left(\sum y_i\right)}{n\sum x_i^2 - \left(\sum x_i\right)^2}$$

$$b = \frac{\left(\sum y_i\right)\left(\sum x_i^2\right) - \left(\sum x_i y_i\right)\left(\sum x_i\right)}{n\sum x_i^2 - \left(\sum x_i\right)^2}$$

In order to assess how well the mathematical model fits the data, we use the correlation coefficient R:

$$r = \left[1 - \frac{\sigma_{y,x}^2}{\sigma_y^2}\right]$$

where :

$$\sigma_y = \left[\frac{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}{n-1}\right]$$

$$\sigma_{y,x} = \left[\frac{\sum_{i=1}^{n}\left(y_i - y_{ic}\right)^2}{n-2}\right]$$

$\bar{y}$ = mean of y population

y_{ic} = value of y computed from correlation equation

n = size of population

Procedure:

For a given set of data (provided by the instructor), perform the following:

- Fit the data using EES and the following models:
  - Y= a*x +b
  - Y= a* exp(b*x)
  - Y=a*x^2+bx+c
- Select model with the highest correlation value
- Fit the data using EES with the model you selected in the previous step.

<u>Please attach the in-class calculation Table (handouts) in the lab report that will be submitted (if applicable and instructed).</u>

Experiment 2: Properties of Pure Substances

EES Activity

Objectives:

- To use EES database to find thermophysical properties of engineering fluids.
- To enforce the concepts of thermodynamics properties

Theory:

In the scope of MMET 370, we are only going to deal with pure substances. Pure substances can be classified in two categories. The first category comprises substances with fixed chemical compositions such as water, hydrogen, and nitrogen. The second category includes the homogenous mixture of various chemical elements or components; air is included in this category. It is worth to point out that heterogeneous mixtures such as oil and water cannot be modeled as pure substances.

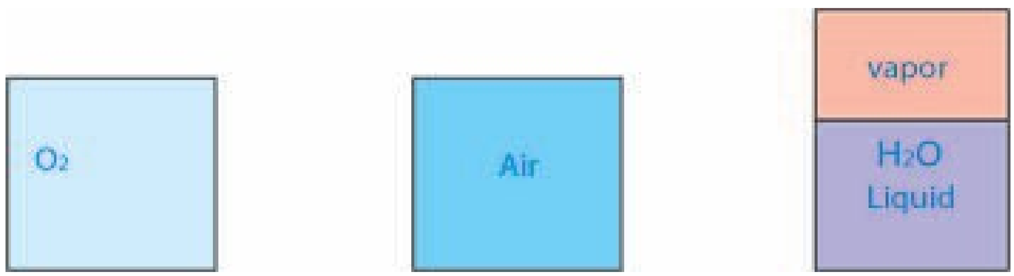


Figure 1: Pure Substances

A pure substance can exist in three different phases: solid, liquid and gas. It is important to point out that in certain conditions, two phases can coexist. It is possible to find liquid and gas phase coexisting in the evaporator and condenser of a refrigerator or in the boiler of a steam power plant.

The properties of a substance can be classified as intensive and extensive properties. Intensive properties are the ones that are not dependent on the mass of the substance; among intensive properties we have temperature and pressure. Extensive properties depend on the mass of the substance; examples of extensive properties are Volume and Total Energy. It is possible to change an extensive property into an intensive property by specifying the property per unit mass (specific property).

A state of a substance is completely specified by two independent properties. This means that given two independent properties, we can find all the other properties of the substance at this state. If the substance is in a single phase, pressure and temperature are the most common independent properties. In the case the substance has two or more phases in equilibrium, pressure and temperature are no longer independent. When we are dealing with gas and liquid mixtures, the quality of the mixture (mass fraction of vapor) is an independent property that should be used with either pressure or temperature in order to specify the state of the substance.

Procedure:

- Solve a thermodynamics problem involving computing thermodynamic properties (text of the problem provided by the instructor). The problem must be solved using the manual calculation method as well as EES to show the comparison of results obtained through the calculation process. Show each step of the problem solution involving EES by taking snapshots of the screen and pasting in the lab report.

Experiment 3: Four-stroke Gasoline & Diesel Engine (Otto & Diesel Cycle) Lab Activity

Objective:

The objective of the experiment is to understand the operation of a four-stroke petrol (gasoline) and diesel engine. The four-stroke internal combustion engine makes use of the theoretical Otto & Diesel Cycle. These are the most commonly used thermodynamic cycles in engines for many industrial and automotive applications. In order to familiarize students with the core engine performance evaluation parameters and procedures, a comprehensive engine test will be carried out along with simultaneous data recording using a DAQ display panel. With these parameters and procedures one can gain insight on the general characteristics of the Otto & Diesel cycle as well as the performance of a particular engine.

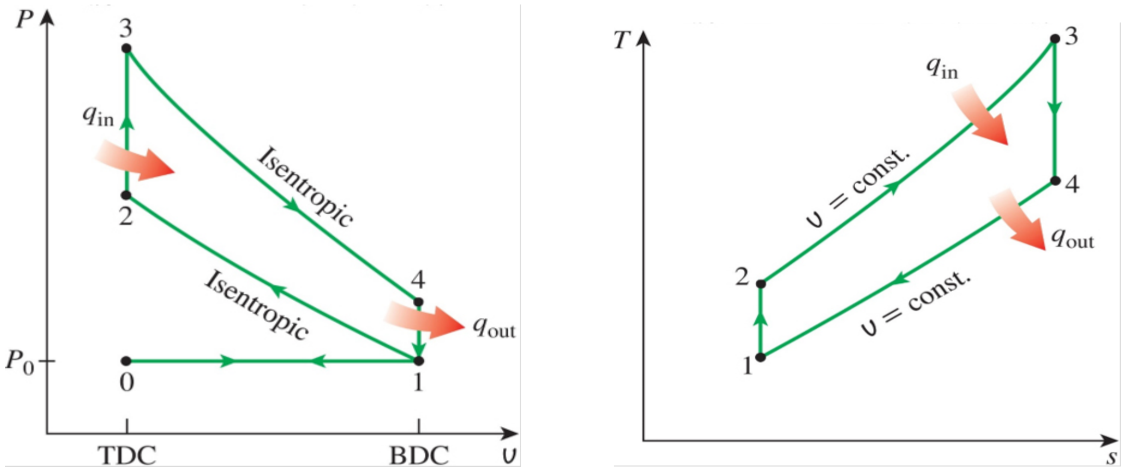
Theory:

<u>The Otto Cycle</u>:

The Otto cycle is a set of 4 processes used by spark ignition internal combustion engines (4-stroke cycles). These engines a) ingest a mixture of fuel and air, b) compress it, c) cause it to react, thus effectively adding heat through the conversion of chemical energy into thermal energy, d) expand the combustion products, and then e) eject the combustion products and replace them with a new charge of fuel and air. The different processes are shown in Figure 1 on both of P-V and T-S diagrams:

1. Intake stroke, gasoline vapor and air drawn into engine (0→1).
2. Compression stroke, isentropic process (adiabatic), $\boldsymbol{p}$, $\boldsymbol{T}$ increase (1→2).
3. Combustion (spark), short time, essentially constant volume (2→3). Model: heat absorbed by a reservoir whose temperature changing from T_2 to T_3.
4. Power stroke: expansion, isentropic process (adiabatic), (3→4).
5. Valve exhaust: valve opens, gas escapes.
6. (4→1) Model: heat absorbed by a reservoir whose temperature changing from T_4 to T_1.
7. Exhaust stroke, piston pushes remaining combustion products out of chamber (1→0).

However, the actual Otto cycle does not have the sharp transitions between the different processes that the ideal cycle has, and can be sketched as in Figure 2. Furthermore, the described Otto cycle processes are illustrated in greater detail in Figure 3.



F Figure 1. The ideal Otto cycle

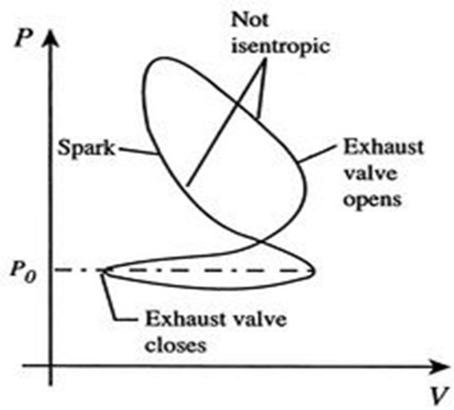


Figure 2. Sketch of an actual Otto cycle

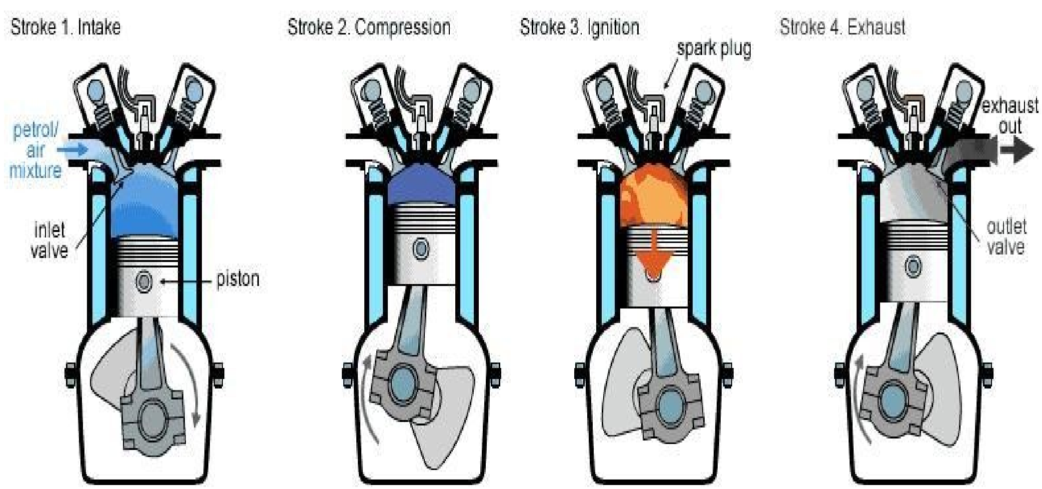


Figure 3. Otto cycle processes with pistons/valves movements

<u>The Diesel Cycle</u>:

The Diesel cycle is a set of 4 processes used by compression ignition internal combustion engines (4-stroke cycles). These engines a) ingest air, b) compress it, c) add fuel spray and cause it to react, thus effectively adding heat through the conversion of chemical energy into thermal energy, d) expand the combustion products, and then e) eject the combustion products and replace them with a new charge of air. The different processes are shown in Figure 1 on both of P-V and T-S diagrams:

1. Intake stroke, air is drawn into engine (0→1).
2. Compression stroke, isentropic process (adiabatic), ***p***, ***T*** increase (1→2).
3. Combustion, due to fuel spray introduced by the fuel injector, at constant pressure (2→3). Model: heat absorbed by a reservoir whose temperature changing from T_2 to T_3.
4. Power stroke: expansion, isentropic process (adiabatic), (3→4).
5. Valve exhaust: valve opens, gas escapes.
6. (4→1) Model: heat absorbed by a reservoir whose temperature changing from T_4 to T_1.
7. Exhaust stroke, piston pushes remaining combustion products out of chamber (1→0).

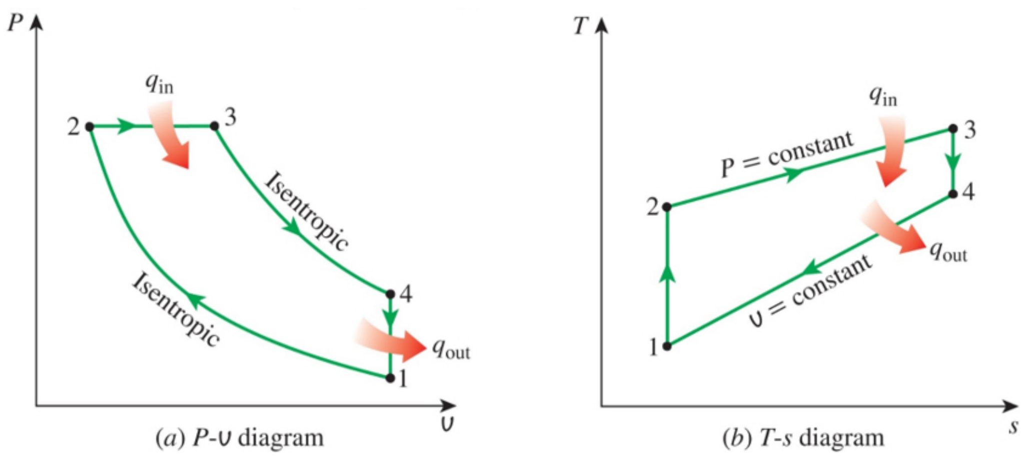


Figure 4. The ideal Diesel cycle

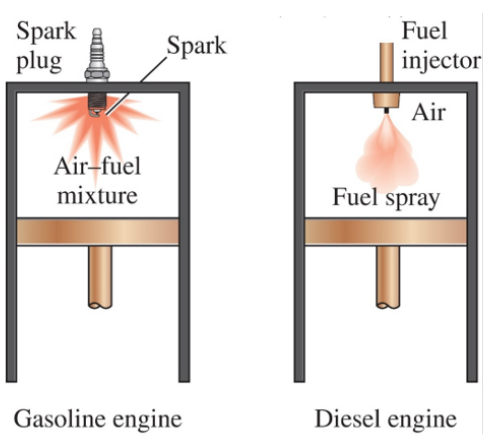


Figure 5. Difference between Otto & Diesel cycle

Set-up:

TD 211 modified four stroke petrol engine

A high-quality and cost-effective four-stroke, single-cylinder petrol (gasoline) engine is available, the TecQuipment's Small Engine Test Set (TD200). The engine includes an exhaust thermocouple, a half-coupling to link the test set dynamometer and all essential hoses and fittings. In addition, the engine includes a color-coded fuel tank with self-sealing couplings. The couplings ensure the engines can be connected and disconnected quickly and efficiently with minimum loss or spillage of fuel. The engine has a modified cylinder head and crank. These allow use of the Cylinder Head Pressure Transducer and the Crank Angle Encoder. These can be connected to the Engine Cycle Analyzer to be able to run different experiments. The engine is mounted on a sturdy precision bedplate. The bedplate has dowels and slots which align and locate it accurately with the dynamometer test set. This minimizes the time spent replacing one engine with another. The real engine is shown in Figure 6.

