AN AMERICAN NATIONAL STANDARD

ANSI/ASME PTC 2 - 1980

Definitions and Values

PERFORMANCE TEST CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
345 East 47th Street New York, N.Y. 10017

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FOREWORD

Precise definitions of terms and exact values of the constants employed in the various Performance Test Codes of this Society are fundamentally important. This Code is intended to provide standard definitions and values required by each respective Performance Test Code and to supplement each of them. Aside from the establishment of the value of basic units common to all of the codes, the principal purpose of the Definitions and Values Code as defined by the Performance Test Codes Supervisory Committee is to provide a source for any item used by more than one of the Performance Test Codes committees. The Code herewith presented is an outgrowth of four previous codes on Definitions and Values, issued and adopted by the Society, and is intended to supersede them. A draft of the first code was printed in the December 1921 issue of *Mechanical Engineering* in preliminary form and was presented to the Society during the Spring Meeting held in Atlanta, Georgia, May 1922. At the December 1, 1924 meeting of the Standing Committee, the Code was approved for submission to the Council and on January 21, 1926 was approved and adopted by the latter as a standard practice of the Society.

The first edition was exhausted in the fall of 1928. Accordingly, acting under instructions from the Standing Committee, PTC Committee No. 2 revised the Code. At the June 2, 1930 meeting of the Standing Committee, this second edition was approved in its finally revised form. The Council approved this revised Code on May 14, 1931.

In June 1936, the Council approved the reorganization of Committee No. 2 to undertake a thorough review of this Code. The reorganized Committee No. 2 proceeded to completely rewrite the Code. At the April 4, 1945 meeting of the Standing Performance Test Codes Committee, this revision was approved and on June 17, 1945, it was approved and adopted by the Council.

In June 1969, PTC Committee No. 2, acting under instructions from the Standing Committee, proceeded to revise and rewrite the Code. The final draft was presented to the Society as a paper during the 1970 Winter Annual Meeting held in New York, New York. The Code in final form was approved by the Performance Test Codes Committee on January 4, 1971 and adopted by the Council of the Society by action of the Policy Board on Codes and Standards on February 26, 1971.

In June 1972, PTC Committee No. 2, acting under instructions of the Supervisory Committee, proceeded to revise the Code to include SI (Metric) units and to include more up-to-date values. This Code was approved by the Performance Test Codes Supervisory Committee on February 26, 1979 and was approved as an American National Standard by the ANSI Board of Standards Review on July 21, 1980.

PERSONNEL OF PERFORMANCE TEST CODES COMMITTEE NO. 2 ON DEFINITIONS AND VALUES

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AN AMERICAN NATIONAL STANDARD

ASME PERFORMANCE TEST CODES
Code on
DEFINITIONS AND VALUES

SECTION 1 — OBJECT AND SCOPE

1.01 The purpose of this Code is to provide the necessary information and data to comply with the requirement of PTC 1 that "all individual codes shall conform to the Code on Definitions and Values (PTC 2)."

1.02 This Code contains standards for terms, units, values of constants, symbols and technical nomenclature, which, where applicable, are to be component parts of all individual test codes.

1.03 By necessity all the information contained in this document represents the state-of-the-art at the time of its preparation. In order that the Performance Test Codes may continue to be dynamic useful documents, any part of this Code is automatically superseded by any or all of the following:

(a) Approval by ASME Council of new or revised units, values of constants or fluid properties.

(b) Inclusion in the Performance Test Code series of equipment not covered by this Code.

(c) Approval by the Supervisory Committee of an individual test code not conforming to this document.

1.04 The exceptions described in Par. 1.03 will be published in *Mechanical Engineering* as they occur, and this Code will be amended as soon thereafter as practical.

SECTION 2 — DEFINITIONS

2.01 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, it being assumed that the atmosphere is at rest.

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

The International Standard Atmosphere is 760 mm of mercury (at 0°C) which is equal to 29.921 in. of mercury (at 32°F). In English units this is 14.695 95 lbf/in.^{2} at the standard gravity of 32.174 06 ft/sec^2. In the SI (Metric) system the standard atmosphere is 101 325 N/m^2 or 101.325 kPa at the standard gravity of 9.806 65 m/s^2 and should be used as the reference pressure.

For other relationships of the International Standard Atmosphere, 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.

2.02 Boiler Horsepower. The boiler horsepower no longer has any real meaning in steam generator performance. As a matter of historical interest, it was originally standardized by the ASME in 1889 based on an engine steam rate of 30 lb of steam per hphr at 70 psig and a feed water temperature of 100°F. This corresponds to 34.5 lbm/hr evaporated from and at 212°F (33,475 Btu/hr). At the time boiler horsepower was standardized, boilers could develop one boiler horsepower with 10 sq ft of heating surface, and this was used by manufacturers to rate boilers on heating surface.

2.03 Combustion, Rate of. The rate of combustion is defined as follows:

(a) All fuels: Heat value of fuel as fired per unit of furnace volume per unit time, Btu/ft^3-hr [J/(m^3·s)]

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

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

2.04 Condensers, Surface. The rate of heat transfer is:

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

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 hot well, Btu/lbm (J/kg)

The values of all the enthalpies except h_3 may be obtained from temperature readings and the ASME Steam Tables (latest edition). The value of h_3 must be determined indirectly because the quality (dryness) of steam has so far defied all attempts at measurements. Until the problem of direct measurement has been solved, the indirect methods prescribed in PTC 12.2 Steam Condensing Apparatus shall be used.

2.05 Efficiency, Ideal Cycle. Ideal cycle efficiency is the ratio of the work of the ideal cycle to the heat supplied. This efficiency of an ideal cycle is often referred to as the efficiency of an ideal engine.

2.06 Efficiency, Engine. The engine efficiency is defined as the ratio of 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, it is possible to have three engine efficiencies.

2.07 Efficiency, Thermal. The thermal efficiency of any engine or turbine is defined as the ratio of the work done divided by the heat supplied.

$$\text{Indicated thermal efficiency} = \frac{A\,W_i}{Q}$$

$$\text{Brake thermal efficiency} = \frac{A\,W_b}{Q}$$

$$\text{Combined thermal efficiency} = \frac{B\,W_k}{Q}$$

where

A = 2544.43 Btu/hp-hr [1 J/(kW•s)]
B = 3412.14 Btu/kW-hr [1 J/(kW•s)]
Q = heat added, Btu/hr (J/s)
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 efficiency of a complete plant will be expressed in the same manner as that for a turbine or engine. It should be noted that thermal efficiency and cycle as used in codes may not always be correct in the classical thermodynamic sense but they are a result of engineering practice and do conform with what is now called thermodynamics by practicing engineers.

2.08 Efficiency, Volumetric. Volumetric efficiency applies only to reciprocating machinery. The volumetric efficiency of centrifugal or other kinetic machinery cannot be obtained as there is no measurable displacement.

For compressors:

$$\eta_v = \frac{\text{Volumetric capacity of compressor}}{\text{Displacement}}$$

For pumps:

$$\eta_v = \frac{\text{Actual pump delivery}}{\text{Displacement}}$$

2.09 Efficiency, Isentropic Compression. The isentropic compression efficiency is defined as the ratio of theoretical isentropic power to the fluid power developed.

2.10 Efficiency, Mechanical. Mechanical efficiency is defined as the ratio of actual work to indicated internal work.

2.11 Efficiency, Overall, Compressor. Overall compressor efficiency is the ratio of isentropic power to the actual power supplied.

2.12 Energy of a Substance, Thermal. Internal energy is a "point" function; its change of value from one state to another is independent of the "path" of the process undergone to produce the change. Since changes in internal energy are of importance rather than absolute values, the internal energy may be set to any convenient arbitrary base. For steam this base has been set at the Triple Point 273.15K and 611.2 Pa. The symbol for internal energy is u and its units are Btu/lbm (J/kg).

