Blender Exercise

ME 321, Spring 2010

Before coming to the lab, read sections 1 through 3 of this document.

Engineering of Everyday Things
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Blender Laboratory Exercise **Participant Code:** ____________

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1 Apparatus

Figure 1 shows the equipment for this laboratory exercise. The key components are

1. A food blender, partially filled with water.
2. Thermocouples (temperature sensors) suspended in the water.
3. A data acquisition device (DAQ) for digitizing the thermocouple output.
4. A computer to record, display and analyze the digitized thermocouple readings.

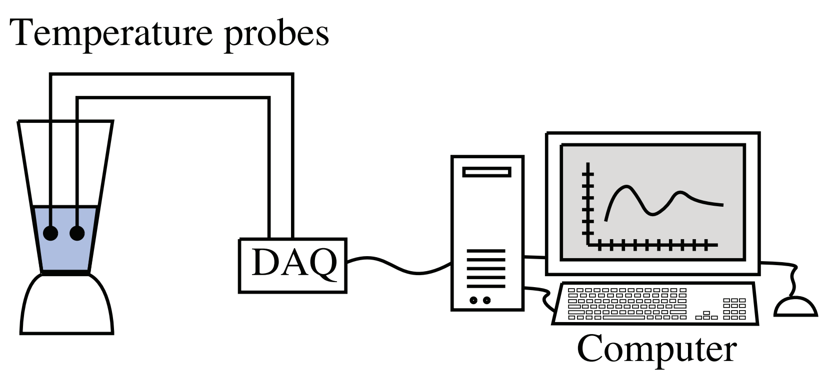


Figure 1: Apparatus for the blender experiment.

2 Learning Objectives

As a result of completing this laboratory exercise you will be able to

1. Recognize and describe the roles of heat, work, and energy storage in the operation of a food blender.
2. Use qualitative reasoning to predict and verify the changes in measurable system parameters (temperature, power input) that result from changing blender speed, quantity of liquid in the blender, and initial temperature of the liquid in the blender.

3 Lab Warm-up

It is helpful to use a common language when describing the behavior of the blender. Work through the questions in this section to prepare for the measurement exercises. Return to the concepts developed here as you work in the lab.

Try your best to answer the questions on your own. Consult with your teammates or the teaching assistant only *after* you have completely worked through the warm-up exercises. Make sure you are comfortable with your answers before moving on to section 4.

3.1 First Law of Thermodynamics

The First Law of Thermodynamics can be written in two forms

$$\Delta U = Q + W \tag{1}$$

$$\frac{dU}{dt} = \dot{Q} + \dot{W}. \tag{2}$$

1. What is the primary difference between these two equations?

2. Can both versions of the First Law be true for a given situation?

3. Which of these equations do you think will be most useful in analyzing the behavior of the blender?

   Why?

3.2 Lab Preview

For a system consisting of a fixed mass and fixed volume we can write Equation (2) as

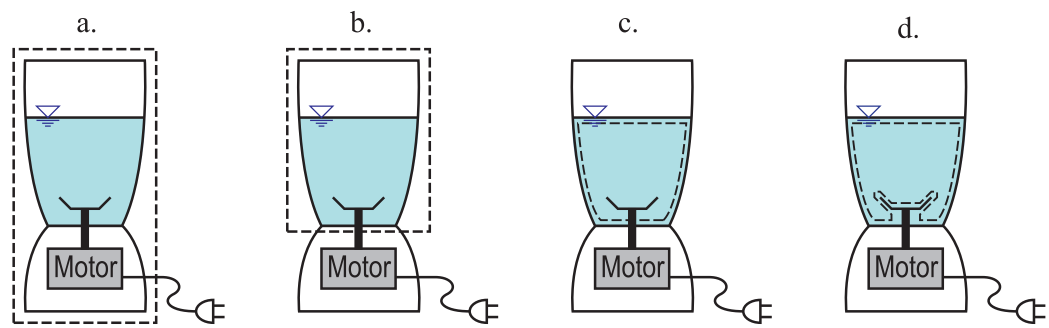
$$mc_v \frac{dT}{dt} = \dot{Q} + \dot{W} \tag{3}$$

where m is the mass of the system, and c_v is the specific heat at constant volume. In the lab exercise, each term in Equation (3) will be studied.