Figure 6. TD 211 Modified Four-Stroke Petrol (gasoline) Engine

Procedure:

1. Slowly pull the starting handle of the Test Engine until you can feel that it has passed the compression stroke and is easy to turn. Allow the starting handle to return to its original position.

2. Gently rock the Dynamometer, then press the 'Press and hold to zero' button on the Torque and Speed display. This will zero the Torque reading.

3. Press and hold the 'Zero airbox pressure' button on the DPT1 instrument Module. Release the button, the differential pressure is zero.

4. Open both valves on the Fuel Gauge and make sure that fuel has passed down the fuel feed pipe to the Test Engine.

5. Turn on the water supply to the Dynamometer. Open the control valve by half a turn. Fully open the water outlet valve and make sure the water flows through the Dynamometer.

6. Start and run the Test Engine. (Refer to next section “engine start” for details).

7. Allow the engine to reach normal operating temperature.

8. Set the Test Engine throttle (or rack) for maximum speed.

9. Use the Dynamometer Control Valve to adjust the engine speed and record all Test Engine results as described in the Blank Results Table.

OTTO CYCLE

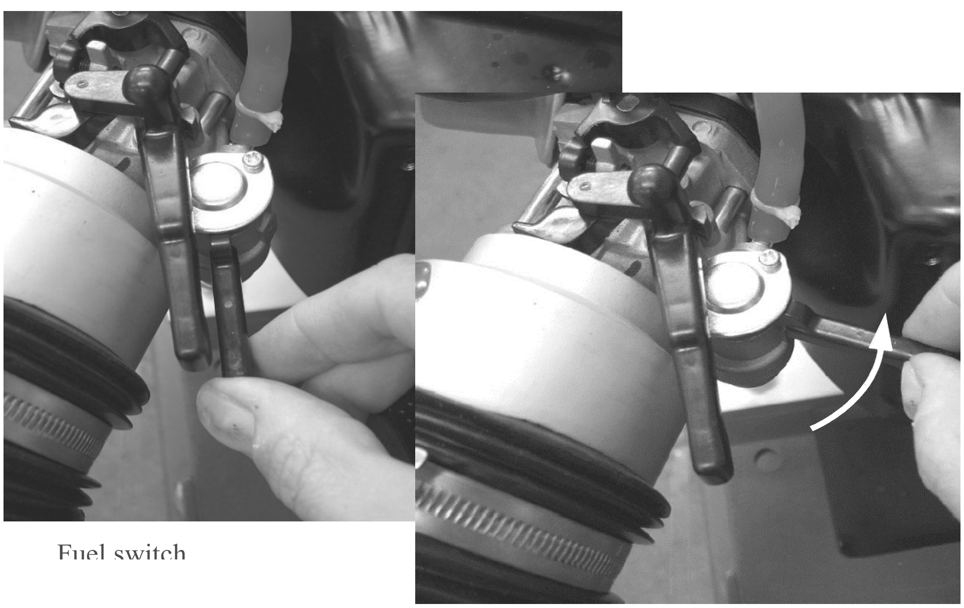
Engine start:

1. Make sure that the Test Engine Fuel Tank has enough fuel for your test.

2. Turn on the electrical and water supplies to the TD200 Test Bed.

3. Open any fuel taps on your Fuel Gauge to allow fuel to flow to the Test Engine. If necessary, tap the fuel line to remove any air bubbles.

4. Set the engine fuel switch on.



Fuel switch

Fuel switch ON (1)

Figure 7. Turn the Engine Fuel switch to ON

5. If the engine is cold, fully shut the choke device on the carburetor. If it is still warm, set the choke to half open.

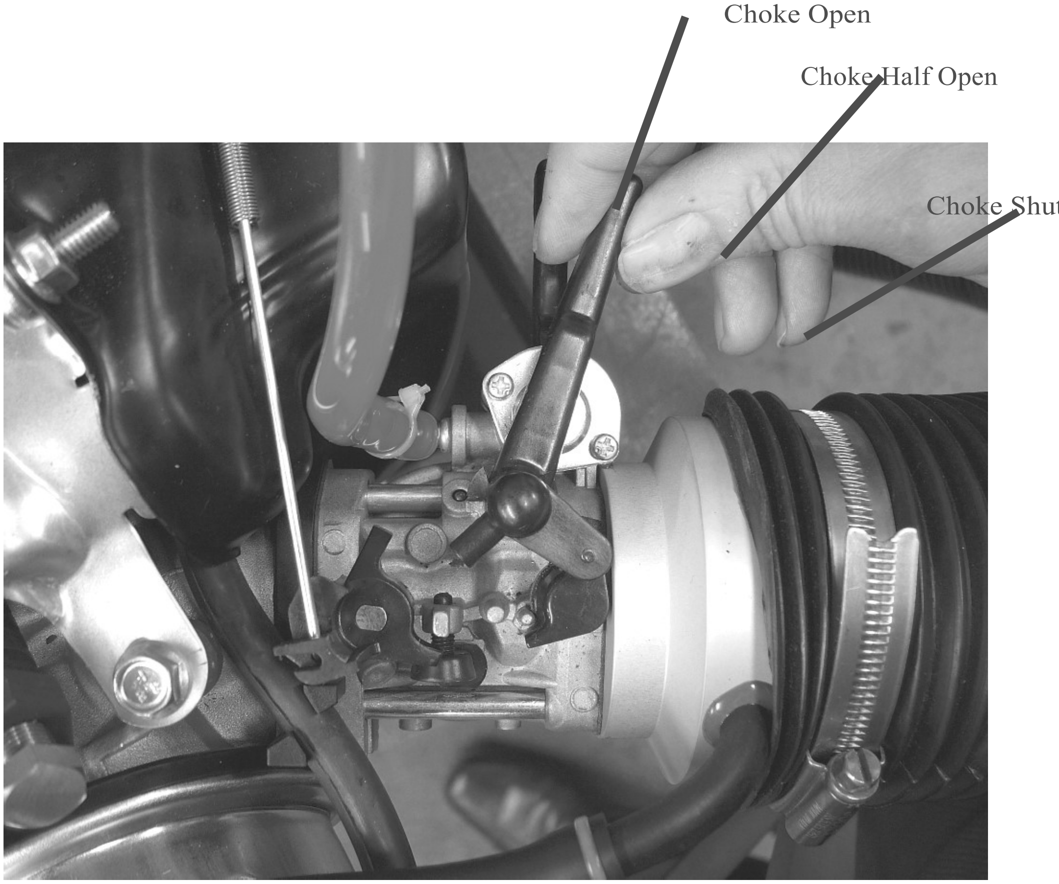


Figure 8. Choke Adjustment

6. Adjust the engine throttle (speed control) to half-way.

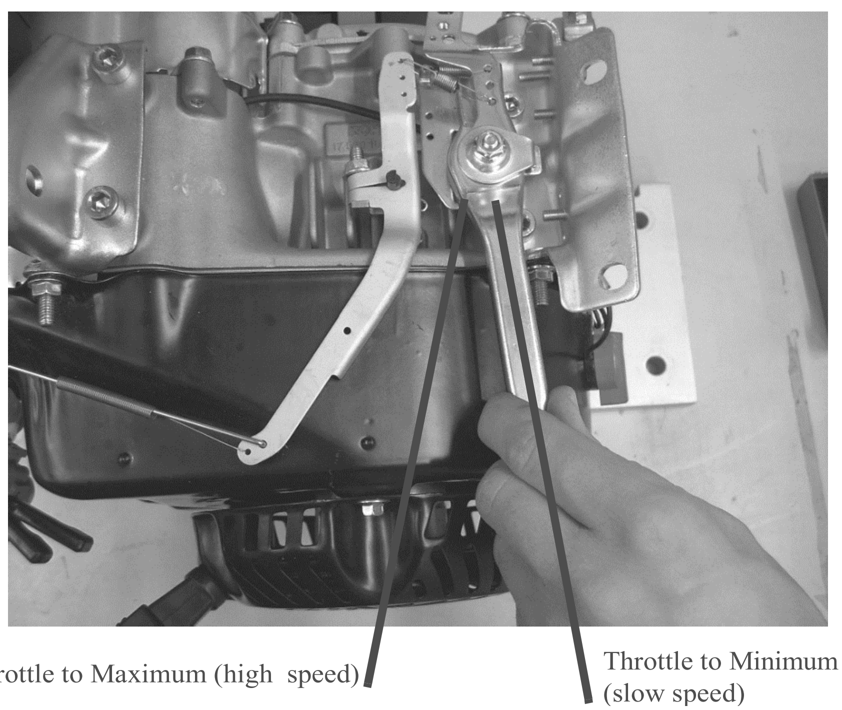


Figure 9. Throttle Adjustment

7. Switch the ignition switch on.

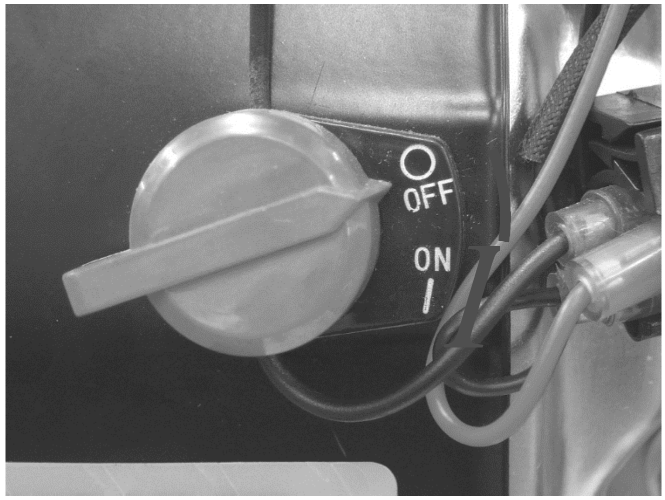


Figure 10. Put the Ignition Switch to the ON position

8. Slowly pull out the engine start handle until you feel resistance, then allow the handle to return to its original position. This puts the engine at the start of a compression cycle.

9. Firmly pull out the starting handle. The engine should start. Keep your hand on the starting handle and allow it to return back down to the engine, then let it go.

10. If the engine does not start, then repeat previous three steps.

11. Allow the engine run for a few minutes until it reaches normal operating temperature and runs steadily.

12. Fully open the choke.

13. Measure the volumetric flow rate of fuel by using a stop watch and measuring the time for 8mL fuel consumption and then for 16mL fuel consumption.

<u>Engine Stop:</u>

1. Use the engine throttle to reduce the engine speed to minimum.

2. Allow the engine to run for two minutes at minimum speed.

3. Turn the ignition switch to the OFF position.

4. Turn OFF the engine fuel switch.

5. Turn off the fuel supply to the engine.

6. Slowly pull out the engine start handle until you feel resistance. Then allow it to return. This sets the engine at the beginning of the compression cycle with both valves closed. This helps to prevent any damp air or moisture entering the cylinder while it is not in use.

Emergency Engine Stop:

1. Turn the ignition switch to the OFF position.
2. Turn off the fuel supply to the engine.

DIESEL CYCLE

Engine start:

1. Make sure that the Test Engine Fuel Tank has enough fuel for the test.

2. Switch on the electrical and water supplies to the TD200 Test Bed.

3. Open any fuel taps on the Fuel Gauge to allow fuel to flow to the Test Engine. If necessary, tap the fuel line to remove any air bubbles.

