Glossary

to accompany
Thermodynamics: An Engineering Approach, 8th edition
by Yunus A. Çengel and Michael A. Boles

Absolute entropy is entropy calculated relative to the absolute reference point determined by the third law of thermodynamics.

Absolute humidity (specific humidity or humidity ratio) is the mass of water vapor present in a unit mass of dry air; that is, it is the ratio of the mass of water vapor to the mass of dry air in atmospheric air.

Absolute pressure is the actual pressure at a given position and it is measured relative to absolute vacuum (i.e., absolute zero pressure). Throughout this text, the pressure *P* will denote absolute pressure unless specified otherwise.

Absolute temperatures are temperatures measured on the Kelvin scale or Rankine scale, and these temperatures vary between zero and infinity.

Absorption chillers are air-conditioning systems based on absorption refrigeration, and they perform best when the heat source can supply heat at a high temperature with little temperature drop.

Absorption refrigeration systems involve the absorption of a refrigerant by a transport medium. The most widely used absorption refrigeration system is the ammonia–water system, where ammonia (NH_3) serves as the refrigerant and water (H_2O) as the transport medium. Absorption refrigeration systems are economically attractive when there is a source of inexpensive heat energy at a temperature of 100 to 200°C. Some examples of inexpensive heat energy sources include geothermal energy, solar energy, and waste heat from cogeneration or process steam plants, and even natural gas when it is available at a relatively low price.

Absorptivity is the fraction of the radiation energy incident on a surface that is absorbed by the surface.

Acid rain is defined as rain or snow that washes acid-laden droplets from the air on to the soil.

Adiabatic combustion temperature (see adiabatic flame temperature)

Adiabatic flame temperature is the maximum temperature the products of combustion will reach in the limiting case of no heat loss to the surroundings during the combustion process. The adiabatic flame temperature attains its maximum value when complete combustion occurs with the theoretical amount of air.

Adiabatic process is a process during which there is no heat transfer. The word adiabatic comes from the Greek word *adiabatos*, which means not to be passed.

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Adiabatic saturation process is the process in which a steady stream of unsaturated air of unknown specific humidity is passed through a long insulated channel that contains a pool of water. As the air flows over the water, some water will evaporate and mix with the airstream. The moisture content of air will increase during this process, and its temperature will decrease, since part of the latent heat of vaporization of the water that evaporates will come from the air. If the channel is long enough, the airstream will exit as saturated air (100 percent relative humidity) at the exit temperature.

Adiabatic saturation temperature is the exit temperature that air attains in the adiabatic saturation process.

Afterburner is a section added between the turbine and the nozzle of an aircraft turbine engine where additional fuel is injected into the oxygen-rich combustion gases leaving the turbine. As a result of this added energy, the exhaust gases leave at a higher velocity, providing extra thrust for short takeoffs or combat conditions.

Air conditioners are refrigerators whose refrigerated space is a room or a building instead of the food compartment.

Air–fuel ratio AF is a frequently used quantity in the analysis of combustion processes to quantify the amounts of fuel and air. It is usually expressed on a mass basis and is defined as the ratio of the mass of air to the mass of fuel for a combustion process.

Air-source heat pumps use the cold outside air as the heat source in winter.

Air-standard assumptions reduce the analysis of gas power cycles to a manageable level by utilizing the following approximations:

1. The working fluid is air, which continuously circulates in a closed loop and always behaves as an ideal gas.
2. All the processes that make up the cycle are internally reversible.
3. The combustion process is replaced by a heat-addition process from an external source.
4. The exhaust process is replaced by a heat rejection process that restores the working fluid to its initial state.

Air-standard cycle is a cycle for which the air-standard assumptions are applicable.

Amagat's law of additive volumes states that the volume of a gas mixture is equal to the sum of the volumes each gas would occupy if it existed alone at the mixture temperature and pressure.

Annual fuel utilization efficiency AFUE is the efficiency of space heating systems of residential and commercial buildings which accounts for the combustion efficiency as

well as other losses such as heat losses to unheated areas and start-up and cool-down losses.

Apparent gas constant of a mixture is the universal gas constant divided by the apparent molar mass of the mixture.

Apparent molar mass of a mixture can be expressed as the sum of the products of the mole fraction and molar mass of each component in the mixture.

Atmospheric air is the air in the atmosphere, which normally contains some water vapor (or moisture).

Autoignition is the premature ignition of the fuel that produces an audible noise, which is called engine knock.

Average gas constant (see apparent gas constant)

Average molar mass (see apparent molar mass)

Average velocity is the average value of the normal velocity across an entire flow cross section and if the velocity were the average velocity all through the cross section, the mass flow rate would be identical to that obtained by integrating the actual velocity profile.

Back pressure is the pressure applied at the nozzle discharge region.

Back work ratio is the ratio of the compressor work to the turbine work in gas-turbine power plants.

Bar is the unit of pressure equal to 10^5 pascal.

Barometer is a device that measures the atmospheric pressure**;** thus, the atmospheric pressure is often referred to as the barometric pressure.

Beattie-Bridgeman equation of state is one of the best known and is a reasonably accurate equation of state. It is given by

$$P = \frac{R_u T}{\overline{v}^2}\left(1 - \frac{c}{\overline{v} T^3}\right)(\overline{v} + B) - \frac{A}{\overline{v}^2}$$

where the constants for various substances are found in Table 2-4.

Benedict-Webb-Rubin equation of state is one of the more recent and very accurate equations of state. It is given by

$$P = \frac{R_u T}{\bar{v}} + \left(B_o R_u T - A_o - \frac{C_o}{T^2} \right) \frac{1}{\bar{v}^2} + \frac{bR_u T - a}{\bar{v}^3} + \frac{a\alpha}{\bar{v}^6} + \frac{c}{\bar{v}^3 T^2} \left(1 + \frac{\gamma}{\bar{v}^2} \right) e^{-\gamma/\bar{v}^2}$$

where the constants for various substances are given in Table 2-4.

Bernoulli equation is the result of the energy analysis for the reversible, steady-flow of an incompressible liquid through a device that involves no work interactions (such as a nozzle or a pipe section). For frictionless flow, it states that the sum of the pressure, velocity, and potential energy heads is constant. It is also a form of the conservation of momentum principle for steady-flow control volumes.

Binary vapor cycle is a vapor cycle in which the condenser of the high-temperature cycle (also called the topping cycle) serves as the boiler of the low-temperature cycle (also called the bottoming cycle). That is, the heat output of the high-temperature cycle is used as the heat input to the low-temperature one.

Blackbody is an idealized surface that emits radiation at the maximum rate given by the Stefan-Boltzmann law.

Blackbody radiation is amount of radiation emitted by a blackbody.

Boiler is basically a large heat exchanger where the heat originating from combustion gases, nuclear reactors, or other sources is transferred to the water essentially at constant pressure.

Boiling is the phase change process that occurs at the solid–liquid interface when a liquid is brought into contact with a surface maintained at a temperature sufficiently above the saturation temperature of the liquid.

Boltzmann relation is the expression of the entropy as a function of thermodynamic probability.

Boltzmann's constant, k has the value of 1.3806×10^{23} J/K.

Bore is the diameter of a piston.

Bottom dead center BDC is the position of the piston when it forms the largest volume in the cylinder.

Bottoming cycle is a power cycle operating at lower average temperatures that receives heat from a power cycle operating at higher average temperatures.

Boundary is the real or imaginary surface that separates the system from its surroundings. The boundary of a system can be *fixed* or *movable*.

Boundary work (*Pd*V work) is the work associated with the expansion or compression of a gas in a piston-cylinder device. Boundary work is the area under the process curve on a P-V diagram equal, in magnitude, to the work done during a quasi-equilibrium expansion or compression process of a closed system.

Bourdon tube, named after the French inventor Eugene Bourdon, is a type of commonly used mechanical pressure measurement device which consists of a hollow metal tube bent like a hook whose end is closed and connected to a dial indicator needle.

Bow wave (see detached oblique shock)

Brayton cycle was first proposed by George Brayton around 1870. It is used for gas turbines, which operate on an open cycle, where both the compression and expansion processes take place in rotating machinery. The open gas-turbine cycle can be modeled as a closed cycle by utilizing the air-standard assumptions. The combustion process is replaced by a constant-pressure heat-addition process from an external source, and the exhaust process is replaced by a constant-pressure heat-rejection process to the ambient air. The ideal Brayton cycle is made up of four internally reversible processes:

1-2 Isentropic compression (in a compressor),
2-3 Constant pressure heat addition,
3-4 Isentropic expansion (in a turbine),
4-1 Constant pressure heat rejection.

Brayton cycle with regeneration is the Brayton cycle modified with a regenerator (a counterflow heat exchanger) to allow the transfer of heat to the high pressure air leaving the compressor from the high-temperature exhaust gas leaving the turbine.

British thermal unit BTU is the energy unit in the English system needed to raise the temperature of 1 lbm of water at 68 °F by 1°F.

Caloric is heat treated as a fluidlike substance, according to the caloric theory, that is a massless, colorless, odorless, and tasteless substance that can be poured from one body into another.

Calorie (cal) is the amount of energy in the metric system needed to raise the temperature of 1 g of water at 15 °C by 1°C.

Carnot cycle was first proposed in 1824 by French engineer Sadi Carnot. It is composed of four reversible processes—two isothermal and two adiabatic, and can be executed either in a closed or a steady-flow system.

Carnot efficiency is the highest efficiency a heat engine can have when operating between the two thermal energy reservoirs at temperatures T_L and T_H; $\eta_{th, rev} = 1 - T_L / T_H$.

Carnot heat engine is the theoretical heat engine that operates on the Carnot cycle.

Carnot heat pump is a heat pump that operates on the reversed Carnot cycle. When operating between the two thermal energy reservoirs at temperatures T_L and T_H, the Carnot heat pump can have a coefficient of performance of $COP_{HP, rev} = 1/ (1- T_L / T_H) = T_H /(T_H - T_L)$.

Carnot principles are two conclusions that pertain to the thermal efficiency of reversible and irreversible (i.e., actual) heat engines and are expressed as follows:

1. The efficiency of an irreversible heat engine is always less than the efficiency of a reversible one operating between the same two reservoirs.

2. The efficiencies of all reversible heat engines operating between the same two reservoirs are the same.

Carnot refrigerator is a refrigerator that operates on the reversed Carnot cycle. When operating between the two thermal energy reservoirs at temperatures T_L and T_H the Carnot refrigerator can have a coefficient of performance of $COP_{R, rev} = 1/ (T_H / T_L - 1) = T_L /(T_H - T_L)$.

Cascade refrigeration cycles perform the refrigeration process in stages, that is, to have two or more refrigeration cycles that operate in series.

Celsius scale (formerly called the *centigrade scale;* in 1948 it was renamed after the Swedish astronomer A. Celsius, 1701–1744, who devised it) is the temperature scale used in the SI system. On the Celsius scale, the ice and steam points are assigned the values of 0 and 100 °C, respectively.

Chemical energy is the internal energy associated with the atomic bonds in a molecule**.**

Chemical equilibrium is established in a system when its chemical composition does not change with time.

Chemical equilibrium reactions are chemical reactions in which the reactants are depleted at exactly the same rate as they are replenished from the products by the reverse reaction. At equilibrium the reaction proceeds in both directions at the same rate.

Chemical potential is the change in the Gibbs function of the mixture in a specified phase when a unit amount of a given component of the mixture in the same phase is added as pressure and temperature and the amounts of all other components are held

constant. The chemical potential of a component of an ideal gas mixture depends on the mole fraction of the components as well as the mixture temperature and pressure, and is independent of the identity of the other constituent gases.

Chemically correct amount of air is the stoichiometric or theoretical air, or 100 percent theoretical air.

Choked flow occurs in a nozzle when the mass flow reaches a maximum value for the minimum flow area. This happens when the flow properties are those required to increase the fluid velocity to the velocity of sound at the minimum flow area location.

Choked Rayleigh flow occurs in a duct when a fluid can no longer be accelerated by heating above sonic velocity to supersonic velocities.

Clapeyron equation, named after the French engineer and physicist E. Clapeyron (1799–1864), relates the enthalpy change associated with a phase change (such as the enthalpy of vaporization h_{fg}) from knowledge of P, v, and T data alone.

Clapeyron–Clausius equation is used to determine the variation of saturation pressure with temperature.

Classical thermodynamics is the macroscopic approach to the study of thermodynamics that does not require knowledge of the behavior of individual particles.

