Engineering Approach to Problem Solving

Energy Flow Diagrams (EFDs)

- Applies to Conservation of Mass (COM), the First Law of Thermodynamics (1^{st} Law), and the Second Law of Thermodynamics (2^{nd} Law)
- Similar to a Free Body Diagram used in Statics and Dynamics
- Identify your system or control volume using a dashed line
- Identify relevant transfers of mass and energy (as heat and/or work) <u>across</u> the boundary

Another view of engineering modeling

1. Clearly define the problem.
   a. What do you want to know?
   b. Identify your system or CV.
2. Model the problem.
   a. What physics are important for the given system and process, e.g., what governing equations are relevant?
   b. Identify the significant mass, energy, and force interactions with the surroundings.
   c. What assumptions can be reasonably made about the system/CV/process/interactions, e.g., steady state, adiabatic, uniform, ideal gas, frictionless, …?
   d. What are the boundary conditions and/or initial conditions?
3. Mathematically analyze the problem.
   a. Simplify and solve governing equations subject to the given assumptions and boundary and initial conditions.
   b. Generate mathematical predictions for the quantities of interest.
4. Review your predictions.
   a. Are the predictions reasonable?
   b. What do the predictions mean in terms of the real world?
5. Make decisions based on the predictions.
   a. If the predictions aren't accurate enough to make confident decisions, then improve the model and start over.
6. Clearly communicate your engineering analysis.
   a. Describe in text, figures, mathematics, and plots each of the previous steps in sufficient detail so that others can follow your analysis.
   b. Keep in mind that in most cases people will rely on written documentation of your work, not a verbal description, so it is essential that you develop good written communication skills.

Advice for Preparing Written Assignments

Having good writing skills is one of the most important skills you can have in engineering. Students are often surprised to hear this, especially since there is such emphasis on technical skill development in the undergraduate curriculum, but consistently employers and alumni say that written communication skills are one of the most important and one of the least developed skills in our graduates. It's, therefore, reasonable to encourage students to practice good communications habits when they can get feedback on their documentation and the stakes are low, e.g., on a homework assignment rather than a critical company document.

Writing is important in engineering because that is how most information is shared. For example, engineers regularly prepare project and status reports, manuals, proposals, work plans, standard operating procedures, training materials, and engineering change requests, as well as emails and memos. Indeed, more people will read an engineer's writing than hear that same engineer's presentations. Even if an engineer has the best ideas, if the ideas aren't communicated effectively, then they aren't likely to be implemented. Thus, expressing yourself competently and clearly in technical writing is essential for sharing ideas and making a good impression.

In this course, you'll be communicating your knowledge of the course material in written form via homework assignments, quizzes, and exams. I strongly encourage you to practice good technical communication skills when preparing these assignments. Please consider the following items when preparing your documents for this class (other classes may have different requirements).

1. Try to emulate the format used in the homework solutions. These solutions have been carefully prepared to make them thorough and easy to follow.
2. Format your work neatly and in a logical manner. Although it's not necessary for homework assignments and not possible for quizzes or exams, the use of a word processor, e.g., Word with Equation Editor (what most of the working world uses) or LaTeX (what is frequently used in academia) is expected in professional practice. It would be to your benefit to learn how to use such software effectively as a student.
3. Fully explain your solution process. Don't just list a bunch of equations on the page, but instead explain what the equation mean in words, then guide the reader on how you're manipulating the equations to arrive at an expression. The idea here is to guide the reader so they can follow your work without ambiguity.
4. Use schematics frequently in your documentation. Most engineers absorb information in visual form better than other methods. Sketch systems and control volumes, free body diagrams, and energy flow diagrams. Put these figures close to where they're used in your documentation.
5. Write the basic equations you're using, e.g., Conservation of Mass or the 1st Law, and simplify from there. Don't immediately jump to a simplified version of the basic equation. It's easier for the reader to follow your work if they understand how the equation is simplified.
6. Clearly identify significant assumptions and how they're used to simplify your equations. Significant assumptions include things that are essential for solving the problem and are not obvious. When in doubt as to whether to include an assumption or not, err on the side of being more explicit than less explicit. However, do not write assumptions that aren't necessary. Including unnecessary assumptions will confuse the reader.
7. In simplifying equations, don't do too many steps in your head. You're more likely to make mistakes that way and it'll be harder for the reader to follow. More detail is better than less detail. If you find that you're uncomfortable writing some part of your solution, then it suggests that you should study that topic in more detail.
8. Define your variables, especially if they're non-standard, and be consistent in their use.