4. Adjust the engine rack (speed control) to half-way (see Figure 11).

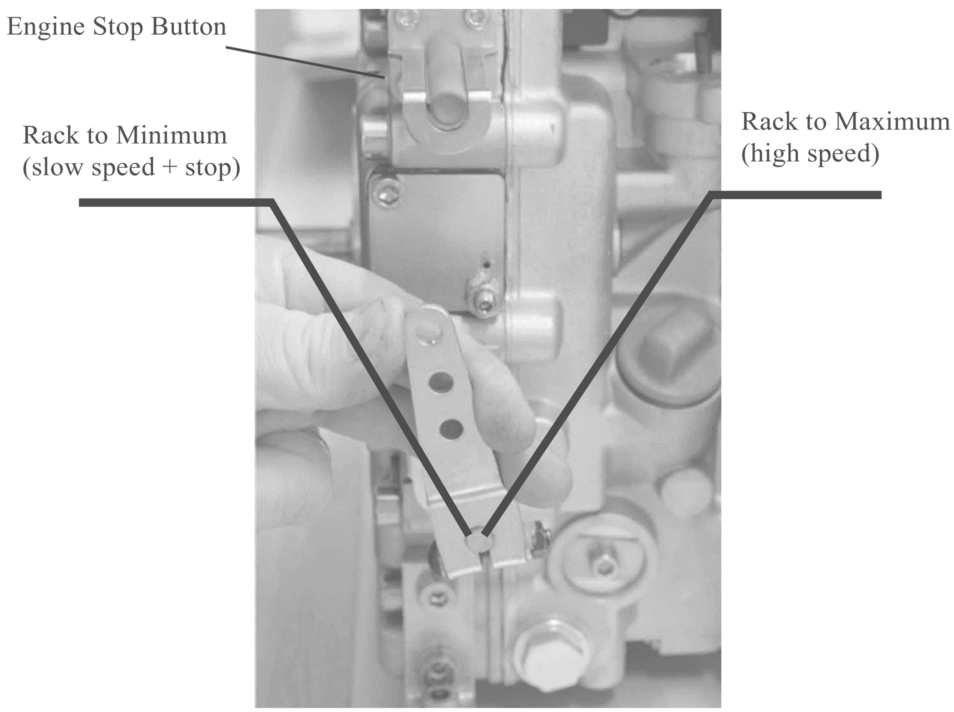


Figure 11. Rack Adjustment and Engine Stop Button

5. Make sure that the switch on the engine is set to 'on'.

6. Slowly pull out the engine start handle until resistance is felt, then slowly let the start handle to return back to its original position. This sets the engine at the start of a compression cycle.

7. Make sure that a stable position is adopted with both hands on the starter handle.

8. Firmly and quickly pull out the starting handle. The engine should start. Keep a hand on the starting handle and allow it to return back down to the engine, then let it go.

9. If the engine does not start, then repeat steps 5, 6 and 7.

10. Allow the engine to run for a few minutes until it reaches normal operating temperature and runs steadily.

11. Measure the volumetric flow rate of fuel by using a stop watch and measuring the time for 8mL fuel consumption and then for 16mL fuel consumption.

Engine Stop(normal):

1. Use the engine rack to reduce the engine speed to minimum.

2. Allow the engine to run for two minutes at minimum speed.

3. Use the engine rack to reduce the engine speed to a stop.

4. Turn off the fuel supply to the engine.

5. Slowly pull out the engine start handle until resistance is felt. Then allow it to return. This sets the engine at the beginning of the compression cycle with both valves closed. This helps to prevent any damp air or moisture entering the cylinder while it is not in use.

Emergency Engine Stop:

1. Press the engine stop button (see Figure 11).

2. Reduce the engine rack to minimum (stop) position.

3. Turn off the fuel supply to the engine.

TecQuipment VDAS interface: TD200 Small Engine Test Bed

1. For both gasoline and diesel engines, connect USB from the DAQ with the computer.
2. Open VDAS and click “Connection” tab and click “Start Communications”. The speed and other parameters will start showing up on the VDAS interface
3. Click “ Data” tab and click “Start timed data acquisition”. The data will now start saving in an excel file.
4. After the experiment, click the Excel file icon “Export recorded data to Excel XLSX file” and save it.

Gasoline Engine Parameters:

Item	Specification
Dimensions (when fitted to Base Plate)	Width 500 mm Height 430 mm Depth 400 mm
Net Weight (with Base Plate)	22 kg
Fuel Type	Unleaded Petrol (Gasoline) Minimum 90 RON Also allowed are: Ethanol mix of 90% Unleaded Gasoline and up to 10% Ethyl Alcohol Methyl tertiary butyl ether (MTBE) mix of up to 15% MTBE by volume Do not use E15, E20 or E85 fuel.
Fuel Tank	Red - Painted steel with vent and filler cap
Exhaust outlet	Nominally 1"BSP
Ignition system	Flywheel magneto
Absolute Maximum Power	5.2 kW (7 hp) at 3600 rev.min-^{1} Gross output to SAEJ1995 tests and without air cleaner and exhaust
Net Power	4.5 kW at 3600 rev.min-^{1} 2.2 kW at 1800 rev.min-^{1}
Bore	70mm
Stroke/Crank Radius	54 mm/27 mm
Connecting Rod Length	84mm
Engine Capacity	208 cm^{3} (0.208 L) or 208 cc
Compression Ratio	8.5:1
Oil Type*	SAE30 or Multigrade 10W-30
Oil Capacity	0.6 Litre

Gasoline Engine, Fuel and Ambient Conditions

Item	Value
Date of Test	
Time of Test	
TD200 Serial Number	
Engine Serial Number	
Engine type	Single Cylinder
Engine size (Litres)	0.208
Engine Cycles (stroke)	4
Fuel type	Petrol/gasoline
Fuel Density (kg.m-^{3})	740
Fuel Calorific Value (MJ.kg-^{1})	43 .8
Ambient Air Pressure (mbar)	1010
Airbox orifice dimensions (m)	0.0185
Throttle/Rack Position	Full

Diesel Engine Parameters:

Item	Specification
Dimensions (when fitted to Base Plate)	Width 400 mm Height 450 mm Depth 350 mm
Net Weight (with Base Plate)	35 kg
Fuel Type	Diesel to minimum specifications: EN590 or BS2869 A1/A2 or ASTM D 975- 1D/2D
Fuel Tank	Caramel/light brown - Painted steel with vent and filler cap
Exhaust outlet	Nominally 1"BSP
Ignition system	None - diesel
Absolute Maximum Power	3.5 kW (4.8 hp) at 3600 rev.min-^{1}
Continuous Rated Power	3.1 kW at 3000 rev.min-^{1}
Bore	69 mm
Stroke/Crank Radius	62 mm/31 mm
Connecting Rod Length	104 mm
Engine Capacity	232 cm^{3} (0.232 L) or 232 cc
Compression Ratio	22:1
Oil Type*	Multigrade SAE 5 W - 40
Oil Capacity	0.9 Litre (standard engine)

Diesel Engine, Fuel and Ambient Conditions

Item	Value
Date of Test	
Time ofTest	
TD200 Serial Number	
Engine Serial Number	
Engine type	Single Cylinder
Engine size (Litres)	0.232
Engine Cycles (stroke)	4
Fuel type	Diesel
Fuel Density (kg.m-3)	840
Fuel Calorific Value (MJ.kg-1)	39
Ambient Air Pressure (mbar)	1009
Airbox orifice dimensions (m)	0.0185
Throttle/Rack Position	Full

Engine Test Parameters:

Ambient Pressure --- P_a (Pa)

Engine Speed --- N (Rev/min)

Ambient Air Temperature (at inlet) --- T_a (K)

Fuel Density --- $\rho_f = 740$ (kg/m^3)

Fuel Heating Value --- $C_L = 43.8$ MJ/kg

Engine Torque --- T_q (N-m)

Engine Power --- P_e (W)

Fuel Volume Flow Rate --- V_f (L/s)

Exhaust Gas Temperature --- $T_{exhaust}$ (K)

Airbox Differential Pressure --- ΔP (Pa)

At the end of Engine Test, there will be a Blank Results Table for students to complete.

Data analysis:

Air Consumption:

Air flow velocity,

$$U = \sqrt{\frac{2 \cdot \Delta p}{\rho_a}}$$

Air mass flow rate:

$$m_a = C_d \cdot \frac{\pi d^2}{4} \cdot \sqrt{\frac{2 \cdot P_a \cdot \Delta P}{R \cdot T_a}}$$

C_d --- Coefficient of Discharge for the Orifice, 0.6

R --- Gas Constant for Air, 0.287 kJ-K/kg

d --- Orifice Diameter, 18.5 mm

Fuel Consumption:

Fuel mass flow rate:

$$m_f = \rho_f \cdot V_f$$

$$\text{Specific Fuel Consumption} = \frac{m_f \cdot 3600}{P_e/1000}$$

Where:

V_f --- Fuel Volume Flow Rate

Specific Fuel Consumption=kg-kW/h

Mass Fuel Consumption=kg/s

Mechanical Power=Watts

Air/Fuel Ratio:

$$\frac{\text{air}}{\text{fuel}}_{\text{ratio}} = \frac{m_a}{m_f}$$

Volumetric Efficiency:

$$\text{Calculated Volume} = \frac{Engine\ Capacity \cdot N}{}$$

$$(Strokes/2) \cdot 60$$

Where:

Engine Capacity = 208 cm^3

Strokes = 4

$$\text{Measured Volume} = \frac{m_a \cdot R \cdot T_a}{P_a \cdot 100}$$

$$\text{Volumetric Efficiency,} \qquad \eta_V = \frac{Measured\ Volume}{Calculated\ Volume} \cdot 100$$

Heat Energy of Combustion and Enthalpy:

Heat energy of combustion: $H_F = m_f \cdot C_L \cdot 10^3$, where $C_L = 43.8$ MJ/kg is the fuel heating value.

Inlet air enthalpy: $H_A = m_a \cdot C_p \cdot T_a \cdot 10^3$, where air C_p= 1 kJ/(kg-K)

Thermal Efficiency:

$$\eta_T = \frac{Mechanical\ Power\ (P_e)}{Heat\ energy\ of\ combustion\ (H_F)} \cdot 100$$

Break Mean Effective Pressure:

$$\text{BMEP} = \frac{60 \cdot Power \cdot (Strokes/2)}{0.1 \cdot Speed \cdot Engine\ Capacity}$$

Where:

BMEP is in bar

Power in Watts

Speed in Rev/min

Engine Capacity=208 cm^3

1. **Record Test Engine performance and complete Table 1 which will be provided during the experiment.**

2. **Perform the data analysis and complete all the required plots and fill out all the blanks in Table 2 given as a handout.**

3. **<u>Also attach the in-class calculation Table (handouts) in the lab report that will be submitted (if applicable and instructed).</u>**

Table 1. Engine parameters need to be recorded

Engine			Fuel		Air and Exhaust		
Engine **Speed (rev/min)**	Engine Torque (Nm)	Engine **Power (W)**	Fuel **Volume (8/16/24** ml)	Fuel **Drain** Time (s)	**Ambient Air Temperature** (^{O}C)	**Exhaust Gas Temperature** (^{O}C)	**Airbox Differential Pressure** (Pa)

Table 2. Engine parameters need to be calculated

Engine Speed (rev/min)	Energy		Air and Fuel				Efficiency		BMEP (bar)
	Heat of Combustion (W)	Inlet Air Enthalpy (W)	Air Mass Flow Rate (kg/s)	Fuel Mass Flow Rate (kg/s)	Air/Fuel Ratio	Specific Fuel Consumption (kg kW/h)	Thermal Efficiency (%)	Volumetric Efficiency (%)	

Questions:

1. Determine the ideal Otto Cycle thermal efficiency (i.e. based on compression ratio, which equals to 8.5:1 for this particular engine) and compare it with the actual value. Discuss the reasons for the difference.
2. Determine the ideal Diesel Cycle thermal efficiency (i.e. based on compression ratio, which equals to 22:1 for this particular engine) and compare it with the actual value. Discuss the reasons for the difference.
3. For both engines, plot:
   A. Engine speed VS Thermal Efficiency
   B. Engine speed VS Volumetric Efficiency
   C. Engine speed VS Engine Torque
   D. Engine speed VS Engine Power
   E. Engine speed VS Exhaust temperature
   F. Engine speed VS Air-Fuel ratio
   G. Engine speed VS Specific Fuel Consumption (SFC)

   Note: Engine speed must be plotted on x-axis while other quantities on y-axis.

Experiment 4: Jet Engine (Brayton Cycle Experiment)

Lab Activity

Objective:
The objective of the experiment is to understand the operation of a Brayton cycle and perform system performance calculations using First Law Energy Conservation Equation for SSSF (Steady State, Steady flow conditions).

Theory:
<u>The Brayton Cycle</u>:
The Brayton cycle makes use of the air-standard model in a gas turbine power cycle. A simple gas turbine is comprised of three main components: a compressor, a combustor, and a turbine. According to the principles of the Brayton cycle, air is compressed in the compressor. The air is then mixed with fuel, and burned under constant pressure conditions in the combustor. The resulting hot gas is allowed to expand through a turbine to perform work.

