MECH 222 Computer Lab 4—Thermodynamic Surfaces

Overview You should emerge from this lab with two new assets.

The first will be a solid 3D model of a thermodynamic surface. Each lab group will work together to produce a different presentation of a standard surface describing the state of water, one of the most important substances in engineering thermodynamics. Each individual will contribute one or two slices that, when assembled, will help constitute the group's surface. The role of the computer is to provide exact cutting and assembly instructions.

Your second produce will be a virtual 3D rendering of the surface your group is building, so you can rotate and inspect it on the computer both before and after construction is finished.

Learning Objectives

- Matlab: After reading the Briefing Notes and completing this lab, you should be able to
  - Use loops to repeat a sequence of calculations that build a curve,
  - Make and manipulate logarithmically-scaled plots in 2D and 3D coordinate systems.
- Mathematics: These readings and activities should help you learn to
  - Work with parametric curves in 2D and 3D coordinate systems.
  - Relate level sets and contours to surfaces in 3D.
- Engineering: This lab should help you
  - Strengthen your 3D visualization skills, useful in every area of engineering.
  - Understand famous thermodynamic surfaces and diagrams in greater depth.
  - Imagine how thermodynamic properties change along standard cycles used in industry.

PRE-LAB ASSIGNMENT

Keep a copy of your pre-lab results with you during the in-lab activities.

PL1: Explore the list of functions provided by `XSteam` in Idea 4 of the Briefing Notes, and study equations (2)–(5) to learn how to make parametric expressions for curves of interest in thermodynamic property space. Write equations analogous to the ones in (2)–(5) when answering the questions below.

(a) How could you use `XSteam` functions to draw parametric curves of constant v on a T–s diagram in 2D? On the PsT surface in 3D?

(b) How could you use `XSteam` functions to draw parametric curves of constant h on a T–s diagram in 2D? On the PsT surface in 3D?

PL2: This continues question PL1 above.

(a) How could you use `XSteam` functions to draw parametric curves of constant s on a T–v diagram in 2D? On the PvT surface in 3D?

(b) How could you use `XSteam` functions to draw parametric curves of constant P on a T–v diagram in 2D? On the PvT surface in 3D?

PL3: Figure out how to use `XSteam` to help you trace the 3D saturation curve parametrically, in both PvT space and PsT space. Plan to do the work in two parts, using a first parametric expression to trace the saturated-liquid points and a second one to show the saturated-vapour points. Take advantage of the special functions provided by `XSteam` to locate points in the saturated region.

PL4: Look up your assigned shape in the Lab Activities that follow. Use the resources in your textbook or online to find 5–10 points on that shape and make an analog sketch of the curve you will compute with great accuracy when you arrive at the Lab.

ACTIVITY 1: *Draw Isobars, Isotherms, and Constant-Property Curves on a 2D Plot*

Each named lab group will do something different. Within each lab group, each numbered team has a special role. The group expectations are shown here; details for each small team are in a separate file. Use these to identify your team's challenge, then start on the numbered activities shown below.

NOTE: In lines (1A)–(1D), the order of variables is essential. Use the indicated variables in their given order to replace x, y, and z and get a surface with a right-handed orientation. Likewise, any phrase like "the (ω, θ) plane" is meant to remind you of the (x, y) coordinate plane: the first-named variable goes along the horizontal axis, and the second-named one goes along the vertical axis. [In general, interchanging axes corresponds to a reflection; the specifications below are intended to produce objects that are the same, not mirror-images of each other.]

(A) Archimedes will produce a PvT surface by cutting and assembling isotherms ($T = \text{const}$), as drawn in the (P, v) coordinate plane. Each small team will make a different sheaf of isotherms. The axis values and limits, defined using $v_0 = 0.001\ \text{m}^3/\text{kg}$, $P_0 = 1$ bar, $T_0 = 1$ C, will be

$$0 \le \log_{10}(v/v_0) \le 6, \qquad 0 \le T/T_0 \le 500, \qquad -2 \le \log_{10}(P/P_0) \le 3. \tag{1A}$$

Decorations in the (P, v) plane will include several lines of constant T and several curves of constant h. Selected values of interest:

$$h/h_0 = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16; \qquad h_0 = 200\ \text{kJ/(kg.K)}.$$

(B) Bernoulli will produce a PsT surface by cutting and assembling isobars ($P = \text{const}$), as drawn in the (s, T) coordinate plane. Each small team will make a different sheaf of isobars.

