ASME PTC 2-2001
[Revision of ASME PTC 2-1980 (R1985)]

DEFINITIONS AND VALUES

PERFORMANCE TEST CODES

An American National Standard

The American Society of
Mechanical Engineers

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The next edition of this Code is scheduled for publication in 2006. There will be no addenda issued to this edition.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this Code. Interpretations are published on the ASME Web site under the Committee Pages at http://www.asme.org/codes/ as they are issued.

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Nonmandatory Appendices

FOREWORD

Precise def nitions of terms and exact values of constants employed in the various Performance Test Codes of this Society are fundamentally important. This Code is intended to provide standard def nitions and values required by each respective Performance Test Code (PTC) and to supplement each of them. The principal purpose of this Code (PTC 2), *Definition and Values*, is to provide a source for any item used by more than one of the PTC committees reporting to the Board on Performance Test Codes. This Code is an outgrowth of f ve previous codes concerning def nitions and values issued and adopted by the Society, and it supersedes them.

A draft of the f rst edition was printed in the December 1921 issue of Mechanical Engineering and was presented to the Society during the spring meeting held in Atlanta, Georgia the following May. On January 21, 1926, the f rst such code was approved and adopted by Council as a standard practice of the Society. The second edition of this code was approved by Council on May 14, 1931.

Beginning in June 1936, a thorough review and a complete rewriting of this code was undertaken, and the fruits of this labor were adopted by Council on June 17, 1945. In June, 1969, Performance Test Code Committee No. 2, acting under instructions from the Standing Committee on Performance Test Codes, proceeded to revise this Code, the draft of which was presented to the Society as a paper during the 1970 Winter Annual Meeting in New York. It was adopted in f nal form by action of the Policy Board on Codes and Standards on February 26, 1971.

The last major revision of this Code began in 1972 to incorporate metrication and the use of Systeme International (SI) units. The values of many of the physical constants and conversion factors were brought up to date as well. The 1980 Code was approved by the Performance Test Codes Supervisory Committee on February 26, 1979, and it was approved as an American National Standard by the ANSI Board of Standards Review on July 21, 1980.

The Code presented herein was revised by the PTC 2 Project Team and approved by the Board on Performance Test Codes on May 29, 2001. This Performance Test Code was also approved as an American National Standard by the ANSI Board of Standards Review on October 31, 2001.

NOTICE

All Performance Test Codes **MUST** adhere to the requirements of **PTC 1, GENERAL INSTRUCTIONS**. The following information is based on that document and is included here for emphasis and for the convenience of the user of the Code. It is expected that the Code user is fully cognizant of Parts I and III of PTC 1 and has read them prior to applying this Code.

ASME Performance Test Codes provide test procedures which yield results of the highest level of accuracy consistent with the best engineering knowledge and practice

currently available. They were developed by balanced committees representing all concerned interests. They specify procedures, instrumentation, equipment operating requirements, calculation methods, and uncertainty analysis.

When tests are run in accordance with a Code, the test results themselves, without adjustment for uncertainty, yield the best available indication of the actual performance of the tested equipment. ASME Performance Test Codes do not specify means to compare those results to contractual guarantees. Therefore, it is recommended that the parties to a commercial test agree **before starting the test and preferably before signing the contract** on the method to be used for comparing the test results to the contractual guarantees. It is beyond the scope of any Code to determine or interpret how such comparisons shall be made.

BOARD ON PERFORMANCE TEST CODES

(The following is the roster of the Committee at the time of approval of this Code.)

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SECTION 1
OBJECT AND SCOPE

1.1 OBJECT

The purpose of this Code is to provide definition of terms and values of physical constants and conversion factors to comply with the requirements of ASME PTC 1, *General Instructions*.

1.2 SCOPE

This Code contains standards for terms, units of measure, values of constants, symbols, and technical nomenclature that are to be used in all individual test codes. The implication of the words "must," "shall," and "will" is mandatory. The use of "should," "would," and "ought" denotes recommended practice. All the information contained herein represents the state of the art at the time of its preparation. In order that the PTC may continue to be useful, any part of this Code is automatically superseded by any of the following actions:

(a) approval of new or revised units, values of physical constants, or fluid properties;

(b) inclusion of equipment not covered by this Code in the PTC series; or

(c) approval by the Board on Performance Test Codes of a new Code not conforming to this document.

Such actions will be published in *Mechanical Engineering* as they occur, and this Code will be amended thereafter.

SECTION 2
MEASUREMENT OF PERFORMANCE

2.1 INTRODUCTION

The Codes provide test procedures which yield results of the highest level of accuracy consistent with the best engineering knowledge and practice, taking into account the cost of tests and monetary value of eff ciency to industry. Performance of equipment is determined in part by measurements of physical quantities. A measurement consists of sensing a physical variable and translating this result into data that is either indicated or recorded. Analog data are indicated by the position of a pointer on a dial or by a point or line on a chart. Digital data are indicated by a visual display of numbers or by a numerical printout. Devices used to make measurements are called instruments but many devices called instruments must be used with additional components to measure certain physical variables and quantities. A millivoltmeter, for example, can measure voltage but a thermocouple must be used in conjunction with the voltmeter to obtain a temperature measurement.

2.2 MEASUREMENT SYSTEM

In order to make a measurement of a physical quantity it must f rst be sensed, and the information about the energy change due to sensing must be transmitted to a component that communicates the data. The requirements for measurement are met by the system shown in Fig. 2.2.

The primary element is that part of the measurement system that f rst senses the variable to be measured. The energy change produced by the sensing must be transmitted to an information-communicating unit where it may be used directly or changed (transduced) to some other form to indicate or record data. The measurement system may be very simple or very complex but the three functions appearing in Fig. 2.2 are required to make a physical measurement. The measurement system may be a single component such as a liquid-in-glass thermometer

where the sensing is done by the bulb, the transmitting by the liquid column, and the data display by the scale. On the other hand, the measurement system may be multi-component such as f ow measurement with orif ces where the primary element (the orif ce) causes f uid acceleration to produce a pressure differential which is transmitted via tubing to a manometer where the data are displayed on the scale.

2.3 UNCERTAINTY OF MEASURING SYSTEMS

Measurement of a physical quantity never continuously gives a result which is correct in an absolute sense. The numerical value determined nearly always differs by some amount from the true value, and the extent of the deviation (called error) depends upon the type of measurement system used. Code writers and test engineers must demonstrate that the test measurements used will provide results suff - ciently accurate to accomplish the purposes of the test.

The accuracy obtainable for a given measurement is dependent upon the following three components:

(a) the characteristics of the measured quantity,

(b) the accuracy of the observation, and

(c) the measurement system used.

(1) The intrinsic accuracy of the measurement system.

(2) The in-situ conditions of its use.

Item (c)(1) is generally well treated by most engineers and data concerning measurement system components is given in the Instruments and Apparatus Supplements. Item (c)(2) is often responsible for gross errors of measurement. Specif c analysis is necessary for each application and installation.

ASME PTC 19.1, *Test Uncertainty*, def nes *accuracy* as the closeness of agreement between a measured value and the true value; *error* as the difference between the true value and the measured value; and *uncertainty* as a numerical estimate of the error.

SENSOR   **TRANSMITTER**   **INDICATOR and RECORDER**

```
┌─────────────┐      ┌──────────┐      ┌──────────────────┐
│ Senses and  │      │ Transmits│      │ Transforms energy│
│ obtains     │ ───► │ energy   │ ───► │ into useable form│
│ energy      │      │          │      │ for display of   │
│ change from │      │          │      │ data             │
└─────────────┘      └──────────┘      └──────────────────┘
      ▲
      │
┌─────────────┐
│ Measured    │
│ quantity    │
└─────────────┘
```
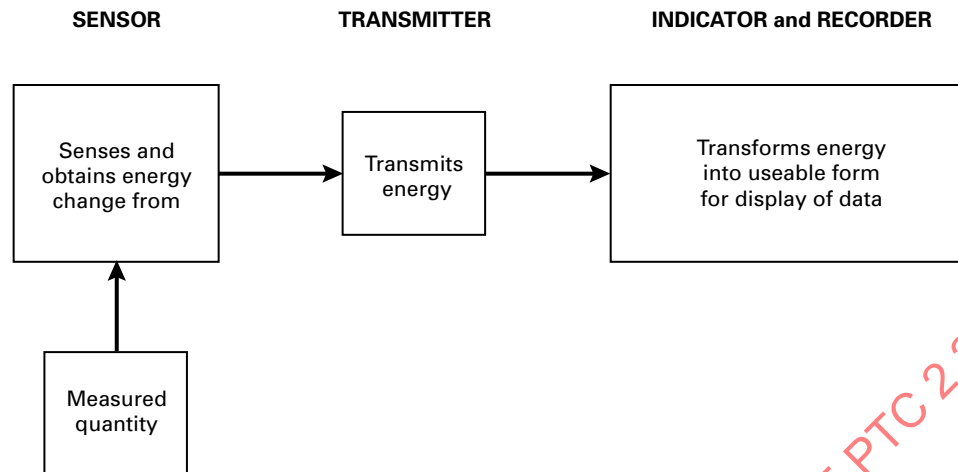
FIG. 2.2 MEASURING SYSTEM

2.4 INTRINSIC ACCURACY

The intrinsic or inherent accuracy of a measurement system depends upon
  (a) materials,
  (b) construction, and
  (c) physical condition at time of use.

While the inherent accuracy of the first two items can be estimated from published data concerning an individual measuring system component, the actual accuracy at the time of use must be determined by calibration. For this reason, all significant and primary measuring system components must be calibrated or checked before and after PTC tests to establish the effect of their physical condition on inherent accuracy, unless there is no cause for their calibration to change.

2.5 IN SITU CONDITIONS

The accuracy of a measurement system as used depends upon its ability to
  (a) sense the variable to be measured,
  (b) transmit energy change,
  (c) apply or transduce energy, and
  (d) display data.

The last two items are essentially independent of use unless environmental conditions such as vibration, temperature, humidity, etc., are of such magnitude as to prevent normal operation. If care is taken to ensure proper environmental conditions, then the communication function of accuracy is simply the intrinsic accuracy of the components.

2.6 OBSERVATION ACCURACY

Accuracy of observation depends primarily upon the following two factors:
  (a) accidental mistakes, e.g., misreading of scales, parallax, incorrect log entries, failure to perform some required manipulation, etc.; and
  (b) personal characteristics, e.g., ability to interpolate between graduations, bias in observation (tendency to read high or low), speed of observation.

These types of errors may be minimized (but never completely eliminated) by selection and training of test personnel, by selection of scales with easily-read graduations, and by other human-factor engineering. Modern technology permits the design of instrument systems that will give digital printout, and the use of these should be encouraged to eliminate observation error when their inherent accuracy and in situ conditions permit. However, digital systems may contain programming mistakes, and these systems must be debugged thoroughly.