2.13 Enthalpy. Enthalpy is defined as:

$$h = u + pv/J \quad \text{Btu/lbm (J/kg)}$$

where

h = enthalpy, Btu/lbm (J/kg)
u = internal energy, Btu/lbm (J/kg)
p = pressure of fluid, lbf/ft^2 (Pa)
v = specific volume of fluid, ft^3/lbm (m^3/kg)
J = mechanical equivalent of heat, 778.169 262 ft-lbf/Btu (1 J/J)

2.14 Evaporators. The rate of heat transfer is:

$$q = w_e\,(h_2 - h_1);\ \text{or}\ q = w_s\,(h_v - h_f) \quad \text{Btu/hr (J/s)}$$

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_v = enthalpy of entering steam, Btu/lbm (J/kg)
h_f = enthalpy of condensed water, Btu/lbm (J/kg)

The left-hand equation is to be preferred as the right-hand will give higher values if heat is lost during the process.

2.15 Fuel Rate. The fuel rate for solid and liquid fuels is defined as mass of fuel fired per unit of output. For gaseous fuels it is defined as cu ft of gas at 59°F and 14.696 psia per hr (m^3 at 15°C and 101.325 kPa). Fuel rates should be qualified by reference to the unit of output.

2.16 Furnace Volume, Total. Under the original scope of the Performance Test Codes Committee, the use of furnace volume was limited to steam generators. Since this volume may be used for other equipment, it shall be as defined by the individual code.

2.17 Grate Surface. Grate surface is defined as the horizontal fuel or combustible supporting structure within the walls of the furnace. This would also include fluidized bed support surface.

2.18 Gravity, Standard. The International Standard Gravity has the value:

$$g = 9.806\ 65\ \text{m/s}^2 = 32.174\ 06\ \text{ft/sec}^2$$

which is the actual value at sea level and a latitude of 45 deg. Values for other latitudes at sea level are given in PTC 19.2 Pressure Measurement. PTC 19.2 gives actual values of gravity for various locations in the United States and these values shall be used for all Performance Test Code work.

2.19 Heat Absorbed by Water and Steam (Btu/hr)

$$q = w_v\,(h_v - h_f)\quad \text{Btu/hr}\ \ (\text{J/s})$$

where

w_v = heat exchanger fluid rate, lbm/hr (kg/s)
h_f = enthalpy of fluid at inlet, Btu/lbm (J/kg)
h_v = enthalpy of fluid at outlet, Btu/lbm (J/kg)

2.20 Heat Absorption, Rate of. Rate of heat absorption is the energy absorbed per unit time, Btu/hr (J/s).

2.21 Heat Rate. The basic definition for heat rate is:

$$\text{Heat Rate} = \frac{\text{Heat supplied} - \text{Heat returned}}{\text{Output}}$$

Because of the complexity of modern power cycles, each code should define heat rate in terms of specific equipment covered.

2.22 Heat Transfer Coefficient. The heat transfer coefficient is defined as the energy transmitted per unit area of heating surface per temperature degree per unit time, Btu/(ft^2-°R-hr) [W/(m^2·K)]

2.23 Heat Transfer of Heat Exchangers. The rate of heat transfer is:

$$q = w_f\,(h_1 - h_2)\quad \text{Btu/hr}\ \ (\text{J/s})$$

where

w_f = heat exchanger fluid rate, lbm/hr (kg/s)
h_1 = enthalpy of fluid at inlet, Btu/lbm (J/kg)
h_2 = enthalpy of fluid at outlet, Btu/lbm (J/kg)

2.24 Heat Value. The heating value of fuels shall be determined in accordance with the procedures set forth in the PTC 3 series as follows:

PTC 3.1 Diesel and Burner Fuels
PTC 3.2 Solid Fuels
PTC 3.3 Gaseous Fuels

The determination as to the use of the higher or lower heating value will be made by each individual code.

2.25 Ice Point and Steam Point

(a) Ice point is defined as the temperature of frozen pure water when melting under standard atmospheric pressure, 32°F (273.15 K)

(b) Steam point is defined as the temperature of condensing water vapor at standard atmospheric pressure, 212°F (373.15 K)

2.26 Internal Combustion Cycles. For internal-combustion engines, several cycles are in common use, for example, the Otto cycle and the Diesel cycle. Although it is possible to compute an engine efficiency based on ideal cycle assumptions and also a thermal efficiency of ideal cycles, all calculations for thermal efficiency of internal-combustion engines for Performance Test Code work shall be made on a measured work output over a measured heat input basis and not that of any idealized cycle. Engine efficiency shall not be calculated as part of any internal-combustion engine (including gas turbine) code.

2.27 Mean Effective Pressure. The mean effective pressure of an engine is the work divided by its displacement. Combined brake, friction or indicated mean effective pressures may be calculated by using the applicable values for work.

2.28 Mercury, Density of. The density of mercury at 32°F (0°C) is 13 595.1 kg/m^3 or 0.491154 lbm/in^3. For other values and conversions, consult PTC 19.2 Pressure Measurement.

2.29 Noise. Noise is undesired sound. Sound pressure level is measured in decibels. A decibel (db) is 20 times the logarithm to the base 10 of the ratio of the sound pressure to the reference sound pressure. The reference pressure (RMS) is 20 μPa.

2.30 Output, Net. The net output of an engine or turbine generator unit is defined by the formula:

$$\text{Net output (kW)} = \left\{\begin{matrix}\text{Electrical power}\\ \text{output of}\\ \text{generator (kW)}\end{matrix}\right\} - \left\{\begin{matrix}\text{Auxiliary}\\ \text{power}\\ \text{supplied (kW)}\end{matrix}\right\}$$

Auxiliary power supplied is that external power which is 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, seal evacuators, etc.

2.31 Power, Air or Gas. Air or gas power may be defined as that required for (a) isentropic or (b) isothermal compression for the same quantity through the same pressure range. Either standard may be used but it must be specified.

2.32 Power, Drawbar. The drawbar power is:

$$P_D = FV/B$$

where

P_D = drawbar power, hp (W)
F = pull at drawbar, 1bf (N)
V = speed, ft/min (m/s)
B = 33,000 ft-lbf/min/hp (1 W/W)

2.33 Power, Water. Water power is to be computed from the equation:

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

where

P_w = water power, hp (W)
ρ = density weight of water, lbm/ft^3 (kg/m^3)
Q = volumetric flow rate, ft^3/sec (m^3/s)
H_1 = higher head, ft-lbf/lbm (J/kg)
H_2 = lower head, ft-lbf/lbm (J/kg)
p_1 = higher pressure, lbf/in.^{2} (Pa)
p_2 = lower pressure, lbf/in.^{2} (Pa)
A = 550 ft-lbf/sec/hp (1 W/W)
B = 144 in.^{2}/ft^2 (1 m^2/m^2)

All heads and pressures shall be measured under or corrected to stagnation conditions.

2.34 Pump, Energy Added by. The energy added by the pump plus its internal losses is:

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

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 ASME Steam Tables* (latest edition) including the work of isentropic compression of water (Δh_s).

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

in which h_{s2} is taken at the pressure of the pump discharge, and at the entropy as determined at the pump inlet conditions.

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

It should be noted that any compression, other than isothermal, including an isentropic will raise the temperature of water, and that at higher pressure this will be a sensible amount.

2.35 Standards, Primary. Pursuant to statute authority, the following exact conversion factors between the international metric units (SI units) and the foot-pound units have been adopted and published by the National Bureau of Standards:

1 ft = 0.3048 m
1 in. = 0.0254 m = 25.4 mm
1 lb = 0.453 592 37 kg
1 cu ft = 0.028 316 85 m^3

Standard atmospheric pressure = 101 325 N/m^2 = 14.695 95 lbf/in.^{2}

Standard gravity = 9.806 65 m/s^2 = 32.174 06 ft/sec^2

Data from NBS Miscellaneous Publication 286, May 1967.