Clausius inequality, first stated by the German physicist R. J. E. Clausius (1822–1888), is expressed as the cyclic integral of $\delta Q/T$ is always less than or equal to zero. This inequality is valid for all cycles, reversible or irreversible.

Clausius statement of the second law is expressed as follows: It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body.

Clearance volume is the minimum volume formed in the cylinder when the piston is at top dead center.

Closed feedwater heater is a feedwater heater in which heat is transferred from the extracted steam to the feedwater without any mixing taking place. The two streams are typically not at the same pressures, since they do not mix. In an ideal closed feedwater heater the feedwater is heated to the exit temperature of the extracted steam, which ideally leaves the heater as a saturated liquid at the extraction pressure. In actual power plants the feedwater leaves the heater below the exit temperature of the extracted steam because a temperature difference of at least a few degrees is required for any effective heat transfer to take place.

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Closed system consists of a fixed amount of mass (control mass), and no mass can cross its boundary. But energy, in the form of heat or work, can cross the boundary.

Closed system exergy (nonflow exergy) is the reversible work that could be done by a closed system undergoing a reversible process to equilibrium with its surroundings. For a mass m the exergy is $X = (U - U_0) + P_0(V - V_0) - T_0(S - S_0) + m\vec{V}^2/2 + mgz$. On a unit mass basis, the exergy of a closed system is expressed as $\phi = (u - u_0) + P_0(v - v_0) - T_0(s - s_0) + \vec{V}^2/2 + gz$ where u_0, v_0, and s_0 are the properties of the system evaluated at the dead state. Note that the exergy of a system is zero at the dead state since $u = u_0$, $v = v_0$, and $s = s_0$ at that state. The exergy change of a closed system during a process is simply the difference between the final and initial exergies of the system.

Coefficient of performance COP is the measure of performance of refrigerators and heat pumps. It is expressed in terms of the desired result for each device (heat absorbed from the refrigerated space for the refrigerator or heat added to the hot space by the heat pump) divided by the input, the energy expended to accomplish the energy transfer (usually work input).

Cogeneration is the production of more than one useful form of energy (such as process heat and electric power) from the same energy source.

Cold-air-standard assumption combines the air-standard assumptions with the assumption that the air has constant specific heats whose values are determined at room temperature (25°C, or 77°F).

Combined cycle (see combined gas–vapor cycle)

Combined efficiency (see overall efficiency)

Combined gas–vapor cycle, or just the combined cycle, is the gas-turbine (Brayton) cycle topping a steam-turbine (Rankine) cycle, which has a higher thermal efficiency than either of the cycles executed individually.

Combustion is a chemical reaction during which a fuel is oxidized and a large quantity of energy is released.

Combustion air is dry air which can be approximated as 21 percent oxygen and 79 percent nitrogen by mole numbers. Therefore, each mole of oxygen entering a combustion chamber will be accompanied by 0.79/0.21 = 3.76 mol of nitrogen. To supply one mole of oxygen to a combustion process, 4.76 mol of combustion air are required.

Combustion efficiency is defined as the ratio of the amount of heat released during combustion to the heating value of the fuel burned.

Complete combustion is a combustion process in which all the carbon in the fuel burns to CO_2, all the hydrogen burns to H_2O, and all the sulfur (if any) burns to SO_2. That is, all the combustible components of a fuel are burned to completion during a complete combustion process.

Component pressure is the pressure a component in a gas mixture would have if it existed alone at the volume and temperature of the mixture.

Component volume is the volume a component in a gas mixture would occupy if it existed alone at the temperature and pressure of the mixture.

Compressed liquid has a pressure greater than the saturation pressure corresponding to the temperature.

Compressed liquid region is all compressed liquid states located in the region to the left of the saturated liquid line and below the critical temperature line. In the absence of compressed liquid data, a general approximation is to treat compressed liquid as saturated liquid at the given temperature.

Compressibility factor Z is a correction factor to account for deviation from ideal-gas behavior at a given temperature and pressure. $Z = Pv/RT$.

Compressing flow is a flow that produces an oblique shock.

Compression-ignition (CI) engines are reciprocating engines in which the combustion of the air–fuel mixture is self-ignited as a result of compressing the mixture above its self-ignition temperature.

Compression ratio r of an engine is the ratio of the maximum volume formed in the cylinder to the minimum (clearance) volume. Notice that the compression ratio is a *volume ratio* and should not be confused with the pressure ratio.

Compressor is a device that increases the pressure of a gas to very high pressures (typical pressure ratios are greater than 3).

Condenser is a heat exchanger in which the working fluid condenses as it rejects heat to the surroundings. For example, in the condenser of a steam power plant steam leaving the turbine as a vapor condenses to the saturated liquid state as the result of heat transfer to a cooling medium such as the atmosphere or water from a lake or river.

Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interaction between particles.

Conservation of energy principle states that during an interaction, energy can change from one form to another but the total amount of energy remains constant. That is, energy cannot be created or destroyed (see first law of thermodynamics).

Conservation of mass principle is expressed as net mass transfer to or from a control volume during a time interval is equal to the net change (increase or decrease) in the total mass within the control volume during the time interval.

Conservation of mass principle for combustion (or the **mass balance**) is the principle used to balance chemical reaction equations. It can be stated as the total mass of each element is conserved during a chemical reaction. The total mass of each element on the right-hand side of the reaction equation (the products) must be equal to the total mass of that element on the left-hand side (the reactants) even though the elements exist in different chemical compounds in the reactants and products. Even though the mass must be conserved, the total number of moles is not necessarily conserved during a chemical reaction.

Constant-volume gas thermometer measures the temperature on the ideal-gas temperature scale using a rigid vessel filled with a gas, usually hydrogen or helium, at low pressure. The temperature of a gas of fixed volume varies linearly with pressure at sufficiently low pressures.

Continuity equation is the conservation of mass equation as it is often referred to in fluid mechanics.

Continuum is a view of mass as continuous, homogeneous matter with no holes. Matter is made up of atoms that are widely spaced in the gas phase. Yet it is very convenient to disregard the atomic nature of a substance**.** The continuum idealization allows us to treat properties as point functions, and to assume the properties to vary continually in space with no jump discontinuities. This idealization is valid as long as the size of the system we deal with is large relative to the space between the molecules. This is the case in practically all problems, except some specialized ones.

Control mass (see closed system)

Control surface is the boundary of a control volume, and it can be real or imaginary.

Control volume (also see open system) is any arbitrary region in space through which mass and energy can pass across the boundary. Most control volumes have fixed boundaries and thus do not involve any moving boundaries. A control volume may also involve heat and work interactions just as a closed system, in addition to mass interaction.

Convected energy (see flow work)

Convection is the mode of energy transfer between a solid surface and the adjacent fluid that is in motion, and it involves the combined effects of conduction and fluid motion.

Convection heat transfer coefficient is the experimentally determined parameter that is the ratio of the rate of convection heat transfer and the product of the heat transfer area and surface to bulk fluid temperature.

Converging–diverging nozzle, also called Laval nozzle after Carl G. B. de Laval, is a duct in which the flow area first decreases and then increases in the direction of the flow and is used to accelerate gases to supersonic speeds.

Cooling capacity is the rate of heat removal from the refrigerated space by a refrigeration system.

Cooling pond is a large lake open to the atmosphere into which warm water containing waste heat is pumped. Heat transfer from the pond surface to the atmosphere is very slow; thus, the cooling pond requires much more surface area than that of a spray pond to achieve the same cooling.

Criterion for chemical equilibrium is the equation set equal to zero that involves the stoichiometric coefficients and the molar Gibbs functions of the reactants and the products in the equilibrium reaction.

Critical point is defined as the point at which the saturated liquid and saturated vapor states are identical.

Critical pressure P_{cr} is the pressure of a substance at the critical point.

Critical properties are the properties of a fluid at a location where the Mach number is unity.

Critical ratios are the ratios of the stagnation to static properties when the Mach number is unity.

Critical temperature T_{cr} is the temperature of a substance at the critical point.

Critical volume v_{cr} is the volume of a substance at the critical point.

Cutoff ratio r_c is the ratio of the cylinder volumes after and before the combustion process in the Diesel cycle.

Cycle is a process, or series of processes, that allows a system to undergo state changes and returns the system to the initial state at the end of the process. That is, for a cycle the initial and final states are identical.

Cyclic relation of partial derivatives shows that the derivatives of a function of two variables are related in a cyclic manner by

$$\left(\frac{\partial x}{\partial y}\right)_z \left(\frac{\partial y}{\partial z}\right)_x \left(\frac{\partial z}{\partial x}\right)_y = -1$$

Daily calorie needs depends on the nutrition levels of people and will vary greatly with age, gender, the state of health, the activity level, the body weight, and the composition of the body as well as other factors.

Dalton's law of additive pressures states that the pressure of a gas mixture is equal to the sum of the pressures each gas would exert if it existed alone at the mixture temperature and volume.

Dead state is the state a system is said to be in when it is in thermodynamic equilibrium with its environment.

Decrease of exergy principle states the exergy of an isolated system during a process always decreases or, in the limiting case of a reversible process, remains constant. In other words, exergy never increases, and it is destroyed during an actual process. For an isolated system, the decrease in exergy equals exergy destroyed.

Deficiency of air results when the amounts of air are less than the stoichiometric amount.

Deflection angle (see turning angle)

Dehumidifying is the process of removing moisture from atmospheric air.

Density is defined as mass per unit volume.

Derivative of a function *f(x)* with respect to *x* represents the rate of change of *f* with *x*. The derivative is equivalent to steepness of a curve at a point as measured by the slope of a line tangent to the curve at that point.

$$\frac{d f}{dx} = \lim_{\Delta x \to 0} \frac{\Delta f}{\Delta x} = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

Derived dimensions (see secondary dimensions)

Detached oblique shock or a **bow wave** is an oblique shock that has become curved and detached from the nose of a wedge.

Dew-point temperature is defined as the temperature at which condensation begins when the air is cooled at constant pressure.

Diesel cycle is the ideal cycle for compress-ignition reciprocating engines, and was first proposed by Rudolf Diesel in the 1890s. Using the air-standard assumptions, the cycle consists of four internally reversible processes:

1-2 Isentropic compression,
2-3 Constant pressure heat addition,
3-4 Isentropic expansion,
4-1 Constant volume heat rejection.

Diffuser is a device that increases the pressure of a fluid by decreasing the fluid velocity.

Dimensionally homogeneous means that every term in an equation must have the same unit. To make sure that all terms in an engineering equation have the same units is the simplest error check one can perform.

Dimensions are any physical characterizations of a quantity.

Direct-contact feedwater heater (see open feedwater heater)

Displacement volume is the volume displaced by the piston as it moves between top dead center and bottom dead center.

Dodecane, $C_{12}H_{26}$, is a common liquid fuel that approximates diesel fuel.

Dome is the saturation states located beneath the joined saturated liquid line and saturated vapor line.

Dry air is air that contains no water vapor.

Dry-bulb temperature is the ordinary temperature of atmospheric air.

Dual cycle is the ideal cycle which models the combustion process in both gasoline and diesel engines as a combination of two heat-transfer processes, one at constant volume and the other at constant pressure.

Dynamic temperature is the kinetic energy per unit mass divided by the constant pressure specific heat and corresponds to the temperature rise during the stagnation process.

Efficiency is defined as the ratio of desired result for an event to the input required to accomplish the event. Efficiency is one of the most frequently used terms in

thermodynamics, and it indicates how well an energy conversion or transfer process is accomplished.

Efficiency of a cooking appliance is defined as the ratio of the useful energy transferred to the food to the energy consumed by the appliance.

Efficiency of a water heater is defined as the ratio of the energy delivered to the house by hot water to the energy supplied to the water heater.

Efficiency of resistance heaters is 100 percent as they convert all the electrical energy they consume into heat.

Electrical polarization work is the product of the generalized force taken as the electric field strength and the generalized displacement taken as the polarization of the medium (the sum of the electric dipole rotation moments of the molecules).

Electrical power is the rate of electrical work done as electrons in a wire move under the effect of electromotive forces, doing work. It is the product of the potential difference measured in volts and the current flow measured in amperes.

Electrical work is work done on a system as electrons in a wire move under the effect of electromotive forces while crossing the system boundary.

Emissivity is a surface property that is a measure of how closely a surface approximates a blackbody for which the emissivity equal to one.

Energy Balance is the net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during that process.

Energy efficiency rating EER is the performance of refrigerators and air conditioners, and is the amount of heat removed from the cooled space in Btu's for 1 Wh (watt-hour) of electricity consumed.