$mc_v \frac{dT}{dt}$	Energy storage: energy content of the system increases when $dT/dt > 0$.
$\dot{Q}$	Heat transfer *to* the system from the surroundings.
$\dot{W}$	Work done *on* the fluid by the surroundings.

3.3 Define the System

The following diagrams show four ways of defining the system boundary for the blender. The First Law of Thermodynamics can be applied to each of the four systems, but some system definitions are easier to work with than others. The table below the diagram describes the advantages and disadvantages of each system definition. Use the diagram and the table to assist with your answers to the questions on the next page.



	Work input	Heat Gain/Loss	Energy Storage
a.	Electrical work enters the control volume through the wires.	Small heat loss from outside surface of pitcher because the air is calm and the thick walls of the pitcher heat up slowly.	Energy storage occurs in the motor, blades, pitcher, and water, but only water temperature is measured.
b.	Work enters through the rotating shaft.	Small heat loss from outside surface of pitcher because the air is calm and the thick walls of the pitcher heat up slowly.	Energy storage occurs in the blades, pitcher, and water, but only water temperature is measured.
c.	Work enters through the rotating shaft.	When the pitcher is cooler or warmer than the water, significant heat transfer occurs between the water and the pitcher because the water is vigorously mixed.	Energy storage occurs in the water, and is indicated directly by water temperature.
d.	Work is applied to the system surface by shear stress between the blades and water.	When the pitcher is cooler or warmer than the water, significant heat transfer occurs between the water and the pitcher because the water is vigorously mixed.	Energy storage occurs in the water, and is indicated directly by water temperature.

3.4 Study Questions

Review the following questions by yourself. These questions are intended to help you prepare for the lab exercise, and consolidate your knowledge during and after the exercise. Your answers to these questions will not be graded.

1. Which control volume(s) provides the easiest way to measure $\dot{W}$?

2. When a wattmeter is used to measure the electrical power input, $\dot{W}_{e,\mathrm{in}}$, and the motor efficiency is η, how much power is delivered to the water in the pitcher?

3. Which control volume(s) provides the easiest definition for measuring the increase in energy storage, which is indicated by dT/dt.

4. Which of the control volume definitions is *least* likely to show heat transfer effects during a brief, say 5 minute long, experiment?

3.4.1 Share and Compare

Discuss your answers with other members of your group. Keep your answers on the worksheet, and write the group's consensus next to your answer. Label the groups' consensus with a mark like "G" or "Group".

3.4.2 Reconsider

As you work through the lab exercise, your opinion, and that of the group may change. Record your final opinion on the answer sheet and label it with a mark like "F" or "Final".

4 Energy Storage Experiments

The first set of experiments is focused on the energy storage term in the First Law. The learning objectives are

- Be able to identify the independent and dependent variables in the energy storage term.
- Be able to quantitatively predict the effect of changing the amount of water in the blender.
- Be able to verify the effect of changing the amount of water in the blender.

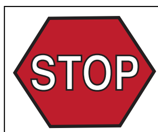
4.1 Preliminary Analysis

1. The energy storage term is
$$\frac{dU}{dt} = mc_v \frac{dT}{dt}$$
where m is the mass of the system, c_v is the specific heat at constant volume, T is temperature, and t is time. The following table lists the separate terms that make up dU/dt. If these experiments are conducted with water, which of the terms that make up dU/dt can be readily controlled by adjusting the blender settings given the materials in the laboratory? Which of the terms can only be measured? Which of the terms are constant, e.g., intrinsic properties that cannot be changed.

