

Solving Thermodynamics Problems

Solving thermodynamic problems can be made significantly easier by using the following procedure:

1. Summarize given data in own words, leave out unneeded information
2. Clearly understand/identify what is being asked for – draw a sketch showing interactions/states and identify a solution strategy. Keep in mind that a multi-step approach may be the easiest
3. Define system boundaries, noting if it is an open or closed system
4. Fix the known states on a P-v/T-v/T-s diagram, using given information
5. Apply conservation of mass to process

- For a control mass/closed system:

$$m_2 - m_1 = 0$$

- For a control volume/open system:

$$\frac{dm}{dt} = \sum \dot{m}_i - \sum \dot{m}_e$$

6. Apply conservation of energy to process (1st law of thermodynamics)

- For a control mass/closed system:

$$\Delta E = Q - W \quad (\text{equilibrium process})$$

$$\frac{dE}{dt} = \dot{Q} - \dot{W} \quad (\text{rate form})$$

- For a control volume/open system:

$$\frac{dE_{cv}}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_i \left(h + \frac{V^2}{2} + gz \right)_{in} - \sum \dot{m}_o \left(h + \frac{V^2}{2} + gz \right)_{out}$$

7. Solve algebraically for desired quantity using combination of mass balance, energy balance, and definitions (like mass flow rate, volume, etc.)
8. Perform heat transfer analysis to get Q, if necessary (use catalog of heat transfer or steady flow device in appendix)
9. Perform work analysis to get W, if necessary (use catalog of work or steady flow device in appendix)
10. Find properties using Tables or models, such as ideal gas relationship
11. Substitute numbers into equation and solve for desired quantity

12. Sanity check magnitude of answer and direction (if any) to see if the solution “makes sense”.

Appendix

This appendix contains a series of Tables for common parameters that are needed in solving thermodynamics problems. The user should consult the Cengel book details.

Heat Transfer

Heat Transfer Mode	Equation
Conduction (Fourier's Law)	$\dot{Q} = -kA \frac{dT}{dx}$
Convection (Newton's Law)	$\dot{Q} = hA(T_{\text{wall}} - T_{\text{ambient}})$
Radiation	$\dot{Q} = F_{1-2} \sigma \varepsilon A (T_1^4 - T_2^4)$

Work

Work Mode	Equation
Electric	$W = VI\Delta t$
Spring	$W = \frac{1}{2} k(x_2^2 - x_1^2)$
Expansion/Compression	$W = \int PdV$

Steady Flow Devices

Device	Conversion Process	Typical Assumptions
<ul style="list-style-type: none"> ▪ Nozzle ▪ Diffuser 	<ul style="list-style-type: none"> ▪ Flow energy(T, P) to KE ▪ KE to flow energy (T, P) 	S.S., adiabatic, no work, $\Delta PE = 0$
<ul style="list-style-type: none"> ▪ Turbine ▪ Compressor ▪ Pump 	<ul style="list-style-type: none"> ▪ Flow energy (T, P) to work ▪ Work to flow energy (T, P) ▪ Work to flow energy (P) 	S.S, adiabatic, $\Delta KE \approx \Delta PE \approx 0$
<ul style="list-style-type: none"> ▪ Throttle Device 	<ul style="list-style-type: none"> ▪ Relieve pressure 	S.S., adiabatic, no work, $\Delta KE \approx \Delta PE \approx 0$
<ul style="list-style-type: none"> ▪ Heat Exchanger 	Transfer heat between flow streams	S.S., no work, $\Delta KE \approx \Delta PE \approx 0$, external surfaces adiabatic

Substance Models

Substance Model	Application Domain	Characteristics
Property Tables – solid, liquid, vapor	Whenever experimental data is available for substance of interest	Real data, thus it is ideal as long as the experimental conditions used to make table are broadly applicable to the problem.
Incompressible – liquid	Most liquids and processes where volume expansion is not of interest	Properties are approximated by the saturated liquid properties at the system temperature. Specific heats are temperature dependent only. $C_p = C_v = C$ & $du = CdT = f(T)$ $y \approx y_f(T)$ $h \approx h_f(T) + v_f(T) \cdot [P - P_{sat}(T)]$
Incompressible – solid	Most solids and processes where volume expansion is not of interest	Specific heats are temperature dependent only. $C_p = C_v = C$ & $du = CdT = f(T)$
Compressibility Chart - vapor	Vapors that cannot be classified as an ideal gas	Assumes that the vapors of all substances are qualitatively similar, relative to their critical state. Scaling relative to the critical state allows the generalized compressibility chart to be used to find relation between P-v-T. $Z = P v / RT$ $P_R = P / P_{crit}$ and $T_R = T / T_{crit}$
Ideal Gas	Special case vapor where P_R (P/P_{crit}) is nearly 0.	Allows use of ideal gas equation of state, $PV = m R T$. Also, specific heats are only temperature dependent, therefore, energies are also only functions of temperature $du = C_v dT = f(T)$ $dh = C_p dT = f(T)$