2.7 SENSING ACCURACY

The accuracy of sensing depends upon the following factors:
  (a) Effect of the Primary Element on the Measured Quantity

For example, a Pitot tube installed in a flow stream to sense a local velocity must be designed so that its presence does not change the original velocity profile.

(b) Mutual Effects of Primary Element and the Measured Quantity

When the temperature of a f uid f owing in a pipe under pressure is to be measured, it is usually necessary to encase the primary element in a protection tube or well. The following temperatures must be considered:

(1) f uid temperature,

(2) well outer-wall temperature,

(3) well inner-wall temperature, and

(4) primary element temperature.

Only this last temperature is sensed; that is, the system is capable of measuring only the temperature of its primary element. A heat-transfer study is necessary to estimate the f uid temperature. The factors involved in such a study are

(a) the physical properties of the f uid and materials used in the construction of the well and primary element;

(b) the net heat transfer by radiation, conduction, and convection from the well to the f uid, to the pipe wall, and to the primary element; and

(c) the f uid velocity: for compressible f uids the difference between static and stagnation temperatures may be appreciable at Mach numbers greater than 0.25.

Most of the above factors may be rendered negligible by proper design of the system, but unless they are all investigated, serious errors may result.

(c) Improper Installation

A Pitot tube designed, constructed, and installed in such manner as to cause a disturbance of the velocity prof le (for example, installed at an angle to the velocity) senses only a fraction of the velocity.

(d) Location of Primary Element

Care must be taken not to locate primary elements too close to f ow-disturbing f ttings such as bends, elbows, and valves. For example, the velocity prof les of f uids downstream of such f ttings are distorted, and the coeff cients of orif ces, nozzles, and Venturis will be signif cantly different from those installed downstream of long lengths of straight pipe, thus giving rise to serious f ow-measurement bias errors.

(e) Sampling

In many cases of composition analysis, the variable to be measured is not evenly distributed in the mixture (such as the moisture content of steam or the oxygen content of boiler f ue gas). In such cases, it is important that a representative sample be taken. The distribution must be investigated and properly-designed probes installed in suff cient numbers and at representative locations to minimize errors from nonuniform spatial distribution.

(f) Effect of Other Variables

In many cases where indirect methods of measurement are used, for example the determination of the chemical composition of a gas by measuring its conductivity, the system is designed to measure by inference. The accuracy of this type of measurement depends upon the assumed presence or absence from the mixture of certain gases. If any gas is present that should not be, or in greater or lesser amounts than that for which the system was calibrated, bias error will result.

The preceding examples and discussion are far from all-inclusive but give some insight into the problems faced by the PTC writer and the test engineer in the measurement of physical quantities.

SECTION 3
DEFINITIONS

3.1 PRIMARY DEFINITIONS AND SYSTEMS OF UNITS

The dimensions of mass, length, and time are related to forces as follows in the various systems of units.

A force of one pound applied to a mass of one slug (also known as the geepound) will accelerate the mass at the rate of one ft/sec^2.

A force of one newton applied to a mass of one kilogram will accelerate the mass at the rate of one m/s^2.

Equations written in these units will appear identical. Converting measured values from the U.S. customary units to the primary pound-slug-second system of units will simplify the expression of test results in Systeme International (SI).

By way of contrast and for clarif cation, a force of one pound applied to a mass of one pound will accelerate the mass at a rate numerically equal to "g_c" ft/sec^2. This fact is the origin of the appearance of the conversion factor, g_c, in engineering equations expressed in the U.S. customary units. Note that g_c is not the local acceleration of gravity at the test site; it is simply a ratio of masses and a constant.

3.2 HISTORICAL DEFINITIONS OF UNITS OF MEASURE

It is often useful to be aware of the historic physical bases for many of the units of performance measurement. The reader is cautioned that the numerical values of these physical def nitions have been ref ned over the years, so that the following historic def nitions may be no longer numerically exact. Nonetheless, the embodied physical concepts can improve one's understanding of a measurement or test result. The current values and def nitions for use are given starting in para. 3.3.

boiler horsepower: standardized by the ASME in 1889, it was based on an engine steam rate of 30 lbm of steam per horsepower-hour at 70 psig and a feedwater temperature of 100°F. This corresponds to 34.5 lbm/hr evaporated from and at 212°F (33,475

Btu/hr). At the time of standardization, boilers were rated by manufacturers at one horsepower hour per 10 ft^2 of surface heated. Boiler horsepower no longer has much signif cance in steam generator performance.

British thermal unit (Btu):   a unit of energy equal to that needed to raise the temperature of one pound-mass of air-free water from 60°F to 61°F at a constant pressure of one standard atmosphere; the mean Btu is equal to $1/180$ of the energy needed to raise one pound-mass of air-free water from its freezing point to its boiling point at a constant pressure of one standard atmosphere.

calorie: the amount of energy required to raise the temperature of one gram of pure water from 14.5°C to 15.5°C at a constant pressure of one standard atmosphere.

Celsius scale: invented in 1742 by Anders Celsius, a Swedish astronomer, who graduated the interval between the freezing point and the boiling point of water into one hundred degrees (hence centigrade) at an atmospheric pressure of 760 mm of mercury. The present scale has the freezing point at 0 deg and the boiling point at 100 deg, just the reverse of the numbering by Celsius.

Fahrenheit scale: the temperature scale used by Daniel Gabriel Fahrenheit who invented a thermometer containing alcohol in 1709 and a mercury thermometer in 1714. The zero point on the scale was established by mixing equal quantities by weight of snow and common salt. The freezing point was found to be at 32 deg of graduation and the boiling point very near 212 deg under standard atmospheric pressure.

foot: $1/3$ of a yard, originally based on the length of a man's foot.

force: the inf uence on a body which causes it to accelerate; quantitatively, it is a vector, equal to the body's time rate of change of momentum; units of pound or newton; also see para. 3.1.

gram: the mass of one cubic centimeter of pure water in a vacuum at its maximum density.

heat: energy in transit between a source at a higher temperature from which the energy is coming, to a sink at a lower temperature toward which the energy is going. Other types of energy in transit are called work.

inch: $\frac{1}{12}$ of a foot, originally established by statute, to be that of three grains of barley, dry and round, placed end-to-end lengthwise.

joule: the unit of work or energy equal to the work done by a force of one newton when the point at which the force is applied is displaced one meter in the direction of the force. It is also known as a newton-meter of energy. It is also practically equivalent to the energy expended by an electric current of one ampere f owing for one second through a resistance of one ohm.

meter: a unit of length in the SI system, originally intended to be one ten-millionth of the distance along a meridian on Earth from the equator to the pole. Also proposed as the length of a pendulum with a period of one second at sea level and 45 deg N latitude (the middle of France).

power, drawbar: drawbar power is:
$$P_D = FV/B$$

where
P_D = drawbar power, hp [W]
F = pull at drawbar, lbf [N]
V = speed, ft/sec [m/s]
B = 550 (ft-lbf)/(hp-sec) [W/W]
  = [1.000 for Watts]

second: one part in 86,400 of the mean solar day. The universal world standard consists of the average of over 180 atomic clocks (which count the vibrations of atomic cesium) located in 26 countries.

slug, geepound: one slug weighs 32.174 lb at sea level and 45 deg of latitude.

temperature: the property of an object which determines the direction of heat f ow when that object is placed in thermal contact with another object at a different temperature.

yard: a unit of length containing 36 in.; it is the distance, at 62°F, between two transverse lines in gold plugs set in a bronze bar, called the British

Imperial Yard and kept at the Standards Off ce of the Board of Trade at Westminster in Great Britain.

3.3 DEFINITIONS FOR USE

The following def nitions are approved for use in ASME PTCs.

air: the natural atmospheric mixture of nitrogen, oxygen, water vapor, carbon dioxide, argon, and small quantities of other rare gases. The psychometric properties of air are given in ASHRAE's *Brochure on Psychrometry*, in which the reference conditions are 59°F and 29.921 in.Hg.

atmospheric pressure, standard: when pressure is measured in atmospheres it is measured in terms of units which approximate the vertical air pressure on a horizontal unit area at sea level. This unit then becomes the weight of the superincumbent atmosphere, assuming that the atmosphere is at rest.

Methods of measurement of atmospheric pressure are contained in ASME PTC 19.2, *Pressure Measurement.* All corrections required by ASME PTC 19.2 in reducing observations to standard conditions must be followed in all ASME PTC calculations.

The International Standard Atmosphere is 760 mm of mercury at the standard gravity of 9.806 65 m/s^2 at 0°C which is equal to 29.921 in. of mercury at the standard gravity of 32.174 06 ft/sec^2 at 32°F. In U.S. Customary units, this is equal to 14.695 95 lbf/in.^{2}. In the SI system, this is equal to 101.325 kPa.

For other relationships of the International Standard Atmosphere, ASME PTC 19.2 should be consulted. When the barometric pressure is not stated, it is understood that a vacuum below atmosphere or a gage pressure above atmosphere is based on the standard atmosphere of 760 mm of mercury at 0°C.

bulk modulus of elasticity (E): a measure of the f uid's compressibility. That compressibility is measured in terms of the f uid's decrease in volume, ΔV, compared to its original volume, V, when subjected to an incremental pressure change, Δp. E is path- or process-dependent. Thus,

$$E_N = \ell\text{im}\left\{-\left[\frac{\Delta p}{\left(\frac{\Delta V}{V}\right)}\right]_N\right\} = -V\left(\frac{\partial p}{\partial V}\right)$$

where
N = the path or process

For water, two commonly-used bulk moduli are def ned corresponding to isothermal and isentropic processes. Empirical equations have been developed and are available to calculate these two numbers for water.

combustion: the process of rapid oxidation of fuel. Unit rate of combustion may be def ned as follows.

(a) All fuels: heating value of fuel as f red per unit of furnace volume per unit time, Btu/(ft^3-hr) [W/m^3].

(b) Mass burning of solid fuels: mass of fuel as f red per unit of grate surface area per unit time, lbm/(ft^2-hr) [kg/(m^2-s)].