Energy transport by mass is the product of the mass of the flowing fluid and its total energy. The rate of energy transport by mass is the product of the mass flow rate and the total energy of the flow.

English system, which is also known as the *United States Customary System* (USCS), has the respective units the pound-mass (lbm), foot (ft), and second (s). The pound symbol *lb* is actually the abbreviation of *libra*, which was the ancient Roman unit of weight.

Enthalpy *H* (from the Greek word *enthalpie*n, which means *to hea*t) is a property and is defined as the sum of the internal energy *U* and the *PV* product.

Enthalpy change of an ideal gas is given as $\Delta h = \int C_{\mathrm{P}}(T)dT \cong C_{\mathrm{P,\,av}}(T_2 - T_1)$.

Enthalpy departure is the difference between the enthalpy of a real gas and the enthalpy of the gas at an ideal gas state and it represents the variation of the enthalpy of a gas with pressure at a fixed temperature.

Enthalpy departure factor is the nondimensionalized form of the enthalpy departure.

Enthalpy of a chemical component at a specified state is the sum of the enthalpy of formation of the component at 25°C, 1 atm, and the sensible enthalpy of the component relative to 25°C, 1 atm, which is the difference between the sensible enthalpy at the specified state ad the sensible enthalpy at the standard reference state of 25°C and 1 atm. This definition enables us to use enthalpy values from tables regardless of the reference state used in their construction.

Enthalpy of combustion h_{C} is the enthalpy of reaction during a steady-flow combustion process when 1 kmol (or 1 kg) of fuel is burned completely at a specified temperature and pressure and represents the amount of heat released.

Enthalpy of formation is the enthalpy of a substance at a specified state due to its chemical composition. The enthalpy of formation of all stable elements (such as O_2, N_2, H_2, and C) has a value of zero at the standard reference state of 25°C and 1 atm.

Enthalpy of reaction h_{R} is defined as the difference between the enthalpy of the products at a specified state and the enthalpy of the reactants at the same state for a complete reaction.

Enthalpy of vaporization (or latent heat of vaporization) is the quantity h_{fg} listed in the saturation tables.

Entropy (from a classical thermodynamics point of view) is a property designated *S* and is defined as $dS = (\delta Q/T)_{\mathrm{int\ rev}}$.

Entropy (from a statistical thermodynamics point of view) can be viewed as a measure of molecular disorder, or molecular randomness. The entropy of a system is related to the total number of possible microscopic states of that system, called thermodynamic probability *p*, by the Boltzmann relation**,** expressed as $S = k \ln p$ where *k* is the Boltzmann constant.

Entropy balance for any system (including reacting systems) undergoing any process can be expressed as net entropy transfer entropy by heat and mass plus entropy generation equals the change in entropy.

Entropy balance relation for a control volume states that the rate of entropy change within the control volume during a process is equal to the sum of the rate of entropy transfer through the control volume boundary by heat transfer, the net rate of entropy transfer into the control volume by mass flow, and the rate of entropy generation within the boundaries of the control volume as a result of irreversibilities.

Entropy balance relation in general is stated as the entropy change of a system during a process is equal to the net entropy transfer through the system boundary and the entropy generated within the system as a result of irreversibilities.

Entropy change of a closed system is due to the entropy transfer accompanying heat transfer and the entropy generation within the system boundaries and is greater than or equal to the integral over the process of $\delta Q/T$.

Entropy departure is the difference between the entropy of a real gas at a given P and T and the entropy of the gas at an ideal gas state at the same P and T .

Entropy departure factor is the nondimensionalized form of the entropy departure.

Entropy generation S_{gen} is entropy generated or created during an irreversible process, is due entirely to the presence of irreversibilities, and is a measure of the magnitudes of the irreversibilities present during that process. Entropy generation is always a positive quantity or zero. Its value depends on the process, and thus it is not a property.

Entropy transfer is the transfer of entropy across a boundary by heat or mass.

Environment refers to the region beyond the immediate surroundings whose properties are not affected by the process at any point.

Equation of state is any equation that relates the pressure, temperature, and specific volume of a substance. Property relations that involve other properties of a substance at equilibrium states are also referred to as equations of state.

Equilibrium implies a state of balance. In an equilibrium state there are no unbalanced potentials (or driving forces) within the system. A system in equilibrium experiences no changes when it is isolated from its surroundings.

Equilibrium constant for an equilibrium reaction is the ratio of the product of the product component's partial pressure raised to their stoichiometric coefficients and the product of the reactant component's partial pressure raised to their stoichiometric coefficients. The equilibrium constant of an ideal-gas mixture at a specified temperature can be determined from knowledge of the standard-state Gibbs function change at the same temperature. The number of equilibrium constant relations needed to determine the

equilibrium composition of a reacting mixture is equal to the number of chemical species minus the number of elements present in equilibrium.

Equivalence ratio is the ratio of the actual fuel–air ratio to the stoichiometric fuel–air ratio.

Ericsson cycle is made up of four totally reversible processes:

1-2 *T* = constant expansion (heat addition from the external source),
2-3 P = constant regeneration (internal heat transfer from the working fluid to the regenerator),
3-4 T = constant compression (heat rejection to the external sink),
4-1 P = constant regeneration (internal heat transfer from the regenerator back to the working fluid).

Evaporation is the phase change from liquid to vapor and occurs at the liquid–vapor interface when the vapor pressure is less than the saturation pressure of the liquid at a given temperature.

Evaporative coolers, also known as swamp coolers, use evaporative cooling based on the principle that as water evaporates, the latent heat of vaporization is absorbed from the water body and the surrounding air. As a result, both the water and the air are cooled during the process. Evaporative coolers are commonly used in dry climates and provide effective cooling.

Evaporator is a heat exchanger in which the working fluid evaporates as it receives heat from the surroundings.

Exact differentials are the differential changes for point functions (i.e., they depend on the state only, and not on how a system reaches that state), and they are designated by the symbol *d*. Properties are an example of point functions that have exact differentials.

Excess air is the amount of air in excess of the stoichiometric amount.

Exergy (availability or available energy) is property used to determine the useful work potential of a given amount of energy at some specified state. It is important to realize that exergy does not represent the amount of work that a work-producing device will actually deliver upon installation. Rather, it represents the upper limit on the amount of work a device can deliver without violating any thermodynamic laws.

Exergy balance can be stated as the exergy change of a system during a process is equal to the difference between the net exergy transfer through the system boundary and the exergy destroyed within the system boundaries as a result of irreversibilities (or entropy generation).

Exergy balance for a control volume is stated as the rate of exergy change within the control volume during a process is equal to the rate of net exergy transfer through the control volume boundary by heat, work, and mass flow minus the rate of exergy destruction within the boundaries of the control volume as a result of irreversibilities.

Exergy destroyed is proportional to the entropy generated and is expressed as $X_{destroyed} = T_0 S_{gen} \geq 0$. Irreversibilities such as friction, mixing, chemical reactions, heat transfer through a finite temperature difference, unrestrained expansion, non-quasi-equilibrium compression, or expansion always generate entropy, and anything that generates entropy always destroys exergy.

Exergy of the kinetic energy (work potential) of a system is equal to the kinetic energy itself regardless of the temperature and pressure of the environment.

Exergy of the potential energy (work potential) of a system is equal to the potential energy itself regardless of the temperature and pressure of the environment.

Exergy transfer by heat X_{heat} is the exergy as the result of heat transfer Q at a location at absolute temperature T in the amount of $X_{heat} = (1-T_0/T)Q$.

Exergy transfer by mass results from mass in the amount of m entering or leaving a system and carries exergy in the amount of $m\psi$, where $\psi = (h - h_0) - T_0(s - s_0) + \vec{V}^2/2 + gz$, accompanies it. Therefore, the exergy of a system increases by $m\psi$ when mass in the amount of m enters, and decreases by the same amount when the same amount of mass at the same state leaves the system.

Exergy transfer by work is the useful work potential expressed as $X_{work} = W - W_{surr}$ for closed systems experiencing boundary work where $W_{surr} = P_0(v_2 - v_1)$ and P_0 is atmospheric pressure, and V_1 and V_2 are the initial and final volumes of the system, and $X_{work} = W$ for other forms of work.

Exhaust valve is the exit through which the combustion products are expelled from the cylinder.

Exothermic reaction is a reaction during which chemical energy is released in the form of heat.

Expanding flow are those flows where supersonic flow is turned in the opposite direction; however, the flow does not turn suddenly, as through a shock, but gradually—each successive Mach wave turns the flow by an infinitesimal amount.

Expansion fan is a continuous expanding region of supersonic flow composed of an infinite number of Mach waves called Prandtl–Meyer expansion waves**.**

Extensive properties are those whose values depend on the size—or extent—of the system. Mass *m*, volume *V*, and total energy *E* are some examples of extensive properties. Extensive properties of a nonreacting ideal-or real-gas mixture are obtained by just adding the contributions of each component of the mixture.

External combustion engines are engines in which the fuel is burned outside the system boundary.

Externally reversible process has no irreversibilities to occur outside the system boundaries during the process. Heat transfer between a reservoir and a system is an externally reversible process if the surface of contact between the system and the reservoir is at the temperature of the reservoir.

Fahrenheit scale (named after the German instrument maker G. Fahrenheit, 1686–1736) is the temperature scale in the English system. On the Fahrenheit scale, the ice and steam points are assigned 32 and 212 °F.

Fan is a device that increases the pressure of a gas slightly (typical pressure ratios are less than 3) and is mainly used to mobilize a gas.

Fan-jet engine (see turbofan engine)

Fanno line is the locus of all states for frictionless adiabatic flow in a constant-area duct plotted on an h-s diagram. These states have the same value of stagnation enthalpy and mass flux (mass flow per unit area).

Feedwater heater is the device where the feedwater is heated by regeneration. This technique is used to raise the temperature of the liquid leaving the pump (called the feedwater) before it enters the boiler. A practical regeneration process in steam power plants is accomplished by extracting, or "bleeding," steam from the turbine at various points. This steam, which could have produced more work by expanding further in the turbine, is used to heat the feedwater instead.

First law (see first law of thermodynamics)

First law of thermodynamics is simply a statement of the conservation of energy principle, and it asserts that total energy is a thermodynamic property. Joule's experiments indicate the following: For all adiabatic processes between two specified states of a closed system, the net work done is the same regardless of the nature of the closed system and the details of the process. It may be expressed as follows: Energy can be neither created nor destroyed; it can only change forms. The net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during that process. The energy balance can be written explicitly as

$$E_{in} - E_{out} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}) + (E_{mass,\,in} - E_{mass,\,out}) = \Delta E_{system}$$

First law of thermodynamics for a closed system using the classical thermodynamics sign convention is

$$Q_{net,\,in} - W_{net,\,out} = \Delta E_{system} \quad \text{or} \quad Q - W = \Delta E$$

where $Q = Q_{net,\,in} = Q_{in} - Q_{out}$ is the net heat input and $W = W_{net,\,out} = W_{out} - W_{in}$ is the net work output. Obtaining a negative quantity for Q or W simply means that the assumed direction for that quantity is wrong and should be reversed.

Flow energy (see flow work).

Flow exergy results from mass entering or leaving a system and carries exergy per unit mass in the amount $\psi = (h - h_0) - T_0(s - s_0) + \vec{V}^2/2 + gz$ with it. Therefore, the exergy of a system increases by ψ when mass enters, and decreases by the same amount when mass at the same state leaves the system.

Flow work (flow energy) is work required to push mass into or out of control volumes. On a unit mass basis this energy is equivalent to the product of the pressure and specific volume of the mass Pv.

Forced convection (convected energy) is convection heat transfer when the fluid is forced to flow in a tube or over a surface by external means such as a fan, pump, or the wind.

Forced-draft cooling tower, or induced-draft cooling tower, is a wet cooling tower in which the air is drawn through the tower by fans.

Formal sign convention (classical thermodynamics sign convention) for heat and work interactions is as follows: heat transfer to a system and work done by a system are positive; heat transfer from a system and work done on a system are negative.

Four-stroke internal combustion engines are engines in which the piston executes four complete strokes (two mechanical cycles) within the cylinder, and the crankshaft completes two revolutions for each thermodynamic cycle.

Fourier's law of heat conduction states that rate of heat conduction in a direction is proportional to the temperature gradient in that direction.

Free convection (natural convection) is convection heat transfer when the fluid motion is caused by buoyancy forces induced by density differences due to the variation of temperature in the fluid.

Friction is a familiar form of irreversibility associated with bodies in motion which results from the force that opposes the motion developed at the interface of the two bodies in contact when the two bodies are forced to move relative to each other.