9. Include units with your numerical values. Verify that your unit conversions are correct.
10. Clearly identify when a variable is a vector. Just like with units, your use of vectors in equations should be consistent.
11. If using word processing software:
    a. Put a space between numbers and units, e.g., write “10 mm” instead of “10mm”.
    b. Don’t italicize units, e.g., write “10 mm” instead of “10 *mm*”.
    c. Italicize mathematical symbols in the text of the document, e.g., “The parameter *x* increases as…” instead of “The parameter x increases as…”
12. Include equation numbers for all significant equations. Equation numbers make it easier to refer back to them, especially when explaining your solution approach.
13. Include page numbers.
14. Review your completed work at least once from your reader’s perspective and edit as needed. In this case, your reader is another student, teaching assistant, or your professor, i.e., people with technical backgrounds who are trying to understand the details of your work. It has been said that the key to good writing is good editing.
15. When preparing plots:
    a. Make sure the font type and size are easy to read in the document.
    b. Don’t use a figure title. The plot should be understandable from the axis titles and legend.
    c. Be sure plot symbols are discernable.
    d. Use descriptive text in plot axis titles rather than just symbols, e.g., “pressure, p [Pa]” rather than just “p [Pa]”.
    e. Use a consistent precision for plot numbers, e.g., “0.000”, “0.001”, “0.010”, instead of “0”, “0.001”, “0.01”.
    f. Use reasonable axis divisions in plots. Normally divisions of two, five, ten, etc. are used.
    g. If comparing data in different plots or figures, be sure to use consistent axes and legends.
    h. Use lines for values found from an equation and symbols for discrete data coming from experiments or computations. Normally we don’t connect data points with lines unless it helps to guide the reader.
    i. Include a legend that describes what each data point or line represents. Make sure the legend is easy to read.
    j. Don’t embed an MS Excel document within the figure. Doing so can greatly increase the size of the resulting document and make it unwieldy to edit. Instead, embed figures as standard image files, e.g., PNG, TIFF, JPG, PDF, etc.
16. When preparing tables:
    a. Tables should be reserved for when the reader needs to know the specific values of parameters, e.g., the mass of a sample or the diameter of a cylinder. It’s much easier to observe trends using a plot rather than a table of numbers.
17. Sources for additional help with technical writing:
    a. ENGL 42100 – Technical Writing (3 credit hours) Workplace writing in networked environments for technical contexts. Emphasizes context and user analysis, data analysis/display, project planning, document management, usability, ethics, research, team writing. Typical genres include technical reports, memos, documentation, Web sites. Typically offered Fall Spring Summer.
    b. The Purdue Online Writing Laboratory.

Homework Solution Example

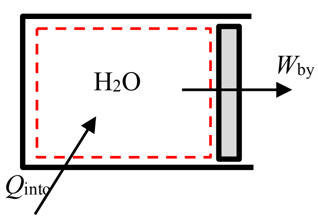
Water with an absolute pressure of 1 bar (abs) and a quality of 0.25 (State 1) is expanded in a closed piston-cylinder device along a path for which $pv^{1.5}$ = constant until the absolute pressure drops to 0.5 bar (abs) (State 2).

(a) Find the final quality. Report your answer in %.
(b) Calculate the work per unit mass of water during the process. Report your answer in kJ/kg.
(c) Determine the heat transfer per unit mass of water during the process. Report your answer in kJ/kg.
(d) Show the process on a p-v diagram relative to the vapor dome and the lines of constant temperature for the two states. Label the axes, two states, and indicate the process direction with an arrow.

Identify the system, show mass/energy interactions (EFD), list any assumptions and basic equations, and provide your solution. There is no need to re-write the given and find.

SOLUTION:

Identify the system/CV.



Show an EFD.

p_1 = 1 bar (abs)
x_1 = 0.25

p_2 = 0.5 bar (abs)

$pv^{1.5}$ = constant

Part (a):

Guide the reader with explanatory text.

Given the pressure (p_1) and quality (x_1) at State 1, we can determine the other properties for this state, e.g., specific volume (v_1) and specific internal energy (u_1). We're only given the pressure at State 2 (p_2) so we need one more property there to determine the rest of the properties. The connection between States 1 and 2 is the polytropic process, $pv^{1.5}$ = constant. Thus, if we can find v_1, then we can use the polytropic process to find v_2. First, find v_1,

$$v_1 = (1 - x_1)v_{f1} + x_1 v_{g1}, \quad (1)$$

Write basic equations in symbolic form.

Equation number to make it easy to reference.

where,

x_1 = 0.25 (given),
v_{f1} = 0.0010432 m^3/kg (from the SLVM table using p_1 = 1 bar (abs)),
v_{g1} = 1.6939 m^3/kg (from the SLVM table using p_1 = 1 bar (abs)).
⇨ v_1 = 0.4242574 m^3/kg.

Identify variable values, including units, and how they were found.

Also note that $T_{sat@p1}$ = 99.61 °C.

Now determine v_2 using the polytropic process,

$$p_1 v_1^{1.5} = p_2 v_2^{1.5} \;\Rightarrow\; v_2 = v_1\left(\frac{p_1}{p_2}\right)^{\frac{1}{1.5}} \;\Rightarrow\; v_2 = 0.67346664 \text{ m}^3/\text{kg}. \quad (2)$$

Now determine the quality at State 2 using p_2 and v_2,

$$v_2 = (1 - x_2)v_{f2} + x_2 v_{g2} \;\Rightarrow\; x_2 = \frac{v_2 - v_{f2}}{v_{g2} - v_{f2}}. \;\Rightarrow\; \boxed{x_2 = 20.8\%}, \quad (3)$$

Clearly identified answer to three significant digits.

where,

v_{f2} = 0.0010299 m^3/kg (from the SLVM table using p_2 = 0.5 bar (abs)),
v_{g2} = 3.2400 m^3/kg (from the SLVM table using p_2 = 0.5 bar (abs)).