2.36 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.

2.37 Steam Cycle Efficiency, Rankine. This is the ideal cycle efficiency, defined in Par. 2.05, of the Rankine steam cycle defined in Par. 2.36.

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

where

h_1 = initial enthalpy of steam, Btu/lbm (J/kg)

*For fluids other than water use the appropriate standard reference.

h_s = enthalpy after isentropic expansion, Btu/lbm (J/kg)

h_f = enthalpy of saturated liquid at exhaust pressure, Btu/lbm (J/kg)

For feed pump work refer to Par. 2.34.

2.38 Steam, Quality of. If the steam is superheated, its state is fully defined by its temperature and pressure. If the steam is "wet", its state is defined by its temperature and/or pressure and the amount of steam in the vapor phase and/or liquid phase. Quality of steam is denoted by the amount of vapor phase present in the mixture, for example, if it is stated that the quality of the steam is 97.5 percent, this means that its "dryness fraction" is 0.975. In a like manner, the term moisture is often used to denote the amount in the liquid phase; in this example the percent moisture is 2.5 percent.

Dry and saturated steam exist when all of the steam is in the vapor state at saturation pressure and temperature. Under these conditions, the quality is 100 percent and the moisture is 0 percent.

2.39 Steam Rate. The steam rate of an engine, turbine, or complete plant is expressed as mass of steam per unit time under actual conditions per unit of output.

2.40 Thermal Unit, British. The current ASME Steam Tables (1977) define the British Thermal Unit as follows:

1 Btu = 2.326 x 0.453 592 37 kJ

1 Btu/lbm = 2.326 kJ/kg

From these values the following may be derived:

$$1 \text{ Btu} = \frac{(2.326 \times 10^7)}{(980.665 \times 30.48)} = 778.169\ 262 \text{ ft-lbf}$$

$$1 \text{ hp hr} = \frac{(550 \times 3600)}{(778.169\ 262)} = 2544.433\ 58 \text{ Btu}$$

$$1 \text{ international kWh} = \frac{(3600 \times 1000)}{(2.326 \times 453.592\ 37)} = 3412.141\ 63 \text{ Btu}$$

Formerly, the British thermal unit (or "mean Btu") was defined as 1/180 of the heat required to raise 1 lbm of water from the ice point to the steam point under a constant pressure of 1 standard atm.

2.41 Temperature, Absolute. The absolute temperature is the approximate value of the thermodynamic temperature as defined by the International Practical Temperature Scale. In the U.S. system, the absolute temperature is in degrees Rankine. In the SI (Metric) system it is called the Kelvin. For relations between these scales, see Par. 3.01.

2.42 Temperature of Reference. The datum for the steam tables is the Triple Point of water. The 1968 International Practical Temperature Scale fixes this at 0.01°C or 32.018°F.

For gases the preferred standard temperature to be used for Performance Test Code work is 59°F (15°C).

The prior edition of PTC 2-1945 on Definitions and Values recommended a standard temperature of 68°F based on projections of the International Committee on Weights and Measures. Since that time, 59°F (15°C) has been increasingly used as a standard, and it is recommended that as each Test Code is revised the base of 59°F (15°C) be adopted.

2.43 Viscosity. Viscosity is defined as the ratio of shearing stress to the rate of shearing strain of a fluid. For further details on viscosity, PTC 19.17 Determination of the Viscosity of Liquids should be consulted.

2.44 Watt. The absolute watt is one newton meter per second.

SECTION 3 — COMMON CONVERSION FACTORS

3.01 Conversions to SI (Metric) Units

Quantity	Conversion		Multiplication Factor	
Acceleration-Linear	ft/sec^2	to m/s^2	3.048 *	E-01
	standard gravity	m/s^2	9.806 65 *	E+00
Area	$in.^2$	to m^2	6.451 6	E-04
	ft^2	to m^2	9.290 304*	E-02
Coefficient of thermal expansion	$°R^{-1}$	to K^{-1}	1.8 *	E+00
Density	lbm/ft^3	to kg/m^3	1.601 846	E+01
	$slugs/ft^3$	to kg/m^3	5.153 788	E+02
Energy, work, heat	Btu (IT)	to J	1.055 056	E+03
	ft-lbf	to J	1.355 818	E+00
Flow rate, mass	lbm/sec	to kg/s	4.535 924	E-01
	lbm/min	to kg/s	7.559 873	E-03
	lbm/hr	to kg/s	1.259 979	E-04
	slugs/sec	to kg/s	1.459 390	E+01
Flow rate, volume	ft^3/min	to m^3/s	4.719 474	E-04
	ft^3/sec	to m^3/s	2.831 685	E-02
	gallons (US liquid)/min	to m^3/s	6.309 020	E-05
Force	lbf (avoirdupois)	to N	4.448 222	E+00
Frequency	sec^{-1}	to Hz	1 *	E+00
Gas constant	Btu/lbm-°R	to J/(kg • K)	4.186 8*	E+03
	ft-lbf/lbm-°R	to J/(kg • K)	5.380 320	E+00
Heat transfer coefficient	$Btu/hr\text{-}ft^2\text{-}°R$	to $W/(m^2 \cdot K)$	5.678 263	E+00
Length	in.	to m	2.54 *	E-02
	ft	to m	3.048 *	E-01
	mile (U.S.)	to m	1.609 344 *	E+03
Mass	lbm (avoirdupois)	to kg	4.535 924	E-01
	slug	to kg	1.459 390	E+01
Plane angle	degrees	to rad	1.745 329	E-02
Power	Btu (IT)/hr	to W	2.930 711	E-01
	ft-lbf/sec	to W	1.355 818	E+00
	hp (550 ft-lbf/sec)	to W	7.456 999	E+02
Pressure	standard atmosphere	to Pa	1.013 25 *	E+05
	bar	to Pa	1 *	E+05
	lbf/ft^2	to Pa	4.788 026	E+01
	$lbf/in.^2$	to Pa	6.894 757	E+03
Rotational frequency	min^{-1}	to s^{-1}	1.666 667	E-02
Specific enthalpy	Btu/lbm	to J/kg	2.326	E+03
Specific entropy	Btu/lbm-°R	to J/(kg • K)	4.186 8*	E+03
Specific heat	Btu/lbm-°R	to J/(kg • K)	4.186 8*	E+03
Specific internal energy	Btu/lbm	to J/kg	2.326	E+03

Quantity	Conversion		Multiplication Factor	
Specific volume	ft^3/lbm	to m^3/kg	6.242 797	E-02
Specific weight (force)	lbf/ft^3	to N/m^3	1.570 875	E+02
Surface tension	lbf/ft	to N/m	1.459 390	E+01
Temperature interval	°F	to °C	5.555 556	E-01
Temperature, measured	°F	to °C	$t_C = (t_F - 32)/1.8$	
Temperature, thermodynamic	°C	to K	$T_K = t_C + 273.15$	
	°F	to K	$T_K = (t_F + 459.67)/1.8$	
	°R	to K	$T_K = T_R/1.8$	
Thermal conductivity	Btu-ft/hr-ft^2-°R	to W/(m • K)	1.730 735	E+00
Time	hr	to s	3.6 *	E+03
	min	to s	6 *	E+01
Torque	lbf-in.	to N • m	1.129 848	E-01
	lbf-ft	to N • m	1.355 818	E+00
Velocity	ft/hr	to m/s	8.466 667	E-05
	ft/min	to m/s	5.08 *	E-03
	ft/sec	to m/s	3.048 *	E-01
	knot (international)	to m/s	5.144 444	E-01
	mile (U.S.)/hr	to m/s	4.470 4 *	E-01
Viscosity, dynamic	centipoise	to Pa • s	1 *	E-03
	poise	to Pa • s	1 *	E-01
	lbm/ft-sec	to Pa • s	1.488 164	E+00
	lbf-sec/ft^2	to Pa • s	4.788 026	E+01
	slug/ft-sec	to Pa • s	4.788 026	E+01
Viscosity, kinematic	centistoke	to m^2/s	1 *	E-06
	stoke	to m^2/s	1 *	E-04
	ft^2/sec	to m^2/s	9.290 304 *	E-02
Volume	gallon (U.S. liquid)	to m^3	3.785 412	E-03
	ft^3	to m^3	2.831 685	E-02
	in.^{3}	to m^3	1.638 706	E-05
	liter	to m^3	1 *	E-03

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

*Exact relationship in terms of the base units.