Frosting, which occurs in humid climates when the temperature falls below 2 to 5°C, is the major problem with air-source systems. The frost accumulation on the evaporator coils is highly undesirable since it seriously disrupts heat transfer. The coils can be defrosted, however, by reversing the heat pump cycle (running it as an air conditioner). This results in a reduction in the efficiency of the system.

Fuel is any material that can be burned to release energy.

Fuel–air ratio is the reciprocal of air–fuel ratio.

Fuel cells operate on the principle of electrolytic cells in which the chemical energy of the fuel is directly converted to electric energy, and electrons are exchanged through conductor wires connected to a load. Fuel cells are not heat engines, and thus their efficiencies are not limited by the Carnot efficiency. They convert chemical energy to electric energy essentially in an isothermal manner.

Fundamental dimensions (see primary dimensions)

Gage pressure is the difference between the absolute pressure and the local atmospheric pressure.

Gas constant R is different for each gas and is determined from $R = R_u/M$.

Gas phase of a substance has molecules that are far apart from each other, and a molecular order is nonexistent. Gas molecules move about at random, continually colliding with each other and the walls of the container they are in.

Gas power cycles are cycles where the working fluid remains a gas throughout the entire cycle. Spark-ignition automobile engines, diesel engines, and conventional gas turbines are familiar examples of devices that operate on gas cycles.

Gas refrigeration cycle is based on the reversed Brayton cycle where the compressor exit gases are cooled and then expanded in a turbine to further reduce the temperature of the working fluid. The lower-temperature fluid is used to produce the refrigeration effect.

Generalized compressibility chart shows that by curve-fitting all the data, gases seem to obey the principle of corresponding states reasonably well.

Generalized enthalpy departure chart is a plot of the enthalpy departure factor as a function of reduced pressure and reduced temperature. It is used to determine the deviation of the enthalpy of a gas at a given *P* and *T* from the enthalpy of an ideal gas at the same *T*.

Generalized entropy departure chart is a plot of the entropy departure factor as a function of reduced pressure and reduced temperature. It is used to determine the deviation of the entropy of a gas at a given *P* and *T* from the entropy of an ideal gas at the same *P* and *T*.

Generator efficiency is defined as the ratio of the electrical power output to the mechanical power input to a generator.

Geothermal heat pumps (also called ground-source heat pumps) use the ground as the heat source.

Gibbs–Dalton law, an extension of Dalton's law of additive pressures, states that under the ideal-gas approximation, the properties of a gas in a mixture are not influenced by the presence of other gases, and each gas component in the mixture behaves as if it exists alone at the mixture temperature and mixture volume.

Gibbs function is defined as the enthalpy minus the product of the temperature and entropy ($G = H - TS$).

Gibbs phase rule provides the number of independent variables associated with a multicomponent, multiphase system.

Gravimetric analysis is one way to describe the composition of a mixture that is accomplished by specifying the mass of each component.

Gravitational acceleration g is 9.807 m/s^2 at sea level and varies by less than 1 percent up to 30,000 m. Therefore, g can be assumed to be constant at 9.81 m/s^2.

Greenhouse effect is the heating effect causing the increase in temperature of the earth's atmosphere as the result of solar radiation entering the earth's atmosphere during the day, but heat radiated by the earth at night is blocked by gases such as carbon dioxide and trace amounts of methane, nitrogen oxides and other gases.

Gobal climate change (see global warming).

Global warming (gobal climate change) is the undesirable consequence of the greenhouse effect.

Heat (see heat transfer).

Heat-driven systems are refrigeration systems whose energy input is based on heat transfer from an external source. Absorption refrigeration systems are often classified as heat-driven systems.

Heat engines are devices designed for the purpose of converting other forms of energy (usually in the form of heat) to work. Heat engines differ considerably from one another, but all can be characterized by the following:

1. They receive heat from a high-temperature source (solar energy, oil furnace, nuclear reactor, etc.).
2. They convert part of this heat to work (usually in the form of a rotating shaft).
3. They reject the remaining waste heat to a low-temperature sink (the atmosphere, rivers, etc.).
4. They operate on a cycle.

Heat exchangers are devices where two moving fluid streams exchange heat without mixing. Heat exchangers are widely used in various industries, and they come in various designs. The simplest form of a heat exchanger is a double-tube (also called tube-and-shell) heat exchanger composed of two concentric pipes of different diameters. One fluid flows in the inner pipe, and the other in the annular space between the two pipes. Heat is transferred from the hot fluid to the cold one through the wall separating them. Sometimes the inner tube makes a couple of turns inside the shell to increase the heat transfer area, and thus the rate of heat transfer.

Heat pump is a cyclic device which operates on the refrigeration cycle and discharges energy to a heated space to maintain the heated space at a high temperature. It is a cyclic device which causes the transfer of heat from a low-temperature region to a high-temperature region.

Heat pump coefficient of performance is the efficiency of a heat pump, denoted by COP_{HP}, and expressed as desired output divided by required input or $COP_{HP} = Q_H/W_{net, in}$.

Heat rate is the expression of the conversion efficiency of power plants in the United States and is the amount of heat supplied, in Btu's, to generate 1 kWh of electricity. The smaller the heat rate, the greater the efficiency.

Heat reservoir is a thermal energy reservoir since it can supply or absorb energy in the form of heat.

Heat sink is a heat reservoir that absorbs energy in the form of heat.

Heat source is a heat reservoir that supplies energy in the form of heat.

Heat transfer (heat) is defined as the form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature difference. It is the

area under the process curve on a *T*-*S* diagram during an internally reversible process; however, this area has no meaning for irreversible processes.

Heating value of a fuel is defined as the amount of heat released when a fuel is burned completely in a steady-flow process and the products are returned to the state of the reactants. In other words, the heating value of a fuel is equal to the absolute value of the enthalpy of combustion of the fuel.

Helmholtz function *a* is defined as $a = u - Ts$.

Henry's constant is the product of the total pressure of the gas mixture and the mole fraction of a specie in the liquid phase.

Henry's law states that the mole fraction of a weakly soluble gas in the liquid is equal to the partial pressure of the gas outside the liquid divided by Henry's constant.

Higher Heating value HHV of fuel is the amount of heat released when a specified amount of fuel (usually a unit of mass) at room temperature is completely burned and the combustion products are cooled to the room temperature when the water formed during the combustion process is completely condensed and leaves as a liquid.

Humidity ratio (see absolute humidity)

Humidifying is the process of adding moisture to atmospheric air.

Hydrocarbon fuels are the most familiar fuels and consist primarily of hydrogen and carbon. They are denoted by the general formula C_nH_m. Hydrocarbon fuels exist in all phases, some examples being coal, gasoline, and natural gas.

Hypersonic flow occurs when a flow has a Mach number $M >> 1$.

Ideal cycle is an actual cycle stripped of all the internal irreversibilities and complexities. The ideal cycle resembles the actual cycle closely but is made up totally of internally reversible processes.

Ideal gas is a gas that obeys the ideal-gas equation of state.

Ideal-gas equation of state (or ideal-gas relation) predicts the *P*-*v*-*T* behavior of a gas quite accurately within some properly selected region where $Pv = RT$.

Ideal gas specific heat relation is $C_p = C_v + R$.

Ideal gas temperature scale is a temperature scale that turns out to be identical to the Kelvin scale. The temperatures on this scale are measured using a **constant-volume gas**

thermometer, which is basically a rigid vessel filled with a gas, usually hydrogen or helium, at low pressure. The temperature of a gas is proportional to its pressure at constant volume.

Ideal mixture or **ideal solution** is a mixture where the effect of dissimilar molecules in a mixture on each other is negligible and the chemical potential of a component in such a mixture is simply taken to be the Gibbs function of the pure component.

Ideal vapor-compression refrigeration cycle completely vaporizes the refrigerant before it is compressed and expands the refrigerant with a throttling device, such as an expansion valve or capillary tube. The vapor-compression refrigeration cycle is the most widely used cycle for refrigerators, air-conditioning systems, and heat pumps. It consists of four processes:

1-2 Isentropic compression in a compressor,
2-3 Constant-pressure heat rejection in a condenser,
3-4 Throttling in an expansion device,
4-1 Constant-pressure heat absorption in an evaporator.

Ignition temperature is the minimum temperature to which a fuel must be brought to start the combustion.

Immediate surroundings refer to the portion of the surroundings that is affected by the process.

Incomplete combustion is a combustion process in which the combustion products contain any unburned fuel or components such as C, H_2, CO, or OH.

Incompressible substances, such as liquids and solids, have densities (or specific volumes) that have negligible variation with pressure.

Increase of entropy principle (see second law of thermodynamics)

Independent properties exist when one property can be varied while another property is held constant.

Inert gas is a gaseous component in a chemical reaction that does not react chemically with the other components. The presence of inert gases affects the equilibrium composition (although it does not affect the equilibrium constant).

Inexact differentials are the differential amount of change for path functions and are designated by the symbol δ. Therefore, since heat and work are path functions, a differential amount of heat or work is represented by δQ or δW, respectively, instead of dQ or dW.

Intake valve is an inlet through which the air or air–fuel mixture is drawn into the cylinder.

Intensive properties are those that are independent of the size of a system, such as temperature, pressure, and density. Intensive properties of a nonreacting ideal-or real-gas mixture are obtained by dividing the extensive properties by the mass or the mole number of the mixture in the gas mixture. The internal energy, enthalpy, and entropy of a gas mixture per unit mass or per unit mole of the mixture can be determined by summing the products of the mass fractions and the specific property or summing the products of the mole fractions and the molar specific property. That is, the intensive properties of a gas mixture are determined by either a mass weighted or a mole weighted average of the properties.

Intercooling is a technique used to reduce the compression work for the gas turbine cycle. The compression process is completed in stages while cooling the working fluid between stages. Since the steady-flow compression work is proportional to the specific volume of the flow, the specific volume of the working fluid should be as low as possible during a compression process.

Internal combustion engines are engines where the energy is provided by burning a fuel within the system boundaries.

Internal energy U of a system is the sum of all the microscopic forms of energy.

Internal energy change of an ideal gas is given as $\Delta u = \int C_{\mathrm{v}}(T)dT \cong C_{\mathrm{v,\,av}}(T_2 - T_1)$.

Internally reversible process has no irreversibilities that occur within the boundaries of the system during the process. During an internally reversible process, a system proceeds through a series of equilibrium states, and when the process is reversed, the system passes through exactly the same equilibrium states while returning to its initial state.

Inversion line is the line that passes through the points of zero slope of constant-enthalpy lines or zero Joule-Thomson coefficient on the *T-P* diagram. The slopes of the h = constant lines are negative ($\mu_{\mathrm{JT}} < 0$) at states to the right of the inversion line and positive ($\mu_{\mathrm{JT}} > 0$) to the left of the inversion line.

Inversion temperature is the temperature at a point where a constant-enthalpy line intersects the inversion line.

Irreversible processes are processes which, once having taken place in a system, cannot spontaneously reverse themselves and restore the system to its initial state.

Irreversibilities are the factors that cause a process to be irreversible. They include friction, unrestrained expansion, mixing of two gases, heat transfer across a finite

temperature difference, electric resistance, inelastic deformation of solids, and chemical reactions.

Irreversibility I is any difference between the reversible work W_{rev} and the useful work W_u due to the irreversibilities present during the process. Irreversibility can be viewed as the wasted work potential or the lost opportunity to do work.

Isentropic efficiency of a compressor is defined as the ratio of the work input required to raise the pressure of a gas to a specified value in an isentropic manner to the actual work input.

Isentropic efficiency of a nozzle is defined as the ratio of the actual kinetic energy of the fluid at the nozzle exit to the kinetic energy value at the exit of an isentropic nozzle for the same inlet state and exit pressure.

Isentropic efficiency of a turbine is defined as the ratio of the actual work output of the turbine to the work output that would be achieved if the process between the inlet state and the exit pressure were isentropic.

Isentropic process is an internally reversible and adiabatic process. In such a process the entropy remains constant**.**

Isentropic stagnation state is the stagnation state when the stagnation process is reversible as well as adiabatic (i.e., isentropic). The entropy of a fluid remains constant during an isentropic stagnation process.

Iso- prefix is often used to designate a process for which a particular property remains constant.

Isobaric process is a process during which the pressure P remains constant.

Isochoric process (isometric process) is a process during which the specific volume v remains constant.

Isolated system is a closed system in which energy is not allowed to cross the boundary.

Isometric process (see isochoric process).