The axis values and limits, defined using $s_0 = 1$ kJ/(kg.K), $P_0 = 1$ bar, $T_0 = 1$ C, will be

$$0 \le s/s_0 \le 10, \qquad 0 \le T/T_0 \le 500, \qquad -2 \le \log_{10}(P/P_0) \le 3. \tag{1B}$$

Decorations in the (s, T) plane will include several lines of constant T and several curves of constant v. Selected values of interest:

$$\log_{10}(v/v_0) = 0.5, 1.0, 1.5, 2.0, 2.5, \ldots, 5.5, 6.0; \qquad v_0 = 0.001\ \text{m}^3/\text{kg}$$

(C) Carnot will produce a PsT surface by cutting and assembling isotherms ($T = \text{const}$), as drawn in the (P, s) coordinate plane. Each small team will make a different sheaf of isotherms.

The axis values and limits, defined using $s_0 = 1$ kJ/(kg.K), $P_0 = 1$ bar, $T_0 = 1$ C, will be

$$0 \le s/s_0 \le 10, \qquad 0 \le T/T_0 \le 500, \qquad -2 \le \log_{10}(P/P_0) \le 3. \tag{1C}$$

Decorations in the (P, s) plane will include several curves of constant h. Selected values of interest:

$$h/h_0 = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16; \qquad h_0 = 200\ \text{kJ/(kg.K)}.$$

(D) da Vinci will produce a PvT surface by cutting and assembling isobars ($P = \text{const}$), as drawn in the (v, T) coordinate plane. Each small team will make a different sheaf of isobars.

The axis values and limits, defined using $v_0 = 0.001$ m^3/kg, $P_0 = 1$ bar, $T_0 = 1$ C, will be

$$0 \le \log_{10}(v/v_0) \le 6, \qquad 0 \le T/T_0 \le 500, \qquad -2 \le \log_{10}(P/P_0) \le 3. \tag{1D}$$

Decorations in the (v, T) plane will include several lines of constant T and several curves of constant s. Selected values of interest:

$$s/s_0 = 1, 2, 3, 4, 5, 6, 7, 8, 9.$$

It's strongly recommended to write a script to carry out steps 1.1–1.4 below. This will simplify debugging and submission, and make for a smoother transition to Activity 2. Also, you may need to repeat steps 1.1–1.6 for several iso-property values.

1.1. Set up the requested 2D coordinate frame for your lab group. Use the axis orientation and scaling specified for your group.

1.2. Draw a reasonable number of isobars and isotherms on the diagram above. One family of curves will be easy—a bunch of straight lines parallel to one of the coordinate axes; just include the plotting command `grid on` to add enough of these. The other family will take some work. *Suggestion*: Decide on your parametric representation for the curve of interest. It should already be written down either in the Briefing Notes or in your answer to PreLab question PL1 or PL2. Create two Matlab vectors: one to hold 500 parameter values in the desired interval, generated by `linspace` or `logspace` as appropriate, and another one to hold a list of the constant pressure- or temperature-values that will define the contours of interest. Then use a `for`-loop to carry out a curve-drawing operation for each particular value of the constant pressure- or temperature-value of interest. The curve-drawing operation (inside the main loop) will use its own mini-`for` loop to work through the parameter vector, using `XSteam` to calculate one point to plot for each parameter value. When that mini-loop completes, a single call to `plot` will produce the iso-property curve. Remember to say `hold on` so that each new curve gets added to the ones already in the picture.