3.02 Conversion Factors for Pressure (Force/Area)

To obtain → / Multiply, by ↓	atm	bar	$\frac{lbf}{in.^2}$	in. Hg (0°C)	ft H_2O (20°C)	mm Hg (0°C)	kPa (SI Units)
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	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	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	$\frac{453.592\,37/2.54^3}{13.595\,088\,9}$ = 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	$\frac{980.665 \times 453.592\,3}{2.54^2 \times 10^4}$ = 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	$\frac{13.595\,088\,9 \times 2.54}{10^4/980.665}$ = 3.386 385 88
ft H_2O (20°C)	$\frac{0.998\,278\,282 \times 30.48}{1\,013\,250/980.665}$ = 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	$\frac{0.998\,278\,282 \times 12}{13.595\,088\,9}$ = 0.881 151 971	1	$\frac{9.982\,782\,82 \times 30.48}{13.595\,088\,9}$ = 22.381 260 1	$\frac{0.998\,278\,282 \times 30.4}{10^4/980.665}$ = 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	$\frac{13.595\,088\,9 \times 2.54^2}{453.592\,37 \times 10}$ = 0.019 336 761 7	$\frac{1.0}{25.4}$ = 0.039 370 078 7	$\frac{13.595\,088\,9}{9.982\,782\,82 \times 30.48}$ = 0.044 680 236 8	1	$\frac{13.595\,088\,9}{10^5/980.665}$ = 0.133 322 279
kPa (SI Units)	$\frac{1.0}{101.325}$ = 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	1

All values given in the rational fractions are exact except the densities of water and mercury. The density of water (0.998 278 282 g/cm^3 at 20°C) is computed from the IFC Formulation. The density of mercury (13.595 0889 g/cm^3 at 0°C) is taken from NBS Monograph 8, P3-4.

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

3.03 Conversion Factors for Specific Volume (Volume/Mass)

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

All values given in the rational fractions are exact.

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

3.04 Conversion Factors for Specific Enthalpy and Specific Energy (Energy/Mass)

To obtain → / Multiply, by ↓	$\frac{Btu}{lbm}$	$\frac{ft \times lbf}{lbm}$	$\frac{hp \times hr}{lbm}$	$\frac{lbf/in.^2}{lbm/ft^3}$	$\frac{kp \times m}{g}$	$\frac{kcal}{g}$	$\frac{kJ}{kg}$ (SI Units)
$\frac{Btu}{lbm}$	1	$\frac{2.326\times10^7}{980.665\times30.48}$ = 778.169 262	$\frac{2.326}{980.665\times30.48\times0.198}$ = 3.930 147 79 $\times10^{-4}$	$\frac{2.326\times10^7}{980.665\times30.48\times144}$ = 5.403 953 21	$\frac{2.326}{9.806\ 65}$ = 0.237 185 991	$\frac{2.326}{4\ 186.8}$ = 5.555 555 6 $\times10^{-4}$	2.326
$\frac{ft \times lbf}{lbm}$	$\frac{980.665\times30.48}{2.326\times10^7}$ = 0.001 285 067 46	1	$\frac{1.0}{1\ 980\ 000}$ = 5.050 505 05 $\times10^{-7}$	$\frac{1.0}{144}$ = 0.069 444 444 4	30.48 $\times10^{-5}$ = 0.000 304 8	$\frac{980.665\times30.48}{4\ 186.8\times10^7}$ = 7.139 263 69 $\times10^{-7}$	980.665 $\times$ 30.48 $\times10^{-7}$ = 0.002 989 066 920
$\frac{hp \times hr}{lbm}$	$\frac{980.665\times30.48\times0.198}{2.326}$ = 2 544.433 58	1 980 000	1	$\frac{1\ 980\ 000}{144}$ = 13 750	30.48 $\times$ 19.8 = 603.504	$\frac{980.665\times30.48}{4\ 186.8/0.198}$ = 1.413 574 21	$\frac{980.665\times30.48\times198}{1000}$ = 5 918.352 50
$\frac{lbf/in.^2}{lbm/ft^3}$	$\frac{980.665\times30.48\times144}{2.326\times10^7}$ = 0.185 049 715	144	$\frac{144}{1\ 980\ 000}$ = 7.272 727 27 $\times10^{-5}$	1	30.48 $\times$ 144 $\times10^{-5}$ = 0.043 891 2	$\frac{980.665\times30.48\times144}{4\ 186.8\times10^7}$ = 1.028 053 97 $\times10^{-4}$	$\frac{980.665\times30.48\times144}{10^7}$ = 0.430 425 636
$\frac{kp \times m}{g}$	$\frac{9.806\ 65}{2.326}$ = 4.216 100 60	$\frac{10^5}{30.48}$ = 3 280.839 90	$\frac{1.0}{30.48\times19.8}$ = 0.001 656 989 85	$\frac{10^5}{30.48\times144}$ = 22.783 610 4	1	$\frac{9.806\ 65}{4\ 186.8}$ = 0.002 342 278 11	9.806 65
$\frac{kcal}{g}$	$\frac{4\ 186.8}{2.326}$ = 1800	$\frac{4\ 186.8\times10^7}{980.665\times30.48}$ = 1 400 704.67	$\frac{4\ 186.8\times10^3}{980.665\times30.48\times198}$ = 0.707 426 602	$\frac{4\ 186.8\times10^7}{980.665\times30.48\times144}$ = 9 727.115 78	$\frac{4\ 186.8}{9.806\ 65}$ = 426.934 784	1	4 186.8
$\frac{kJ}{kg}$ (SI Units)	$\frac{1.0}{2.326}$ = 0.429 922 614	$\frac{10^7}{980.665\times30.48}$ = 334.552 563	$\frac{10^3}{980.665\times30.48\times198}$ = 1.689 659 41 $\times10^{-4}$	$\frac{10^7}{980.665\times30.48\times144}$ = 2.323 281 69	$\frac{1.0}{9.806\ 65}$ = 0.101 971 621	$\frac{1.0}{4\ 186.8}$ = 2.388 458 97 $\times10^{-4}$	1

All values given in the rational fractions are exact.

Example: $1 \frac{Btu}{lbm} = 1 \frac{Btu}{lbm} \times 778.169\ 262 \frac{ft \times lbf/lbm}{Btu/lbm} = 778.169\ 262 \frac{ft \times lbf}{lbm}$

