Experiment: Analysis of a Mass Lifting Heat Engine

In this experiment, your group will construct a device that utilizes thermal energy to lift small gram masses. This device is a real closed gas heat engine that will utilize a four stage expansion and compression cycle to do useful mechanical work by lifting small masses.

The purpose of this endeavor is to analyze the heat engine, to determine the heat absorbed/released and the net work performed during one cycle of operation. Moreover, you will compare the thermodynamic work performed by the gas with the corresponding mechanical work and determine the thermodynamic efficiency of the heat engine.

Objectives:

1. to analyze a heat engine cycle & identify the various phases of the heat engine cycle
2. to identify the stages of the heat engine cycle when useful work is performed
3. to determine the efficiency of the heat engine & compare to the ideal "Carnot" cycle

Materials:

- Low friction 10-mL glass syringe
- Tygon tubing & plastic 3-way stopcock valve
- Small Erlenmeyer flask with one-hole rubber stopper
- 2 large beakers (to use as temperature reservoirs)
- 1 50-100 g mass
- warm hot water (about 50 to 60 ^{o}C)
- ice water
- LoggerPro software w/pressure and temperature sensor

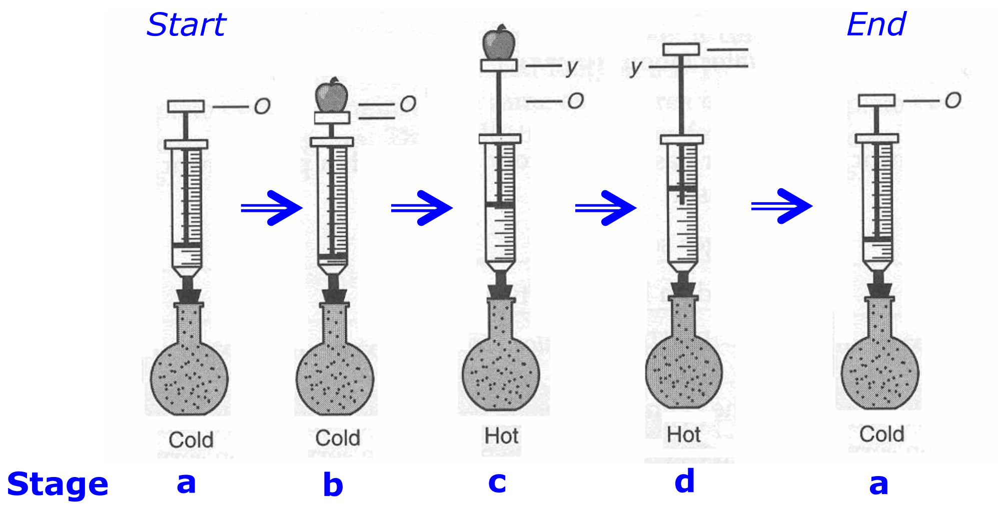
Overview

The cylinder of the heat engine apparatus is closed by a movable low-friction piston. The flat top of the handle piston serves as a platform for rising masses. The flask and the pressure sensor are connected to the cylinder using short lengths of Tygon tubing. The flask connected to the heat engine will be placed in the hot reservoir to increase the temperature of the gas and to make the gas expand (useful work). When the flask is placed in the cold reservoir, the air inside will contract bringing the piston in its original position. Starting from equilibrium, the mass will be placed on the handle. Then the flask will be placed in the hot reservoir, causing the mass to rise. The mass will be then removed from the platform, causing the piston to rise a little bit more. Then the flask is placed in the cold reservoir, causing the volume to decrease to its original value.

The lifting and lowering parts of the cycle should be approximately isobaric, since the pressure of the air trapped inside the cylinder is determined by the weight of the piston (and the mass on top of the handle) and the atmospheric pressure pushing down on the gas.

The other two parts of the cycle, when the mass is added and removed from the platform, are adiabatic, since they occur very quickly and the heat can not be transferred between the gas and its surroundings.

Figure 1: The Heat Engine



Procedure:

1. Obtain and wear goggles and heat gloves. Heat up roughly 400 mL water in a large beaker, using an immersion heater or hot plate.
2. Prepare another large beaker with ice water.
3. Determine the volume of the flask and the Tygon tubing. Remember, the total volume of the gas in the heat engine is: $V_{flask} + V_{tubing} + V_{syringe}$. Enter your results below:

$\mathbf{V_{flask}}$ = ______________

$\mathbf{V_{tubing}}$ = ______________

4. Connect the pressure sensor to CH 1 and the temperature sensor to CH2 of the LabPro interface.
5. Start-up the LoggerPro software then open the experiment file:

   /Experiments/Additional Physics/RealTimePhysics/Heat & Thermodynamics/L6A3-2.xmbl

6. Attach the rubber stopper to the Erlenmeyer flask and establish a good seal.
7. Connect the top of the stopcock valve to the glass syringe and the bottom of the valve to the rubber stopper then secure the syringe using a ring stand and clamp.
8. Attach the tubing to the pressure sensor at one end and the side of the stopcock valve. *You will use the stopcock valve to open the various chambers of the sealed engine during your experiment.*
9. Record the initial pressure, volume and temperature of the sealed heat engine at room temperature. Then calculate the number of moles in your closed system.