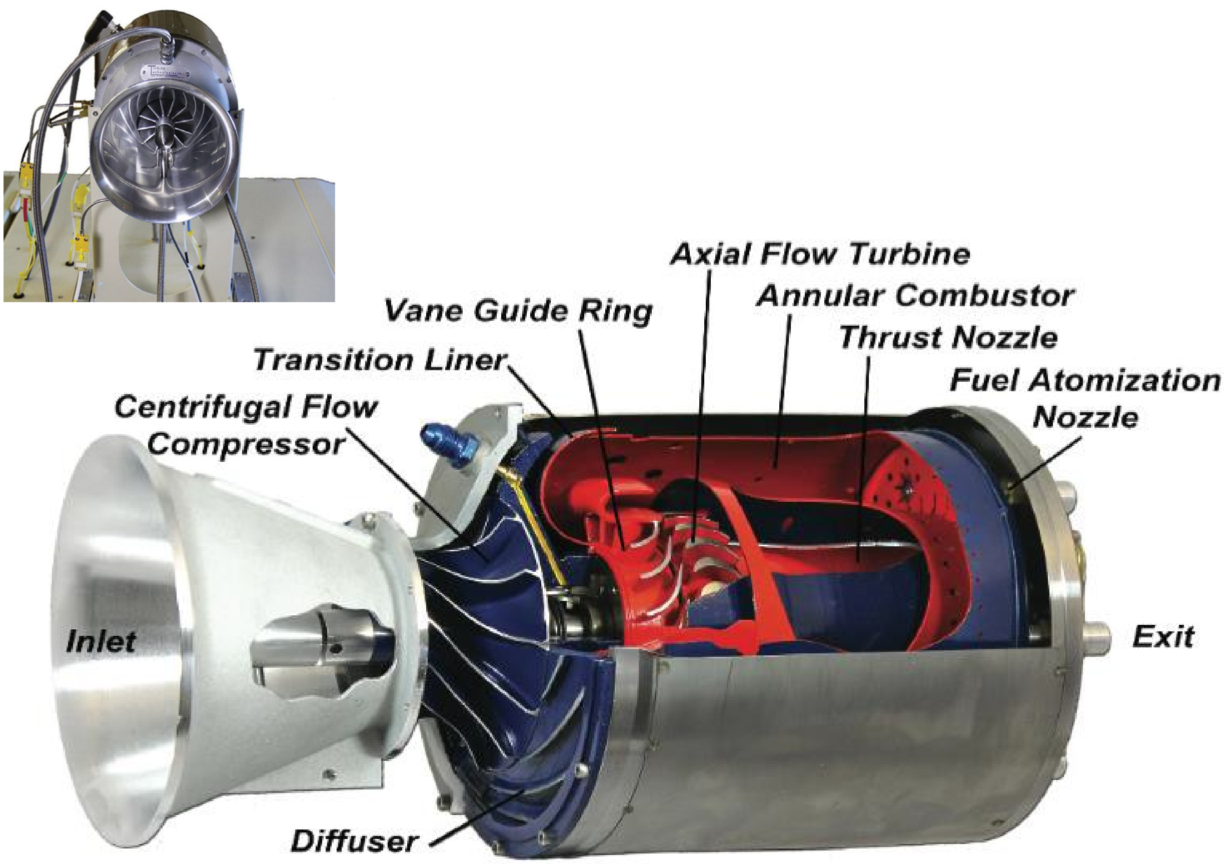


Figure 1. Cut-away View of the SR-30 Engine.

(1. Compressor Inlet; 2. Compressor Outlet; 3. Turbine Inlet; 4. Turbine Outlet; 5. Nozzle Exit)

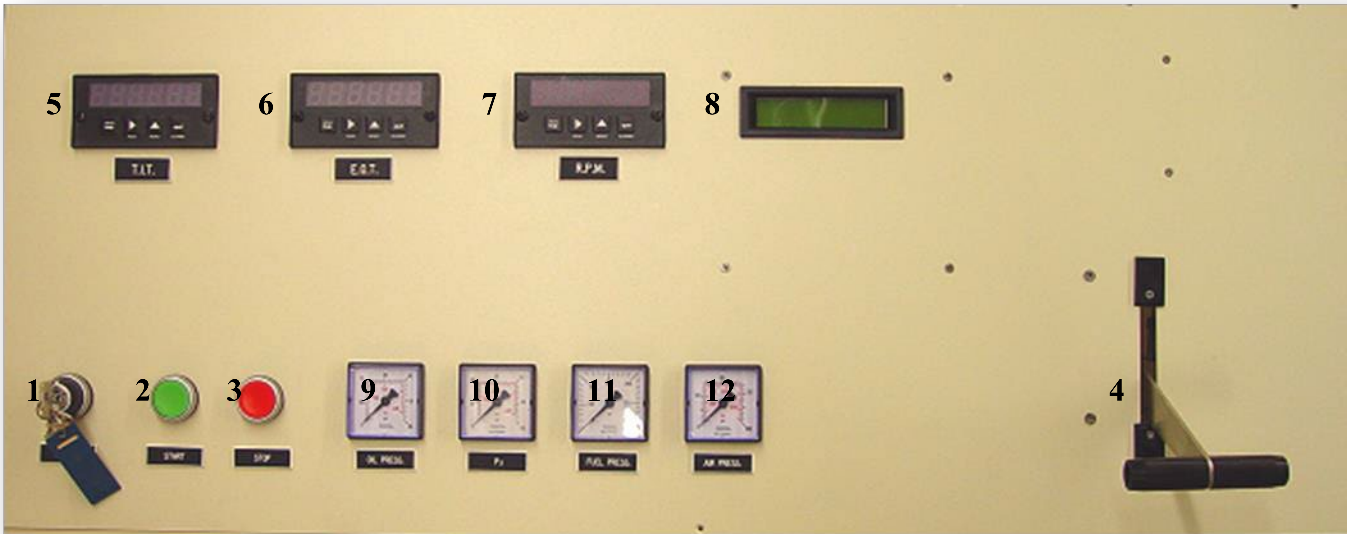


Figure 2: System Control/Display Panel

1. **MASTER SWITCH, KEYED:** Secured control of access and engine operation
2. **GREEN START BUTTON:** Automated Engine Start, Multiple Functions
3. **RED STOP BUTTON:** Immediate EngineStop, Multiple Functions
4. **T-HANDLED POWER LEVER:** Engine RPM/Thrust Control, Forward Increases
5. Digital Turbine Inlet Temperature (TIT)
6. **Exhaust Gas Temperature (EGT)**
7. **Digital Engine Rotational Speed (RPM)**
8. **AUTOSTART LCD DISPLAY:** Real Time System Status Automatically Shuts Off Unit if Parameters Exceeded.
9. Analog Oil Pressure
10. **Analog Engine Pressure (P3)**
11. **Analog Fuel Pressure**
12. **Analog Starting Air Pressure**

A schematic of the Brayton cycle is given in Figure 3.

a) 1 → 2: Isentropic Compression (Reversible Adiabatic Process)
b) 2 → 3: Reversible Constant Pressure Heat Addition (Isobaric Process)
c) 3 → 4: Isentropic Expansion (Reversible Adiabatic Process)
d) 4 → 1: Reversible Constant Pressure Heat Rejection (Isobaric Process)

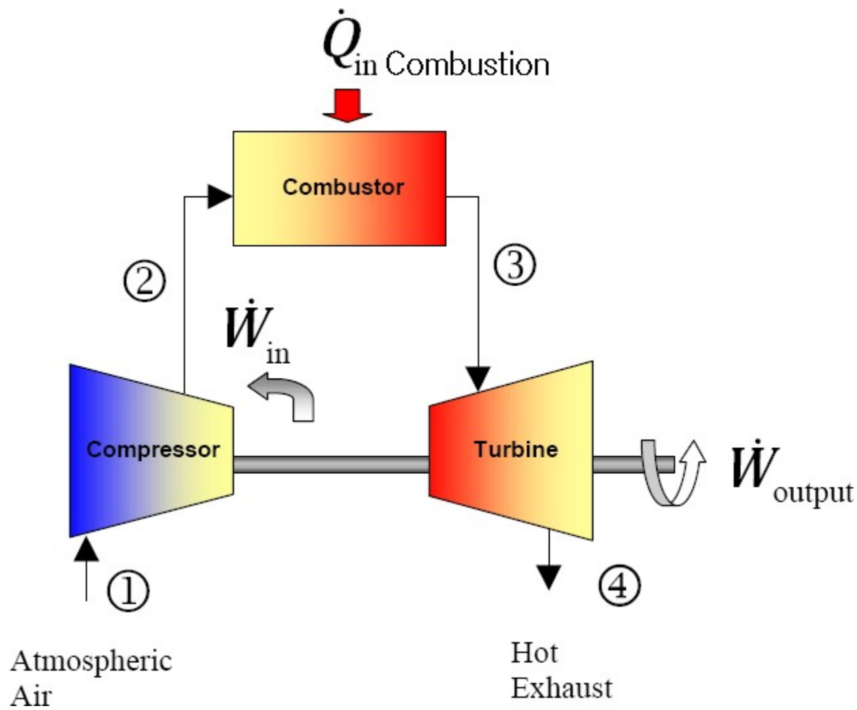


Figure 3. Open Cycle Gas Turbine Engine (Brayton Cycle)

Low-pressure air is drawn into a compressor (state 1) where it compressed to higher pressure (state 2). Fuel is added to the compressed air and the mixture is burnt in a combustion chamber. The resulting hot gases enter the turbine (state 3) and expand to state 4.

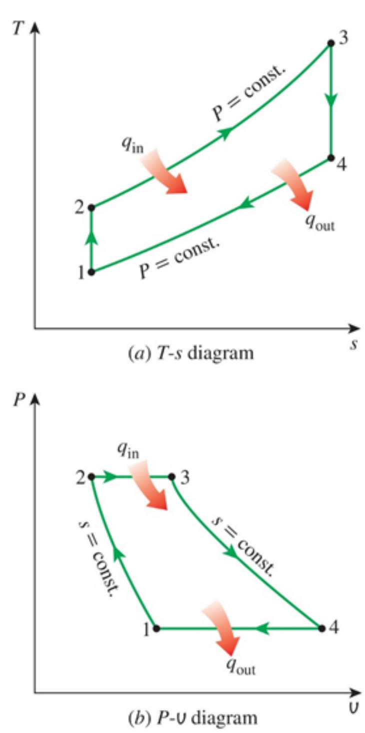


Figure 4. P-v and T-s Diagram

Set-up:

SR-30 Gas Turbine Cutaway

A pure turbojet, the SR-30 is representative of all straight jet engines in which combustion results in an expanding gas that is sufficiently capable of producing useful work and propulsive thrust. Consisting of a centrifugal flow compressor, annular combustor and axial flow power turbine, the SR-30 engine is the typical of the gas generator core found in turbofan, turboprop and turboshaft gas turbine engines, which are typically used for aircraft and marine propulsion, as well as stationary and industrial power generation.