3.05 Conversion Factors for Specific Entropy, Specific Heat and Gas Constant (Energy/Mass × Temperature)

To obtain → / Multiply, by ↓	$\frac{Btu}{lbm \times {}^\circ R}$	$\frac{ft \times lbf}{lbm \times {}^\circ R}$	$\frac{kw \times hr}{lbm \times {}^\circ R}$	$\frac{bar \times cm^3}{g \times K}$	$\frac{kcal}{g \times K}$	$\frac{kp \times m}{g \times K}$	$\frac{kJ}{kg \times K}$ (SI Units)
$\frac{Btu}{lbm \times {}^\circ R}$	1	$\frac{2.326\times10^7}{980.665\times30.48}$ = 778.169 262	$\frac{2.326\times453.592\ 37}{3\ 600\ 000}$ = 0.000 293 071 070	41.868	0.001	$\frac{4.186\ 8}{9.806\ 65}$ = 0.426 934 784	4.186 8
$\frac{ft \times lbf}{lbm \times {}^\circ R}$	$\frac{980.665\times30.48}{2.326\times10^7}$ = 0.001 285 067 46	1	$\frac{453.592\ 37\times30.48}{3.6\times10^{13}/980.665}$ = $3.766\ 160\ 97\times10^{-7}$	$\frac{30.48\times980.665\times9/5}{10^6}$ = 0.053 803 204 6	$\frac{980.665\times30.48}{2\ 326\times10^7}$ = $1.285\ 067\ 46\times10^{-6}$	$30.48\times10^{-5}\times9/5$ = 0.000 548 64	$\frac{980.665\times30.48\times1}{5/9}$ = 0.005 380 320 4
$\frac{kw \times hr}{lbm \times {}^\circ R}$	$\frac{3\ 600\ 000}{2.326\times453.592\ 37}$ = 3 412.141 63	$\frac{3.6\times10^{13}/980.665}{453.592\ 37\times30.48}$ = 2 655 223.73	1	$\frac{3.6\times10^7\times9/5}{453.592\ 37}$ = 142 859.546	$\frac{3\ 600\ 000}{2.326\times453.592\ 37}$ = 3.412 141 63	$\frac{3.6\times10^8\times9/5}{980.665\times453.592\ 37}$ = 1.456 761 95	$\frac{3.6\times10^6\times9}{453.592\ 37}$ = 14 285.954 6
$\frac{bar \times cm^3}{g \times K}$	$\frac{1.0}{41.868}$ = 0.023 884 589 7	$\frac{10^6}{30.48\times980.665\times9/5}$ = 18.586 253 5	$\frac{453.592\ 37}{3.6\times10^7\times9/5}$ = $6.999\ 882\ 25\times10^{-6}$	1	$\frac{1.0}{41\ 868}$ = $2.388\ 458\ 97\times10^{-5}$	$\frac{1.0}{98.066\ 5}$ = 0.010 197 1621	0.1
$\frac{kcal}{g \times K}$	1000	$\frac{2\ 326\times10^7}{980.665\times30.48}$ = 778 169.262	$\frac{2\ 326\times453.592\ 37}{3\ 600\ 000}$ = 0.293 071 070	41 868	1	$\frac{4\ 186.8}{9.806\ 65}$ = 426.934 784	4 186.8
$\frac{kp \times m}{g \times K}$	$\frac{9.806\ 65}{4.186\ 8}$ = 2.342 278 11	$\frac{10^5}{30.48\times9/5}$ = 1 822.688 83	$\frac{980.665\times453.592\ 37}{3.6\times10^8\times9/5}$ = 0.000 686 453 953	98.066 5	$\frac{9.806\ 65}{4\ 186.8}$ = 0.002 342 278 11	1	9.806 65
$\frac{kJ}{kg \times K}$ (SI Units)	$\frac{1.0}{4.186\ 8}$ = 0.238 845 897	$\frac{10^7\times5/9}{980.665\times30.48}$ = 185.862 535	$\frac{453.592\ 37}{3.6\times10^6\times9/5}$ = $6.999\ 882\ 25\times10^{-5}$	10	$\frac{1.0}{4\ 186.8}$ = 0.000 238 845 897	$\frac{1.0}{9.806\ 65}$ = 0.101 971 621	1

All values given in the rational fractions are exact.

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

3.06 Conversion Factors for Thermal Conductivity (Energy/Time × Length × Temperature Difference ~ Power/Length × Temperature Difference)

To obtain → / Multiply, by ↓	$\frac{Btu}{hr \times ft \times °F}$	$\frac{ft \times lbf}{hr \times ft \times °F} = \frac{lbf}{hr \times °F}$	$\frac{Watt}{ft \times °F}$	$\frac{Watt}{m \times K}$ (SI Units)	$\frac{kp^* \times m}{hr \times m \times °C} = \frac{kp^*}{hr \times °C}$	$\frac{cal}{sec \times cm \times °C}$	$\frac{kcal}{hr \times m \times °C}$
$\frac{Btu}{hr \times ft \times °F}$	1	$\frac{2.326 \times 10^7}{980.665 \times 30.48}$ = 778.169 262	$\frac{2.326 \times 453.592\,37}{3\,600}$ = 0.293 071 070	$\frac{4.186\,8 \times 453.592\,37}{3\,600 \times 0.304\,8}$ = 1.730 734 67	$\frac{4.186\,8 \times 453.592\,37}{980.665 \times 30.48 \times 10^{-4}}$ = 635.348 952	$\frac{453.592\,37}{3\,600 \times 30.48}$ = 0.004 133 788 73	$\frac{453.592\,37}{10 \times 30.48}$ = 1.488 163 94
$\frac{ft \times lbf}{hr \times ft \times °F}$	$\frac{980.665 \times 30.48}{2.326 \times 10^7}$ = 0.001 285 067 46	1	$\frac{980.665 \times 453.592\,37}{3\,600 \times 10^7/30.48}$ = 0.000 376 616 097	$\frac{980.665 \times 453.592\,37}{3\,600 \times 10^5 \times 5/9}$ = 0.002 224 110 81	$\frac{453.592\,37 \times 9/5}{1\,000}$ = 0.816 466 266 000	$\frac{980.665 \times 453.592\,37}{3\,600 \times 2.326 \times 10^7}$ = $5.312\,197\,40 \times 10^{-6}$	$\frac{980.665 \times 453.592\,37}{2.326 \times 10^8}$ = 0.001 912 391 06
$\frac{Watt}{ft \times °F}$	$\frac{3\,600}{2.326 \times 453.592\,37}$ = 3.412 141 63	$\frac{3\,600 \times 10^7/30.48}{980.665 \times 453.592\,37}$ = 2 655.223 74	1	$\frac{9/5}{0.304\,8}$ = 5.905 511 81	$\frac{3\,600 \times 10^4 \times 9/5}{980.665 \times 30.48}$ = 2 167.900 61	$\frac{1.0}{30.48 \times 2.326}$ = 0.014 105 072 6	$\frac{360}{30.48 \times 2.326}$ = 5.077 826 15
$\frac{Watt}{m \times K}$ (SI Units)	$\frac{3\,600 \times 0.304\,8}{4.186\,8 \times 453.592\,37}$ = 0.577 789 316	$\frac{3\,600 \times 10^5 \times 5/9}{980.665 \times 453.592\,37}$ = 449.617 886	$0.304\,8 \times 5/9$ = 0.169 333 333	1	$\frac{3\,600 \times 100}{980.665}$ = 367.097 837	$\frac{1.0}{418.68}$ = 0.002 388 458 97	$\frac{360}{418.68}$ = 0.859 845 228
$\frac{kp^* \times m}{hr \times m \times °C}$	$\frac{980.665 \times 30.48 \times 10^{-4}}{4.186\,8 \times 453.592\,37}$ = 0.001 573 938 22	$\frac{10^3 \times 5/9}{453.592\,37}$ = 1.22479 035	$\frac{980.665 \times 30.48 \times 5/9}{3\,600 \times 10^4}$ = 0.000 461 275 759	$\frac{980.665}{3\,600 \times 100}$ = 0.002 724 069 44	1	$\frac{980.665}{3\,600 \times 4.186\,8 \times 10^4}$ = $6.506\,328\,09 \times 10^{-6}$	$\frac{980.665}{4.186\,8 \times 10^5}$ = 0.002 342 278 11
$\frac{cal}{sec \times cm \times °C}$	$\frac{3\,600 \times 30.48}{453.592\,37}$ = 241.908 831	$\frac{3\,600 \times 2.326 \times 10^7}{980.665 \times 453.592\,37}$ = 188 246.017	2.326×30.48 = 70.896 48	418.68	$\frac{3\,600 \times 4.186\,8 \times 10^4}{980.665}$ = 153 696.522	1	360
$\frac{kcal}{hr \times m \times °C}$	$\frac{10 \times 30.48}{453.592\,37}$ = 0.671 968 975	$\frac{2.326 \times 10^8}{980.665 \times 453.592\,37}$ = 522.905 602	$\frac{2.326 \times 30.48}{360}$ = 0.196 934 667	$\frac{418.68}{360}$ = 1.163	$\frac{4.186\,8 \times 10^5}{980.665}$ = 426.934 784	$\frac{1.0}{360}$ = 0.002 777 777 78	1

All values given in the rational fractions are exact and are taken from Appendix 4 of the 1967 ASME Steam Tables.

Example:

$$1 \frac{Watt}{ft \times °F} = 1 \frac{w}{ft \times °F} \times 3.412\,141\,632 \frac{Btu/(hr \times ft \times °F)}{w/(ft \times °F)} = 3.412\,141\,632 \frac{Btu}{hr \times ft \times °F}$$

*kp = kilopond, lbf = 0.453 592 37 kp

3.07 Conversion Factors for Viscosity (Force × Time/Area) or (Mass/Length × Time)

To obtain → / Multiply, by ↓	$\frac{\text{lbf} \times \text{sec}}{\text{ft}^2}$	$\frac{\text{lbm}}{\text{ft} \times \text{sec}}$	$\frac{\text{lbm}}{\text{hr} \times \text{ft}}$	$\frac{\text{lbf} \times \text{hr}}{\text{ft}^2}$	$\frac{\text{g}}{\text{cm} \times \text{sec}}$ (poise)	$\frac{\text{kg}}{\text{m} \times \text{s}}$ (SI Units)
$\frac{\text{lbf} \times \text{sec}}{\text{ft}^2}$	1	$\frac{980.665}{30.48}$ = 32.174 048 6	$\frac{980.665 \times 3\,600}{30.48}$ = 115 826.575	$\frac{1.0}{3\,600}$ = 0.000 277 777 778	$\frac{980.665 \times 453.592\,37}{30.48^2}$ = 478.802 590	$\frac{980.665 \times 453.592\,37}{10 \times 30.48^2}$ = 47.880 259 0
$\frac{\text{lbm}}{\text{ft} \times \text{sec}}$	$\frac{30.48}{980.665}$ = 0.031 080 950 2	1	3 600	$\frac{30.48}{980.665 \times 3\,600}$ = $8.633\,597\,27 \times 10^{-6}$	$\frac{453.592\,37}{30.48}$ = 14.881 639 4	$\frac{453.592\,37}{304.8}$ = 1.488 163 94
$\frac{\text{lbm}}{\text{hr} \times \text{ft}}$	$\frac{30.48}{980.665 \times 3\,600}$ = $8.633\,597\,27 \times 10^{-8}$	$\frac{1.0}{3\,600}$ = 0.000 277 777 778	1	$\frac{30.48}{980.665 \times 3\,600^2}$ = $2.398\,221\,46 \times 10^{-9}$	$\frac{453.592\,37}{30.48 \times 3\,600}$ = 0.004 133 788 73	$\frac{453.592\,37}{304.8 \times 3\,600}$ = 0.000 413 378 873
$\frac{\text{lbf} \times \text{hr}}{\text{ft}^2}$	3 600	$\frac{980.665 \times 3\,600}{30.48}$ = 115 826.575	$\frac{980.665 \times 3\,600^2}{30.48}$ = 416 975 669	1	$\frac{980.665 \times 453.592\,37}{30.48^2/3\,600}$ = 1 723 689.32	$\frac{980.665 \times 453.592\,37}{30.48^2 \times 10/3\,600}$ = 172 368.932
$\frac{\text{g}}{\text{cm} \times \text{sec}}$ (poise)	$\frac{30.48^2}{980.665 \times 453.592\,37}$ = 0.002 088 543 42	$\frac{30.48}{453.592\,37}$ = 0.067 196 897 5	$\frac{3\,600 \times 30.48}{453.592\,37}$ = 241.908 831	$\frac{30.48^2/3\,600}{980.665 \times 453.592\,37}$ = $5.801\,509\,51 \times 10^{-7}$	1	0.1
$\frac{\text{kg}}{\text{m} \times \text{s}}$ (SI Units)	$\frac{10 \times 30.48^2}{980.665 \times 453.592\,37}$ = 0.020 885 434 2	$\frac{304.8}{453.592\,37}$ = 0.671 968 975	$\frac{10 \times 3\,600 \times 30.48}{453.592\,37}$ = 2 419.088 31	$\frac{10 \times 30.48^2/3\,600}{980.665 \times 453.592\,37}$ = $5.801\,509\,51 \times 10^{-6}$	10	1

All values given in the rational fractions are exact and are taken from Appendix 4 of the 1967 ASME Steam Tables.
Example: 1 lbf × sec/ft^2 = 32.174 048 6 lbm/(ft × sec).
From definitions: 1 poise = 1 P = 1 g/cm × sec = 1 dyne × sec/cm^2 = 0.1 kg/m × sec = 0.1 Newton × sec/m^2 = 0.1 Pascal × sec = 0.1 Pa × sec.

3.08 Conversion Factors for Kinematic Viscosity (Area/Time)

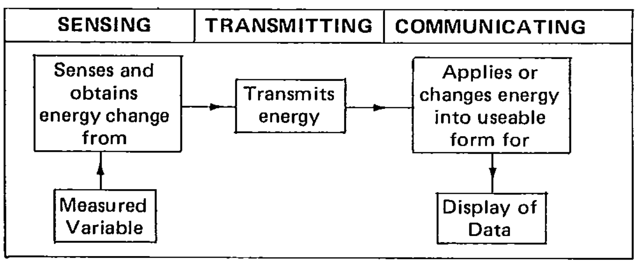
To obtain → / Multiply, by ↓	$\frac{ft^2}{sec}$	$\frac{ft^2}{hr}$	$\frac{cm^2}{sec}$ (stoke)	$\frac{cm^2}{hr}$	$\frac{m^2}{s}$ (SI Units)
$\frac{ft^2}{sec}$	1	3 600	$(30.48)^2$ = 929.030 4	$(30.48)^2 \times 3\,600$ = 3 344 509.440 000	$(0.304\,8)^2$ = 0.092 903 04
$\frac{ft^2}{hr}$	$\frac{1.0}{3\,600}$ = $2.777\,777\,78 \times 10^{-4}$	1	$\frac{(30.48)^2}{3\,600}$ = 0.258 064	$(30.48)^2$ = 929.030 4	$\frac{(0.304\,8)^2}{3\,600}$ = $2.580\,64 \times 10^{-5}$
$\frac{cm^2}{sec}$	$\frac{1.0}{(30.48)^2}$ = 0.001 076 391 04	$\frac{3\,600}{(30.48)^2}$ = 3.875 007 75	1	3 600	$\frac{1.0}{(100)^2}$ = 0.0001
$\frac{cm^2}{hr}$	$\frac{1.0}{(30.48)^2 \times 3\,600}$ = $2.989\,975\,12 \times 10^{-7}$	$\frac{1.0}{(30.48)^2}$ = 0.001 076 391 04	$\frac{1.0}{3\,600}$ = 0.000 277 777 778	1	$\frac{1.0}{(100)^2 \times 3\,600}$ = $2.777\,778 \times 10^{-8}$
$\frac{m^2}{s}$ (SI Units)	$\frac{1.0}{(0.304\,8)^2}$ = 10.763 910 4	$\frac{3\,600}{(0.3048)^2}$ = 38 749.69	$(100)^2$ = 10 000	$(100)^2 \times 3\,600$ = 36 000 000	1

All values given in the rational fractions are exact and are taken from Appendix 4 of the 1967 ASME Steam Tables.
Example: 1 ft^2/sec = 3600 ft^2/hr.

SECTION 4 — MEASUREMENT OF PERFORMANCE

4.01 Introduction. 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. A millivoltmeter, for example, can measure voltage but a thermocouple must be used in conjunction with the voltmeter to obtain a temperature measurement.

4.02 Measurement System. In order to make a measurement of a physical variable it must first be sensed, 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 below:



The primary element is that part of the measurement system that first senses the variable to be measured. The energy change produced by the sensing must be transmitted to a 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 above three functions must be performed in order to measure a physical variable. 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 flow measurement with orifices where the primary element (the orifice) causes fluid acceleration to produce a pressure differential which is transmitted via tubing to a manometer where the data are displayed on the scale.

4.03 Accuracy of Measuring Systems. Measurement of a physical quantity never gives a result which is correct in an absolute sense. The numerical value determined always differs by some amount from the real value being measured, and the extent of the deviation depends upon the type of measurement system used. This fact imposes upon code writers and test engineers the duty of studying measurement systems to such an extent that they can show in a given case that the system used will provide results which are within the confidence interval necessary to accomplish the purposes of the test.

The accuracy obtainable for a given measurement is dependent upon three things:

(a) The measurement system used.
(b) The characteristics of the variable being measured.
(c) The accuracy of observation.

The first of these (a) breaks down into two radically different considerations, both of which are of equal importance:

(a) The *intrinsic accuracy* of the measurement system.
(b) The *accuracy* resulting from *conditions of use.*

The former is generally well treated by most engineers and data concerning measurement system components is given in the Instruments and Apparatus Supplements. The latter is the least understood and most neglected, and may be responsible for gross errors of measurements. The primary reason for the neglect of use-accuracy is that an individual analysis is necessary for each application and installation.

4.04 Intrinsic Accuracy. The intrinsic or inherent accuracy of a measurement system depends upon the following factors:

(a) Materials.
(b) Construction.
(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 measuring system components must be calibrated before and after Performance Test Code tests to establish the effect of physical condition on their inherent accuracy.

4.05 Use Accuracy. 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.
(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 to prevent their normal operation. If care is taken to ensure proper environmental conditions then the communication function accuracy reduces to the intrinsic accuracy of the components used.

4.06 Observation Accuracy. Accuracy of observation depends primarily upon two factors as follows:

(a) Accidental mistakes—due to misreading of scales, incorrect log entries, failure to perform some manipulation required, etc.

(b) Personal characteristics—ability to interpolate between graduations, bias in observation (tendency to read high or low), speed of observation.

These types of error may be minimized but never completely eliminated by careful choice of and training of test personnel and by selection of scales with easily read graduations and other human engineering considerations. 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 and use accuracy permits.

4.07 Sensing Accuracy. The accuracy of sensing depends upon the following factors:

(a) **Installation of the primary element**

(1) *Effect of the Primary Element on the Measured Variable*

For example, consider a pitot tube installed in a flow stream to sense a local velocity. Care must be taken in the design of the pitot tube that its presence does not change the original velocity profile.

(2) *Mutual Effects of Primary Element and the Measured Variable*

For example, when the temperature of a fluid flowing in a pipe under pressure is to be measured, it is usually necessary to encase the primary element in a protection tube or wall. The following temperatures must then be considered:

(i) The fluid temperature.
(ii) Well outer wall temperature.
(iii) Well inner wall temperature.
(iv) Primary element temperature.

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

(i) The physical properties of the fluid and materials used in the construction of the well and primary element.

(ii) The net heat-transfer by radiation, conduction, and convection from the well to the fluid, and to the pipe wall, and to the primary element.

(iii) Fluid Velocity—For compressible fluids the difference between static and stagnation temperatures may be appreciable above 300 ft/sec (90 m/s).

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

(3) *Improper Installation*

For example, consider a pitot tube designed and constructed in such a manner as not to cause minimum disturbance of the velocity profile but installed at an angle to the velocity. Such a tube senses only a part of the velocity.

(4) *Location of Primary Element*

Care must be taken not to locate primary elements too close to flow disturbing fittings such as bends, elbows, valves, etc. For example, the velocity profiles of fluids downstream of such fittings are distorted and the coefficients of orifices, nozzles and Venturis will be significantly different from those preceded by long lengths of straight pipe, thus giving rise to serious flow measurement errors.

(b) *Sampling.* In many cases of composition analysis, either physical such as the moisture content of steam, or chemical such as the carbon dioxide content of boiler flue gas, the variable to be measured is not evenly distributed in the mixture. In such cases, it is important that a representative sample be taken. The distribution must be investigated and properly designed probes installed in sufficient numbers and at representative locations to minimize errors from this source.

(c) *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 presence or absence from the mixture of predetermined amounts 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, then error will result.

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

SECTION 5 — LETTER SYMBOLS

5.01 Introduction. In order to render the terminology of the ASME Performance Test Code consistent, certain letter symbols in general use have been adopted. These letter symbols, from the American National Standards Institute, are published by the ASME who is the sponsor of this work. ANSI originally was called American Standards Association (ASA) and many of the symbols have the ASA designation. On August 24, 1966, the American Standards Association was reconstituted as the United States of America Standards Institute (USASI). In October of 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.

5.02 Preferred Letter Symbols. The preferred letter symbols for Performance Test Code work are those for heat and thermodynamics Y10.4 (see Par. 5.03). However, when additional letter symbols are needed, the use of the following ANSI Standards is approved:

Hydraulics	Y10.2
Rocket Propulsion	Y10.14
Mechanics of Solids	Y10.3
Structural Analysis	Y10.8
Aeronautical Sciences	Y10.7
Meteorology	Y10.10
Acoustics	Y10.11
Chemical Engineering	Y10.12
Petroleum Reservoir Engineering and Electric Logging	Y10.15
Shell Theory	Y10.16
Guide for Selecting Greek Letters Used as Letter Symbols for Engineering Mathematics	Y10.17
Illuminating Engineering	Y10.18
Letter Symbols for Units Used in Science and Technology	Y10.19
Glossary of Terms Concerning Letter Symbols	Y10.1

5.03 Letter Symbols for Heat and Thermodynamics*

(a) **General principles of letter symbol standardization**

(1) *Letter Symbols.* A letter symbol for a physical quantity is a single letter, specified as to general form of type. It is available for use within a mathematical expression. This primary symbol may be modified 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 and of special values assigned.

Usually, one may readily distinguish between letter symbols for physical quantities and other published symbols and signs. The latter, while more or less analogous, belong largely to topics not treated here, such as:

Mathematical signs
Chemical symbols
Punctuation
Proofreading signs
Abbreviations (widely used in tabulations)

(2) *Four General Requirements for Published Symbols and Signs.* As is generally recognized, each published symbol or sign, of whatever kind, should be at least

(i) 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 he uses and their respective interpretations, or else refer to a standard list as source for symbols which he is using but does not explain. For work in a specialized or developing field, the author may need symbols in addition to those already contained in standard lists. In such a case, he should be careful to select simple suggestive symbols which yet avoid conflict in the given field and in other closely related special fields. Except in this situation, he should not introduce new symbols or depart from currently accepted notation.

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*From ANSI Standard Y10.4, 1957.

(ii) Clear in reference. One should not assign to a given symbol different meanings in such a manner as to make its interpretation in a given context ambiguous. Conflicts 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 have its meaning defined in the text. The units should be indicated whenever necessary.

(iii) Easily identified. Because of the many numerals, letters, and signs which are similar in appearance, a writer should be careful in calling for 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.

(iv) Economical in publication. One should try to keep at a minimum the cost of publishing symbols. In particular:

- Notations which call for handsetting of movable type should be rejected in favor of forms adapted to modern mechanical methods of composition.
- No one work should use a great variety of types and special characters.
- Handwriting of inserted symbols, in copy largely typewritten and to be reproduced in facsimile, should not be excessive.
- Often a complicated expression appears as component part of a complex mathematical formula, for example, as an exponent of a given base. Instead, one may introduce, locally, a single letter to stand for such a complicated component. An explanatory definition should then appear in the immediate context.

(3) *Secondary Symbols.* Subscripts and superscripts are widely used and for a variety of conventional purposes. For example, a subscript may indicate:

(i) The place of a term in a sequence or matrix.
(ii) A designated state, point, part, or time, or system of units.
(iii) The constancy of one independent physical quantity, among others, on which a given quantity depends for its value.
(iv) A variable with respect to which the given quantity is a derivative.

Likewise, for example, a superscript may indicate:
(i) The exponent for a power.
(ii) A distinguishing label.
(iii) A unit.
(iv) A tensor index.

The intended sense must be clear in each case.

Several subscripts or superscripts, sometimes separated by commas, may be attached to a single letter. A symbol with a superscript, such as a prime (′) or second (″), or a tensor index should be enclosed in parentheses, braces, or brackets before an exponent is attached. So far as logical clarity permits, one should avoid attaching subscripts and superscripts to subscripts and superscripts. Abbreviations, themselves standardized, may appear among subscripts. A conventional sign, or abbreviation, indicating the adopted unit may be attached to a letter symbol or corresponding numeral. Reference marks, such as numbers in distinctive type, may be attached to words and abbreviations but not to letter symbols.

(4) *Typography.* Letter symbols for physical quantities, and their subscripts and superscripts (whether upper case, lower case, or small capitals), when appearing as lightface letters of the English alphabet, are printed in italic (sloping) type. Arabic numerals, and letters of other alphabets, used in mathematical expressions are normally printed in vertical type. When a special alphabet is required, boldface type is to be preferred to German, Gothic, or script type. In material to be reproduced in facsimile from copy largely typewritten, letters which would be boldface in print may be indicated to be such by special underscoring, while the few distinct letters used from other alphabets, if carefully made, should be self-explanatory. It is important to select a type face which has italic forms and clearly distinguished upper case, lower case, and small capitals. Only type faces with serifs are recommended.

(b) **Special principles of letter symbol standardization**

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

(2) 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.

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

(4) 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.

(5) Components as occurring in mixtures of chemical 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 i'th component would be μ_i, or the enthalpy of carbon dioxide, $H(CO_2)$. Thermodynamic properties so designated are to be under-

stood, in relation to mixtures, as either partial molar or partial specific quantities.

(6) Extensive thermodynamic properties are designated by italic capitals. Specific properties (per unit mass) are designated by the corresponding lower-case 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, according to Principle (5).

(7) 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.

(8) Dimensionless groups are designated by a single letter symbol or by the symbol, N, with suitable subscripts. The use of two-letter symbols, while indicated as accepted usage in certain well-established cases, is to be discouraged. See General Principle (1).

(9) Subscripts and superscripts other than those specified in the preceding principles or those occurring as part of listed symbols are not part of the Standard. However, in general, subscripts should either be selected from the standard symbols or be essentially an abbreviation.

(10) Certain symbols, enclosed by parentheses, have been included in the list for information. These are not a part of the Standard but do represent generally accepted usage. In each case, an alternate standard is indicated.

(c) Alphabetical listing by concepts

Concept	Symbols
Absolute temperature	T
Absolute viscosity	η,μ
Absorptance	α
Absorptivity	α
Acceleration	a
Acoustic velocity	a
Activity	a
Activity coefficient, stoichiometric	γ
Affinity	A
Angular velocity, radians per unit time	ω
Angular velocity, revolutions per unit time	n
Arc length	s
Area	A, S
Avogadro's number	N_o
Boltzmann's constant	k
Chemical equilibrium constant	K
Chemical potential	μ
Compressibility coefficient	$(k), \kappa$

Concept	Symbols
Compressibility factor	Z
Concentration, mass	c
Concentration, mole	C
Degree of reaction	α
Density	ρ
Diameter	d, D
Diffusivity, mass	D
Diffusivity, thermal	α
Dimensionless number	N
Dynamic viscosity	η,μ
Efficiency	η
Emissivity	ϵ
Emittance	ϵ
Energy	E
Enthalpy	H
Enthalpy, specific	h
Entropy	S
Entropy, specific	s
Entropy production rate	σ
Equilibrium constant, chemical	K
Extent of chemical reaction	ξ
Force	F
Free energy, Gibbs function	F, G
Free energy, Helmholtz function	A
Friction factor	f
Fugacity	f
Gas constant	R
Gibbs function	F, G
Gibbs function, molar	μ
Gibbs function, specific	g
Gravitational acceleration	g
Heat	Q
Heat capacity, constant pressure	C_p
Heat capacity, constant volume	C_v
Heat capacity, general	C
Heat capacity ratio	y, k
Heat rate	q, Q
Heat transfer coefficient, overall	U
Heat transfer coefficient, surface	h
Heat transfer factor	j
Helmholtz function	A
Helmholtz function, specific	a
Inertia proportionality factor	g_c
Internal energy	U
Internal energy, specific	u
Irradiance	H
Joule-Thomson coefficient	μ
Kinematic viscosity	ν
Latent heat	ΔH
Latent heat, specific	Δh

Concept	Symbols
Length	l, L
Light, velocity	c
Linear thermal expansion coefficient	α
Mach number	M
Mass	m
Mass concentration	c
Mass current density	G
Mass diffusion coefficient	D
Mass diffusivity	D
Mass flow rate	w, m
Mass fraction	w
Mass velocity	G
Mechanical equivalent of heat	J
Molality	m
Molar mass	M
Mole concentration	C
Mole fraction	x
Mole fraction, gas phase	y
Mole quantity	n
Molecular weight	M
Normal angle	θ
Number of molecules	N
Number of moles	n
Nusselt number	(Nu)
Overall heat transfer coefficient	U
Path length	s
Planck constant	h
Polytropic exponent	n
Power	P, W
Prandtl number	$(Pr), \sigma$
Pressure	p
Quality	x
Radiance	N
Radiant energy	U
Radiant flux	Φ
Radiant flux density	W
Radiant intensity	J
Radiation frequency	ν
Radiation wavelength	λ
Radius	r
Reflectance	ρ
Reflectivity	ρ
Reynolds number	$R, (Re)$
Second virial coefficient	B

Concept	Symbols
Solid angle	ω, Ω
Sound velocity	a
Specific enthalpy	h
Specific entropy	σ
Specific Gibbs function	g
Specific heat capacity, constant pressure	c_p
Specific heat capacity, constant volume	c_v
Specific heat capacity, general	c
Specific Helmholtz function	a
Specific internal energy	u
Specific latent heat	Δh
Specific volume	v
Stefan-Boltzmann constant	σ
Stoichiometric number of molecules in a chemical reaction	ν
Surface heat transfer coefficient	h
Surface tension	y, σ
Temperature	t, θ
Temperature, absolute or thermodynamic	T
Thermal conductivity	k, λ
Thermal diffusion coefficient	D_T
Thermal diffusion ratio	k_T
Thermal diffusivity	α
Thermal expansion coefficient, linear	α
Thermal expansion coefficient, volumetric	β
Thermal resistance	R
Thermodynamic temperature	T
Time	t, r
Transmissivity	r
Transmittance	r
Turbulence exchange coefficient	ϵ
Velocity	v, V
Velocity of light	c
Velocity of sound	a
Virial coefficient, second	B
Viscosity, dynamic (absolute)	η, μ
Viscosity, kinematic	ν
Viscosity, volume	κ
Volume	V
Volume flow rate	Q, V
Volumetric thermal expansion coefficient	β
Weight	W
Work	W

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PTC 6A	— Appendix A to Test Code for Steam Turbines	(1964)
PTC 6 Report	— Guidance for Evaluation of Measurement Uncertainty in Performance Tests of Steam Turbines	(1969)
PTC 6S Report	— Simplified Procedures for Routine Performance Tests of Steam Turbines	(1970)
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