$\mathbf{V_{engine}}$ = ______________

$\mathbf{P_{engine}}$ = ______________

$\mathbf{T_{room}}$ = ______________

n = ______________

10. Now, run a trial/practice cycle, as follows:

a. Bring the ice water beaker up to the Ehrlenmeyer flask and submerge the flask. Place the temperature sensor in the ice water. This is the initial state of your system (a).

b. With the flask in the ice water, place a 50-100g mass on the top of the syringe plunger (the platform). Notice that the piston was lowered, changing the total volume of the gas. The transformation occurs very quickly, so it is an ___________ process. At the end of this stage, the system is in state (b).

c. Now remove the ice water and repeat with the warm water. The piston should rise, doing useful work on the gram mass. This process is _______________. At the end of this transformation, the system has reached the third state, (c).

d. Now remove the mass from the piston. The piston will rise further. This process occurs very quickly, so it is _________________. This is the fourth state of the engine cycle, (d).

e. Remove the warm water flask and replace it with the ice water. The piston should return in the initial position (how can you tell?). This transformation is __________.

11. Based on your observations and understanding of this heat engine, sketch a P vs. V graph for 1 cycle.

12. Identify any errors that you noticed during the trial run and adjust your procedure appropriately. (i.e. if the piston reached the top or the bottom of the cylinder during the cycle, adjust the original position of the piston). *If the piston returned to a position much lower than the original position (more than a 1 mL difference), see your instructor.*

13. Get ready for taking measurements, by assigning roles (i.e. Who reads the height of the cylinder? Who calculates (fast!!) the total volume to be entered for each state? Who operates the computer? Who moves the flask/mass/temperature sensor?).

    Since the apparatus is not perfectly sealed, long delays during the experiment may result in significant leakage and flawed data. Try to perform the experiment as quickly as possible to avoid gas leakage.

14. Now run the same heat engine cycle and collect pressure and volume data as follows:

    a. Place the flask and the temperature sensor in the ice water. Push "Collect". Stir until the temperature and the pressure readings are stable. Record the temperature of the water in Table 1. Push "Keep" then read the height of the cylinder, calculate the total volume of the gas and enter this value. This is the initial state of your system (a).

    b. With the flask in the ice water, place the mass on the platform. Select "Keep" then enter the calculated volume. This is your second state, (b).

c. Now move the flask and the temperature sensor in the hot water. Record the temperature of the water in Table 1. When the reading is stable, select "Keep" then enter the calculated volume. This is the third state of your system, (c).

d. Remove the mass from the piston. Wait until the pressure is stable then collect the pressure and volume. This is the fourth state of the system, (d).

e. Move the flask and the temperature sensor back to the cold water. The piston should return to the initial position (approximately). Collect the pressure and calculated volume values.

15. Record the values for pressure and volume for each engine stage in the table below.

16. Cut-and-paste the graphs into Microsoft Word then print.

Table 1: Heat Engine Data				
Volume of flask + Volume of tubing				
Temperature of hot water (T_{hot})				
Temperature of ice water (T_{cold})				
State	**Volume of syringe (mL)**	**V_{Tot} (mL)**	**P (kPa)**	**T_{gas} (K)**
A				
B				
C				
D				
A				

17. Perform the following steps.

a. On the printed P-V graph, label the type of thermodynamic process for each transformation and label the states a, b, c, d.

b. Applying the Ideal Gas Law, use the P, V and n values to estimate the temperature ($T_{estimate}$) for each state above. Record values in the Table 1.

c. Estimate the amount of heat absorbed by the gas during 1 complete cycle. *Note: Air can be treated as a diatomic ideal gas, $C_v = (5/2)R$ and $C_p = (7/2)R$.*

Q_H =______________

18. The area enclosed by the P-V graph represents the net thermodynamic work (W_{thermo}) performed during one cycle. Using the "Integral" tool on the toolbar, find the area enclosed by the cycle and convert it into SI units. Enter the result below, including the calculated error.

W_{thermo} = ______________

Note: *If the resultant P-V graph is not closed, LoggerPro cannot properly calculate the enclosed area. If your complete engine cycle is nearly closed, P & V (initial) are very close to P & V (final), but the graph is just not quite closed, and thus the enclosed area cannot adequately be computed, cut and paste the P-V data into Graphical analysis and manually set the final A state values to the same as the initial P, V values.*

If your final P & V values for state A are significantly different than your initial values it is likely that you:

1. *have a significant leak in your heat engine, or*
2. *miscalculated your one or more of your volume values, or*
3. *took too long to perform a complete cycle and the final temperature at state A is different than the starting value.*

In any case, you will need to identify what went afoul then repeat the heat engine cycle and collect new P and V values.

19. Calculate the net mechanical work (W_{mech}) performed by the heat engine on the small mass. The mechanical work can be calculated by: $W_{mech} = mg\Delta y$, since the force exerted to lift the mass is equal to the weight of the object, F = mg and the distance traveled by the object during the lifting phase (Δy), between states B and C, can be obtained using the data in your table.

W_{mech}= ______________

Analysis Questions:

1. How did the 2 values for work calculated in steps 18 and 19 above compare? Calculate the % Error between them.

2. What can you conclude from the % Error calculated in (1)?

3. Calculate the net work for 1 cycle of the heat engine using only the temperature, pressure and volume values in Table 1. *You will need to apply the 1st Law of Thermodynamics to each of the heat engine states.*

4. Compare the calculated net work in (3) with the measured value above (step 15). Calculate the % error.

5. Calculate and the efficiency of the heat engine, using the thermodynamic work value and the heat absorbed by the gas:

$e = W_{thermo}/Q_H$ = _______________

6. Calculate the efficiency of an ideal Carnot engine operating between the same 2 temperature reservoirs, T_{hot} & T_{cold}.

7. Calculate the % error between the efficiency of the heat engine and the Carnot engine.