Term	Controllable, measurable, or constant?	How to control, or how to measure?
$\frac{dT}{dt}$		
m		
c_v		

2. For each of the parameters that can be adjusted to change dU/dt, predict whether the change will increase or decrease the magnitude of dU/dt when all other system settings, e.g., blender speed, are kept constant. Enter your response in the last column of the preceding table.

3. How would you design an experiment that would allow you to measure the effect of c_v?



Before continuing, show your lab manual to the instructor. It's important at this point to make sure you are on the right track. INSTRUCTOR APPROVAL ☐

4.2 Measurement

The experimental results are improved by using water that is at room temperature. If the Teaching Assistant has not provided a pitcher of room temperature water, adjust the tap water temperature so that you put room temperature water in the blender.

Preliminary Set-up

1. Add water so that the blender is about half full. Record the amount of water in the blender pitcher.
2. Start the data acquisition program.
   (a) The teaching assistant should have the LabVIEW program running. If not, launch the LabVIEW Virtual Instrument by double-clicking on it.
   (b) Define a file name for storing the results of this exercise.
   (c) Click on the *run* arrow to start the VI.
3. Use the "pulse" feature of the blender to turn on the motor for two or three short bursts (approximately one second each). Pulsing the motor will mix the water so that the temperature is uniform at the start of the experiment.
4. Wait for the temperature readings of the thermocouples to stabilize.

While you are waiting for the thermocouples to stabilize, decide what blender speed to use for the energy storage experiment. Should the speed matter?

First Reading

1. When the temperature of the thermocouples has stabilized (near room temperature), and with the data acquisition program running, turn on the blender at a chosen speed.
2. Record the blender speed, the wattmeter reading, and the volume of water in Table 1 on the next page.
3. Let the blender run until you can see a clear trend in the temperature, say one or two minutes. versus time data.
4. Do not stop the data acquisition program.
5. Turn off the blender

Second Reading

1. Add water to the blender pitcher until the pitcher is approximately three quarters full. Record the volume of water in the blender.
2. With the data acquisition program running, turn on the blender to the same speed as in the preceding experiment.
3. Record the blender speed, the wattmeter reading, and the amount of water in Table 1.
4. Let the blender run for one or two minutes.
5. Turn off the blender when a clear trend in T versus t is evident, say after a minute.
6. Stop the data acquisition program.

Extracting the Slope of Temperature versus Time

1. Load the data into the MATLAB slope extractor tool.
2. Using the MATLAB program, extract the slope of temperature versus time for the First and Second Readings, and record the data in Table 1.

4.3 Analysis

The experiment is performed with two different amounts of water in the blender. We start by setting up a formula by taking the ratio of the First Law for two different experiments. You are then asked to complete the derivation and apply the formula to your data..

4.3.1 Scaffolding: Form a Ratio of Terms

If we write the First Law for each experiment we get

$$m_1 c_1 \left(\frac{dT}{dt}\right)_1 = \dot{Q}_1 - \dot{W}_1 \qquad\qquad m_2 c_2 \left(\frac{dT}{dt}\right)_2 = \dot{Q}_2 - \dot{W}_2$$

Taking the ratio those two instances of the energy equation gives

$$\frac{m_2 c_2 \left(\dfrac{dT}{dt}\right)_2}{m_1 c_1 \left(\dfrac{dT}{dt}\right)_1} = \frac{\dot{Q}_2 - \dot{W}_2}{\dot{Q}_1 - \dot{W}_1} \tag{4}$$

Equation (4) can be simplified by assuming that $\dot{Q}_2 - \dot{W}_2 \approx \dot{Q}_1 - \dot{W}_1$, which is reasonable since the speed does not change and $\dot{Q}$ is small.

4.3.2 Complete the Analysis

Using the following steps, transform Equation (4) into a formula for analyzing your measurements.

1. Write a simplified form of Equation (4) obtained by assuming that $\dot{Q}_2 - \dot{W}_2 \approx \dot{Q}_1 - \dot{W}_1$.