(c) Gaseous fuels: volume of gas f red per unit of furnace volume per unit time, ft^3/(ft^3-hr) [m^3/(m^3-s)].

condenser, surface: a device which reduces a thermodynamic f uid from its vapor phase to its liquid phase. In the case of steam, the rate of heat transfer is:

$$q = w_c (h_2 - h_1) = w_v (h_3 - h_4) \text{ Btu/hr [J/s]}$$

where

w_c = cooling water, lbm/hr [kg/s]
w_v = steam condensed, lbm/hr [kg/s]
h_1 = enthalpy of cooling water entering condenser, Btu/lbm [J/kg]
h_2 = enthalpy of cooling water leaving condenser, Btu/lbm [J/kg]
h_3 = enthalpy of steam entering condenser, Btu/lbm [J/kg]
h_4 = enthalpy of water in hotwell, Btu/lbm [J/kg]

The values of all the enthalpies except h_3 are obtainable from temperature readings and the ASME steam tables (latest edition). The value of h_3 must be determined indirectly because practical procedures for measuring average steam quality exhausting the steam turbine into the condenser have not been developed. Until direct measurement becomes possible, the indirect methods prescribed in ASME PTC 12.2, *Steam Surface Condensers*, shall be used.

density: the mass per unit volume of a material at a specif ed pressure and temperature.

Water density values are given in the latest ASME steam tables. Dry air density values are tabulated in the latest ASHRAE *Thermodynamic Properties of Refrigerants*.

efficiency ideal cycle: the ratio of the work of the ideal cycle to the heat supplied. This eff ciency is often termed ideal engine eff ciency.

efficiency engine: the actual work of a system divided by the work of a corresponding ideal system. Since indicated, brake, or combined actual work may be involved, three engine eff ciency measurement values are possible.

efficiency thermal: def ned as the work done divided by the heat supplied for any engine turbine, entire plant, or power island.

$$\text{indicated thermal efficiency} = \frac{AW_i}{Q}$$

$$\text{brake thermal efficiency} = \frac{AW_b}{Q}$$

$$\text{combined thermal efficiency} = \frac{BW_k}{Q}$$

where

A = 2544.43 Btu/(hp-hr) [1 J/(W−s)]
B = 3412.14 Btu/(kW−hr) [1 J/(W−s)]
Q = heat added, Btu [J]
W_i = indicated net work, hp−hr [J]
W_b = brake net work, hp−hr [J]
W_k = combined net work, kW−hr [J]

The thermal eff ciency of a complete plant is expressed similarly to that of a turbine or engine.

efficiency volumetric (η_v): applies only to positive displacement machinery. The volumetric eff ciency of centrifugal or other kinetic machinery cannot be obtained because there is no measurable displacement.

For compressors:

$$\eta_v = \frac{\text{volumetric capacity of compressor}}{\text{displacement}}$$

For pumps:

$$\eta_v = \frac{\text{actual pump delivery}}{\text{displacement}}$$

efficiency isentropic compression: the ratio of theoretical isentropic power to the f uid power developed.

efficiency mechanical: the ratio of actual work to internal work for a turbine or engine, and the inverse for a pump or compressor.

efficiency overall, compressor: the ratio of isentropic power to the actual power supplied.

energy of a substance, internal: a state variable; its change from one state to another is independent of the process which produces the change. Internal energy changes, rather than absolute values, are of importance. Internal energy may be set to any convenient base. For steam this base has been set at the triple point, 32°F and 0.0891 psia (273.15 K and 611.2 Pa). The symbol for internal energy is u and its units are Btu/lbm [J/kg].

enthalpy: the sum of internal energy plus the product of the volume and the pressure. It is also known as the sensible, or total, heat or heat content. It may be expressed as:

$$h = u + pv/J \qquad \text{Btu/lbm [J/kg]}$$

where

h = enthalpy, Btu/lbm [J/kg]

u = internal energy, Btu/lbm (J/kg)

p = pressure of f uid, lbf/ft^2 [Pa]

v = specif c volume of f uid, ft^3/lbm [m^3/kg]

J = mechanical equivalent of heat, 778.169 262 (ft–lbf)/Btu, 4.184 J/cal, [1J / J]

entropy: a term f rst coined by Clausius to mean "transformation." Only changes in entropy can be measured; an overall increase in entropy measures a loss in the ability to do work. *S* is measured in units of heat/temperature. Unlike energy, entropy is not conserved in nature. The rate of production of entropy serves as the index of irreversibility.

evaporator: a thermodynamic device in which liquid is changed to vapor phase by the addition of heat. The mathematical description of the heat transfer involved is:

$$q = w_e (h_2 - h_1); \text{ or,}$$
$$q = w_s (h_v - h_f) \text{ Btu/hr [W]}$$

where

w_e = mass evaporated per unit time, lbm/hr [kg/s]

w_s = mass of steam condensed per unit time, lbm/hr [kg/s]

h_1 = enthalpy of entering water, Btu/lbm [J/kg]

h_2 = enthalpy of leaving steam, Btu/lbm [J/kg]

h_f = enthalpy of condensed water, Btu/lbm [J/kg]

The f rst equation is preferred as the second produces higher values if heat is lost during the process.

f ow: the rate of passage of a quantity of material through a f xed reference surface per time, measured either in units of mass/time or volume/time.

fuel rate: for solid and liquid fuels, the mass of fuel f red per unit of output. For gaseous fuels it is def ned as ft^3 of gas at 59°F and 14.696 psia per unit of output [m^3 at 15°C and 101.325 kPa]. Fuel rates should be qualif ed by reference to the unit of output.

furnace volume, total: the original scope of the PTC Committee limited the use of furnace volume to steam generators. Since this volume may be used for other equipment, it shall be as def ned by the individual code.

grate surface: the horizontal fuel or combustible supporting structure within the walls of a furnace. This would also include f uidized bed support surface.

gravity, standard: international standard gravity is def ned at sea level, latitude of 45°32′33″ and equals an acceleration of g_o = 9.806 65 m/s^2 = 32.174 06 ft/sec^2. Sea-level acceleration of gravity at any specif ed latitude can be calculated from the equation:

$$g_\phi = 999.95 \times 10^{-3} g_o$$
$$(1 - 2.637\ 3 \times 10^{-3} \cos 2\phi + 5.9 \times 10^{-6} \cos^2 2\phi)$$

where

ϕ = latitude, deg

g_ϕ = sea-level acceleration of gravity at latitude ϕ, m/s^2

g_o = international standard gravity, 9.806 65 m/s^2

A tabulation of sea level gravity corrections for selected latitudes is presented in ASME PTC 19.2, *Pressure Measurement.*

Variation of free-air acceleration of gravity with elevation above or below sea level can be calculated from the equation:

$$g_H = g_\phi - 3.086 \times 10^{-6} H$$

where

H = height above or below sea level, m ($H > 0$ above sea level; $H < 0$ below sea level)

g_ϕ = sea-level acceleration of gravity at latitude ϕ, m/s^2

g_H = acceleration of gravity at height H, above or below sea level and latitude ϕ, m/s^2

A tabulation of free-air gravity correction values for selected elevations is presented in ASME PTC 19.2.

ASME PTC 19.2 presents gravitational acceleration values for selected U.S. locations; values for selected international locations are given in the American Institute of Physics Handbook.

heat absorption, rate of: energy absorbed per unit time, Btu/hr [J/s].

heat rate: the classic def nition of heat rate is the reciprocal of the thermodynamic eff ciency of a prime mover, such as a combustion or steam turbine, or of an entire power plant or power island. It is an indication of how much thermal input is required to produce a unit of power.

heat rate = Q/P, Btu/kWhr   [dimensionless]
Q = heat input, Btu/hr   [kJ/s]
P = power, kW   [kW]

For each type of prime mover or plant, the heat input, Q, is further def ned in each applicable Code.

When there are secondary heat inputs or outputs, such as steam for the process generated by a cogeneration power plant, the heat rate is expressed at the specif ed reference values of those secondary heat f ows. Measured heat rate is corrected to the reference values of the secondary heat f ows at the test boundary.

Heat rate can be considered from either gross power or net power.

heat transfer coeff cient: the energy transmitted per unit area of heating surface per temperature difference per unit time, Btu/(ft^2–°R–hr) [W/(m^2–K–s)]

heat exchanger: a thermodynamic device which transfers heat between two f uids. The rate of heat transfer is

$$q = w_f(h_1 - h_2) \text{ Btu/hr [W]}$$

where

w_f = heat exchanger f uid rate, lbm/hr [kg/s]
h_1 = enthalpy of f uid at inlet, Btu/lbm [J/kg]
h_2 = enthalpy of f uid at outlet, Btu/lbm [J/kg]

heating value: heat released from the rapid oxidation of fuel. Heating value of fuels is determined in accordance with the following codes:
ASME PTC 3.1, *Diesel and Burner Fuels*
ASME PTC 3.2, *Solid Fuels*
ASME PTC 3.3, *Gaseous Fuels*

Each code will specify using either the higher or lower heating value, typically expressed in units of Btu/lbm, [kJ/kg].

Water vapor is one of the products of combustion for all fuels which contain hydrogen. The lower or higher heating value of a fuel depends on whether this water vapor is allowed to remain in the vapor state or is condensed to liquid. In a bomb calorimeter, the products of combustion are cooled to the initial temperature and all of the water vapor formed during combustion is condensed to liquid. This gives the higher, or gross, heating value of the fuel with the heat of vaporization included in the reported value. For the lower, or net heating value, it is assumed that all products of combustion remain in the gaseous state.

While the higher, or gross, heating value can be accurately determined by established (ASTM) procedures, direct determination of the lower heating value is diff cult. Therefore, it is usually calculated.

horsepower: the term was originated by Boulton and Watt to state the power of their steam engines. In a practical test, it was found that the average horse could work constantly at a rate of 22,000 (ft-lb)/min. This was increased arbitrarily by half to def ne the now universal unit of power: 550 (ft-lb)/sec.

hydrocarbons: any chemical compounds containing only hydrogen and carbon; these are frequently used as fuels. Physical properties in NIST database IDMIX permits the determination of thermodynamic and transport properties of f uid mixtures of various pure gases and heavy hydrocarbons.

ice point: the temperature of an equilibrium mixture of liquid and frozen pure water melting under one standard atmospheric pressure absolute (273.15 K).

internal combustion cycles: for internal-combustion engines, several cycles are in common use, e.g., the Otto and Diesel cycles. It is possible to compute an engine eff ciency of ideal cycles. For PTC work, all internal-combustion engine thermal eff ciencies shall be determined by a measured work output divided by measured heat input. Engine eff ciency shall not be calculated as based on any idealized cycle for internal-combustion engines.

mean effective pressure: for an engine, the work divided by its displacement. Combined brake, friction, or indicated mean effective pressures may be calculated by using the applicable def nition and values for work.