RPM Tachometer Generator: (Displayed on Panel as RPM and Data Acquisition Screen).
P1: Compressor Inlet Pressure (Displayed on Data Acquisition Screen)
T1: Compressor Inlet Temperature (Displayed on Data Acquisition Screen)
P2: Compressor Exit Pressure (Displayed on Data Acquisition Screen)
T2: Compressor Exit Temperature (Displayed on Data Acquisition Screen)
P3: Turbine Inlet Pressure (Displayed on Panel and Data Acquisition Screen)
T3: Turbine Inlet Temperature (Displayed on Panel as TIT and Data Acquisition Screen)
P4: Turbine Exit Pressure (Displayedon Data Acquisition Screen)
T4: Turbine Exit Temperature (Displayed on Data Acquisition Screen)

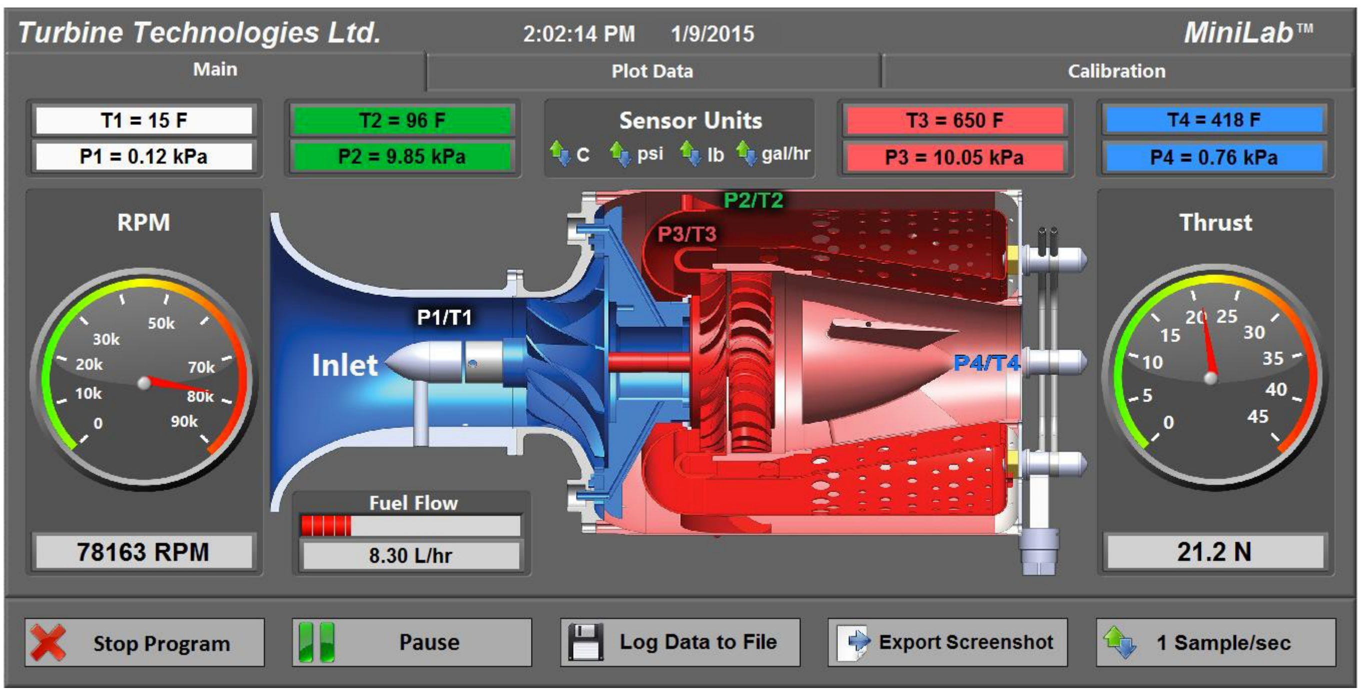


Figure 5: Virtual Instrument Display Panel

Before Experiment

- What is the present barometric pressure in your area? (Check the weather forecast)_______________
- Why would barometric pressure be important when planning to operate the Gas Turbine System?

Procedure:

1. The keyed master switch should be turned on.
2. Verify that the TIT, TET and RPM panel meter powers ON. RPM panel should be zero (0000).
3. Verify freedom of throttle lever movement and verify that the THROTLE POSITION FLAG ILLUMINATES on the LCD display.
4. With the engine throttle lever pulled back and check RDY on LCD display.

5. Open the MiniLab1.1 LabView program and set Sampling Rate and do Sensor Calibration by comparing with TIT(T3), TET(T5) and RPM numbers on LCD display.
6. ENGINE START can be initiated by pressing the GREEN START BUTTON
7. Once the GREEN START BUTTON has been pressed, wait a few seconds for the engine is running at idle.
8. The engine is ready for data collection or demonstration
9. The full range of engine power is now available. Turn the power lever toward the test cell 1/4th of a turn to the full range power for about 20 sec.
   @ AVOID RAPID OR JERKY MOVEMENTS OF THE POWER LEVER
10. The engine STOPS at any time by pressing the RED STOP BUTTON.
11. Log data to a file

Data analysis:

1. Plot the following:
   - Compressor Inlet & Outlet Pressure (y-axis) vs. Time (x-axis)
   - Compressor Inlet & Outlet Temperature (y-axis) vs. Time (x-axis)
   - Turbine Inlet & Outlet Pressure (y-axis) vs. Time (x-axis)
   - Turbine Inlet & Outlet Temperature (y-axis) vs. Time (x-axis)
   - RPM vs. Time

2. Choose and mark an analysis point where engine RPM is at peak during the data run on each plot for the same time point.
   1) Compressor Inlet Temperature (T1): ________________________________
      Compressor Inlet Pressure (P1): ____________________________________
   2) Compressor Exit Temperature (T2): _________________________________
      Compressor Exit Pressure (P2): ____________________________________
   3) Turbine Inlet Temperature (T3): ___________________________________
      Turbine Inlet Pressure (P3): ______________________________________
   4) Turbine Exit Temperature (T4): ___________________________________
      Turbine Exit Pressure (P4): _______________________________________

3. For the analysis point chosen in #2, find the Specific Enthalpy at each Cycle Point (Using air tables): h1, h2, h4, h3
4. Note: You can do the following calculations in the SI units by converting the pressures from psig to psia and eventually into MPa and temperatures into K.
   A. For the Compression Stage, Find Specific Work Done by the Compressor (1-2).

$$w_{\text{comp,in}}\left(\frac{kJ}{kg}\right) = h_2 - h_1$$

   B. For Combustion Stage, Find Specific Energy Added by the Fuel (2-3).

$$q_{\text{add,in}}\left(\frac{kJ}{kg}\right) = h_3 - h_2$$

   C. For the Turbine Expansion, Find the Specific Work of the Turbine (3-4).

$$w_{\text{turb,out}}\left(\frac{kJ}{kg}\right) = h_4 - h_3$$

   D. Find the Specific Work done by the Cycle:

$$w_{cycle,net} = w_{Turb,out} - w_{comp,in} = q_{add,in} - q_{rej,out}$$

E. Find the Thermodynamic Efficiency of the Cycle

Thermal Efficiency:

$$\eta_{th} = \frac{W_{cycle,net}}{q_{add,in}}$$

5. Brayton Cycle Efficiency: (k=1.4)

$$\eta_{\text{th,Brayton}} = 1 - \frac{1}{r_p^{(k-1)/k}}$$

$$r_p = \frac{P_2}{P_1}$$

6. Show the thermodynamic efficiency and Brayton efficiency, r_p and T_{max} in a table.
7. Find power of the system (use Air Tables, R_{air} = 0.287 kJ/kg-K)
   a. $P_{abs} = P_{ATM} + P_{gage}$ (where $\mathbf{P_{gage}}$ = P4)
   Area of Inlet = Bell Opening – RPM Generator Housing = 0.00311m^2

   a) $\rho = \dfrac{P_{abs}}{R \cdot T_{abs}}$

   From Bernoulli's equation,

   b) $V = \sqrt{\dfrac{2P_{gage}}{\rho}}$

   c) Q = A x V

   d) $\dot{m} = \rho A V$

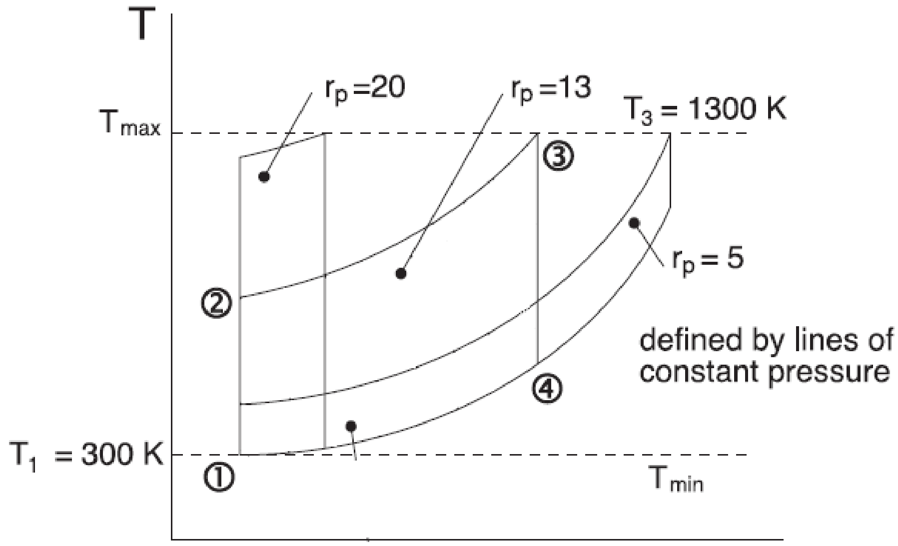
   e) $Power\ (\dot{W}) = \dot{m} \times w_{cycle,\ net}$

8. Show Power and r_p in a table.

<u>Please attach the in-class calculation Table (handouts) in the lab report that will be submitted (if applicable and instructed).</u>

Questions:

1. Why would barometric pressure be important when operating a Gas Turbine System?
2. Which pressure ratio can result in the highest efficiency among r_p = 20, r_p=13, and r_p =5? Why?



Reference:

1. Mini-Lab Gas Turbine Power System Sample Lab Experiment Procedure
2. T. Witkowski et. 3., Characterizing the Performance of the SR-30 Turbojet Engine, 2003, University of Minnesota
3. Brayton Cycle Experiment – Jet Engine, University of Toledo
4. Wikipedia.com

Experiment 5: Thermal Power Plant

Lab Activity

Objective:
The objective of the experiment is to observe a steam power plant in operation and measure and analyze data to compute specific work, isentropic turbine efficiency and overall efficiency and construct property diagram from the experimental data.

Theory:
The Rankine Cycler:
The Rankine cyclerTM is an open cycle, where liquid water is heated in a boiler until steam is formed and further superheated in the boiler. The boiler has electrical heaters located at different points for heating the water. The heaters are controlled by a variable-voltage transformer (variac) where the voltage can be controlled and adjusted to any level between 0 and 240 V. The lower part of the boiler contains water and the upper part contains steam. Once the boiler has reached a saturation conditions, the steam then passes through a steam valve where it is throttled to a lower pressure and then expands as it passes through the steam turbine.

The turbine drives a generator which can be controlled using the through the trainer. After expansion in the turbine, the steam is exhausted into the cooling tower, where part of the steam condenses. There is no condenser used in this system and fresh water must be filled into the boiler at regular intervals. This is not a continuous operation cycler.