Isothermal compressibility relates how volume changes when pressure changes as temperature is held constant.

Isothermal efficiency of a compressor is defined as the ratio of the work input to a compressor for the reversible isothermal case and the work input to a compressor for the actual case.

Isothermal process is a process in which the temperature is maintained constant.

Jet-propulsion cycle is the cycle used in aircraft gas turbines. The ideal jet-propulsion cycle differs from the simple ideal Brayton cycle in that the gases are not expanded to the ambient pressure in the turbine. Instead, they are expanded to a pressure such that the power produced by the turbine is just sufficient to drive the compressor and the auxiliary equipment. The gases that exit the turbine at a relatively high pressure are subsequently accelerated in a nozzle to provide the thrust to propel the aircraft.

Joule (J) is a unit of energy and has the unit "newton-meter (N·m)."

Joule-Thomson coefficient μ_{JT} is a measure of the change in temperature with pressure during a constant-enthalpy process.

Kay's rule, proposed by W. B. Kay in 1936, predicts the P-v-T behavior of a gas mixture by determining the compressibility factor for a gas mixture at the reduced pressure and reduced temperature defined in terms of the pseudocritical pressure (the sum of the products of the mole fraction and critical pressure of each component) and pseudocritical temperature (the sum of the products of the mole fraction and critical temperature of each component).

kelvin is the temperature unit of the Kelvin scale in the SI.

Kelvin-Planck statement of the second law of thermodynamics is expressed as follows: It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work. This statement can also be expressed as no heat engine can have a thermal efficiency of 100 percent, or as for a power plant to operate, the working fluid must exchange heat with the environment as well as the furnace.

Kelvin scale is the thermodynamic temperature scale in the SI and is named after Lord Kelvin (1824–1907). The temperature unit on this scale is the kelvin**,** which is designated by K (not °K; the degree symbol was officially dropped from kelvin in 1967). The lowest temperature on the Kelvin scale is 0 K.

Kilojoule (1 kJ) is 1000 joules.

Kilopascal (kPa) is the unit of pressure equal to 1000 pascal or 1000 N/m^2.

Kinetic energy KE is energy that a system possesses as a result of its motion relative to some reference frame. When all parts of a system move with the same velocity, the kinetic energy is expressed as $KE = m V^2/2$.

Kinetic theory treats molecules as tiny balls that are in motion and thus possess kinetic energy. Heat is then defined as the energy associated with the random motion of atoms and molecules.

Kirchhoff's law is defined for radiation that the emissivity and the absorptivity of a surface are equal at the same temperature and wavelength.

Knock, or engine knock, is the audible noise occurring in the engine because of autoignition, the premature ignition of the fuel.

Latent energy is the internal energy associated with the phase of a system**.**

Latent heat is the amount of energy absorbed or released during a phase-change process.

Latent heat of fusion is the amount of energy absorbed during melting and is equivalent to the amount of energy released during freezing.

Latent heat of vaporization is the amount of energy absorbed during vaporization and is equivalent to the energy released during condensation.

Laval nozzles (see converging–diverging nozzles)

Lighting efficacy is defined as the ratio of the amount of light output by lighting devices in lumens of light output to the electrical energy input in W.

Liquefied petroleum gas LPG is a byproduct of natural gas processing or crude oil refining. It consists mainly of propane (over 90 percent), and thus LPG is usually referred to as propane. However, it also contains varying amounts of butane, propylene, and butylenes.

Liquid phase has a molecular spacing not much different from that of the solid phase, except the molecules are no longer at fixed positions relative to each other. In a liquid, chunks of molecules float about each other; however, the molecules maintain an orderly structure within each chunk and retain their original positions with respect to one another. The distances between molecules generally experience a slight increase as a solid turns liquid, with water being a rare exception.

Liquid–vapor saturation curve is a plot of saturation temperature T_{sat} versus saturation pressure P_{sat}.

Lower heating value LHV of fuel is the amount of heat released when a specified amount of fuel (usually a unit of mass) at room temperature is completely burned, and the combustion products are cooled to the room temperature when the water formed during the combustion process leaves as a vapor.

Mach angle is the shock angle for Mach waves and is a unique function of the Mach number.

Mach number, named after the Austrian physicist Ernst Mach (1838–1916), is the ratio of the actual velocity of the fluid (or an object in still air) to the speed of sound in the same fluid at the same state.

Mach wave is the weakest possible oblique shock at a Mach number.

Macroscopic forms of energy are those a system possesses as a whole with respect to some outside reference frame, such as kinetic and potential energies.

Magnetic work is the product of the generalized force as the magnetic field strength and the generalized displacement as the total magnetic dipole moment.

Manometer is a device based on the principle that an elevation change of Δz of a fluid corresponds to a pressure change of $\Delta P/ \rho g$, which suggests that a fluid column can be used to measure pressure differences. The manometer is commonly used to measure small and moderate pressure differences.

Mass fraction is the ratio of the mass of one component in a mixture to the total mass of the mixture.

Mass flow rate is the amount of mass flowing through a cross section per unit time.

Mass of a system is equal to the product of its molar mass *M* and the mole number N.

Maximum inversion temperature is the temperature at the intersection of the $P = 0$ line (ordinate) on the *T*-*P* diagram and the upper part of the inversion line.

Maxwell relations are equations that relate the partial derivatives of properties *P*, *v*, *T*, and *s* of a simple compressible system to each other.

Mayer relation, named in honor of the German physician and physicist J. R. Mayer (1814–1878, shows how the difference between the constant-pressure specific heat and constant-volume specific heat is related to the specific volume, temperature, isothermal compressibility, and volume expansivity.

Mean effective pressure MEP is a fictitious pressure that, if it acted on the piston during the entire power stroke, would produce the same amount of net work as that produced during the actual cycle. The mean effective pressure can be used as a parameter to compare the performances of reciprocating engines of equal size. The engine with a larger value of MEP will deliver more net work per cycle and thus will perform better.

Mechanical efficiency of a device or process is the ratio of the mechanical energy output to the mechanical energy input.

Mechanical energy is the form of energy that can be converted to mechanical work completely and directly by an ideal mechanical device such as an ideal turbine.

Mechanical equilibrium is related to pressure, and a system is in mechanical equilibrium if there is no change in pressure at any point of the system with time.

Mechanical work is work associated a force acting in the direction of motion that causes the movement of the boundary of a system or the movement of the entire system as a whole

Mechanisms of entropy transfer S_{in} and S_{out} are heat transfer and mass flow. Entropy transfer is recognized at the system boundary as it crosses the boundary, and it represents the entropy gained or lost by a system during a process. The only form of entropy interaction associated with a fixed mass or closed system is heat transfer, and thus the entropy transfer for an adiabatic closed system is zero.

Megapascal MPa is the unit of pressure equal to 10^6 pascal.

Melting line separates the solid and liquid regions on the phase diagram.

Metabolism is the thousands of chemical reactions that occur every second in the cells of a body during which some molecules are broken down and energy is released and some new molecules are formed. This high level of chemical activity in the cells maintains the human body at a temperature of 37°C while performing the necessary bodily tasks.

Methane, CH_4, is the approximation to gaseous hydrocarbon fuel natural gas that is a mixture of methane and smaller amounts of other gases.

Methyl alcohol, CH_3OH, is a common liquid hydrocarbon fuel that is also called methanol and is used in some gasoline blends.

Metric SI (from *Le Système International d' Unité*s), which is also known as the *International System*, is based on six fundamental dimensions. Their units, adopted in 1954 at the Tenth General Conference of Weights and Measures, are: *meter* (m) for length, *kilogram* (kg) for mass, *second* (s) for time, *ampere* (A) for electric current, *degree Kelvin* (K) for temperature, *candela* (cd) for luminous intensity (amount of light), and *mole* (mol) for the amount of matter.

Microscopic forms of energy are those related to the molecular structure of a system and the degree of the molecular activity, and they are independent of outside reference frames.

Mixing chamber is the section of a control volume where the mixing process takes place for two or more streams of fluids**.** The mixing chamber does not have to be a distinct "chamber.'' Mixing chambers are sometimes classified as direct-contact heat exchangers.

Molar analysis is one way to describe the composition of a mixture that is accomplished by specifying the number of moles of each component.

Molar mass *M* can simply be defined as the *mass of one mole* (also called a *gram-mol*e, abbreviated gmol) *of a substance in gram*s, or the *mass of one kmol* (also called a *kilogram-mol*e, abbreviated kgmol) *in kilogram*s. In English units, it is the mass of 1 lbmol in lbm. Notice that the molar mass of a substance has the same numerical value in both unit systems because of the way it is defined.

Mole fraction is the ratio of the number of moles of one component in a mixture to the total moles of the mixture. Note that for an ideal-gas mixture, the mole fraction, the pressure fraction, and the volume fraction of a component are identical.

Mollier diagram, after the German scientist R. Mollier (1863–1935), is the plot of property data on the *h-s* diagram. The Mollier diagram is useful when solving isentropic, steady flow process problems dealing with nozzles, turbines, and compressors.

Motor efficiency is defined as the ratio of the mechanical energy output of a motor to the electrical energy input.

Moving boundary work (see boundary work)

Multistage compression refrigeration system is a cascade refrigeration system where the fluid used throughout the cascade refrigeration system is the same, and the heat exchanger between the stages is replaced by a device that has better heat-transfer characteristics, a mixing chamber (called a flash chamber).

Multistage compression with intercooling requires the compression process in a compressor to be carried out in stages and to cool the gas in between each stage such that the work required to compress a gas between two specified pressures can be decreased.

Multistage expansion with reheating requires the expansion process in a turbine be carried out in stages and reheating the gas between the stages such that the work output of a turbine operating between two pressure levels can be increased.

Natural convection (see free convection)

Natural-draft cooling tower uses the naturally occurring density gradients between the inside air-water vapor mixture and the outside air which create an airflow from the bottom to the top of a wet cooling tower.

Natural gas is produced from gas wells or oil wells rich in natural gas. It is composed mainly of methane, but it also contains small amounts of ethane, propane, hydrogen, helium, carbon dioxide, nitrogen, hydrogen sulfate, and water vapor. It is stored either in the gas phase at pressures of 150 to 250 atm as CNG (compressed natural gas) or in the liquid phase at 162°C as LNG (liquefied natural gas).

Newton (N), in SI, is the force unit defined as the force required to accelerate a mass of 1 kg at a rate of 1 m/s^2.

Newton's law of cooling defines the heat transfer by convection as the product of the convection heat transfer coefficient, heat transfer area, and the difference between the heat transfer surface temperature and the fluid bulk temperature away from the surface.

Nonflow system exergy (see closed system exergy)

Nonreacting gas mixture is a mixture of gases not undergoing a chemical reaction and can be treated as a pure substance since it is usually a homogeneous mixture of different gases.

Normal components are components that are perpendicular to the quantity in question.

Normal shock wave is a shock wave resulting in an abrupt change over a very thin section normal to the direction of flow.

Nozzle is a device that increases the velocity of a fluid at the expense of decreasing pressure.

Nuclear energy is the tremendous amount of energy associated with the strong bonds within the nucleus of the atom itself.

Oblique shock is a complicated shock pattern consisting of inclined shock waves in which some portions of an oblique shock are curved, while other portions are straight.

Octane, C_8H_{18}, is a common liquid fuel that approximates gasoline.

Octane rating of a fuel is a measure of the engine knock resistance of a fuel.

Open (or **direct-contact**) **feedwater heater** is basically a mixing chamber, where the steam extracted from the turbine mixes with the feedwater exiting the pump. Ideally, the mixture leaves the heater as a saturated liquid at the heater pressure.

Open system is any arbitrary region in space through which mass and energy can pass across the boundary.

Orsat gas analyzer is a commonly used device to analyze the composition of combustion gases. The amounts of carbon dioxide, carbon monoxide, and oxygen are measured on a percent by volume and are based on a dry analysis.

Osmotic pressure is the pressure difference across a semipermeable membrane that separates fresh water from the saline water under equilibrium conditions.

Osmotic rise is the vertical distance saline water would rise when separated from the fresh water by a membrane that is permeable to water molecules alone at equilibrium.

Otto cycle is the ideal cycle for spark-ignition reciprocating engines. It is named after Nikolaus A. Otto, who built a successful four-stroke engine in 1876 in Germany using the cycle proposed by Frenchman Beau de Rochas in 1862. The ideal Otto cycle, which closely resembles the actual operating conditions, utilizes the air-standard assumptions. It consists of four internally reversible processes:

1-2 Isentropic compression,
2-3 Constant volume heat addition,
3-4 Isentropic expansion,
4-1 Constant volume heat rejection.

