THERMODYNAMICS LABORATORY EQUIPMENT

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True learning is by experimenting. Professors of Thermodynamics must propose to the students some key experimental work to be set up adequately (in a faculty lab or at the home sink) to gain hands-on experience in preparation, execution and analysis (and overall documentation) of experimental trials (the objective of experimentation), and to learn generic instrumentation and experimental techniques.

An experiment is a purposely-executed trial which is set up, measured and compared with expectations.

Care must be paid to safety and simplicity of the test-rig, and reliability of measurement, enhanced by proper redundancy and uncertainty estimation. Since most thermal processes involve invisible fluids, visualisation techniques are very helpful (seeing is believing).

A trade-off between allotted time and desired wide scope dictates that individual students cannot do everything. As a trade-off here, they work in groups of three, and most routine tasks in preparation and termination of the experimental work are done off-line by laboratory staff.

The types of feasible experiment heavily depend on available material.

MATERIALS

We have available at the lab:

- Several types of thermometers: thermocouples, thermo-resistances, integrated circuits, infrared radiometers, liquid-in-glass, ,vapour pressure, bimetallic, chromophoric tapes, thermo-cameras, etc.
- Several types of pressure transducers: U-tubes and different aneroid capsules (mechanical and electrical).
- Several types of humidity transducers: sling psicrometer, capacitive probes and resistive probes.
- Several types of anemometers: hot-wire tachometric turbine.
- Thermal baths: ambient air, tap water, water heater, air heater, Dewar flask, ice cubes.
- Mixing calorimeters (insulated flasks).
- Several types of heat exchangers (plates and tube-and-shell).

- Burners for heating and flame studies, with a propagating flame transparent duct.
- Piping (glass, plastic and rubber) and supports (tripods, rods, nuts).
- In-house rigs: sudden gas expansion experiment (Clément-Désormes method and Rütchhard method), adiabatic humidifier, metal-tube dilatometer, distillation energy balance, etc.
- Assembled equipment: educational heat pump (instrumented in-house), educational cooling tower.

VARIABLES USUALLY MEASURED

In thermodynamic experiments, variables to measure may be:

- Geometrical variables: lengths, diameters, areas, and volumes.
- Material properties
    - Mass and its derivatives: m, r, a, k, nrefract. M.
    - Chemical composition: x_i.
    - Other equilibrium properties: c_p, κ.
    - Non-equilibrium: k, μ, D_i,.
    - Other: surface tension, electrical conductivity...
- Thermodynamic variables
    - Temperature, pressure (thermodynamic), energy (U,H,S,Q,W...).
- Kinematic variables
    - Time and frequency.
    - Position (linear), displacement (linear), velocity (linear), acceleration (linear), momentum (linear). Mass flow-rate, volume flow-rate.
    - Position (angular), displacement (angular, velocity (angular), acceleration (angular, momentum (angular).
    - Displacement field, displacement gradient, i.e. strain tensor (deformations), and rotation tensor.
    - Displacement rate (velocity), velocity gradient, i.e. strain-rate tensor (deformations), and rotation-rate tensor.
- Dynamic variables
    - Force, torque, work, mechanical energy.
    - Stress, pressure (mechanical).

SAMPLE EXPERIMENTS

(Includes som documentation prepared by students.)

Trials on thermometry

1. Measure ambient temperature at several points (surface and bulk) with several instruments, to see applicability and uncertainty.
2. Measure boiling and freezing temperature of pure water and aqueous solutions with several instruments.
3. Measure the heating curve, fusion, cooling and solidification of a salt.
4. Measure temperature distribution in the interior and the external surface of an electric water heater, with thermometers and a thermo-camera.

5. Measure temperature distribution in a hot-air jet, with thermocouples and a moiré refractometer.

Trials on piezoometry and flowmetry

1. Measure ambient pressure and pressure differences at several points (in a gas container and in a liquid container) with several instruments, to see applicability and uncertainty.
2. Test Boyle's law with an instrumented syringe.
3. Set up a gas thermometer at constant volume and determine absolute zero.
4. Measure the isentropic coefficient of air by the Clément-Désormes method and by the Rütchhard method.
5. Test water boiling at different pressures.

Trials on thermal properties

1. Measure the coefficient of thermal expansion of solids, liquids and gases.
2. Measure the compressibility coefficient of air through the piezothermic coefficient.
3. Measure the thermal capacity of solids, liquids and gases.
4. Measure the vapour pressure of water as a function of temperature.
5. Measure the enthalpy of fusion, solidification, boiling and condensation of water.
6. Measure the dependence of boiling and condensation temperature of water on salt concentration in solution.

Trials on heat transfer (and their numerical simulation)

1. Measure the thermal conductivity of solids (conductors and insulators).
2. Measure the overall heat transfer coefficient from a hot slab to ambient air (influence of geometry).
3. Numerical simulation of the heating of a compound wall with radiation and convection.
4. Numerical simulation of the heating at one end in ambient air.
5. Measure the temperature profile during heating at one end in ambient air.
6. Numerical simulation of the cooling of a hot solid (sphere, cylinder and slab) by ambient air.
7. Numerical simulation of the temperature profile inside a concentric heat exchanger (counter-current and co-current).
8. Dismount a tube-and shell heat exchanger and a plate heat exchanger to see the construction details.
9. Measure temperatures and flow-rates in a tube-and shell heat exchanger and a plate heat exchanger.

Trials on thermal machines

1. See the elements, piping and operation of different heat engines: reciprocating, gas turbine, steam, Stirling, and thermoelectric.
2. Measure the performances of a heat engine.
3. See the elements, piping and operation of a refrigerator / heat pump.
4. Measure the performances of a refrigerator / heat pump.

Trials on combustion

1. Predict and measure the fuel/air ratio for stabilising a premixed flame in a Bunsen burner.
2. See the separation of premixed and diffusion flames by the Smithels method.
3. Measure the laminar flame speed along a horizontal tube (see videoclip).
4. Ignitition by compression (see videoclip).
5. Combustion calorimetry.

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