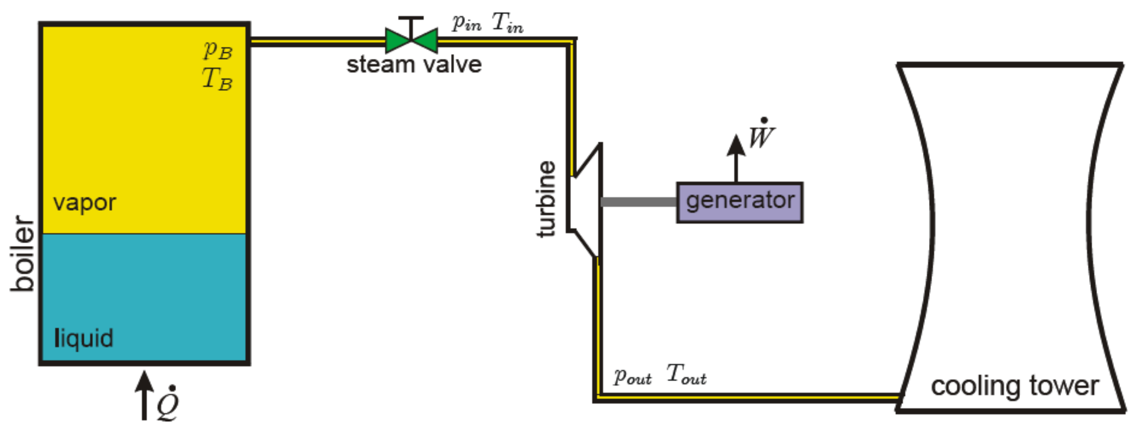


Fig 1: Schematic of the Rankine Cycler

RankineCycler™ Steam Turbine Power System
Major Component Callout

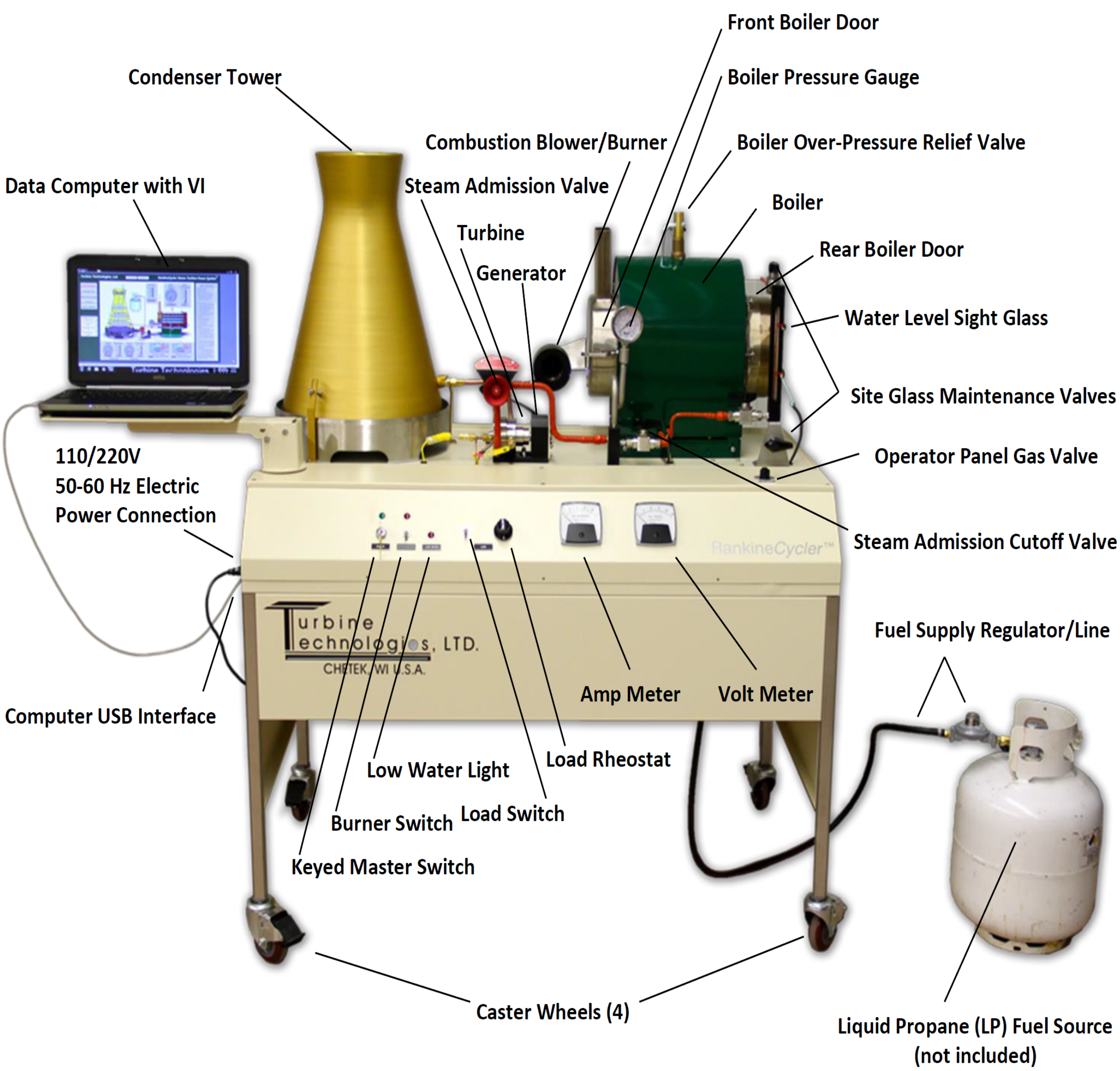


Figure 1.0 RankineCycler Features

Procedure:

Unscrew oiler caps and add turbine oil to the front and rear turbine bearings to within 3 mm of the top of the oiler. This is necessary to keep turbine bearing lubricated at high speed.

1. Turn on steam valve to vent any air in the boiler.
2. Fill around 6 liters of water in the boiler using the sight glass as level indicator.
3. Turn off steam valve and turn the load switch to the off position.
4. Switch on the electrical heaters by slowly turning the transformer knob to 75% of input.
5. Continue heating until the boiler temperature on the data logger reads 165 °C.
6. Turn on steam valve. The generator should be spinning at fast speed.
7. Turn on load switch and adjust the steam valve such that the amp-meter reads about 0.2 A at 4 Volts.
8. Take readings for two cases:
   (a) Keep boiler pressure constant at 90 psi and take readings at loads of 0.2A, 0.3A **AND** 0.4A.
   (b) Keep load constant at either of the one value (0.2, 0.3 **OR** 0.4A) and take readings at 90, 70 and 50 psi.
9. Record the boiler temperature, boiler pressure, turbine inlet and outlet temperatures.

- T_{boiler} =_______°C
- P_{boiler} =_______psig (psig to kPa (abs) conversion is required; check steam tables)
- $T_{turbine\ inlet}$ =_______°C
- $T_{turbine\ outlet}$ =_______°C

10. Record the current and voltage being supplied to the heater's by using a fluke meter.
- $I_{heaters}$ =_______Amps
- $V_{heaters}$ =_______Volts

To shut down the system, switch off the electrical heaters and slowly and completely turn on the steam valve until all the pressure is released from the boiler.

Data analysis:

1. Find the output power from the system, which is the product of the voltage and current produced by the generator (Pout = V_{out}*I_{out} [W]).
2. Find the input power of the system, which is the product of the supply voltage from transformer and current supplied to heaters (Pin = V_{in}*I_{in} [W]).
3. The overall efficiency of the system can then be defined as,
   Overall efficiency:

$$\eta_{overall} = \frac{P_{out}}{P_{in}}$$

4. For each sets of reading of two cases calculate the following:

   (i) Enthalpy and entropy at all points where measurements are taken.

   (ii) Compute the specific work and the isentropic efficiency of the turbine.

(iii) Determine the mass flow of Propane (C_3H_8) per kg of steam generated in the boiler under the assumption that gaseous propane obeys the ideal gas law, and compute the heat added to the system (heating value LHV_{C3H8} =46332 kJ/kgK, molecular mass: M_{C3H8} = 44 kg/kmol).

5. Discuss the performance of the system altogether. What could be done to improve performance?

6. Using the values of the boiler temperature and pressure, find enthalpy and entropy values, h_1 and s_1 respectively.

7. Across the steam admission valve, which is a throttling operation the enthalpy h_1 can be considered as constant ($h_1 = h_{turbine\ inlet}$).
8. Using the turbine inlet temperature and enthalpy h_1 values, find entropy $s_{turbine\ inlet}$ at the inlet of the turbine using steam tables.
9. Using temperature at the turbine outlet ($T_{turbine\ outlet}$), and considering outlet pressure to be atmospheric ($P_{turbine\ outlet}$ = 100 kPa), find actual enthalpy $h_{turbine\ outlet}$ at the turbine outlet.
10. Compute the specific work of the turbine:
$W_{turbine,actual} = h_{turbine\ inlet} - h_{turbine\ outlet}$

11. Considering the turbine to be isentropic, in which case $s_{2turbine\ inlet} = s_{turbine\ outlet}$, find enthalpy $h_{turbine\ outlet\ ideal}$ (s) at turbine outlet, using $s_{turbine\ outlet}$ and turbine outlet pressure (P_{atm}) using steam tables.

12. The isentropic efficiency of the turbine can be defined as,

Isentropic efficiency:

$$\eta_T = \frac{w_{T,a}}{w_{T,s}}$$

$$\eta_T = \frac{h_{T,inlet} - h_{T,outlet,actual}}{h_{T,inlet} - h_{T,outlet,isentropic}}$$

13. Estimate the mass flow rate ($\dot{m}$) in [kg/sec] by using the following equation (assume a $\eta_{generator}$ = 65%):

$$\frac{\dot{W}_{generator}}{\eta_{generator}} = \dot{W}_{turbine} = \dot{m}_{steam} \bullet (w_{net}) = \dot{m}_{steam}\left(h_{turbine,inlet} - h_{turbine,outlet\_(actual)}\right)$$

14. Plot the steam expansion process through the turbine on the T-s diagram provided below (Figure A-9, T-s diagram for water) using the pressures and temperatures recorded above:
http://highered.mcgraw-hill.com/sites/dl/free/0073529214/395307/appdxs1_2.pdf

Please also attach the in-class calculation Table (handouts) in the lab report that will be submitted (if applicable and instructed).

Questions:

1. Suggest at least one way to increase the overall efficiency of the cycle. In others words, what experimental variable should you tweak (increase or decrease) to increase the overall efficiency

without modifying the system?

2. Does the turbine oil have any impact on the turbine's isentropic efficiency? Please explain.
3. Draw a qualitative *T-s-diagram for the above cycle* for the data obtained from the experiment and indicate the principal points with respect to saturation lines and critical point.
4. Consider an isentropic turbine expanding the fresh boiler steam (at P_B = 90 psig) to atmospheric pressure. Compare the specific work output of the turbine to the actual one as obtained in **Case 1** and discuss.

Experiment 6: Refrigeration Cycle

Lab Activity

Objective:
The objective of the experiment is to observe a refrigeration cycle in operation and measure and analyze data to compute the coefficient of performance for refrigerator and heat pump along with constructing property diagrams from the data obtained from the experiment.

Theory:
The Hampden H-RST-2 Refrigeration System Trainer is charged with refrigerant R-123.

- Chemical name: 2-2 dichloro-1, 1, 1-trifluoroethane
- Chemical formula: CF_3CHCl_2

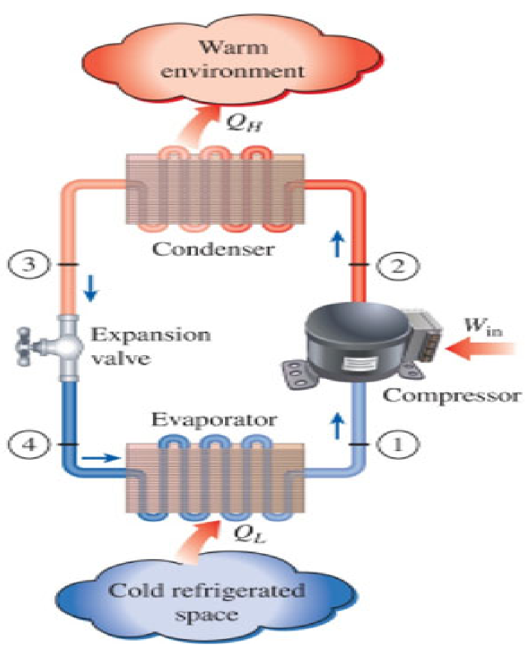
This is a nonflammable hydroflurocarbon compound which has an ozone depletion potential (ODP of 0.02), as opposed to R-11 which has an ODP of 1.0.

In a refrigeration system or air conditioning system, refrigerant goes through a continuous cycle. The five principle devices in a refrigeration cycle are:
1. Evaporator
2. Compressor
3. Condenser
4. Liquid control device
5. High pressure control

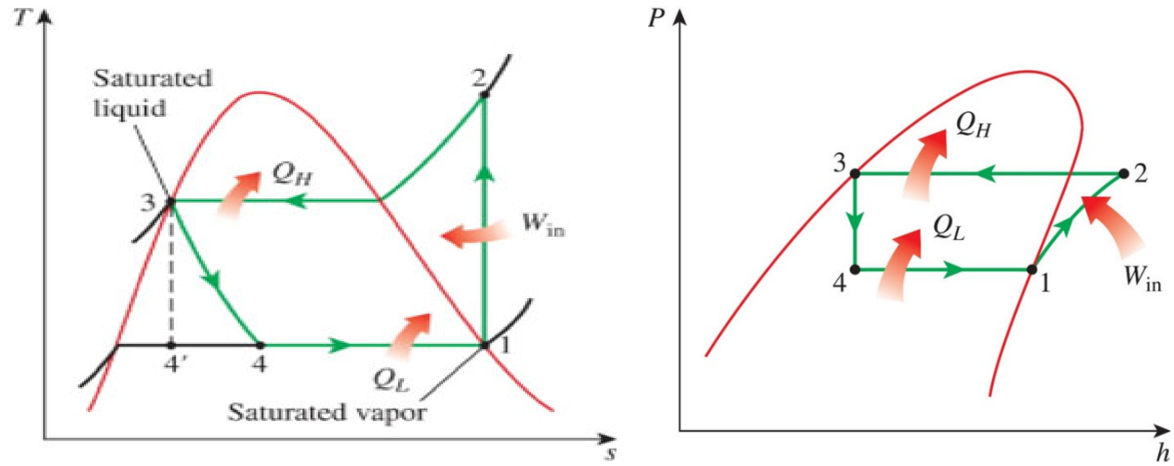
$$\text{COP}_R = \frac{q_L}{w_{\text{net,in}}} = \frac{h_1 - h_4}{h_2 - h_1} \qquad \text{COP}_{HP} = \frac{q_H}{w_{\text{net,in}}} = \frac{h_2 - h_3}{h_2 - h_1}$$

For isentropic process (ideal):