Overall efficiency (combined efficiency) for a power plant is defined as the ratio of the net electrical power output to the rate of fuel energy input and is expressed as the product of the combustion efficiency, thermal efficiency and generator efficiency.

Package icing is the practice of using ice in product packages to remove heat and keep the products cool during transit by taking advantage of the large latent heat of fusion of water commonly, but its use is limited to products that are not harmed by contact with ice and the moisture provided by the ice.

Partial derivative is the change in a function that depends on two (or more) variables, such as $z = z\,(x, y)$, when allowing one variable to change while holding the others constant and observing the change in the function as another variable is held constant. The variation of $z(x, y)$ with x when y is held constant is called the partial derivative of z with respect to x.

$$\left(\frac{\partial z}{\partial x}\right)_y = \lim_{\Delta x \to 0}\left(\frac{\Delta z}{\Delta x}\right)_y = \lim_{\Delta x \to 0}\frac{z(x+\Delta x, y) - z(x, y)}{\Delta x}$$

Partial pressure of a component in a gas mixture is defined by Dalton's law as the product of the mole fraction and the mixture pressure. The partial pressure is identical to the component pressure for ideal gas mixtures.

Partial volume of a component in a gas mixture is the product of the mole fraction and the mixture volume. The partial volume is identical to the component volume for ideal gas mixtures.

Pascal (Pa) is the unit of pressure defined as newtons per square meter (N/m^2).

Pascal's law allows us to "jump" from one fluid column to the next in manometers without worrying about pressure change as long as we don't jump over a different fluid, and the fluid is at rest.

Pascal's principle, after Blaise Pascal (1623–1662), states that the consequence of the pressure in a fluid remaining constant in the horizontal direction is that the pressure applied to a confined fluid increases the pressure throughout by the same amount.

Path functions are functions whose magnitudes depend on the path followed during a process as well as the end states.

Path of a process is the series of states through which a system passes during a process.

Peltier effect is the cooling effect that occurs when a small current passes through the junction of two dissimilar wires. This effect forms the basis for thermoelectric refrigeration and is named in honor of Jean Charles Athanase Peltier, who discovered this phenomenon in 1834.

Percent deficiency of air is the deficiency of air expressed as a percent of stoichiometric air. For example, 90 percent theoretical air is equivalent to 10 percent deficiency of air.

Percent excess air or **percent theoretical air** is the amount of excess air usually expressed in terms of the stoichiometric air. For example, 50 percent excess air is equivalent to 150 percent theoretical air.

Perpetual-motion machine is any device that violates either the first or second law of thermodynamics.

Perpetual-motion machine of the first kind PMM1 is a device that violates the first law of thermodynamics (by creating energy).

Perpetual-motion machine of the second kind PMM2 is a device that violates the second law of thermodynamics.

Phase diagram is the *P-T* diagram of a pure substance and shows all three phases separated from each other by the sublimation line, vaporization line, and melting line.

Phase equilibrium is the condition that the two phases of a pure substance are in equilibrium when each phase has the same value of specific Gibbs function. Also, at the triple point (the state at which all three phases coexist in equilibrium), the specific Gibbs function of each one of the three phases is equal.

Phase equilibrium for liquid water that is open to the atmosphere can be expressed as follows: The vapor pressure of the water in the air must be equal to the saturation pressure of water at the water temperature.

Piezoelectric effect is the emergence of an electric potential in a crystalline substance when subjected to mechanical pressure**,** and this phenomenon forms the basis for the widely used strain-gage pressure transducers.

Piezoelectric transducers, also called solid-state pressure transducers, work on the principle that an electric potential is generated in a crystalline substance when it is subjected to mechanical pressure. This phenomenon, first discovered by brothers Pierre and Jacques Curie in 1880, is called the piezoelectric (or press-electric) effect. Piezoelectric pressure transducers have a much faster frequency response compared to the diaphragm units and are very suitable for high-pressure applications, but they are generally not as sensitive as the diaphragm-type transducers.

Polytropic process is a process in which pressure and volume are often related by $PV^n = C$, where n and C are constants, during expansion and compression processes of real gases.

Potential energy PE is the energy that a system possesses as a result of its elevation in a gravitational field and is expressed as PE = mgz.

Pound-force lbf, in the English system, is the force unit defined as the force required to accelerate a mass of 32.174 lbm (1 slug) at a rate of 1 ft/s^2.

Power is the work done per unit time is called and has the unit kJ/s, or kW.

Prandtl–Meyer expansion waves are the Mach waves that compose a continuous expanding region called an expansion fan**.**

Prandtl–Meyer function is the angle through which flow must expand, starting with the function value of zero at Ma = 1, in order to reach a supersonic Mach number, Ma > 1.

Pressure is defined as the force exerted by a fluid per unit area.

Pressure fraction of a gas component in a gas mixture is the ratio of the component pressure to the mixture pressure. Note that for an ideal-gas mixture, the mole fraction, the pressure fraction, and the volume fraction of a component are identical.

Pressure ratio is the ratio of final to initial pressures during a compression process.

Pressure transducers are made of semiconductor materials such as silicon and convert the pressure effect to an electrical effect such as a change in voltage, resistance, or capacitance. Pressure transducers are smaller and faster, and they are more sensitive, reliable, and precise than their mechanical counterparts.

Primary or **fundamental dimensions,** such as mass m, length L, time t, and temperature *T*, are the basis for the derivation of secondary dimensions.

Principle of corresponding states is the fact that compressibility factor *Z* for all gases is approximately the same at the same reduced pressure and temperature.

Problem-solving technique is a step-by-step approach to problem solving discussed in Chapter 1.

Process is any change that a system undergoes from one equilibrium state to another. To describe a process completely, one should specify the initial and final states of the process, as well as the path it follows, and the interactions with the surroundings.

Process heat is required energy input in the form of heat for many industrial processes. The process heat is often obtained as heat transfer from high-pressure, high-temperature steam. Some industries that rely heavily on process heat are chemical, pulp and paper, oil production and refining, steel making, food processing, and textile industries.

Products are the components that exist after the reaction in a combustion process.

Property is any characteristic of a system**.** Some familiar properties are pressure P, temperature T, volume V, and mass m. The list can be extended to include less familiar ones such as viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, electric resistivity, and even velocity and elevation.

Propjet engine is a turbojet engine in which the shaft work is used to drive the propeller.

Propulsive efficiency of an aircraft turbojet engine is the ratio of the power produced to propel the aircraft and the thermal energy of the fuel released during the combustion process.

Propulsive power is the power developed from the thrust of the aircraft gas turbines and is the propulsive force (thrust) times the distance this force acts on the aircraft per unit time, that is, the thrust times the aircraft velocity.

Pseudo-reduced specific volume v_R is used with the generalized compressibility chart to determine the third property when P and v, or T and v, are given instead of P and T.

Psychrometric chart presents the properties of atmospheric air at a specified pressure and two independent intensive properties. The psychrometric chart is a plot of absolute humidity versus dry-bulb temperature and shows lines of constant relative humidity, wet-bulb temperature, specific volume, and enthalpy for the atmospheric air.

Pump is a steady flow device used to increase the pressure of a liquid while compressors increase the pressure of gases.

Pump efficiency is defined as the ratio of the mechanical energy increase of the fluid as it flows through the pump to the mechanical energy input to the pump.

Pure substance is a substance that has a fixed chemical composition throughout.

***P-v-T* surface** is a three-dimensional surface in space which represents the *P-v-T* behavior of a substance. All states along the path of a quasi-equilibrium process lie on the *P-v-T* surface since such a process must pass through equilibrium states. The single-phase regions appear as curved surfaces on the *P-v-T* surface, and the two-phase regions as surfaces perpendicular to the *P-T* plane.

Quality x is the ratio of the mass of vapor to the total mass of a saturated mixture. The quality lies in the range $0 \le x \le 1$.

Quality of energy is a measure of how much of the energy can be converted to work. More of energy at high temperatures can be converted to work. Therefore, the higher the temperature, the higher the quality of the energy.

Quasi-equilibrium process (see quasi-static process).

Quasi-static, or **quasi-equilibrium, process** is a process which proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times**.** A quasi-equilibrium process can be viewed as a sufficiently slow process that allows the system to adjust itself internally so that properties in one part of the system do not change any faster than those at other parts.

Radiation is the transfer of energy due to the emission of electromagnetic waves (or photons).

Ramjet engine is a properly shaped duct with no compressor or turbine, and is sometimes used for high-speed propulsion of missiles and aircraft. The pressure rise in the engine is provided by the ram effect of the incoming high-speed air being rammed against a barrier. Therefore, a ramjet engine needs to be brought to a sufficiently high speed by an external source before it can be fired.

rankine is the temperature unit for the Rankine scale in the English system.

Rankine cycle is the ideal cycle for vapor power plants. The ideal Rankine cycle does not involve any internal irreversibilities and consists of the following four processes:

1-2 Isentropic compression in a pump,
2-3 Constant pressure heat addition in a boiler,
3-4 Isentropic expansion in a turbine,
4-1 Constant pressure heat rejection in a condenser.

Rankine scale, named after William Rankine (1820–1872), is the thermodynamic temperature scale in the English system. The temperature unit on this scale is the rankine**,** which is designated by R.

Raoult's law applies to a gas-liquid mixture when a gas is highly soluble in a liquid (such as ammonia in water) and relates the mole fractions of the species of a two-phase mixture in the liquid and gas phases in an approximate manner.

Rarefied gas flow theory applies to a substance in which the mean free path of its molecules is large compared to the characteristic length of the systems such that the impact of individual molecules should be considered, and the substance cannot be modeled as a continuum.

Rate form is the form of a quantity expressed per unit time.

Rate of heat transfer is the amount of heat transferred per unit time.

Rayleigh flow is the steady one-dimensional flow of an ideal gas with constant specific heats through a constant–area duct with heat transfer, but with negligible friction.

Rayleigh line is the locus of all states for frictionless flow in a constant-area duct with heat transfer plotted on an h-s diagram and results from combining the conservation of mass and momentum equations into a single equation.

Reactants are the components that exist before the reaction in a combustion process.

Reciprocity relation shows that the inverse of a partial derivative is equal to its reciprocal.

$$\left(\frac{\partial x}{\partial z}\right)_y = \frac{1}{\left(\partial z / \partial x\right)_y}$$

Reduced pressure P_R is the ratio of the pressure to the critical pressure.

Reduced temperature T_R is the ratio of the temperature to the critical temperature.

Reference state is chosen to assign a value of zero for a convenient property or properties at that state.

Refrigerant is the working fluid used in the refrigeration cycle.

Refrigerator is a cyclic device which causes the transfer of heat from a low-temperature region to a high-temperature region. The objective of a refrigerator is to maintain the refrigerated space at a low temperature by removing heat from it.

Refrigerator coefficient of performance is the efficiency of a refrigerator, denoted by COP_R, and expressed as desired output divided by required input or $COP_R = Q_L/W_{net, in}$.

Regeneration is the process of transferring energy with in a cycle from a working fluid in a high temperature in part of the cycle to a lower temperature part of the cycle to reduce the amount of external heat transfer required to drive the cycle.

Regenerator (see feedwater heater)

Regenerator effectiveness is the extent to which a regenerator approaches an ideal regenerator and is defined as the ratio of the heat transfer to the compressor exit gas to the maximum possible heat transfer to the compressor exit gas.

Reheat Rankine cycle is a modification of the Rankine cycle in which the steam is expanded in the turbine in two stages and reheated in between. Reheating is a practical solution to the excessive moisture problem in the lower-pressure stages of turbines, and it is used frequently in modern steam power plants.

Reheating is a technique used to increase the expansion work for the gas turbine cycle. The expansion process is completed in stages while reheating the working fluid between stages. Since the steady-flow compression work is proportional to the specific volume of the flow, the specific volume of the working fluid should be as large as possible during a expansion process.

Relative density (see specific gravity)

Relative humidity is the ratio of the amount of moisture (water) in atmospheric air at a given temperature to the maximum amount the air can hold at the same temperature. The

relative humidity can be expressed as the ratio of the vapor pressure to the saturation pressure of water at that temperature.

Relative pressure P_r is defined as the quantity exp*(s°/R)* and is a dimensionless quantity that is a function of temperature only since *s*° depends on temperature alone. Relative pressure is used to relate the ratio of final to initial pressure in isentropic processes of ideal gases where variable specific heats are required.