Also note that $T_{sat@p2}$ = 81.32 °C.

Part (b):

The work done by the H_2O is pressure (aka boundary) work,

$$W_{by} = \int_{V_1}^{V_2} p dV = m \int_{v_1}^{v_2} p dv \;\; => \;\; \frac{W_{by}}{m} = \int_{v_1}^{v_2} p dv \tag{4}$$

The pressure is related to the volume from the given polytropic relation and so,

$$\frac{W_{by}}{m} = \int_{v_1}^{v_2} \left(\frac{p_1 v_1^{1.5}}{v^{1.5}}\right) dv = p_1 v_1^{1.5} \int_{v_1}^{v_2} \frac{dv}{v^{1.5}} = \frac{p_1 v_1^{1.5}}{-1.5+1}\left(v_2^{-1.5+1} - v_1^{-1.5+1}\right), \tag{5}$$

Show derivation steps.

$$\frac{W_{by}}{m} = \frac{p_1 v_1^{1.5}}{-0.5}\left(v_2^{-0.5} - v_1^{-0.5}\right) \;\; => \;\; \boxed{W_{by}/m = 17.5 \text{ kJ/kg}}, \text{ (Work is done by the system on the surr.)} \tag{6}$$

using the previously given and calculated values for p_1, v_1, and v_2 to calculate the work per unit mass.

Interpretation of result.

Part (c):

To determine the heat transfer per unit mass, make use of the 1st Law applied to the H_2O,

$$\Delta E_{sys} = Q_{into} - W_{by} \;\; => \;\; m\Delta e_{sys} = Q_{into} - W_{by} \;\; => \;\; \frac{Q_{into}}{m} = \Delta e_{sys} + \frac{W_{by}}{m}. \tag{7}$$

If we neglect changes in kinetic and potential energies (reasonable since this is a closed system that's not moving significantly and there are no appreciable elevation changes), then $\Delta e_{sys} = \Delta u_{sys}$. Equation (7) now becomes,

State assumptions where you use them.

$$\frac{Q_{into}}{m} = \Delta u_{sys} + \frac{W_{by}}{m}. \tag{8}$$

The work per unit mass was found in part (b) (Eq. (6)). The change in specific internal energy can be found in a manner similar to how the specific volumes were found in part (a),

$$u_1 = (1 - x_1)u_{f1} + x_1 u_{g1}, \tag{9}$$

and,

$$u_2 = (1 - x_2)u_{f2} + x_2 u_{g2}, \tag{10}$$

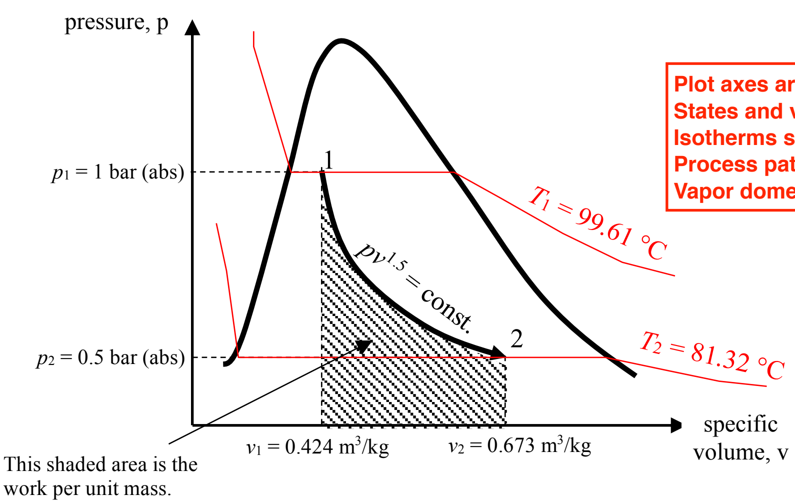
where,

$x_1 = 0.25$ (given),
$u_{f1} = 417.40$ kJ/kg (from the SLVM table using $p_1 = 1$ bar (abs)),
$u_{g1} = 2505.6$ kJ/kg (from the SLVM table using $p_1 = 1$ bar (abs)).
⇨ $u_1 = 939.45$ kJ/kg,
x_2 (found in part (a)),
$u_{f2} = 340.49$ kJ/kg (from the SLVM table using $p_1 = 0.5$ bar (abs)),
$u_{g2} = 2483.2$ kJ/kg (from the SLVM table using $p_1 = 0.5$ bar (abs)).
⇨ $u_2 = 785.3342$ kJ/kg.

Substituting values into Eq. (8),

$\boxed{Q_{into}/m = -137 \text{ kJ/kg}}$. (Energy is removed from the system via heat transfer.)

Part (d):



Plot axes are labeled.
States and values identified.
Isotherms shown, with temperature values.
Process path shown, with an arrow for direction.
Vapor dome shown since it's relevant to the problem.