2. Rearrange the equation obtained in the preceding step by to the form $(dT/dt)_2/(dT/dt)_1$.

$$\frac{\left(\dfrac{dT}{dt}\right)_2}{\left(\dfrac{dT}{dt}\right)_1} =$$

Table 1: Data for the energy storage experiment. The dT/dt value is extracted from the data stored by the LabVIEW program.

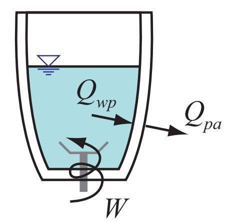
Run	Blender speed	Water volume	Electrical Power (W)	$\dfrac{dT}{dt}$
1				
2				

3. Use the formula you just derived to check the data in Table 1. Is the data in Table 1 consistent with the Equation obtained in Step 2? If not, suggest at least one reason for the disagreement.

4.3.3 Study Questions

Reconsider the control volumes shown on page 4.

1. How is the magnitude of energy storage in the water affected by heat transfer from the water to the glass? The diagram to the right suggests heat flow from the water to the pitcher, $\dot{Q}_{wp}$ and heat transfer from the pitcher to the ambient, $\dot{Q}_{pa}$.

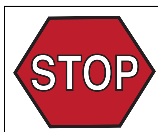


2. For the control volumes that include both the glass pitcher and the water, what is the meaning of (or value of) the product mc for the energy storage term in the First Law? Write a simple formula of the form $mc = \ldots$ where $\ldots$ contains terms for both the water and the solid blender material.

   $mc =$

3. Use qualitative reasoning to compare the relative sizes (i.e., estimate which is bigger) of the rate of heat transfer from the water to the glass versus the rate of heat transfer from the glass to the air.

4. If the glass (or plastic) pitcher contributes to the energy storage, how would you estimate the mc terms in Equation (4) on page 8?



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5 Work Input Experiments

The next set of experiments are focused on the work term in the First Law.

5.1 Preliminary Analysis

Review your answers to the exercises in Section 3.3 regarding the definition of the system for the First Law analysis.

1. List the measurable variables that can be used to quantify the work term in the first law of thermodynamics.

2. Which of these terms can be readily adjusted by changes to the system configuration given the materials in the laboratory? In other words, what can you change to cause a measurable change in the rate of work on the system?

3. For each of the changes listed in item 2, predict whether the change will increase or decrease the magnitude of the work term.

5.2 Measurement

For these measurements the amount of water in the blender is held constant.

Preliminary Set-up

1. Add water so that the blender is about half full. Record the amount of water in the blender pitcher.
2. Start the data acquisition program.
3. Use the "pulse" feature of the blender to turn on the motor for two or three short bursts (approximately one second each).
4. Wait for the temperature readings of the thermocouples to stabilize.

While you are waiting for the thermocouples to stabilize, decide what two blender speeds to use for the energy storage experiment. The goal is to measure the relationship between blender speed and the rate of increase in temperature of the water.

1. As a practical matter, is it easier to measure small differences or large differences?

2. Based on your answer to the preceding question, should you choose two speeds that are very close or very different?

Data Collection

1. When the temperature of the thermocouples has stabilized, and with the data acquisition program running. Turn on the blender and a fixed speed.
2. Record the blender speed, the wattmeter reading, and the amount of water in Table 2 at the bottom of the page.
3. Let the blender run for one or two minutes.
4. Do not stop the data acquisition program.
5. Change the blender speed and let the blender run for one or two more minutes.
6. Turn off the blender.
7. Stop the Data Acquisition program.

Extracting the Slope of Temperature versus Time

1. Load the data into the MATLAB slope extractor tool.
2. Using the MATLAB program, extract the slope of temperature versus time for the First and Second Readings, and record the data in Table 1.

5.3 Analysis

1. Write a simplified form of Equation (4) that applies to this experiment.

2. Is the data in Table 2 consistent with the Equation obtained in Step 2? If not, suggest at least one reason for the disagreement.

Table 2: Data for the experiment to determine the effect of work input.

Run	Blender speed	Water volume	Electrical Power (W)	$\frac{dT}{dt}$
1				
2				