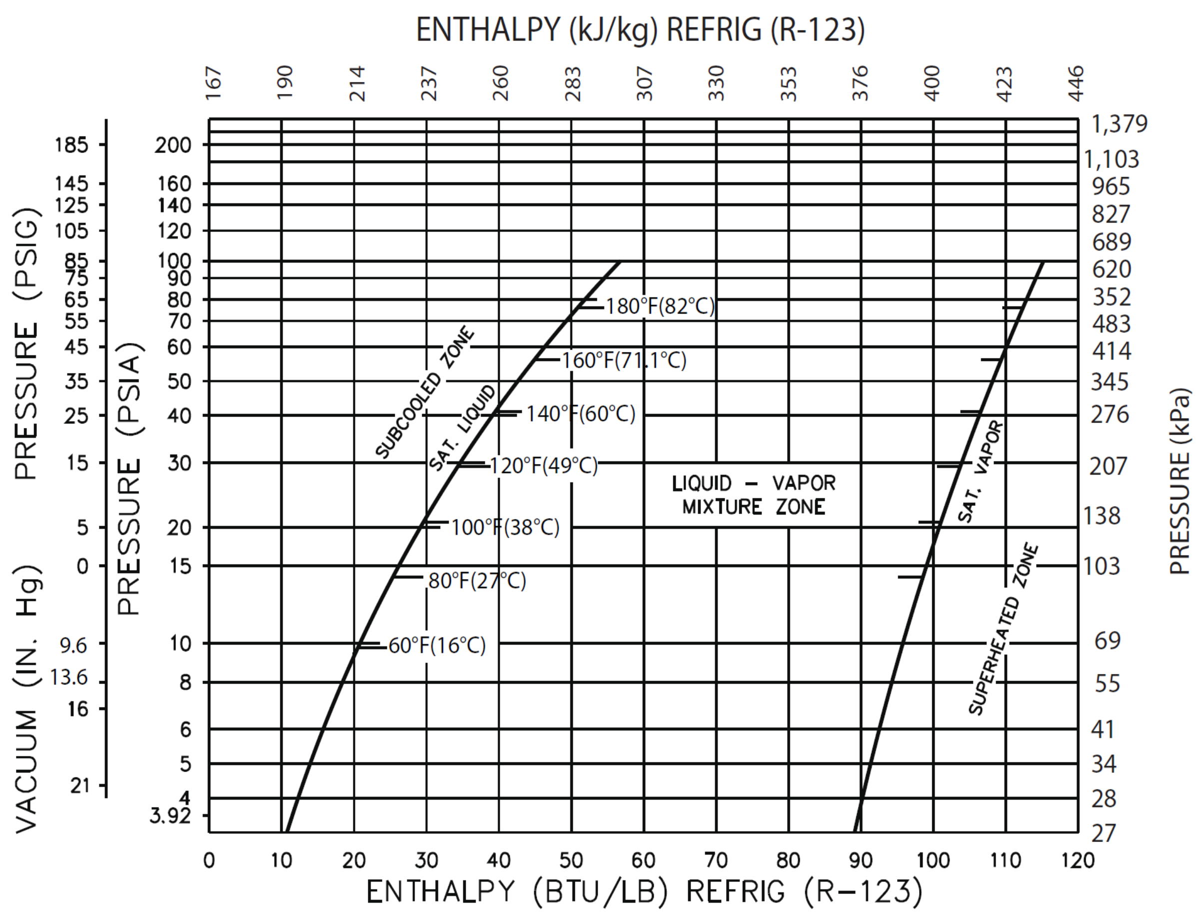
$h_1 = h_{g\ @\ P_1}$, $h_3 = h_{f\ @\ P_3}$



Schematic for the ideal vapor-compression refrigeration cycle

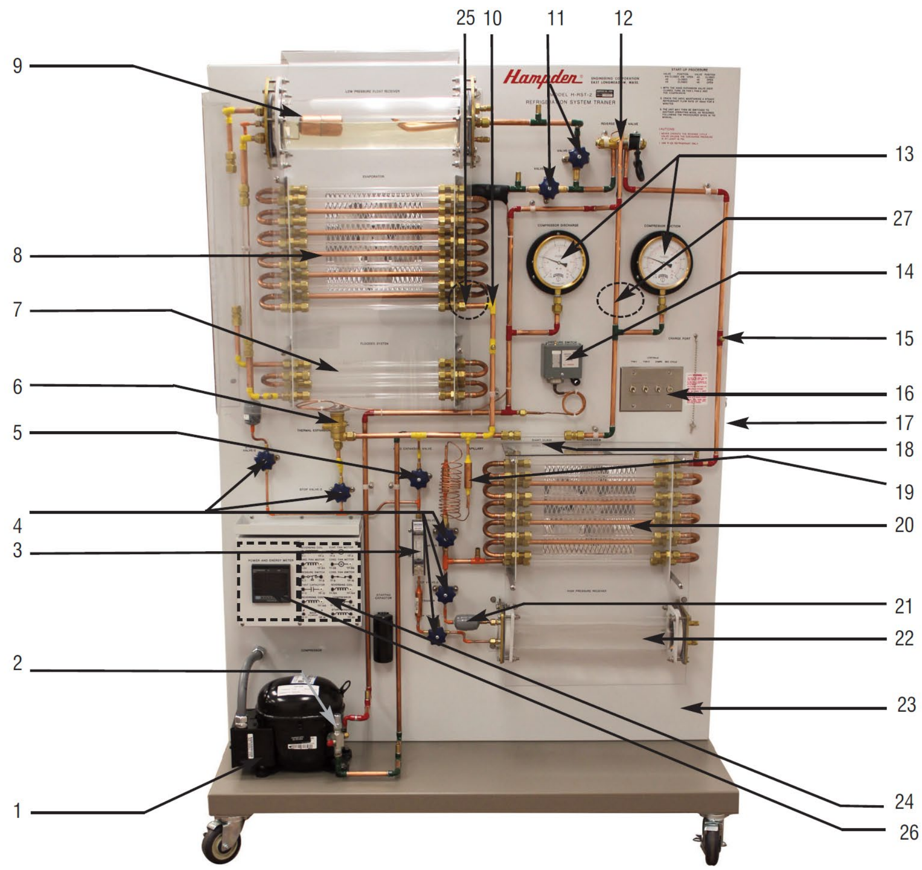


T-s and P-h diagram for the ideal vapor-compression refrigeration cycle



P-h diagram: Depiction of the saturated liquid and saturated vapor lines from the R-123 tables for the vapor-compression refrigeration cycle

TRAINER LAYOUT



1. Compressor
2. Compressor service valve
3. Flowmeter
4. Stop valves (5)
5. Hand expansion valve
6. Thermostatic expansion valve
7. Flooded evaporator
8. Direct expansion evaporator
9. Low side float cylinder
10. Temperature wells (7)
11. 2-way stop valves (2)
12. Reversing valve
13. Pressure gauges (2)
14. Pressure switch
15. Charge port
16. Control switches
    a. Fan 1 (evaporator)
    b. Fan 2 (condenser)
    c. Compressor
    d. Reverse cycle valve
17. Power cord & holder (mounted in rear)
18. Sight glass
19. Capillary tube
20. Condenser
21. Filter/Drier
22. High pressure receiver
23. Mobile base
24. Test Points (-TP Option)
25. Thermocouples (1 of 7) (CDL Option)
26. Digital Meter Package (Option)
27. Pressure Transducers (1 of 2) (CDL Option)

Hampden H-RST-2 Refrigeration System Trainer

HAND EXPANSION VALVE (HEV) CONTROLLED REFRIGERATION SYSTEM

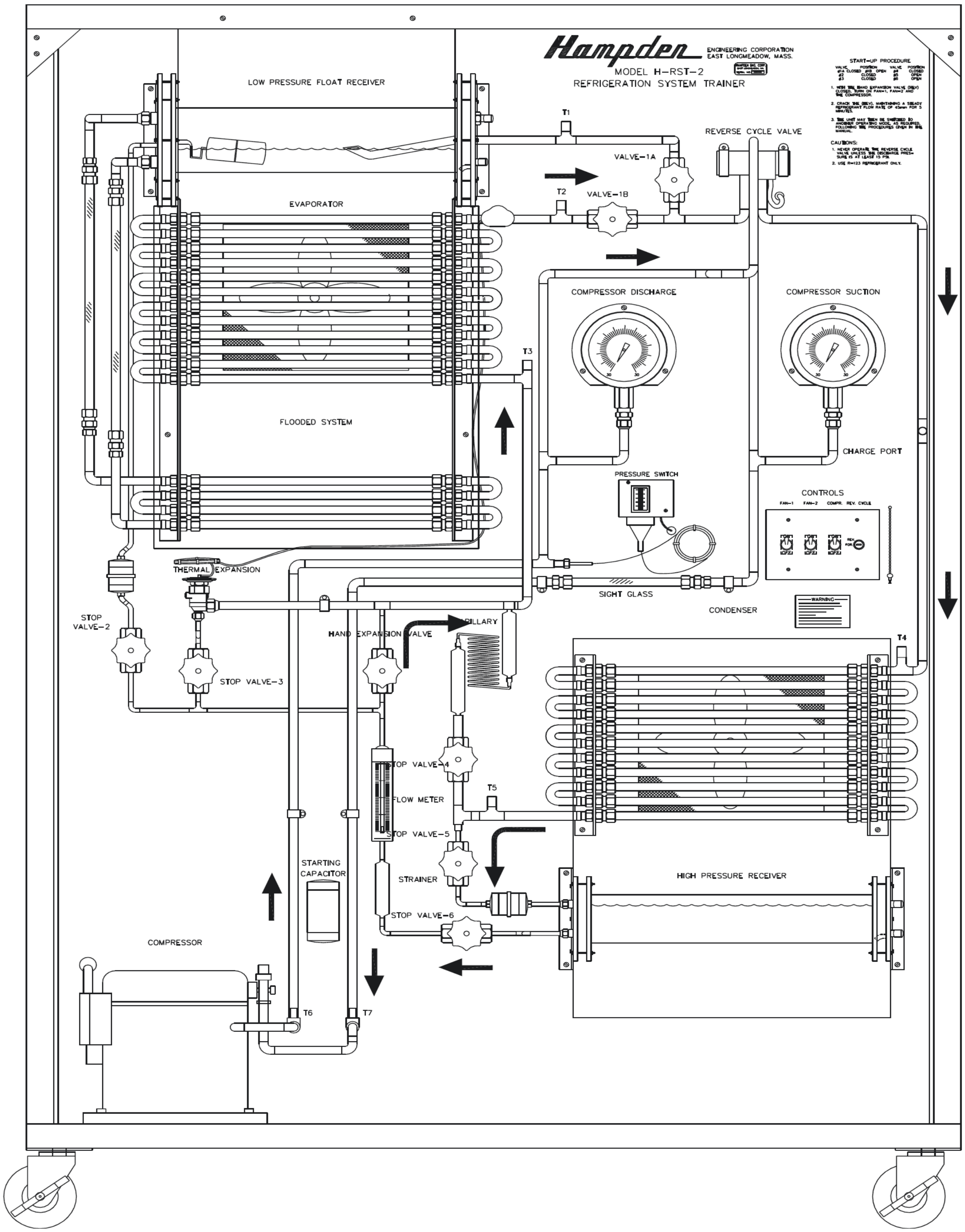


Figure 1-1
Hand Expansion Valve Controlled Refrigeration System

Procedure

1. Turn on fan #1 (evaporator fan), fan #2 (condenser fan), and compressor.
2. Open the hand expansion valve slowly, observing both the flowmeter and the evaporator. Keep the flow rate low enough so the evaporator does not become flooded. All of the liquid refrigerant entering the evaporator should be vaporized before leaving it.
3. While the system is settling down, readjust the hand expansion valve, as necessary, to maintain a flow rate of 45 millimeters (14.0 lb/hr).
4. When the system has settled down so that the flow rate and pressures are steady, read the compressor suction and compressor discharge gauges, and record the readings in Table 1-1.
5. Read and record the temperatures of the six points listed in Table 1-1. Allow three minutes for each temperature reading.
6. From your visual observations, record in Part 1 of Conclusions the state of the refrigerant as it passes through the cycle.
7. From your gauge measurements, record in Part 2 of Conclusions the pressures in the various parts of the refrigeration cycle.
8. From your temperature measurements and by feeling the piping, record in Part 3 of Conclusions the relative temperature of the refrigerant as it passes through the cycle.
9. To produce a starved condition in the evaporator, adjust the hand expansion valve until the flow rate is 2.2 lb/hr (1 kg/hr) (a flowmeter reading of 10 millimeters).
10. Allow five minutes for the system to settle down at this new flow rate. Then repeat steps 4, 5, 6, 7, and 8.
11. To produce a flooded condition in the evaporator, adjust the hand expansion valve until the flow rate is 18.6 lb/hr (8.45 kg/hr) (a flowmeter reading of 60 millimeters).
12. Repeat step 10.
13. Follow the shutdown procedure:

    1. Switch control switch **REV CYCLE** to *forward* (the operating pressure must be at least 15 psig, 103 kPa).
    2. Pump down the refrigerant into the high-pressure receiver.
    a. Close the receiver outlet valve (V6).
    b. Valve V1A should be closed and V1B should be open. Valve V2 should be closed.
    c. Open valve V3 and the HEV.
    d. Close the valve in capillary tube liquid control device line (V4).
    e. Open the receiver inlet valve (V5) so that all of the refrigerant is being pumped into the receiver.
    f. When discharge pressure has fallen to about 8 psig (55 kPa), close the receiver inlet valve (V5) and turn off the compressor (switch **COMP**).
    g. Close all other valves. Valve V1, if used, should remain fully clockwise.
    3. Switch off control switches F1 and F2.
    4. Unplug the trainer, if it is to be left unattended.

14. From the data you have recorded in Table 1-1, diagram each of the three conditions on the pressure-enthalpy and temperature-entropy chart. Label these normal, starved, and flooded.