Relative specific volume v_r is defined as the quantity T/P_r and is a function of temperature only. P_r is the relative pressure. Relative specific volume is used to relate the ratio of final to initial volume in isentropic processes of ideal gases where variable specific heats are required.

Reversed Carnot cycle is a reversible cycle in which all four processes that comprise the Carnot cycle are reversed during operation. Reversing the cycle will also reverse the directions of any heat and work interactions. The result is a cycle that operates in the counterclockwise direction. The reversed Carnot cycle is the Carnot refrigeration cycle.

Reversible adiabatic compression is the process in which a working fluid is compressed (decreases in volume) reversibly and adiabatically.

Reversible adiabatic expansion is the process in which a working fluid expands (increases in volume) reversibly and adiabatically.

Reversible isothermal compression is the process in which the temperature is held constant while a working fluid is compressed (decreases in volume) reversibly.

Reversible isothermal expansion is the process in which the temperature is held constant while a working fluid expands (increases in volume) reversibly.

Reversible process is defined as a process that can be reversed without leaving any trace on the surroundings. Reversible processes are idealized processes, and they can be approached but never reached in reality.

Reversible steady-flow work is defined as the negative of the integral of the specific volume-pressure product. The larger the specific volume, the larger the reversible work produced or consumed by the steady-flow device. Therefore, every effort should be made to keep the specific volume of a fluid as small as possible during a compression process to minimize the work input and as large as possible during an expansion process to maximize the work output.

Reversible work W_{rev} is defined as the maximum amount of useful work that can be produced (or the minimum work that needs to be supplied) as a system undergoes a process between the specified initial and final states. Reversible work is determined from

the exergy balance relations by setting the exergy destroyed equal to zero. The work W in that case becomes the reversible work.

Rocket is a device where a solid or liquid fuel and an oxidizer react in the combustion chamber. The high-pressure combustion gases are then expanded in a nozzle. The gases leave the rocket at very high velocities, producing the thrust to propel the rocket.

Saturated air is air which can hold no more moisture at its state. Any moisture introduced into saturated air will condense.

Saturated liquid is a liquid that is about to vaporize.

Saturated liquid line is the saturated liquid states connected by a line that meets the saturated vapor line at the critical point, forming a dome.

Saturated liquid–vapor mixture (wet region) is a mixture of the liquid and vapor phases that coexist in equilibrium.

Saturated liquid–vapor mixture region is all the states that involve both the liquid and vapor phases in equilibrium and are located under the dome.

Saturated vapor is a vapor that is about to condense.

Saturated vapor line is the saturated vapor states connected by a line that meets the saturated liquid line at the critical point, forming a dome.

Saturation pressure P_{sat} is called the pressure at which a pure substance changes phase at a given temperature.

Saturation temperature T_{sat} is the temperature at which a pure substance changes phase at a given pressure.

Scramjet engine is essentially a ramjet in which air flows through at supersonic speeds (speeds above the speed of sound).

Secondary dimensions, or **derived dimensions**, such as velocity, energy E, and volume V, are expressed in terms of the primary dimensions.

Secondary units are expressed in terms of the primary units.

Second law distinction between heat transfer and work states that an energy interaction that is accompanied by entropy transfer is heat transfer, and an energy interaction that is not accompanied by entropy transfer is work.

Second-law efficiency η_{II} is the ratio of the actual thermal efficiency to the maximum possible (reversible) thermal efficiency under the same conditions. The second-law efficiency of various steady-flow devices can be determined from its general definition, η_{II} = (exergy recovered)/(exergy supplied). The second law efficiency measures how well the performance of actual processes approximate the performance of the corresponding reversible processes. This enables us to compare the performance of different devices that are designed to do the same task on the basis of their efficiencies. The better the design, the lower the irreversibilities and the higher the second-law efficiency.

Second law of thermodynamics (increase of entropy principle) is expressed as the entropy of an isolated system during a process always increases or, in the limiting case of a reversible process, remains constant. In other words, the entropy of an isolated system never decreases. It also asserts that energy has quality as well as quantity, and actual processes occur in the direction of decreasing quality of energy.

Seebeck effect results when two wires made from different metals are joined at both ends (junctions), form a closed circuit, and one of the ends is heated. As a result of the applied heat a current flows continuously in the circuit. The Seebeck effect is named in honor of Thomas Seebeck, who made its discovery in 1821.

Sensible energy is the portion of the internal energy of a system associated with the kinetic energies of the molecules.

Shaft work is energy transmitted by a rotating shaft and is the related to the torque **T** applied to the shaft and the number of revolutions of the shaft per unit time.

Shock angle (wave angle) is the angle at which straight oblique shocks are deflected relative to the oncoming flow as the flow comes upon a body.

Shock wave is an abrupt change over a very thin section of flow in which the flow transitions from supersonic to subsonic flow. This abrupt change in the flow causes a sudden drop in velocity to subsonic levels and a sudden increase in pressure. Flow through the shock is highly irreversible; and, thus, it cannot be approximated as isentropic.

Simple compressible system is a system in which there is the absence of electrical, magnetic, gravitational, motion, and surface tension effects. These effects are due to external force fields and are negligible for most engineering problems.

Simple cooling is the process of lowering the temperature of atmospheric air when no moisture is removed.

Simple heating is the process of raising the temperature of atmospheric air when no moisture is added.

Simultaneous reactions are chemical reactions that involve two or more reactions occurring at the same time.

Sling psychrometer is a device with both a dry-bulb thermometer and a wet-bulb temperature mounted on the frame of the device so that when it is swung through the air both the wet-and dry-bulb temperatures can be read simultaneously.

Solid phase has molecules arranged in a three-dimensional pattern (lattice) that is repeated throughout. Because of the small distances between molecules in a solid, the attractive forces of molecules on each other are large and keep the molecules at fixed positions.

Solubility represents the maximum amount of solid that can be dissolved in a liquid at a specified temperature.

Sonic flow occurs when a flow has a Mach number $M = 1$.

Sonic speed (see speed of sound)

Spark-ignition (SI) engines are reciprocating engines in which the combustion of the air–fuel mixture is initiated by a spark plug.

Specific gravity, or **relative density,** is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C, for which the density is 1000 kg/m^3).

Specific heat is defined as the energy required to raise the temperature of a unit mass of a substance by one degree. In general, this energy will depend on how the process is executed.

Specific heat at constant pressure C_p is the energy required to raise the temperature of the unit mass of a substance by one degree as the pressure is maintained constant. C_p is a measure of the variation of enthalpy of a substance with temperature. C_p can be defined as the change in the enthalpy of a substance per unit change in temperature at constant pressure.

Specific heat at constant volume C_v is the energy required to raise the temperature of the unit mass of a substance by one degree as the volume is maintained constant. C_v is related to the changes in internal energy. It would be more proper to define C_v as the change in the internal energy of a substance per unit change in temperature at constant volume.

Specific heat ratio k is defined as the ratio C_p/C_v.

Specific heats for solids and liquids, or incompressible substances, are equal.

Specific humidity (see absolute humidity)

Specific properties are extensive properties per unit mass. Some examples of specific properties are specific volume ($v=V/m$) and specific total energy ($e= E/m$).

Specific volume is the reciprocal of density and is defined as the volume per unit mass.

Specific weight *w* is the weight of a unit volume of a substance and is determined from the product of the local acceleration of gravity and the substance density.

Speed of sound (sonic speed) is the speed at which an infinitesimally small pressure wave travels through a medium.

Spray pond is a pond where warm water is sprayed into the air and is cooled by the air as it falls into the pond. Spray ponds require 25 to 50 times the area of a cooling tower because water loss due to air drift is high.

Spring work is the work done to change the length of a spring.

Stable form of an element is the chemically stable form of that element at 25°C and 1 atm. Nitrogen, for example, exists in diatomic form (N_2) at 25°C and 1 atm. Therefore, the stable form of nitrogen at the standard reference state is diatomic nitrogen N_2 , not monatomic nitrogen N.

Stagnation enthalpy (total enthalpy) is the sum of the enthalpy and kinetic energy of the flow and represents the total energy of a flowing fluid stream per unit mass. It represents the enthalpy of a fluid when it is brought to rest adiabatically with no work. The stagnation enthalpy equals the static enthalpy when the kinetic energy of the fluid is negligible.

Stagnation pressure is the pressure a fluid attains when brought to rest isentropically. For ideal gases with constant specific heats, the stagnation pressure is related to the static pressure of the fluid through the isentropic process equation relating pressure and temperature.

Stagnation properties are the properties of a fluid at the stagnation state. These properties are called stagnation temperature, stagnation pressure, stagnation density, etc. The stagnation state and the stagnation properties are indicated by the subscript 0.

Stagnation temperature (total temperature) is the temperature an ideal gas will attain when it is brought to rest adiabatically.

Standard reference state for the properties of chemical components is chosen as 25°C (77°F) and 1 atm. Property values at the standard reference state are indicated by a superscript (°) (such as $h°$and $u°$).

Standard-state Gibbs function change is the difference between the sum products of the stoichiometric coefficients and the Gibbs function of a component at 1 atm pressure and temperature T for the products and reactants in the stoichiometric reaction.

State is the condition of a system not undergoing any change gives a set of properties that completely describes the condition of that system. At this point, all the properties can be measured or calculated throughout the entire system.

State postulate specifies the number of properties required to fix the state of a system**:** The state of a simple compressible system is completely specified by two independent, intensive properties.

Static enthalpy is the ordinary enthalpy of the flow measured at the fluid state.

Stationary systems are closed systems whose velocity and elevation of the center of gravity remain constant during a process**.**

Statistical thermodynamics, an approach to thermodynamics more elaborate than classical thermodynamics, is based on the average behavior of large groups of individual particles.

Steady implies no change with time. The opposite of steady is unsteady, or transient.

Steady-flow conservation of mass states that the total rate of mass entering a control volume is equal to the total rate of mass leaving it.

Steady-flow devices operate for long periods of time under the same conditions.

Steady-flow process is a process during which a fluid flows through a control volume steadily. That is, the fluid properties can change from point to point within the control volume, but at any point, they remain constant during the entire process. During a steady-flow process, no intensive or extensive properties within the control volume change with time.

Steam generator is the combination of a boiler and a heat exchanger section (the superheater), where steam is superheated.

Steam power plant is an external-combustion engine in which steam (water) is the working fluid. That is, combustion takes place outside the engine, and the thermal energy released during this process is transferred to the steam as heat. A turbine in the power plant converts some of the energy of the steam into rotating shaft work.

Stefan-Boltzmann law gives the maximum rate of radiation that can be emitted from a surface as product of the Stefan-Boltzmann constant, surface area, and the fourth power of the surface absolute temperature.

Stirling cycle is made up of four totally reversible processes:

1-2 *T constant* expansion (heat addition from the external source),
2-3 *v constant* regeneration (internal heat transfer from the working fluid to the regenerator),
3-4 *T constant* compression (heat rejection to the external sink),
4-1 *v constant* regeneration (internal heat transfer from the regenerator back to the working fluid).

Stoichiometric air is the minimum amount of air, also called theoretical air, needed for the complete combustion of a fuel. When a fuel is completely burned with theoretical air, no uncombined oxygen will be present in the product gases.

Stoichiometric coefficients are the mole numbers in the stoichiometric (theoretical) reaction.

Stoichiometric combustion (theoretical combustion) is the ideal combustion process during which a fuel is burned completely with theoretical air.

Stoichiometric (theoretical) reaction is the balanced reaction equation for a chemical equilibrium reaction.

Stream exergy (see flow exergy)

Stroke is the distance between the top dead center and the bottom dead center and is the largest distance that the piston can travel in one direction within a cylinder.

Strong oblique shocks are straight oblique shocks that have the larger possible values of the shock angles for deflection angles less than the maximum deflection angle.

Subcooled liquid has a temperature less than the saturation temperature corresponding to the pressure.

Sublimation is the process of passing from the solid phase directly into the vapor phase.

Sublimation line separates the solid and vapor regions on the phase diagram.

Subsonic flow occurs when a flow has a Mach number $M < 1$.

Superheated vapor is a vapor that is not about to condense (not a saturated vapor). A superheated vapor has a temperature greater than the saturation temperature for the pressure.

Superheated vapor region is all the superheated states located to the right of the saturated vapor line and above the critical temperature line.

Supersaturated steam is steam that exists in the wet region without containing any liquid. This phenomenon would exist due to the supersaturation process.

