THERMODYNAMIC GLOSSARY

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

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-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

Auto ignition: is the premature ignition of the fuel produces an audible noise, which is called engine knock

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

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

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.

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

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.

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.

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.

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.

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

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

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

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).

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.

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 practically in all problems, except some specialized ones.

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

Control volume, or 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.

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.

Density: is defined as *mass per unit volume*.

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

Dimensions: are any physical characterizations of a quantity.

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

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.

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).

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

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)

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

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

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.

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.

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

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

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.

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.

Heat engines: are devices designed for the purpose of converting other forms of energy (usually in the form of heat) to work.

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 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.

Incompressible substances: liquids and solids, have densities that have negligible variation with pressure

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

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.

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

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

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 (or 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.

Isothermal process: is a process during which the temperature *T* remains 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)."

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 $KE = m V^2/2$.

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

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

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.

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.

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 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.

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

Metric SI: (from *Le System International d' Unit*), 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.

Multistage compression with inter-cooling: 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.

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.

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

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

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

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

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

Phase equilibrium: when a system involves two phases is established when the mass of each phase reaches an equilibrium level and stays there.

Piezoelectric (or press-electric) effect: is the emergence of an electric potential in a crystalline substance when subjected to mechanical pressure. This phenomenon,

first discovered by brothers Pierre and Jacques Curie in 1880, forms the basis for the widely used **strain-gage** pressure transducers

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.

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

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.

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.

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.

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

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.

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 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.

Regeneration: is a process during which heat is transferred to a thermal energy storage device (called a regenerator) during one part of the cycle and is transferred back to the working fluid during another part of the cycle

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.

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.

Scramjet engine: is essentially a ramjet in which air flows through at supersonic 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.

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.

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 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.

State: of a system not undergoing any change gives a set of properties that completely describes the condition of a 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.

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 devices: operate for long periods of time under the same conditions.

Steady-flow process: is defined as 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 fixed point they remain the same during the entire process.

Stirling cycle: is made up of four totally reversible processes

Surroundings: is the mass or region outside the thermodynamic system.

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

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.

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 mat ter.

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 any substance or substances.

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.*

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

Uniform: implies no change with location over a specified region

Units: are the arbitrary magnitudes assigned to the dimensions.

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.

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

Work: which is a form of energy, can simply be defined as force times distance.

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.