VALVE	OPEN	CLOSED	SWITCH	ON	OFF
V1A		X			
V1B	X		F1	X	
V2		X	F2	X	
V3		X	COMP	X	
V4		X	REV CYCLE		FORWARD
V5	X				
V6	X				
HEV	X	See note			

NOTE: The HEV should remain closed until after the compressor has started. Open the HEV slowly to prevent the evaporator from flooding. Initially, set the flow rate to about 45 (13.85 lb/hr, 6.28 kg/hr) on the flowmeter.

VALVE	POSITION	REMARKS
Stop #1A	Closed	Connects evaporator outlet to compressor inlet.
Stop #1B	Open	Connects evaporator outlet to compressor inlet.
Stop #2	Closed	Closes off low side float cylinder.
Stop #3	Closed	Connects thermostatic expansion valve.
Stop #4	Closed	Closes off capillary tube.
Stop #5	Open	Opens inlet to high pressure receiver.
Stop #6	Open	Opens outlet from high pressure receiver.
Hand Expansion Valve	Closed	This valve should be opened gradually when compressor is switched on.

NOTE: Reverse cycle switch must be in the *off* position.

Laboratory Report Sheet—HEV Controlled System

	FLOW RATE (LB/HR) (KG/HR)	
	14.0 (6.4)	18.2 (8.3)
Compressor suction (in. Hg) (kPa)		
Compressor discharge (psig) (kPa)		
Temperature at evaporator inlet		
Temperature at evaporator outlet		
Temperature at compressor inlet		
Temperature at compressor outlet		
Temperature at condenser inlet		
Temperature at condenser outlet		

Table 1-1
Test Results

Conclusions

PART 1

Using the terms *liquid, vapor,* and *liquid-vapor mixture,* describe the state of the refrigerant at the following points.

	FLOW RATE (LB/HR)	
	14.0	18.2
1. Entering evaporator		
2. Leaving evaporator		
3. Entering compressor		
4. Leaving compressor		
5. Entering condenser		
6. Leaving condenser, entering receiver		
7. Leaving receiver, entering HEV		
8. Leaving HEV		

PART 2

Using the terms *high* and *low,* describe the pressure of the refrigerant at the following points of the refrigeration cycle.

	FLOW RATE (LB/HR)	
	14.0	**18.2**
1. Evaporator pressure	________	________
2. Compressor suction	________	________
3. Compressor discharge	________	________
4. Condenser pressure	________	________
5. Receiver pressure	________	________
6. HEV inlet	________	________
7. HEV outlet	________	________

PART 3

Using the terms *hot, cold,* and *warm,* describe the temperature at the following points of the refrigeration cycle.

	FLOW RATE (LB/HR)	
	14.0	**18.2**
1. Evaporator inlet	________	________
2. Evaporator outlet	________	________
3. Compressor inlet	________	________
4. Compressor outlet	________	________
5. Condenser inlet	________	________
6. Condenser outlet	________	________
7. HEV inlet	________	________
8. HEV outlet	________	________

CAPILLARY TUBE CONTROLLED REVERSE CYCLE (HEAT PUMP)

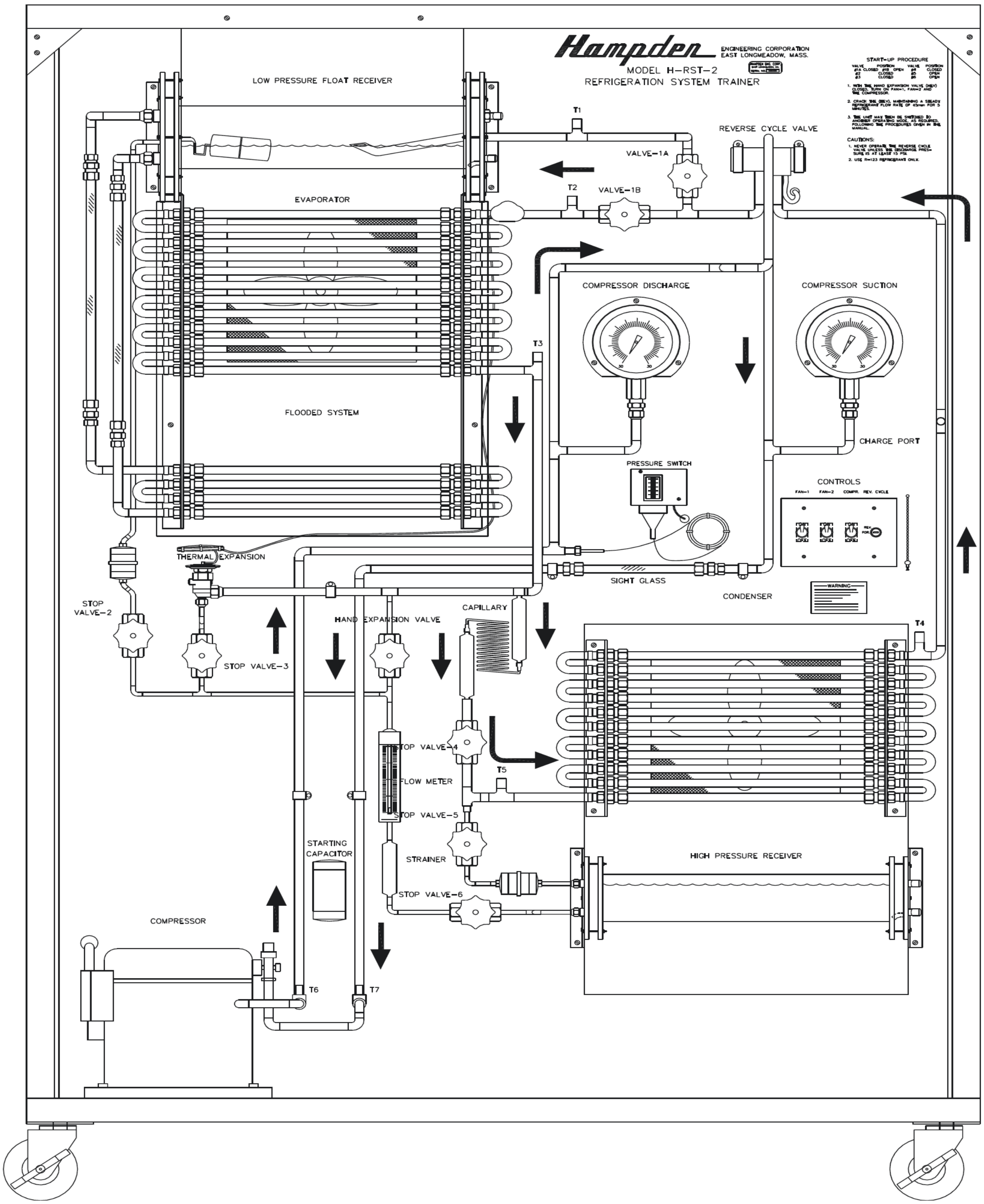


Figure 4-1
Capillary Tube Controlled Reverse Cycle (Heat Pump)

Procedure

1. Turn on fan #1 (evaporator fan), fan #2 (condenser fan), and compressor.
2. Open hand expansion valve slowly, observing both the flowmeter and the evaporator.
3. While the system is settling down, readjust the hand expansion valve, as necessary, to maintain a flow rate of 14.0 lb/hr (6.4 kg/hr) (a flowmeter reading of 45 millimeters).
4. When the system has settled down with constant pressures and constant 14.1 lb/hr (6.4 kg/hr) flow rate, turn off stop valve #5 (closing the inlet to the high-pressure receiver), and stop valve #6 (closing the outlet to the high-pressure receiver).
5. Simultaneously, close the hand expansion valve and open stop valve #4 to switch over from HEV control to capillary tube control.
6. Allow five minutes for the system to settle down while making sure that the refrigerant in the evaporator is liquid in the lower portion and vapor in the upper portion. If there is too much liquid, you can drain some off through stop valve #5. If you need more, you add liquid through stop valve #6 and the HEV. Suction pressure must be *at least 15" vacuum (preferably 20" (4.88 psia) (33.7 kPa)), and discharge pressure must be at least 15 psig (29.7 psia) (204.8 kPa) (preferably 20 psig (34.7 psia) (239.25 kPa))*. If an attempt is made to reverse the cycle before this criterion has been met, the valve may hang in mid position. To correct this situation, it may be necessary to *jog* the valve by repeatedly turning the compressor on and off, until the valve resets.
7. Turn on the reverse cycle switch.
8. Allow 15 minutes for the system to settle down, then read the compressor suction and compressor discharge gauges, and record the readings in Table 2-1. When the system settles down, these gauge readings should compare with the gauge readings taken during normal operation.
9. Read and record the temperature of the six points listed in Table 2-1. Allow three minutes for each temperature reading.
10. From your visual observation, record in Part 1 of Conclusions the pressures at various points in the heat pump cycle.
11. From your gauge measurements, record in Part 2 of Conclusions the pressures at various points in the heat pump cycle.
12. From your temperature measurements and by feeling the piping, record in Part 3 of Conclusions the relative temperature of the refrigerant as it passes through the heat pump cycle.
13. Before returning the reverse cycle valve to its normal position, be sure suction pressure is *at least 15" (preferably 20" (4.88 psia) (33.7 kPa))*, and vacuum and discharge pressure is *at least 15 (29.7 psia) (204.8 kPa) (preferably 20 psig (34.7 psia) (239.25 kPa))*. Turn off the reverse cycle switch and, after flow is reversed, turn off the compressor.
14. Follow the shutdown procedure found in the *Operating Instructions*.
15. On the pressure-enthalpy chart, diagram the heat pump cycle, indicating pressures and temperatures. From the data, construct the temperature-entropy diagram as well.
16. From the Table of Properties for R-123, compute the amount of heat discharged into the room by the evaporator (functioning as a condenser), as outlined in Part 4 of Conclusions.

IMPORTANT: Before attempting to switch on the reversing valve, be sure the discharge pressure is at least 15 psig (103 kPa).

VALVE	OPEN	CLOSED	SWITCH	ON	OFF
V1A		X			
V1B	X		F1	X	
V2		X	F2	X	
V3		X	COMP	X	
V4	X		REV CYCLE	REVERSE	See note
V5		X			
V6		X			
HEV		X			

Switch on the reversing valve. Allow a couple of minutes for the refrigerant flow to reverse. At this time, the pressure will drop drastically and then slowly increase to normal. The final control settings should appear as follows:

NOTE: When shutting down the system, the reversing valve must be switched off before the compressor. Be sure that the discharge pressure is at least 15 psig (103 kPa). Switch the reverse cycle switch to **FORWARD**, wait for the refrigerant flow to reverse (in about 2 minutes), then switch off **F1**, **F2**, and **COMP**.

VALVE	POSITION	REMARKS
Stop #1A	Closed	Connects evaporator outlet to compressor inlet.
Stop #1B	Open	Connects evaporator outlet to compressor inlet.
Stop #2	Closed	Closes off low side float cylinder.
Stop #3	Closed	Connects thermostatic expansion valve.
Stop #4	Open	Closes off capillary tube.
Stop #5	Closed	Opens inlet to high pressure receiver.
Stop #6	Open	Opens outlet from high pressure receiver.
Hand Expansion Valve	Closed	

Laboratory Report Form—Heat Pump System

Compressor suction (in. Hg) (kPa)	____________________
Compressor discharge (psig) (kPa)	____________________
Temperature at evaporator inlet (condenser outlet)	____________________
Temperature at evaporator outlet (condenser inlet)	____________________
Temperature at compressor inlet	____________________
Temperature at compressor outlet	____________________
Temperature at condenser inlet (evaporator outlet)	____________________
Temperature at condenser outlet (evaporator inlet)	____________________

Table 2-1

Conclusions

PART 1

Using the terms *liquid, vapor* and *liquid-vapor mixture,* describe the state of the refrigerant at the following points of the heat pump cycle:

1. Entering evaporator ____________________
2. Leaving evaporator ____________________
3. Entering compressor ____________________
4. Leaving compressor ____________________
5. Entering condenser ____________________
6. Leaving condenser, entering receiver ____________________
7. Leaving receiver, entering TEV ____________________
8. Leaving TEV ____________________

PART 2

Using the terms *high* and *low,* describe the pressure of the refrigerant at the following points in the heat pump cycle.

1. Compressor pressure (functioning as evaporator) ____________________
2. Compressor suction pressure ____________________
3. Compressor discharge pressure ____________________
4. Evaporator pressure (functioning as condenser) ____________________
5. Pressure at capillary tube inlet ____________________
6. Pressure at capillary tube outlet ____________________

PART 3

Using the terms *hot, cold,* and *warm,* describe the temperature at the following points of the heat pump cycle.

1. Condenser inlet (evaporator outlet) ____________________
2. Condenser outlet (evaporator inlet) ____________________
3. Compressor inlet ____________________
4. Compressor outlet ____________________
5. Evaporator inlet (condenser outlet) ____________________
6. Evaporator outlet (condenser inlet) ____________________
7. Capillary tube inlet ____________________
8. Capillary tube outlet ____________________

Questions:

1. Determine the COP of refrigerator and heat pump (formulas shown above in Theory).
2. Draw T-s and P-h diagrams for the refrigerator and heat pump from the experimental data.