Supersaturation is the phenomenon owing to steam flowing through a nozzle with the high velocities and exiting the nozzle in the saturated region. Since the residence time of the steam in the nozzle is small, and there may not be sufficient time for the necessary heat transfer and the formation of liquid droplets, the condensation of the steam may be delayed for a little while.

Supersonic flow occurs when a flow has a Mach number $M > 1$.

Surface tension is the force per unit length used to overcome the microscopic forces between molecules at the liquid–air interfaces.

Surrounding is the mass or region outside the thermodynamic system.

Surroundings are everything outside the system boundaries.

Surroundings work is the work done by or against the surroundings during a process.

Swamp coolers (see evaporative coolers)

***Tds* relations** relate the *Tds* product to other thermodynamic properties. The first Gibbs relation is $Tds = du + Pdv$. The second Gibbs relation is $Tds = dh - vdP$.

Theoretical air (see stoichiometric air)

Theoretical combustion (see stoichiometric combustion)

Therm is defined as an amount of energy produced by the combustion of natural gas and is equal to 29.3 kWh.

Thermal conductivity is defined as a measure of the ability of a material to conduct heat.

Thermal efficiency η_{th} is the ratio of the net work produced by a heat engine to the total heat input, $\eta_{th} = W_{net}/Q_{in}$.

Thermal efficiency of a heat engine is the fraction of the thermal energy supplied to a heat engine that is converted to work.

Thermal efficiency of a power plant is defined as the ratio of the shaft work output of the turbine to the heat input to the working fluid.

Thermal energy is the sensible and latent forms of internal energy.

Thermal energy reservoir, or just a reservoir is a hypothetical body with a relatively large thermal energy capacity (mass specific heat) that can supply or absorb finite amounts of heat without undergoing any change in temperature.

Thermal equilibrium means that the temperature is the same throughout the entire system.

Thermodynamic equilibrium is a condition of a system in which all the relevant types of equilibrium are satisfied.

Thermodynamic system, or simply a **system,** is defined as a quantity of matter or a region in space chosen for study.

Thermodynamic temperature scale is a temperature scale that is independent of the properties of the substances that are used to measure temperature. This temperature scale is called the Kelvin scale**,** and the temperatures on this scale are called absolute temperatures. On the Kelvin scale, the temperature ratios depend on the ratios of heat transfer between a reversible heat engine and the reservoirs and are independent of the physical properties of any substance.

Thermodynamics can be defined as the science of *energy*. Energy can be viewed as the ability to cause changes. The name *thermodynamics* stems from the Greek words *therme* (heat) and *dynamis* (power), which is most descriptive of the early efforts to convert heat into power. Today the same name is broadly interpreted to include all aspects of energy and energy transformations, including power production, refrigeration, and relationships among the properties of matter.

Thermoelectric circuit is a circuit that incorporates both thermal and electrical effects.

Thermoelectric generator uses the Seebeck effect as the basis for thermoelectric power generation.

Thermoelectric refrigerator is a refrigerator using electric energy to directly produce cooling without involving any refrigerants and moving parts.

Thermo-mechanical exergy is the exergy associated with the conversion of thermal energy to mechanical energy and disregards any mixing and chemical reactions.

Third law of thermodynamics states that the entropy of a pure crystalline substance at absolute zero temperature is zero.

Throat is the smallest flow area of a converging-diverging nozzle.

Throttling valves are any kind of flow-restricting devices that cause a significant pressure drop in a flowing fluid. Some familiar examples are ordinary adjustable valves, capillary tubes, and porous plugs. Unlike turbines, they produce a pressure drop without involving any work. The pressure drop in the fluid is often accompanied by a large drop in temperature, and for that reason throttling devices are commonly used in refrigeration and air-conditioning applications. The magnitude of the temperature drop (or, sometimes, the temperature rise) during a throttling process is governed by a property called the Joule-Thomson coefficient, which is discussed in Chapter 12.

Thrust is the unbalanced force developed in a turbojet engine that is caused by the difference in the momentum of the low-velocity air entering the engine and the high-velocity exhaust gases leaving the engine, and it is determined from Newton's second law.

Ton of refrigeration is the capacity of a refrigeration system equivalent to the energy that can freeze 1 ton (2000 lbm) of liquid water at 0°C (32°F) into ice at 0°C in 24 h. One ton of refrigeration is equivalent to 211 kJ/min or 200 Btu/min (12,000 Btu/h). The cooling load of a typical 200-m^2 (2153-ft^2) residence is in the 3-ton (10-kW) range.

Top dead center TDC is the position of the piston when it forms the smallest volume in the cylinder.

Topping cycle is a power cycle operating at high average temperatures that rejects heat to a power cycle operating at lower average temperatures.

Total differential of a dependent variable in terms of its partial derivatives with respect to the independent variables is expressed as, for $z = z\,(x, y)$,

$$dz = \left(\frac{\partial z}{\partial x}\right)_y dx + \left(\frac{\partial z}{\partial y}\right)_x dy$$

Total energy E of a system is the sum of the numerous forms of energy such as thermal, mechanical, kinetic, potential, electric, magnetic, chemical, and nuclear, and their

constituents. The total energy of a system on a unit mass basis is denoted by *e* and is defined as *E/m*.

Total energy of a flowing fluid is the sum of the enthalpy, kinetic, and potential energies of the flowing fluid.

Total enthalpy (see stagnation enthalpy)

Total temperature (see stagnation temperature)

Totally reversible process, or simply **reversible process,** involves no irreversibilities within the system or its surroundings. A totally reversible process involves no heat transfer through a finite temperature difference, no non-quasi-equilibrium changes, and no friction or other dissipative effects.

Transport energy (see flow work).

Transsonic flow occurs when a flow has a Mach number $M \cong 1$.

Trap is a device that allows condensed steam to be routed to another heater or to the condenser. A trap allows the liquid to be throttled to a lower-pressure region but traps the vapor. The enthalpy of steam remains constant during this throttling process.

Triple line is the locus of the conditions where all three phases of a pure substance coexist in equilibrium. The states on the triple line of a substance have the same pressure and temperature but different specific volumes.

Triple point of water is the state at which all three phases of water coexist in equilibrium.

Turbine is a device that produces shaft work due to a decrease of enthalpy, kinetic, and potential energies of a flowing fluid.

Turbine efficiency is defined as the ratio of the mechanical energy output of the turbine to the mechanical energy decrease of the fluid flow through the turbine.

Turbine firing temperature (see turbine inlet temperature)

Turbine inlet temperature (turbine firing temperature) is the temperature of the working fluid at the turbine inlet. Increasing the turbine inlet temperature has been the primary approach taken to improve gas-turbine efficiency. These increases have been made possible by the development of new materials and the innovative cooling techniques for the critical components such as coating the turbine blades with ceramic

layers and cooling the blades with the discharge air from the compressor or injected steam.

Turbofan (or fan-jet) engine is the most widely used engine in aircraft propulsion. In this engine a large fan driven by the turbine forces a considerable amount of air through a duct (cowl) surrounding the engine. The fan exhaust leaves the duct at a higher velocity, enhancing the total thrust of the engine significantly. A turbofan engine is based on the principle that for the same power, a large volume of slower-moving air will produce more thrust than a small volume of fast-moving air. The first commercial turbofan engine was successfully tested in 1955.

Turboprop engine uses propellers powered by the aircraft turbine to produce the aircraft propulsive power.

Turning angle (deflection angle) is the angle at which straight oblique shocks are deflected as flow comes upon a body, like that produced when a uniform supersonic flow impinges on a slender, two-dimensional wedge.

Two-stroke engines execute the entire cycle in just two strokes: the power stroke and the compression stroke.

Uniform implies no change with location over a specified region.

Uniform-flow process involves the following idealization: The fluid flow at any inlet or exit is uniform and steady, and thus the fluid properties do not change with time or position over the cross section of an inlet or exit. If they do change with time, the fluid properties are averaged and treated as constants for the entire process.

Units are the arbitrary magnitudes assigned to the dimensions.

Unity conversion ratios are ratios of units that are based on the definitions of the units in question that are identically equal to 1, are unitless, and can be inserted into any calculation to properly convert units.

Universal gas constant R_u is the same for all substances and its value is 8.314 kJ/kmol·K and 1.986 Btu/lbmol·R.

Unrestrained expansion of a gas is the process of the free expansion of gas, unrestrained by a moving boundary such as the rapid expansion of air from a balloon that has just been burst.

Unsteady-flow, or transient-flow, processes are processes that involve changes within a control volume with time.

Useful pumping power is the rate of increase in the mechanical energy of a fluid as it flows through a pump.

Useful work W_u is the difference between the actual work W and the surroundings work W_{surr}.

Useful work potential is the maximum possible work that a system will deliver as it undergoes a reversible process from the specified initial state to the state of its environment, that is, the dead state.

Utilization factor is a measure of the energy transferred to the steam in the boiler of a steam power plant that is utilized as either process heat or electric power. Thus the utilization factor is defined for a cogeneration plant as the ratio of the sum of the net work output and the process heat to the total heat input.

Vacuum cooling is a way to cool a substance by reducing the pressure of the sealed cooling chamber to the saturation pressure at the desired low temperature and evaporating some water from the products to be cooled. The heat of vaporization during evaporation is absorbed from the products, which lowers the product temperature.

Vacuum freezing is the application of vacuum cooling when the pressure (actually, the vapor pressure) in the vacuum chamber is dropped below 0.6 kPa, the saturation pressure of water at 0°C.

Vacuum pressure is the pressure below atmospheric pressure and is measured by a vacuum gage that indicates the difference between the atmospheric pressure and the absolute pressure.

van der Waals equation of state is one of the earliest attempts to correct the ideal gas equation for real gas behavior. It is given by

$$(P + \frac{a}{v^2})(v - b) = RT$$

where the constants a and b are functions of the critical constants of the gas.

van't Hoff equation is the expression of the variation of the chemical equilibrium constant with temperature in terms of the enthalpy of reaction at temperature T.

Vapor implies a gas that is not far from a state of condensation.

Vapor-compression refrigeration cycle is the most frequently used refrigeration cycle and involves four main components: a compressor, a condenser, an expansion valve, and an evaporator.

Vapor pressure is usually considered to be the partial pressure of water vapor in atmospheric air.

Vaporization line separates the liquid and vapor regions on the phase diagram.

Venturi nozzle is a duct in which the flow area first decreases and then increases in the direction of the flow and is used strictly for incompressible flow.

Virial equations of state is an equation of state of a substance expressed in a series form as

$$P = RT/v + a(T)/v^2 + b(T)/v^3 + c(T)/v^4 + d(T)/v^5 + \ldots$$

where the coefficients a(T), b(T), c(T), and so on, are functions of temperature alone and are called *virial coefficient*s.

Volume expansivity (also called the coefficient of volumetric expansion) relates how volume changes when temperature changes when pressure is held constant.

Volume flow rate is the volume of the fluid flowing through a cross section per unit of time.

Volume fraction of a gas component in a gas mixture is the ratio of the component volume to the mixture volume. Note that for an ideal-gas mixture, the mole fraction, the pressure fraction, and the volume fraction of a component are identical.

Waste heat is energy that must be dissipated to the atmosphere from a process such as the heat transferred from condensing steam in the condenser of a steam power plant.

Wasted work potential represents irreversibility as the energy that could have been converted to work but was not and is the lost opportunity to do work.

Water heater efficiency is defined as the ratio of the energy delivered to a house by hot water to the energy supplied to the water heater.

Wave angle (see shock angle)

Weak oblique shocks are straight oblique shocks that have the smaller of the possible values of the shock angles for deflection angles less than the maximum deflection angle.

Weight is the gravitational force applied to a body, and its magnitude is determined from Newton's second law.

Wet-bulb temperature is temperature measured by using a thermometer whose bulb is covered with a cotton wick saturated with water and blowing air over the wick.

Wet cooling tower is essentially a semienclosed evaporative cooler.

Wet region (see saturated liquid–vapor mixture region)

Wilson line is the locus of points where condensation will take place regardless of the initial temperature and pressure as steam flows through a high-velocity nozzle. The Wilson line is often approximated by the 4 percent moisture line on the *h*-*s* diagram for steam. Therefore, steam flowing through a high-velocity nozzle is assumed to begin condensation when the 4 percent moisture line is crossed.

Work is the energy transfer associated with a force acting through a distance.

Work transfer is the energy in the form of work that is transferred across a system boundary.

Working fluid is the fluid to and from which heat and work is transferred while undergoing a cycle in heat engines and other cyclic devices.

Zeroth law of thermodynamics states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other. By replacing the third body with a thermometer, the zeroth law can be restated as two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact.