

also necessary to obtain the voltage rating at the design operating point, as selected from data similar to that shown in Fig. 12. This is necessary in order to develop a power supply.

In addition to the heat transfer and the thermoelectric aspects of device design, there are mechanical problems to be considered. Thermoelectric material and joints between it and the copper straps are relatively fragile. Since a module is strongest in compression, it is common to mechanically clamp the module between heat transfer surfaces. Stresses developed as a result of thermal expansion and contraction in a module must be minimized by proper design. This is specially true if the heat pumping cycle is reversed, resulting in a reversal of stresses.

Most thermoelectric devices operate with relatively high current and low voltage. For those designed to be powered from a 120 volt alternating-current source, a rectifier unit is necessary. The rectifier unit can consist of a transformer, two silicon diodes for full wave rectification, and a choke to filter the output. Ripple in the direct-current output should be 10 percent or less, to minimize loss in performance which results if pure direct current is not used.

A summary of this section shows that a complete thermoelectric system is usually composed of three major areas: heat transfer, thermoelectric modules, and power supply. In order to design a device of optimum performance and minimum cost, it is necessary to develop all three of these areas concurrently. For example, a high current design will reduce the number of couples, but will probably increase the power supply cost. Large heat transfer surfaces will reduce the couple temperature difference and, therefore, the number of couples, but will increase the cost and weight of the surfaces.

LETTER SYMBOLS USED IN CHAPTER 2

- α = absolute Seebeck coefficient, volts per C deg.
- α_{AB} = relative Seebeck coefficient (the difference between the absolute Seebeck coefficients for materials A and B, volts per C deg.)
- α_m = absolute Seebeck coefficient of material in which conduction occurs principally due to electrons.
- α_p = absolute Seebeck coefficient of material in which conduction occurs principally due to holes.
- α_{mp} = relative Seebeck coefficients, the difference between materials of n and p type.
- ρ = resistivity, ohm centimeter.
- ρ_n, ρ_p = resistivities of materials n and p, ohms centimeter.
- r_c = contact resistance, ohms square centimeter.
- R = total electrical conduction, reciprocal ohms centimeter.
- r_{AB} = relative Peltier coefficient for materials A and B, volts.
- ϕ = coefficient of performance.
- ϕ_{max} = maximum coefficient of performance.
- ϕ_{pump} = coefficient of performance under conditions of maximum heat pumping.
- A_n, A_p = cross sectional area of couple legs, square centimeters.
- C = thermal conductance of couple legs, watts per C deg.
- C_n, C_p = thermal conductance of couple legs, watts per C deg.
- ΔE = open circuit voltage developed, volts.
- I = direct current flowing through couple, amperes.
- K = thermal conductivity, watts per (square centimeter) (Centigrade degree per centimeter).
- K_n, K_p = thermal conductivities of materials n and p, watts per (square centimeter) (Centigrade degree per centimeter).
- L_n, L_p = length of couple legs, centimeters.
- Q = rate of heat emission or absorption in unit time, watts.
- Q_c = rate of heat absorption at cold junction, watts.
- Q_h = rate of heat emission at hot junction, watts.
- Q_{max} = maximum rate of heat absorption at cold junction, watts.
- R = electrical resistance of couple legs, ohms.
- ΔT_{max} = maximum ΔT .
- ΔT = temperature difference between the hot and cold junctions of materials n and p, $(T_h - T_c)$, C deg.
- T = absolute temperature, Kelvin.
- T_h = hot junction temperature, Kelvin.
- T_c = cold junction temperature, Kelvin.
- V = volts generated by couple.
- W = total electrical power supplied to couple, watts.
- Z = figure of merit = $\alpha^2 / (\sqrt{K_n \rho_p} + \sqrt{K_p \rho_n})$
= $\alpha^2 / (gK)$

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PSYCHROMETRICS

Thermodynamic Properties of Moist Air, Thermodynamic Properties of Water at Saturation, Degree of Saturation, Thermodynamic Wet-Bulb Temperature, Perfect Gas Relations, U. S. Standard Atmosphere, Psychrometric Charts, Typical Air-Conditioning Processes

THE earth's atmosphere is a mixture of several gases including nitrogen, oxygen, argon, water vapor, and traces of others. Atmospheric air generally contains various kinds of particulate matter. Often, additional vapors are present.

Before one may consider thermodynamic properties of atmospheric air, the substance must be precisely defined. The working substance in air-conditioning problems is called moist air. Moist air is by definition a binary mixture of dry air and water vapor.

Dry air has the following exact composition, adopted by the International Joint Committee on Psychrometric Data, and expressed in mol fractions: oxygen, 0.2095; nitrogen, 0.7809; argon, 0.0093; carbon dioxide, 0.0003. Traces of other gases are neglected. The molecular weight of dry air is 28.966.

Moist air may contain varying amounts of water vapor ranging from zero (dry air) to that for saturation. Moist air is saturated when it can coexist in neutral equilibrium with a condensed phase (liquid or solid) presenting a flat surface to it.

THERMODYNAMIC PROPERTIES OF MOIST AIR

Various thermodynamic properties are associated with moist air. The thermodynamic state of moist air is established by the pressure and two other independent properties. Pressure may be taken as barometric pressure in practical calculations.

Humidity ratio W is the mass of water associated with unit mass of dry air, pounds of water per pound of dry air.

Degree of saturation μ is the ratio of the humidity ratio of moist air to the humidity ratio at saturation for the same temperature and pressure.

Relative humidity ϕ is the ratio of the mol-fraction of water vapor in moist air to the mol-fraction of water vapor in saturated moist air at the same temperature and pressure.

Dry-bulb temperature t is the true temperature of moist air at rest.

Dew-point temperature t_d is the saturation temperature corresponding to the humidity ratio and pressure of an existing moist air state.

Thermodynamic wet-bulb temperature t^* is the temperature at which water (liquid or solid), by evaporating into moist air, can bring the air to saturation adiabatically at the same temperature.

In an ASHVE cooperative research project at the Towne Scientific School, University of Pennsylvania, Goff and Gratch¹ formulated accurate thermodynamic properties of moist air. Table 1 shows various thermodynamic properties for moist air as determined by Goff and Gratch for standard atmospheric pressure (29.921 in. Hg) and for temperatures from -160 F to 200 F.

Table 1 contains 15 columns of figures. Brief explanations of the data in each column are given in the following paragraphs.

The general responsibility for this chapter is assigned to TC 1.2, Psychrometrics.

$t(F)$ = Fahrenheit temperature defined in terms of absolute temperature T by the relation,

$$T = t + 459.67$$

W_s = humidity ratio at saturation. Saturation is the condition at which the vapor phase (moist air) may exist in equilibrium with a condensed phase (liquid or solid) at the given temperature and pressure (standard atmospheric pressure, in the case of Table 1). At given values of temperature and pressure, the humidity ratio W can have any value from zero to W_s .

v_a = specific volume of dry air, cubic feet per pound.

$v_a - v_s$ = the difference between the volume of moist air at saturation, per pound of dry air, and the specific volume of the dry air itself, cubic feet per pound of dry air.

v_g = volume of moist air at saturation per pound of dry air, cubic feet per pound of dry air.

h_a = specific enthalpy of dry air, Btu per pound of dry air. The specific enthalpy of dry air has been assigned the value zero at 0 F, standard atmospheric pressure. The energy unit Btu is related to the foot-pound by definition, as follows: 1 Btu = 778.3 ft-lb.

$h_g - h_a$ = the difference between the enthalpy of moist air at saturation, per pound of dry air, and the specific enthalpy of the dry air itself, Btu per pound of dry air.

h_s = enthalpy of moist air at saturation per pound of dry air, Btu per pound of dry air.

s_a = specific entropy of dry air, Btu per (pound) (Fahrenheit degree absolute). It will be noticed that the specific entropy of dry air has been assigned the value zero at 0 F and standard atmospheric pressure.

$s_g - s_a$ = the difference between the entropy of moist air at saturation, per pound of dry air, and the specific entropy of the dry air itself, Btu per (pound of dry air) (Fahrenheit degree absolute).

s_g = entropy of moist air at saturation per pound of dry air, Btu per (pound of dry air) (Fahrenheit degree, absolute).

h_w = specific enthalpy of condensed water (liquid or solid) in equilibrium with saturated air at standard atmospheric pressure, Btu per pound of water. The specific enthalpy of liquid water has been assigned the value zero at 32 F, saturation pressure (0.088586 psia).

Note that h_w is greater than the steam-table enthalpy of saturated pure condensed phase by the amount of the enthalpy increase corresponding to the pressure increase from saturation pressure to 1 atmosphere, plus influences from the presence of air.

s_w = specific entropy of condensed water (liquid or solid) in equilibrium with saturated air, Btu per (pound water) (Fahrenheit degree absolute). s_w differs from the entropy of pure water at saturation pressure, similarly to h_w .

p_w = vapor pressure of water in saturated moist air, pounds per square inch or inches of mercury. This pressure, p_w , differs from the saturation pressure of pure water because of the presence of the air.

THERMODYNAMIC PROPERTIES OF WATER AT SATURATION

Table 2 shows thermodynamic properties of water at saturation for temperatures from -160 to 212 F. A detailed explanation of methods employed in constructing Table 2 is given in a paper by Goff and Gratch.² Symbols used in Table 2 follow standard steam-table nomenclature.