mercury, density of: density of mercury at 32°F [0°C] is 0.491 154 lbm/in^3 [13 595.1 kg/m^3]. Density at other temperatures may be computed from the equation:

$$\rho_t = 13\ 595.1/(1 + 1.184\ 56 \times 10^{-4}t + 9.205 \times 10^{-9}t^2 + 6.608 \times 10^{-12}t^3 + 6.732 \times 10^{-14}t^4)$$

where

t = temperature of mercury, °C
ρ_t = density of mercury at temperature t, kg/m^3

sound: acoustic output of a machine or process is its sound power (W). This is usually expressed as a sound power level in decibels. Sound power cannot be measured directly. Instead, sound pressures are measured and sound powers calculated therefrom. Modern instrumentation has imbedded this computational capability. Sound pressures (p) are usually expressed as sound pressure levels, also in decibels. A decibel is the logarithmic expression of the ratio of a quantity to a particular reference quantity. The reference quantity for sound power levels (W_o) is 1 pW and that for sound pressure levels (p_o) is 20 μPa, hence
sound power level (dB) = 10 $\log_{10}$ (W/W_o)
sound pressure level (dB) = 20 $\log_{10}$ (p/p_o)

output, net: of an engine and generator unit, defined by the formula:

$$\text{Net output (kW)} = \begin{pmatrix} \text{electrical power} \\ \text{output of} \\ \text{generator (kW)} \end{pmatrix} - \begin{pmatrix} \text{auxiliary} \\ \text{power} \\ \text{supplied (kW)} \end{pmatrix}$$

Auxiliary power supplied is that external power necessary for the unit's operation and includes, but is not limited to, excitation power, power for separately driven lube oil pumps, hydraulic oil pumps, generator cooling water pumps, fans for generator ventilation, and seal evacuators.

power, air or gas: the equations for air power invoke a compressibility factor K_p in this fashion

$$P = \left\{ (p_2 - p_1)\ Q_1\ K_p + m \left[(\alpha_2\ V_2^2 - \alpha_1\ V_1^2)/2g_c \right. \right.$$
$$\left. \left. + g\ (Z_2 - Z_1)/g_c \right] \right\}/A$$

where

P = power, hp [W]

$$K_p = \ell n\ \frac{p_2/p_1}{\dfrac{p_2}{p_1} - 1}$$

(for a reversible isothermal process)

$$K_p = \frac{\gamma}{\gamma - 1} \left[\left(\frac{p_2}{p_1} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right] \bigg/ \left[\frac{p_2}{p_1} - 1 \right]$$

(for an isentropic process)

$$K_p = \frac{n}{n - 1} \left[\left(\frac{p_2}{p_1} \right)^{\frac{n - 1}{n}} - 1 \right] \bigg/ \left[\frac{p_2}{p_1} - 1 \right]$$

(for a reversible polytropic process)

K_p = 1 [for a reversible isochoric process (constant density)]
γ = ratio of specific heats
n = polytropic exponent
p_1 = inlet pressure, lb/ft^2 [Pa]
p_2 = outlet pressure, lb/ft^2 [Pa]
Q_1 = volumetric flow rate, ft^3/sec [m^3/s]
α_1 = kinetic energy factor at inlet
α_2 = kinetic energy factor at outlet
V_1 = average velocity at inlet, ft/sec [m/s]
V_2 = average velocity at outlet, ft/sec [m/s]
Z_1 = elevation at inlet, ft [m]
Z_2 = elevation at outlet, ft [m]
g = acceleration due to gravity, ft/sec^2 [m/s^2]
g_c = conversion factor, 32.174(ft–lbm)/(lb–sec^2) [1(m–kg)/(N–s^2)]
A = conversion factor, 550 (ft–lb)/(hp–sec) [1(N–m)/(W–s)]

power, water: the energy flux contained in flowing water. Water power is to be computed from the equation

$$P_w = g\rho Q\ (H_1 - H_2)\ /A = Q\ (p_1 - p_2)\ /A$$

where

P_w = water power, hp [W]
ρ = density of water, slug /ft^3 [kg /m^3]
Q = volumetric flow, ft^3/sec [m^3/s]
H_1 = higher head, ft [m]
H_2 = lower head, ft [m]
p_1 = higher pressure, lbf/ft^2 [Pa]
p_2 = lower pressure, lbf/ft^2 [Pa]
A = 550 (ft–lbf) /(hp–sec) [1 W/W]
g = local acceleration of gravity, ft/sec^2 [m /s^2]
All heads and pressures shall be measured at, or corrected to, stagnation conditions.

pressure: a force distributed over an area in units of force/area.

pumps: internal energy added to the fluid by the pump is manifested as an increase in enthalpy, some of which is mechanical energy, and the remainder is heating.

$$E_p = (h_2 - h_1) \qquad \text{Btu/lbm [J/kg]}$$

where

h_1 = measured enthalpy at pump inlet, Btu/lbm [J/kg]

h_2 = measured enthalpy at pump discharge, Btu/lbm [J/kg]

Numerical values for all water enthalpies shall be taken from the latest ASME steam tables[1] including the work of isentropic compression of water (Δh_s).

$$\Delta h_s = (h_{s2} - h_1) \text{ Btu/lbm [J/kg]}$$

in which h_{s2} is derived from the pressure of the pump discharge, and the entropy at the pump inlet.

The internal losses and the internal efficiency of a pump may be deduced from the following:

Internal losses = $(h_2 - h_1)-(h_{s2} - h_1)$ Btu/lbm [J/kg]

Internal efficiency = $100(h_{s2} - h_1)/(h_2 - h_1)$ percent

Any compression (except isothermal) will raise the water temperature. Higher pressures produce higher temperature rises.

specific heat: c, of a substance is the amount of energy required to effect a temperature increase in a unit mass of the substance, which is path- or process-dependent.

For gases, two process paths are used. One is the specific heat at constant pressure, c_p; the other is the specific heat at constant volume, c_v. For a unit mass, these are defined

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p$$

and

$$c_v = \left(\frac{\partial u}{\partial T}\right)_v$$

where

h = enthalpy, Btu/lbm [J/kg]

u = internal energy, Btu/lbm [J/kg]

T = temperature, °R [K]

c = specific heat, Btu/(lbm−°R) [J/(kg−K)]

NBS circular 565 (1955), Tables of Thermal Properties of Gases, provides specific heat data for air, argon, carbon dioxide, carbon monoxide, hydrogen, nitrogen, oxygen, and steam.

standards, primary: by statute authority, the following exact conversion factors between the SI units and the U.S. Customary units have been adopted and published by the National Institute of Standards and Technology:

1 ft = 0.304 8 m

1 in. = 0.025 4 m = 25.4 mm

1 lbm = 0.453 592 37 kg

1 ft^3 = 0.028 316 85 m^3

Standard atmospheric pressure

= 14.695 95 lbf/in.^{2}

= 101.325 N/m^2

Standard acceleration of gravity

= 32.17 406 ft/sec^2

= 9.806 65 m/s^2

These data were taken from NBS Miscellaneous Publication 286, May 1967.

steam cycle, Rankine: the Rankine steam cycle consists of:

(a) Isentropic expansion of steam from the initial state to the exhaust pressure.

(b) Condensation at constant pressure and temperature to saturated liquid.

(c) Isentropic compression of the liquid to the initial pressure.

(d) Heating, evaporating, and superheating (if any) at constant pressure to the original steam conditions.

steam cycle efficiency, Rankine: this equation expresses the ideal cycle efficiency, defined in efficiency, ideal cycle, of the Rankine steam cycle defined previously.

$$\eta = \frac{(h_1 - h_s) - (\text{ideal pump work})}{h_1 - (h_f + \text{ideal pump work})}$$

where

h_1 = initial enthalpy of steam, Btu/lbm [J/kg]

h_s = enthalpy after isentropic expansion, Btu/lbm [J/kg]

h_f = enthalpy of saturated liquid at exhaust pressure, Btu/lbm [J/kg]

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[1] For fluids other than water use an appropriate mutually agreed standard of reference (see Appendix A).
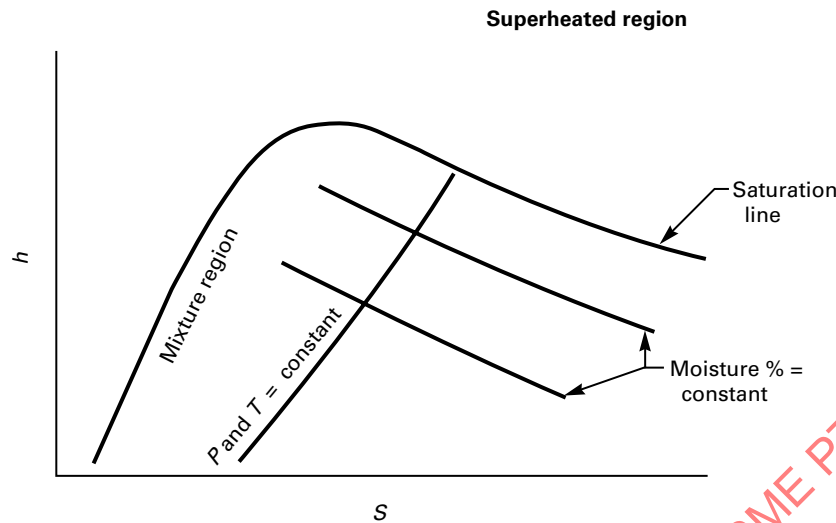
Superheated region

FIG. 3.3 ENTHALPY-ENTROPY DIAGRAM FOR WATER

For ideal pump work, refer to the def nition of *pumps* where internal losses are negligible.

steam point: is def ned as the temperature of an equilibrium mixture of liquid and condensing water vapor at one standard atmospheric pressure (373.15 K).

steam quality: inside the liquid-vapor-mixture re-gion, quality *x* is def ned as the fraction of the mass which is in the vapor state relative to the total mass of the two-phase mixture:

$$x = m_g/(m_g + m_f)$$

For example, if a mixture at saturated pressure and temperature contains 2.5% moisture, its quality is 97.5%. "Wet" steam means its state is in the mixture region wherein its state is def ned by either its pressure or temperature and the portion of water substance which is the vapor phase.

Dry and saturated steam exists when all of the mass of water substance is in the vapor phase at saturation pressure and temperature. This condition exists along the "saturation line" which divides the two-phase mixture region from the superheated re-gion (*x* = 100% and moisture = 0%). See Fig. 3.3.

steam rate: of an engine, turbine, or complete plant, is expressed as the actual mass of steam per unit of time per unit of output, often expressed in units of lbm/kW.

temperature, absolute: the approximate value of the thermodynamic temperature as def ned by the International Practical Temperature Scale. In the U.S. customary system, the absolute temperature is expressed in degrees Rankine, and in the SI (metric) system, in kelvin. For relations between these scales, see Section 5.

temperature, reference: the datum for the steam tables is the triple point of water. The 1968 Interna-tional Practical Temperature Scale establishes this at 0.01°C or 32.018°F.

For gases, the preferred standard temperature for PTC work is 59°F (15°C). Various industries use different reference conditions; caution is advised.

thermal conductivity: the coeff cient of proportion-ality in the equation of heat transfer by steady unidirectional conduction proposed by Fourier in 1882: $q = -k\, A\, dT/dx$ where q is the rate of heat conduction along the x-axis, A is the cross-sectional area of the path normal to the x-axis, and $-dT/dx$ is the temperature gradient along the path. See Table 5.8. The units of k are Btu/(hr-ft-°F) [W/(m-°C)]

thermal unit conversions: using the identities as def ned in the latest edition of ASME steam tables (Appendix 4B) and tables of conversion factors, the following conversions are derived:
Identities:

$$\left(0.453\ 592\ 37\ \frac{kg}{lbm} \right) = 1$$

$$\left(778.169\ 262\ \frac{ft-lbf}{Btu} \right) = 1$$

$$\left(0.3048\ \frac{m}{ft} \right) = 1$$

$$\left(2.326\ \frac{kJ-lbm}{kg-Btu} \right) = 1$$

(mechanical equivalent of heat) $\left(\dfrac{4.184\ J}{cal} \right) = 1$

$$1 = \frac{kg-m}{N-sec^2} = g_c$$

$$= \frac{1}{0.453\ 592}\ \frac{lbm}{kg} \times \frac{N(4.448\ 222)}{lbf} \times \frac{ft}{0.3048}$$

$$g_c = 32.174\ 056\ \frac{ft-lbm}{s^2-lb}$$

Conversions:

$$\left(0.4535\ 9237\ \frac{kg}{lbm} \right)\left(2.326\ \frac{lbm-kJ}{Btu-kg} \right) = 1$$

yields

$$1\ Btu = 1.055\ 055\ 6\ kJ$$

Also

$$\left(550\ \frac{ft-lbf}{s-hp} \right)\left(3600\ \frac{s}{hr} \right)\left(778.169\ 262\ \frac{Btu}{ft-lbf} \right) = 1$$

yields

$$1\ hp-hr = 2544.433\ Btu$$

Finally,

$$\left(3600\ \frac{s}{hr} \right)\left(2.326\ \frac{kg-Btu}{kJ-lbm} \right)\left(0.453\ 59\ 237\ \frac{lbm}{kg} \right) = 1$$

yields

$$\frac{1\ kJ-hr}{sec} = 1\ kWhr = 3412.141\ 63\ Btu$$

time: the fourth dimension in the space-time continuum; the duration of a phenomenon or the period between two events. The universal unit of time is the second, which is one part in 84,600 of the sidereal, mean solar day on Earth.

tolerance: a specif ed allowance for error in weighing, measuring etc., or the maximum allowable error in the value of the quantity indicated, such as the test result (PTCs do not address tolerance; they describe how to measure the relevant performance and how to determine the uncertainty of such measurement).

viscosity: the ratio of shearing stress to the rate of shearing strain of a f uid. For further details on viscosity, PTC 19.17, *Determination of the Viscosity of Liquids* should be consulted. The viscosity of steam and water are given in the latest ASME steam tables.

watt: one newton meter per second.

SECTION 4
LETTER SYMBOLS

4.1 INTRODUCTION

In order to render the terminology of ASME PTCs consistent, certain letter symbols in general use have been adopted. These letter symbols, from the American National Standards Institute (ANSI), are published by the ASME, who sponsors this work. ANSI originally was called American Standards Association (ASA) and many of the symbols have the ASA designation. In August 1966, the American Standards Association was reconstituted as the United States of America Standards Institute (USASI) In October 1969, the name was again changed to the current "American National Standards Institute." The various name changes did not involve any numerical standard designation, simply the "overstamping" of ASA to USASI to ANSI.

4.2 PREFERRED LETTER SYMBOLS

The preferred letter symbols for PTC work are those listed in para. 4.4.

4.2.1 Three General Requirements for Published Symbols and Signs. A letter symbol for a physical quantity is a single letter, specif ed as to general form and typeface. It is available for use within a mathematical expression. This primary symbol may be modif ed by subscript or superscript. In a published work, the same primary letter symbol should appear throughout for the same generic physical quantity, regardless of the units employed or special values assigned. As is generally recognized, each published symbol or sign, of whatever kind, should be

(a) standard, where possible. In the use of published symbols, authors of technical works (including textbooks) are urged to adopt the symbols in this and other current standard lists, and to conform to the principles stated here. An author should give a table of the symbols used and their respective interpretations, or else refer to a standard list. For work in a specialized or developing f eld, the author may need symbols in addition to those already contained in standard lists. In such a case, one should be careful to select simple suggestive symbols which avoid conf ict in the given f eld and in other closely-related f elds. Except in this situation, one should not use new symbols or depart from current notation.

(b) clear in reference. One should not assign to a given symbol different meanings, thereby causing ambiguous interpretation in a given context. Conf icts must be avoided. Often a listed alternative symbol or a modifying subscript is available and should be adopted. Except in brief reports, any symbol not familiar to the reading public should be def ned in the text. The units should be indicated whenever necessary.

(c) easily identif ed. Because of the many numerals, letters, and signs which are similar in appearance, a writer should not use separate symbols which, in published form, might be confused by the reader. For example, many letters in the Greek alphabet (lower case and capital) are practically indistinguishable from English letters; the zero is easily mistaken for a capital O.

4.3 SPECIAL PRINCIPLES OF LETTER SYMBOL STANDARDIZATION

(a) The time rate of change of any quantity may be designated by a dot over the symbol.

(b) Quantities suitable for designation as vectors may be so indicated in print by making the symbol boldface. In manuscript or typescript, this may be indicated by underscoring with a single wavy line.

(c) Components of vector and tensor quantities are to be indicated by suitable subscripts or superscripts.

(d) Subscripts and superscripts as independent symbols are not listed as part of this Standard, since practice in various applications is so diverse. In general, subscripts should be in the nature of abbreviations, such as critical temperature T_c or reduced pressure p_r.

(e) Components as occurring in mixtures of chem-

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ical reactions may be designated by adding suitable subscripts or parenthetical identification. The latter is preferred if the identification is by chemical species. For example, the chemical potential of an ith component would be μ_i; or the enthalpy of carbon dioxide, $h(CO_2)$. Thermodynamic properties so designated are to be understood, in relation to mixtures, as either partial molar or partial specific quantities.

(f) Extensive thermodynamic properties are designated by italic capitals. Specific properties (per unit mass) are designated by the corresponding lowercase italics. Partial molar properties (per mole) are designated by barred capitals, or by plain capitals, if no ambiguity exists with respect to extensive properties. Components may be designated in addition, as above.

(g) Differences in values of thermodynamic quantities as occurring in chemical reactions or phase changes are normally indicated by prefixing the symbol Δ to the symbol for particular quantity and identifying the change by suitable subscripts. If a particular difference occurs repeatedly and if no ambiguity will result, the prefix may be omitted.

(h) Dimensionless groups may be designated by two-letter symbols in most of the well-established cases.

(i) In general, subscripts should either be selected from the standard symbols or be an abbreviation.

(j) Certain symbols, enclosed by parentheses, have been included in the list for information. These represent generally accepted usage. In each case, an alternate standard is indicated.

4.4 DESCRIPTION OF TERMS

a = acceleration
a = acoustic velocity
a = activity
a = Helmholtz function, specific
a = sound velocity
A = affinity
A = free energy, Helmholtz function
A = Helmholtz function
A, S = area
B = virial coefficient, second
c = concentration, mass
c_p = specific heat capacity, constant pressure
c_v = specific heat capacity, constant volume
c = specific heat capacity, general
c = velocity of light

C = heat capacity, general
C = concentration, mole
C_p = heat capacity, constant pressure
C_v = heat capacity, constant volume
d, D = diameter
D = diffusivity, mass
D = mass diffusion coefficient
D_T = thermal diffusion coefficient
E = energy
f = friction factor
f = fugacity
F = force
F, G = free energy Gibbs function
g = Gibbs function, specific
g = gravitational acceleration
g = specific Gibbs function
g_c = inertia proportionality factor
G = mass current density
G = mass velocity
h = enthalpy, specific
h = heat transfer coefficient, surface
h = Planck constant
H = enthalpy
H = irradiance
j = heat transfer factor
J = mechanical equivalent of heat
J = radiant intensity
k = Boltzmann's constant
K = equilibrium constant, chemical
l, L = length
m = mass
m = molality
M = Mach number
M = molar mass
M = molecular weight
n = angular velocity, revolutions per unit time
n = mole quantity
n = number of moles
n = polytropic exponent
N = dimensionless number
N = number of molecules
N = radiance
(Nu) = Nusselt number
N_o = Avogadro's number
p = pressure
P, W = power
$(Pr), \sigma$ = Prandtl number
q = flow, volumetric
q, Q = heat rate
q_m = flow, mass
Q = heat

Q = quantity, usually volume
r = radius
r = transmissivity
r = transmittance
R = gas constant
R = thermal resistance
$(Re), R$ = Reynolds number
s = arc length
s = path length
S = entropy
t, r = time
t, θ = temperature
T = temperature, absolute or thermodynamic
u = internal energy, specif c
u = specif c internal energy
U = heat transfer coeff cient, overall
U = internal energy
U = radiant energy
v = specif c volume
v, V = velocity
V = volume
w, m, q_m = mass f ow
w = mass fraction
W = radiant f ux density
W = weight
W = work
x = mole fraction
x = quality
y = mole fraction, gas phase
y, σ = surface tension
Z = compressibility factor
α = absorptance
α = absorptivity
α = degree of reaction
α = diffusivity, thermal
α = linear thermal expansion coeff cient
α = thermal diffusivity
α = thermal expansion coeff cient, linear

  = thermal expansion coeff cient, volumetric
  = volumetric thermal expansion coeff cient
γ = activity coeff cient, stoichiometric
γ, k = heat capacity ratio
ϵ = emissivity
ϵ = emittance
ϵ = turbulence exchange coeff cient
η = eff ciency
η, μ = viscosity, absolute or dynamic
θ = normal angle
κ = viscosity, volume
$\kappa,$ = temperature conductivity
$(k), \kappa$ = compressibility coeff cient
k_T = thermal diffusion ratio
  = radiation wavelength
μ = chemical potential
μ = Gibbs function, molar
μ = Joule-Thompson coeff cient
ν = kinematic viscosity
ν = radiation frequency
ν = stoichiometric number of molecules in a chemical reaction
ν = viscosity, kinematic
ξ = extent of chemical reaction
ρ = density
ρ = ref ectance
ρ = ref ectivity
σ = entropy production rate
σ = specif c entropy
σ = Stefan-Boltzmann constant
Φ = radiant f ux
ω = angular velocity, radians per unit time
ω, Ω = solid angle
Δh = latent heat, specif c
ΔH = latent heat

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SECTION 5
COMMON CONVERSION FACTORS

Please refer to Tables 5.1 through 5.8 for conversion factors.

TABLE 5.1
CONVERSIONS TO SI (METRIC) UNITS

Quantity	Conversion		Multiplication Factor	
	From	To		
Acceleration, linear	ft/sec^2	m/s^2	3.048 [Note (1)]	E − 01
	standard gravity	m/s^2	9.806 65 [Note (1)]	E + 00
Area	in.^{2}	m^2	6.451 6	E − 04
	ft^2	m^2	9.290 304 [Note (1)]	E − 02
Coefficient of thermal expansion	°R^{-1}	K^{-1}	1.8 [Note (1)]	E + 00
Density	lbm/ft^3	kg/m^3	1.601 846	E + 01
	slugs/ft^3	kg/m^3	5.153 788	E + 02
Energy, work, heat	Btu (IT)	J	1.055 056	E + 03
	ft - lbf	J	1.355 818	E + 00
Flow rate , mass	lbm/sec	kg/s	4.535 924	E − 01
	lbm/min	kg/s	7.559 873	E − 03
	lbm/hr	kg/s	1.259 979	E − 04
	slugs/sec	kg/s	1.459 390	E + 01
Flow rate, volume	ft^3/min	m^3/s	4.719 474	E − 04
	ft^3/sec	m^3/s	2.831 685	E − 02
	gallons (U.S. liquid)/min	m^3/s	6.309 020	E − 05
Force	lbf (avoirdupois)	N	4.448 222	E + 00
Frequency	sec^{-1}	Hz	1 [Note (1)]	E + 00
Gas constant	Btu/lbm−°R	J/(kg • K)	4.186 8 [Note (1)]	E + 03
	ft-lbf/lbm − °R	J/(kg • K)	5.380 320	E + 00
Heat rate	Btu/kWh	kJ/kWh	1.055 056	E + 00
Heat transfer coefficient	Btu/hr-ft^2-°R	W/(m^2 • K)	5.678 263	E + 00
Length	in.	m	2.54 [Note (1)]	E − 02
	ft	m	3.048 [Note (1)]	E − 01
	mile (U.S.)	m	1.609 344 [Note (1)]	E + 03
Mass	lbm (avoirdupois)	kg	4.535 924	E − 01
	slug	kg	1.459 390	E + 01
Plane angle	deg	rad	1.745 329	E − 02
Power	Btu(IT)/hr	W	2.930 711	E − 01
	ft-lbf/sec	W	1.355 818	E + 00
	hp (550 ft-lbf/sec)	W	7.456 999	E + 02
Pressure	standard atmosphere	Pa	1.013 25 [Note (1)]	E + 05
	bar	Pa	1 [Note (1)]	E + 05
	lbf/ft^2	Pa	4.788 026	E + 01
	lbf/in.^{2}	Pa	6.894 757	E + 03
Rotational frequency	min^{-1}	s^{-1}	1.666 667	E − 02
Specific enthalpy	Btu/lbm	J/kg	2.326	E + 03
Specific entropy	Btu/lbm -°R	J/(kg • K)	4.186 8 [Note (1)]	E + 03
Specific heat	Btu/lbm -°R	J/(kg • K)	4.186 8	E + 03
Specific internal energy	Btu/lbm	J/kg	2.326	E + 03
Specific volume	ft^3/lbm	m^3/kg	6.242 797	E − 02
Specific weight (force)	lbf/ft^3	N/m^3	1.570 875	E + 02
Surface tension	lbf/ft	N/m	1.459 390	E + 01
Temperature interval	°F	°C	5.555 556	E − 01
Temperature, measured	°F	°C	$t_C = (t_F - 32)/1.8$	
Temperature, thermodynamic	°C	K	$T_K = t_C + 273.15$	
	°F	K	$T_K = t_F + 459.67)/1.8$	
	°R	K	$T_K = T_R/1.8$	
Thermal conductivity	Btu-ft/hr-ft^2− °R	W/(m • K)	1.730 735	E + 00
Time	hr	s	3.6 [Note (1)]	E + 03
	min	s	6 [Note (1)]	E + 01
Torque	lbf-in.	N • m	1.29 848	E − 01
	lbf-ft	N • m	1.355 818	E + 00

(continued)

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TABLE 5.1
CONVERSIONS TO SI (METRIC) UNITS (CONT'D)

Quantity	From	To	Multiplication Factor	
		Conversion		
Velocity	ft/hr	m/s	8.466 667	E − 05
	ft/min	m/s	5.08 [Note (1)]	E − 03
	ft/sec	m/s	3.048 [Note (1)]	E − 01
	knot (international)	m/s	5.144 444	E − 01
	mile (U.S.)/hr	m/s	4.470 4 [Note (1)]	E − 01
Viscosity, dynamic	centipoise	Pa • s	1 [Note (1)]	E − 03
	poise	Pa • s	1 [Note (1)]	E − 01
	lbm/ft-sec	Pa • s	1.488 164	E + 00
	lbf-sec/ft^2	Pa • s	4.788 026	E + 01
	slug/ft-sec	Pa • s	4.788 026	E + 01
Viscosity, kinematic	centistoke	m^2/s	1 [Note (1)]	E − 06
	stoke	m^2/s	1 [Note (1)]	E − 04
	ft^2/sec	m^2/s	9.290 304	E − 02
Volume	gallon (U.S. liquid)	m^3	3.785 412	E − 03
	ft^3	m^3	2.831 685	E − 02
	in^3	m^3	1.638 706	E − 05
	liter	m^3	1 [Note (1)]	E − 03

GENERAL NOTE: The factors are written as a number greater than one and less than ten with six decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value.

For example:

$$3.785\ 412\ \text{E} - 03 \text{ is } 3.785\ 412 \times 10^{-3} \text{ or } 0.003\ 785\ 412$$

NOTE:
(1) Exact relationship in terms of the base units.

TABLE 5.2
CONVERSION FACTORS FOR PRESSURE (force/area)

To obtain → Multiply, by ↓	atm	bar	$\frac{lbf}{in.^2}$	in. Hg(0°C)	ft H₂O(20°C)	mm Hg(0°C)	$\frac{kp}{cm^2}$	kPa
atm	1	1.013 25	$\frac{1.013\,250 \times 2.54^2}{980.665 \times 453.592\,37}$ = 14.695 948 8	$\frac{1.013\,250/980.665}{13.595\,088\,9 \times 2.54}$ = 29.921 280 0	$\frac{1.013\,250/980.665}{0.998\,278\,282 \times 30.48}$ = 33.957 002 9	$\frac{10\,132\,500/980.665}{13.595\,088\,9}$ = 760.000 512	$\frac{1.013\,25}{0.980\,665}$ = 1.033 227 45	101.325
bar	$\frac{1.0}{1.013\,25}$ = 0.986 923 267	1	$\frac{2.54^2 \times 10^6}{980.665 \times 453.592\,37}$ = 14.503 773 8	$\frac{10^6/980.665}{13.595\,088\,9 \times 2.54}$ = 29.530 007 4	$\frac{10^6/980.665}{0.998\,278\,282 \times 30.48}$ = 33.512 956 2	$\frac{10^7/980.665}{13.595\,088\,9}$ = 750.062 188	$\frac{10^3}{980.665}$ = 1.019 716 21	100
$\frac{lbf}{in.^2}$	$\frac{980.665 \times 453.592\,37}{1\,013\,250 \times 2.54^2}$ = 0.068 045 963 9	$\frac{980.665 \times 453.592\,37}{2.54^2 \times 10^6}$ = 0.068 947 572 9	1	$\frac{453.592\,37/2.54^3}{13.595\,0889}$ = 2.036 022 34	$\frac{453.592\,37/2.54^3}{0.998\,278\,282 \times 12}$ = 2.310 636 99	$\frac{453.592\,37 \times 10}{13.595\,088\,9 \times 2.54^2}$ = 51.714 967 4	$\frac{453.592\,37}{2.54^2 \times 10^3}$ = 0.070 306 958 0	$\frac{980.665 \times 453.592\,37}{2.54^2 \times 10^4}$ = 6.894 757 29
in. Hg (0°C)	$\frac{13.595\,088\,9 \times 2.54}{1\,013\,250/980.665}$ = 0.033 421 030 1	$\frac{13.595\,088\,9 \times 2.54}{10^6/980.665}$ = 0.033 863 858 8	$\frac{13.595\,088\,9 \times 2.54^3}{453.592\,37}$ = 0.491 153 746	1	$\frac{13.595\,088\,9}{0.998\,278\,282 \times 12}$ = 1.134 878 01	25.4	$\frac{13.595\,088\,9 \times 2.54}{10^3}$ = 0.034 531 525 8	$\frac{13.595\,088\,9 \times 2.54}{10^4/980.665}$ = 3.386 385 88
ft H₂O (20°C) [1]	$\frac{0.998\,278\,282 \times 30.48}{1\,013\,250/980.665}$ = 0.029 449 006 6	$\frac{0.998\,278\,282 \times 30.48}{10^6/980.665}$ = 0.029 839 205 9	$\frac{0.998\,278\,282 \times 12}{453.592\,37/2.54^3}$ = 0.432 781 092	$\frac{0.998\,278\,282 \times 12}{13.595\,0889}$ = 0.881 151 971	1	$\frac{9.982\,782\,82 \times 30.48}{13.595\,088\,9}$ = 22.381 260 1	$\frac{0.998\,278\,282 \times 30.48}{10^3}$ = 0.030 427 522 0	$\frac{0.0998\,278\,282 \times 30.48}{10^4/980.665}$ = 2.983 920 59
mm Hg (0°C)	$\frac{13.595\,088\,9}{10\,132\,500/980.665}$ = 0.001 315 788 59	$\frac{13.595\,088\,9}{10^7/980.665}$ = 0.001 333 222 79	$\frac{13.595\,088\,9 \times 2.54^2}{453.592\,37 \times 10}$ = 0.019 336 7617	$\frac{1.0}{25.4}$ = 0.039 370 078 7	$\frac{13.595\,088\,9}{9.982\,782\,82 \times 30.48}$ = 0.044 680 236 8	1	$13.595\,088\,9 \times 10^{-4}$ = 0.001 359 508 89	$\frac{13.595\,088\,9}{10^5/980.665}$ = 0.133 322 279
$\frac{kp}{cm^2}$	$\frac{980.665}{1\,013.25}$ = 0.967 841 105	0.980 665	$\frac{2.54^2 \times 10^3}{453.592\,37}$ = 14.223 343 3	$\frac{10^3}{13.595\,088\,9 \times 2.54}$ = 28.959 044 7	$\frac{10^3}{0.998\,278\,282 \times 30.48}$ = 32.864 983 2	$\frac{10^4}{13.595\,088\,9}$ = 735.559 736	1	$\frac{9.806\,65}{10^{-1}}$ = 98.066 5
kPa	$\frac{1.0}{101.325}$ = 0.009 869 232 67	0.01	$\frac{2.54^2 \times 10^4}{980.665 \times 453.592\,37}$ = 0.145 037 738	$\frac{10^4/980.665}{13.595\,0889 \times 2.54}$ = 0.295 300 074	$\frac{10^4/980.665}{0.998\,278\,282 \times 30.48}$ = 0.335 129 562	$\frac{10^5/980.665}{13.595\,088\,9}$ = 7.500 621 88	$\frac{10^{-1}}{9.806\,65}$ = 0.010 197 162	1

GENERAL NOTE: All values given in the rational fractions are exact and are taken from Appendix 4, except the densities of water and mercury. The density of water (0.998 278 282 g/cm³ at 68 °F) is computed from the IFC Formulation. The density of mercury (13.595 0889 g/cm³ at 32 °F) is taken from NBS Monograph 8, pgs. 3–4.

Example: 1 bar = 1 bar × 0.986 923 267 atm/bar = 0.986 923 267 atm = (1/1.013 25) atm.

From definitions: 1 lbf = 0.453 592 37 kp (kilopond) = kgf = 4.448 221 161 N; 1Pa = 1N/m².

NOTE:
(1) To convert to inches of water gage (iwg) or inches of water, multiply the values in this row by 12.

TABLE 5.3
CONVERSION FACTORS FOR SPECIFIC VOLUME (volume/mass)

To obtain → Multiply, by ↓	$\dfrac{ft^3}{lbm}$	$\dfrac{in.^3}{lbm}$	$\dfrac{U.S.\ gal}{lbm}$	$\dfrac{liter}{kg}$	$\dfrac{m^3}{kg}$
$\dfrac{ft^3}{lbm}$	1	1 728	$\dfrac{1\ 728}{231}$ $= 7.480\ 519\ 48$	$\dfrac{30.48^3}{453.592\ 37}$ $= 62.427\ 960\ 6$	$\dfrac{30.48^3 \times 10^{-6}}{0.453\ 592\ 37}$ $= 0.062\ 427\ 960\ 6$
$\dfrac{in^3}{lbm}$	$\dfrac{1.0}{1\ 728}$ $= 0.000\ 578\ 703\ 704$	1	$\dfrac{1.0}{231}$ $= 0.004\ 329\ 004\ 33$	$\dfrac{2.54^3}{453.592\ 37}$ $= 0.036\ 127\ 292\ 0$	$\dfrac{2.54^3 \times 10^{-6}}{0.453\ 592\ 37}$ $= 0.000\ 036\ 127\ 292$
$\dfrac{U.S.\ gal}{lbm}$	$\dfrac{231}{1\ 728}$ $= 0.133\ 680\ 556$	231	1	$\dfrac{231 \times 2.54^3}{453.592\ 37}$ $= 8.345\ 404\ 45$	$\dfrac{231 \times 2.54^3 \times 10^{-6}}{0.453\ 592\ 37}$ $= 0.008\ 345\ 404\ 45$
$\dfrac{liter}{kg}$	$\dfrac{453.592\ 37}{30.48^3}$ $= 0.016\ 018\ 463\ 4$	$\dfrac{453.592\ 37}{2.54^3}$ $= 27.679\ 904\ 7$	$\dfrac{453.592\ 37}{231 \times 2.54^3}$ $= 0.119\ 826\ 427$	1	0.001
$\dfrac{m^3}{kg}$	$\dfrac{0.453\ 592\ 37}{30.48^3 \times 10^{-6}}$ $= 16.018\ 463\ 4$	$\dfrac{0.453\ 592\ 37}{2.54^3 \times 10^{-6}}$ $= 27\ 679.904\ 7$	$\dfrac{0.453\ 592\ 37}{231 \times 2.54^3 \times 10^{-6}}$ $= 119.826\ 427$	1000	1

GENERAL NOTE:
All values given in the rational fractions are exact except 1 U.S. gal = 231 in.^{3} (NBS Misc. Pub. 233 P5).

Example: 1 U.S. gal/lbm = 0.133 680 556 ft^3/lbm

TABLE 5.4
CONVERSION FACTORS FOR SPECIFIC ENTHALPY AND SPECIFIC ENERGY (energy/mass)

To obtain → Multiply, by ↓	$\dfrac{\text{Btu}}{\text{lbm}}$	$\dfrac{\text{ft} \times \text{lbf}}{\text{lbm}}$	$\dfrac{\text{hp} \times \text{hr}}{\text{lbm}}$	$\dfrac{\text{lbf/in.}^2}{\text{lbm/ft}^3}$	$\dfrac{\text{kp} \times \text{m}}{\text{g}}$	$\dfrac{\text{kcal}}{\text{g}}$	$\dfrac{\text{kJ}}{\text{kg}}$
$\dfrac{\text{Btu}}{\text{lbm}}$	1	$\dfrac{2.326 \times 10^7}{980.665 \times 30.48}$ $= 778.169\ 262$	$\dfrac{2.326}{980.665 \times 30.48 \times 0.198}$ $= 3.930\ 147\ 79 \times 10^{-4}$	$\dfrac{2.326 \times 10^7}{980.665 \times 30.48 \times 144}$ $= 5.403\ 953\ 21$	$\dfrac{2.326}{9.806\ 65}$ $= 0.237\ 185\ 991$	$\dfrac{2.326}{4\ 186.8}$ $= 5.555\ 555\ 6 \times 10^{-4}$	2.326
$\dfrac{\text{ft} \times \text{lbf}}{\text{lbm}}$	$\dfrac{980.665 \times 30.48}{2.326 \times 10^7}$ $= 0.001\ 285\ 067\ 46$	1	$\dfrac{1.0}{1\ 980\ 000}$ $= 5.050\ 505\ 05 \times 10^{-7}$	$\dfrac{1.0}{144}$ $= 0.069\ 444\ 444\ 4$	30.48×10^{-5} $= 0.000\ 304\ 8$	$\dfrac{980.665 \times 30.48}{4\ 186.8 \times 10^7}$ $= 7.139\ 263\ 69 \times 10^{-7}$	$980.665 \times 30.48 \times 10^{-7}$ $= 0.002\ 989\ 066\ 920$
$\dfrac{\text{hp} \times \text{hr}}{\text{lbm}}$	$\dfrac{980.665 \times 30.48 \times 0.198}{2.326}$ $= 2\ 544.433\ 58$	$1\ 980\ 000$	1	$\dfrac{1\ 980\ 000}{144}$ $= 13\ 750$	30.48×19.8 $= 603.504$	$\dfrac{980.665 \times 30.48}{4\ 186.8/0.198}$ $= 1.413\ 574\ 21$	$\dfrac{980.665 \times 30.48 \times 198}{1000}$ $= 5\ 918.352\ 50$
$\dfrac{\text{lbf/in.}^2}{\text{lbm/ft}^3}$	$\dfrac{980.665 \times 30.48 \times 144}{2.326 \times 10^7}$ $= 0.185\ 049\ 715$	144	$\dfrac{144}{1\ 980\ 000}$ $= 7.272\ 727\ 27 \times 10^{-5}$	1	$30.48 \times 144 \times 10^{-5}$ $= 0.043\ 891\ 2$	$\dfrac{980.665 \times 30.48 \times 144}{4\ 186.8 \times 10^7}$ $= 1.028\ 053\ 97 \times 10^{-4}$	$\dfrac{980.665 \times 30.48 \times 144}{10^7}$ $= 0.430\ 425\ 636$
$\dfrac{\text{kp} \times \text{m}}{\text{g}}$	$\dfrac{9.806\ 65}{2.326}$ $= 4.216\ 100\ 60$	$\dfrac{10^5}{30.48}$ $= 3\ 280.839\ 90$	$\dfrac{1.0}{30.48 \times 19.8}$ $= 0.001\ 656\ 989\ 85$	$\dfrac{10^5}{30.48 \times 144}$ $= 22.782\ 610\ 4$	1	$\dfrac{9.806\ 65}{4\ 186.8}$ $= 0.002\ 342\ 278\ 11$	$9.806\ 65$
$\dfrac{\text{kcal}}{\text{g}}$	$\dfrac{4\ 186.8}{2.326}$ $= 1800$	$\dfrac{4\ 186.8 \times 10^7}{980.665 \times 30.48}$ $= 1\ 400\ 704\ 67$	$\dfrac{4\ 186.8 \times 10^3}{980.665 \times 30.48 \times 198}$ $= 0.707\ 426\ 602$	$\dfrac{4\ 186.8 \times 10^7}{980.665 \times 30.48 \times 144}$ $= 9\ 727.115\ 78$	$\dfrac{4\ 186.8}{9.806\ 65}$ $= 426.934\ 784$	1	$4\ 186.8$
$\dfrac{\text{kJ}}{\text{kg}}$	$\dfrac{1.0}{2.326}$ $= 0.429\ 922\ 614$	$\dfrac{10^7}{980.665 \times 30.48}$ $= 334.552\ 563$	$\dfrac{10^3}{980.665 \times 30.48 \times 198}$ $= 1.689\ 659\ 41 \times 10^{-4}$	$\dfrac{10^7}{980.665 \times 30.48 \times 144}$ $= 2.323\ 281\ 69$	$\dfrac{1.0}{9.806\ 65}$ $= 0.101\ 971\ 621$	$\dfrac{1.0}{4\ 186.8}$ $= 2.388\ 458\ 97 \times 10^{-4}$	1

GENERAL NOTE:
All values given in the rational fractions are exact except 1HP $=$ 550 ft-lbf/sec $=$ 1,980,000 ft-lbf/hr.

Example: 1 $\dfrac{\text{Btu}}{\text{lbm}} = $ 1kN·m $\dfrac{1\text{Btu}}{\text{lbm}} \times$ 778.169 262 $\dfrac{\text{ft} \times \text{lbf/lbm}}{\text{Btu/lbm}} = $ 778.169 262 $\dfrac{\text{ft} \times \text{lbf}}{\text{lbm}}$

From definitions: 1 $\dfrac{\text{Joule}}{\text{g}} = 1\ \dfrac{\text{J}}{\text{g}} = 10^7\ \dfrac{\text{erg}}{\text{g}} = 10^7\ \dfrac{\text{dyne-cm}}{\text{g}} = 10^3\ \dfrac{\text{J}}{\text{kg}} = 1\ \dfrac{\text{kw-sec}}{\text{kg}} = 10\ \dfrac{\text{bar-cm}^3}{\text{g}}$

1kJ $=$ 1/(0.45359237 $\times$ 2.326) $=$ 0.947817120 Btu: 1 kcal $= \dfrac{1.8}{0.45359237} =$ 3.96832072 Btu

1kJ $=$ 1/(0.45359237 $\times$ 2.326) $=$ 0.947817120 Btu: 1 kcal $= \dfrac{1.8}{0.45359237} =$ 3.96832072 Btu

TABLE 5.5
CONVERSION FACTORS FOR SPECIFIC ENTROPY, SPECIFIC HEAT, AND GAS CONSTANT
(energy/mass × temperature)

To obtain → / Multiply by ↗	Btu / (lbm × R)	ft × lbf / (lbm × R)	kw × hr / (lbm × R)	bar × cm³ / (g × K)	kcal / (g × K)	kp × m / (g × K)	kJ / (kg × K)
Btu / (lbm × R)	1	$\frac{2.326 \times 10^7}{980.665 \times 30.48}$ $= 778.169\,262$	$\frac{2.326 \times 453.592\,37}{3\,600\,000}$ $= 0.000\,293\,071\,070$	41.868	0.0001	$\frac{4.186\,8}{9.806\,65}$ $= 0.426\,934\,784$	4.186 8
ft × lbf / (lbm × R)	$\frac{980.665 \times 30.48}{2.326 \times 10^7}$ $= 0.001\,285\,067\,46$	1	$\frac{453.592\,37 \times 30.48}{3.6 \times 10^{13}/980.665}$ $= 3.766\,160\,97 \times 10^{-7}$	$\frac{30.48 \times 980.665 \times 9/5}{10^6}$ $= 0.053\,803\,204\,6$	$\frac{980.665 \times 30.48}{2\,326 \times 10^7}$ $= 1.285\,067\,46 \times 10^{-6}$	$30.48 \times 10^{-5} \times 9/5$ $= 0.000\,548\,64$	$\frac{980.665 \times 30.48 \times 10^{-7}}{5/9}$ $= 0.005\,380\,320\,46$
kw × hr / (lbm × R)	$\frac{3\,600\,000}{2.326 \times 453.592\,37}$ $= 3\,412.141\,63$	$\frac{3.6 \times 10^{13}/980.665}{453.592\,37 \times 30.48}$ $= 2\,655\,223.73$	1	$\frac{3.6 \times 10^7 \times 9/5}{453.592\,37}$ $= 142\,859.546$	$\frac{3\,600\,000}{2\,326 \times 453.592\,37}$ $= 3.412\,141\,63$	$\frac{3.6 \times 10^8 \times 9/5}{980.665 \times 453.592\,37}$ $= 1\,456\,761.95$	$\frac{3.6 \times 10^6 \times 9/5}{453.592\,37}$ $= 14\,285.954\,6$
bar × cm³ / (g × K)	$\frac{1.0}{41.868}$ $= 0.023\,884\,589\,7$	$\frac{10^6}{30.48 \times 980.665 \times 9/5}$ $= 18.586\,253\,5$	$\frac{453.592\,37}{3.6 \times 10^7 \times 9/5}$ $= 6.999\,882\,25 \times 10^{-6}$	1	$\frac{1.0}{41\,868}$ $= 2.388\,458\,97 \times 10^{-5}$	$\frac{1.0}{98.066\,5}$ $= 0.010\,197\,1621$	0.1
kcal / (g × K)	1000	$\frac{2\,326 \times 10^7}{980.665 \times 30.48}$ $= 778\,169.262$	$\frac{2\,326 \times 453.592\,37}{3\,600\,000}$ $= 0.293\,071\,070$	41 868	1	$\frac{4\,186.8}{9.806\,65}$ $= 426.934\,784$	4 186.8
kp × m / (g × K)	$\frac{9.806\,65}{4.186\,8}$ $= 2.342\,278\,11$	$\frac{10^5}{30.48 \times 9/5}$ $= 1\,822.688\,83$	$\frac{980.665 \times 453.592\,37}{3.6 \times 10^8 \times 9/5}$ $= 0.000\,686\,453\,953$	98.066 5	$\frac{9.806\,65}{4\,186.8}$ $= 0.002\,342\,278\,11$	1	9.806 65
kJ / (kg × K)	$\frac{1.0}{4.186\,8}$ $= 0.238\,845\,897$	$\frac{10^7 \times 5/9}{980.665 \times 30.48}$ $= 185.862\,535$	$\frac{453.592\,37}{3.6 \times 10^6 \times 9/5}$ $= 6.999\,882\,25 \times 10^{-5}$	10	$\frac{1.0}{4\,186.8}$ $= 0.000\,238\,845\,897$	$\frac{1.0}{9.806\,65}$ $= 0.101\,971\,621$	1

GENERAL NOTE:
All values given in the rational fractions are exact.

Example: 1 Btu / (lbm × R) = 778.169 262 ft × lbf / (lbm × R)

TABLE 5.6
CONVERSION FACTORS FOR VISCOSITY
(force × time/area ~ mass/length × time)

To obtain → / Multiply, by ↓	$Pa \times s$ [Note (1)]	$\dfrac{lbf \times sec}{ft^2}$	$\dfrac{lbm}{ft \times sec}$	$\dfrac{lbm}{hr \times ft}$	$\dfrac{g}{cm \times sec}$ (poise)	$\dfrac{kg}{m \times sec}$
$\dfrac{Pa \times s}{}$ [Note (1)]	1	$\dfrac{(0.3048)^2}{9.80665 \times 0.453\,592\,37}$ $= 0.020\,885\,4342$	$\dfrac{0.3048}{0.453\,592\,37}$ $= 0.671\,968\,975$	$\dfrac{0.3048 \times 3600}{0.453\,592\,37}$ $= 2419.088\,31$	10	1
$\dfrac{lbf \times sec}{ft^2}$	$\dfrac{9.806\,65 \times 0.453\,592\,37}{(0.3048)^2}$ $= 47.880\,259\,0$	1	$\dfrac{980.665}{30.48}$ $= 32.174\,048\,6$	$\dfrac{980.665 \times 3\,600}{30.48}$ $= 115\,826.575$	$\dfrac{980.665 \times 453.592\,37}{30.48^2}$ $= 478.802\,590$	$\dfrac{980.665 \times 453.592\,37}{10 \times 30.48^2}$ $= 47.880\,259\,0$
$\dfrac{lbm}{ft \times sec}$	$\dfrac{0.453\,592\,37}{0.3048}$ $= 1.488\,163\,94$	$\dfrac{30.48}{980.665}$ $= 0.031\,080\,950\,2$	1	$3\,600$	$\dfrac{453.592\,37}{30.48}$ $= 14.881\,639\,4$	$\dfrac{453.592\,37}{304.8}$ $= 1.488\,163\,94$
$\dfrac{lbm}{hr \times ft}$	$\dfrac{0.453\,592\,37}{0.3048 \times 3600}$ $= 0.413\,378\,873 \times 10^{-3}$	$\dfrac{30.48}{980.665 \times 3\,600}$ $= 8.633\,597\,27 \times 10^{-6}$	$\dfrac{1.0}{3\,600}$ $= 0.000\,277\,777\,778$	1	$\dfrac{453.592\,37}{30.48 \times 3\,600}$ $= 0.004\,133\,788\,73$	$\dfrac{453.592\,37}{304.8 \times 3\,600}$ $= 0.000\,413\,378\,873$
$\dfrac{g}{cm \times sec}$ (poise)	0.1	$\dfrac{30.48^2}{980.665 \times 453.592\,37}$ $= 0.002\,088\,543\,42$	$\dfrac{30.48}{453.592\,37}$ $= 0.067\,196\,897\,5$	$\dfrac{3\,600 \times 30.48}{453.592\,37}$ $= 241.908\,831$	1	0.1
$\dfrac{kg}{m \times sec}$ [Note (1)]	1	$\dfrac{10 \times 30.48^2}{980.665 \times 453.592\,37}$ $= 0.020\,885\,434\,2$	$\dfrac{304.8}{453.592\,37}$ $= 0.671\,968\,975$	$\dfrac{10 \times 3\,600 \times 30.48}{453.592\,37}$ $= 2\,419.088\,31$	10	1

GENERAL NOTE:
All values given in the rational fractions are exact.
Example: 1 lbf × sec/ft² = 32.174 048 6 lbm/(ft × sec)
From definitions: 1 poise = 1 P = 1 g/cm × sec = 1 dyne × sec/cm² = 0.1 kg/m × sec = 0.1 Newton × sec/m² = 0.1 Pascal × sec = 0.1 Pa × sec

NOTE:
(1) SI Units for ASME use.

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TABLE 5.7
CONVERSION FACTORS FOR KINEMATIC VISCOSITY (area/time)

To obtain → Multiply, by ↓	$\dfrac{m^2}{s}$ [Note (1)]	$\dfrac{ft^2}{sec}$	$\dfrac{cm^2}{sec}$ (stoke)	$\dfrac{cm^2}{hr}$	$\dfrac{m^2}{hr}$
$\dfrac{m^2}{s}$ [Note (1)]	1	$\dfrac{1.0}{(0.3048)^2}$ $= 10.763\ 9104$	$(100)^2 = 10\ 000$	$(100)^2 \times 3600 = 36 \times 10^6$	3600
$\dfrac{ft^2}{sec}$	$(0.3048)^2 = 0.092\ 903\ 04$	1	$(30.48)^2 = 929.030\ 4$	$(30.48)^2 \times 3\ 600 =$ $3\ 344\ 509.440\ 000$	$(0.304\ 8)^2 \times 3\ 600 =$ $334.450\ 944\ 000$
$\dfrac{cm^2}{sec}$ (stoke)	$\dfrac{1.0}{(100)^2}$ $= 10^{-4}$	$\dfrac{1.0}{(30.48)^2}$ $= 0.001\ 076\ 391\ 04$	1	$3\ 600$	$\dfrac{3\ 600}{(100)^2}$ $= 0.36$
$\dfrac{cm^2}{hr}$	$\dfrac{1.0}{(100)^2 \times 3\ 600}$ $= 27.777\ 777\ 8 \times 10^{-9}$	$\dfrac{1.0}{(30.48)^2 \times 3\ 600}$ $= 0.2\ 989\ 975\ 12 \times 10^{-6}$	$\dfrac{1.0}{3\ 600}$ $0.000\ 277\ 777\ 78$	1	$\dfrac{1.0}{(100)^2}$ $= 0.0000\ 1$
$\dfrac{m^2}{hr}$	$\dfrac{1.0}{3\ 600}$ $= 277.777\ 778 \times 10^{-6}$	$\dfrac{1.0}{(0.3048)^2 \times 3\ 600}$ $= 2.989\ 975\ 12 \times 10^{-3}$	$\dfrac{(100)^2}{3\ 600}$ $2.777\ 777\ 78$	$(100)^2$ $= 10\ 000$	1

GENERAL NOTE:
All values given in the rational fractions are exact.
Example: 1 ft²/sec = 3600 ft²/hr.

NOTE:
(1) SI Units for ASME use.