One of the curves you generate will be special: It's your personal pattern for cutting a slice of the ultimate 3D surface. Draw over that curve with an extra bold line, or special highlight markers, or something that will help you recognize it during the assembly stage of the project.

1.3. Overlay the saturation curves (one branch for saturated liquid, and another for saturated vapour) on your growing 2D plot. Use a distinctive colour.

1.4. Add the corresponding constant-property curves to your plot. The property of interest will be one of $\log_{10}(v/v_0)$, h or s, depending on your group; the list of values of interest is clearly stated above.

1.5. Check that your axis limits correspond exactly to the specifications in lines (1A)–(1D). Add axis labels. Remember the standard Computer Lab expectations and put your name and student number beside a description in the plot title.

1.6. **Print two copies** (one at a time, so you can check the first). You will hand in one copy and use the other as a cutting pattern. To make the cutouts work together, it is imperative that all 30 group members have coordinate frames with identical scales and printed dimensions. So, please,

(a) Double-check that the horizontal axis is the right one;

(b) Double-check that the interval of values shown along each axis matches the one specified in (1A)–(1D) above.

(c) Select "File → Print Preview" in the figure window, and insist on US Letter Paper in Portrait mode. In the "Placement" box on the "Layout" tab, select "Use manual size and position" and demand a width of 7.00 inches and a height of 7.00 inches. Then use the Print command right in that window.

Hand-in Checklist:

- ☐ Your personal plot with your name embedded in it by Matlab.
- ☐ A transcript of the commands you used to make that plot. (If you wrote a script, print that; if you just typed commands one at a time, copy them from the command window into some text document for printing.)

ACTIVITY 2: *Draw a 3D Thermodynamic surface*

Modify your work in Activity 1 to produce a 3D wireframe image of your group's assigned thermodynamic surface.

2.1. Adapt your calculations of the isobars and isotherms from item 1.1 so that they all appear in 3D, on the thermodynamic surface assigned for your group. Review Idea 5 in the Briefing Notes if you need a reminder on how to upgrade a 2D command based on `plot` to a 3D version that uses `plot3`.

Paradoxically, the curve that was harder to draw in the plane view of item 1.1 is not too hard to generate here, whereas the curves that look like parallel straight lines in the plane view are actually harder to display.

2.2. Get the saturation curves to appear on the surface, not just on the plane.

2.3. Lift the iso-property contours described in your paragraph named (A)–(D) of Activity 1 so they appear on your growing 3D surface.

2.4. You should how have a mesh plot of your assigned thermo surface with meaningful extra information. Ideally your personal contour of interest would still have some unique identifying characteristic(s). Rotate your surface, inspect it thoroughly from all sides, spin it into an orientation you consider instructive and presentable, and print that perspective view for submission.

Hand-in Checklist:

- ☐ Your personal 3D plot with your name embedded in it by Matlab.
- ☐ A transcript of the commands you used to make that plot. (If you wrote a script, print that; if you just typed commands one at a time, copy them from the command window into some text document for printing.)

ACTIVITY 3: *Build the Thing!*

Details on this part of the job are still sketchy. We'll figure them out together in the Lab.

The general idea is to tape each plot from Activity 1 to a piece of foamboard, and cut the board along the contour personally assigned to you. Everybody will contribute one or two shaped bits of foamboard and work together to assemble the solid object by stacking up the contours.

Labelling. We'll want to put some ink onto the cut edges of each foamboard slice to show the selected levels of our iso-property curves. Later we will join those and see them clearly on the finished surface. We'll need a volunteer to provide a base plate or plates on which a suitable scale and labels can be shown.

Insurance. This team effort will fail if some participants can't finish the activity, or get their shapes wrong somehow. So the lab personnel will have backup copies of the cutting instructions available to rescue people whose code went wrong. Students should finish with the computations and printing by around 15:30 (or cash in their insurance policy) to allow 30 minutes for playing around with foamboard, tape, and cutters to assemble the finished product.

What Next?. Students with phone cameras can take their pictures with the trophy they have built, but then the TA should take the object and keep it in a safe place until it can be given to Prof Rogak.