PROBLEM TOOLS

Engineering is the art and science of problem solving. Except for the trivial problems (where really there is no problem) you need some tools that may range from paper and pencil and a good head, to large infrastructures. All problems in this Course on Thermodynamics can be solved with paper and pencil and some common tables and graphs of thermodynamic properties, but a programmable calculator surely facilitates the work. Good tools make the work easier, but the more powerful the tool, the more complex to handle, and the more dangerous it can be.

As explained aside, there is not a single tool ideal for every problem, not even for the bunch of Thermodynamic Problems here set. Due to several circumstances (amongst which takes precedence the availability of a campus license at our University), I regularly use the general-purpose mathematical tool **Maple** (from MathSoft Inc.) to try out and solve the problems I invent or I come across. But I want to state the following points:

1. There are quite different tools successfully used at many universities to help solve similar problems on Thermodynamics, particularly EES (from F-Chart Soft.). Yet many other Universities use in-house developed applications in Visual Basic or simply on Excel (both from Microsoft Corp.).
2. I am aware of the fact that many of the details found here in the solutions to the problems are of little interest to learn Thermodynamics (e.g. all the intricacies to automatically read values of thermal properties from a table). Furthermore, the tight syntax rules of any computer language put such an stress on the student (and on the professor), that sometimes the barrier to solve the problem lays not on the subject itself but on the awkward tools at hand. It is far from my intention to force the students to master Maple or any other particular tool in order to learn Thermodynamics.
3. By my using of Maple (from MathSoft Inc.), and surely my lack of expertise on it, I have been compelled to use here some notation and ways of doing things that I explicitly reject (e.g. when it shows $m=kg\_$ for $m=1$ kg, DT for ΔT, $\int f+gdx$ for $\int (f+g)dx$, etc.). You cannot output intermediate numerical computations to help follow the substitutions (e.g. you cannot output $x=2*3$; it always appears as $x=6$). Subindiced variables are not treated as such, and substitution are problematic (e.g. subs(T=400*K_, c*(T-T[b]))). After decades of great developments in computing, I feel sorry for finding it still too tough and awkward to transport my work from a development tool like Maple to a typesetting tool like Word, or to Internet formats. Thus the quality of the outcome here is well below my wishes.
4. I have to acknowledge (and excuse) my using of a mixture of English and Spanish for the wording in the solutions here.
5. Physical quantities are ordering comparisons with a base unit. Units are explicitly used in all computations here (final and intermediate), and the handling is automatic (except when Maple cannot resolve). Numeric values in physical quantities really belong to discrete sets when taking account of uncertainties, but, as usual, the decimalised real continuum is used instead, thus, the uncertainty is conveyed in the number of significant digits shown (what has been fatiguing to implement in Maple, and not in a satisfactory way yet).

The general layout I have tried to follow in each problem solution (and this strategy is far more important to learn than the tools to accomplish it) is:

- Statement of the problem (a copy & paste from my originals in Word, unfortunately deprived of a text-rich format; the typeset statement can be found in the associate *.doc* file for the chapter).
- Data read-out (all, but the last in the following list, automatically read from files), consisting of:
    - Universal constants, e.g. R_u=8.314 J/(mol·K), g_0=9.8 m/s^2, etc.
    - International Units grouping and ungrouping relations (e.g. Pa=N/m^2, N/m^2=Pa). Non-SI unit-conversion factors might also be included here, but it is not done (non-SI units are discouraged).
    - List of equations, both definitions and deductions, found in my book. Some problems deal with these deductions.
    - A default thermodynamic state, assumed to be at T_0=288 K and p_0=100 kPa (a good average at the Earth surface)..
    - List of material properties (gas, liquid, solid, vapour pressure, thermal capacity of ideal gases and thermochemical standard properties), as found in my book, i.e. as tabulated coefficients to be arranged as explained in the next paragraph.
    - Procedures to extract data from the tables and compose thermodynamic functions. I have to acknowledge that only perfect equations of state (constant thermal capacity ideal gases and liquids) are regularly used, to make procedures most transparent, although attention is paid to judge its validity.
    - List of explicit data in the statement of the problem, including the substances actually involved. This input must be provided by the user, the former generalities being read from general files.
- Scheme and nomenclature, comprising simple drawings, and a list of the systems and thermodynamic states chosen. My practice and advice is:
    - Always try to use standard scientific and technical notation in the context (e.g. p for pressure, P for power, t for time and T for temperature). Subindices are used for denoting different systems (but none is used for the main system), for different states (numerals in chronological order are preferred to 'initial', 'final' and the like), for different phases and for different component substances.
    - A simple annotated sketch helps a lot to follow the reasoning (I simply use MS-Paint).
    - A list of the systems and labelling chosen by the user. If there is just one system (plus the ambient) I use no index for the system and subindex '0' for the environment.
    - A list of thermodynamic states (temporal or spatial). I usually use the set {0,1,2,3...}, with 0=ambient, 1=initial, etc. There are also special states as the reference state (subindex '0' or 'ref') and the critical and triple states of a substance (subindices 'cr' and 'tr').
    - Care must be taken to avoid complex nomenclature as e.g. $v_{\text{subsystem,state,phase,component}}$ for the specific volume inside a given 'subsystem' in a certain '*p*-*T*-state', under a physical 'phase' of a given 'component'.
- Development, results and conclusions. For the type of thermodynamic problems here envisaged, there is usually a detailed list of targets to accomplish, made explicit in the statement in order to guide student's work. Every such individual task in the statement is solved by first quoting the question and then by explicitly stating the computations involved. For instance, to know if water at 250 kPa and 400 K is liquid or vapour, knowing that $p_v(T)=\exp(a-b/(c+T))$ is available, one may test if p_v(400 K)<=>250

kPa, or find the saturation temperature at 250 kPa and compare with 400 K, or construct a new Boolean function 'is_liquid(substance,p,T)' or even better construct a new function 'what_phase(substance,p,T)' that returns an element from the set {solid,liquid,gas}; here, the simplest way out is favored. Algebraic variables (e.g. T,p,ϕ,c_p) are mostly used, and particular numeric values are labelled with an underscored variable (e.g. T_, T1_). Constraints are best handled as equations instead of assignments, i.e. use $eq1:=p*V=m*R*T$ better than $p:=m*R*T/V$, to avoid premature substitutions.

To handle the pre-programmed Maple worksheets of my problems (e.g. to change the data and re-compute) you need a copy of the application **Maple** (from MathSoft Inc.) and follow these steps:

- Download my Maple worksheet for the problem you chose to any directory of yours.
- Download my following Maple-compiled files to the parent directory of your previous choice: *Therm_const.m* (stores the usual physical constants and unit conversions), Therm_eq.m (stores the hundreds of equations found in a thermodynamics book), *Therm_proc.m* (stores the Maple procedures to read the data files and find the particular data for the substance of interest), and the data files: gas.asc, liq.asc, sol.asc, cp.asc, and pv.asc. Of course these general files need to be downloaded just once. The compiled files are also available as worksheets (*Therm_const.mw*, *Therm_eq.mw* *Therm_proc.mw*). There is an additional set of files (*Therm_chem.m*, comb.asc, and a *Therm_chem.mw*) for thermochemical problems.
- Open the Maple worksheet for the problem with your Maple application, introduce your changes, save the modified file, exit Maple, re-load your file, and run it.

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Back to Index