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Engineering Thermodynamics-I

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THE SCOPE OF THERMODYNAMICS

- The science of thermodynamics was born in the nineteenth century of the need to describe the operation of steam engines and to set forth the limits of what they can accomplish. Thus the name itself denotes **power developed from heat**, with obvious application to heat engines, of which the steam engine was the initial example.
- However, the principles observed to be valid for engines are readily generalized, and are known as the **first and second laws of thermodynamics**.
- Thus thermodynamics shares with **mechanics and electromagnetism** a basis in primitive laws.
- The **chemical engineer** copes with a particularly wide variety of problems.
- Among them are **calculation of heat and work requirements for physical and chemical processes**, and the determination of **equilibrium conditions for chemical reactions and for the transfer of chemical species between phases**.

THE SCOPE OF THERMODYNAMICS

- Thermodynamic considerations do not establish the *rates* of chemical or physical processes.
- Rates depend on driving force and resistance. Although driving forces are thermodynamic variables, resistances are not. Neither can thermodynamics, a macroscopic-property formulation, reveal the microscopic (molecular) mechanisms of physical or chemical processes. On the other hand, knowledge of the microscopic behavior of matter can be useful in the calculation of thermodynamic properties.

Applications of Thermodynamics

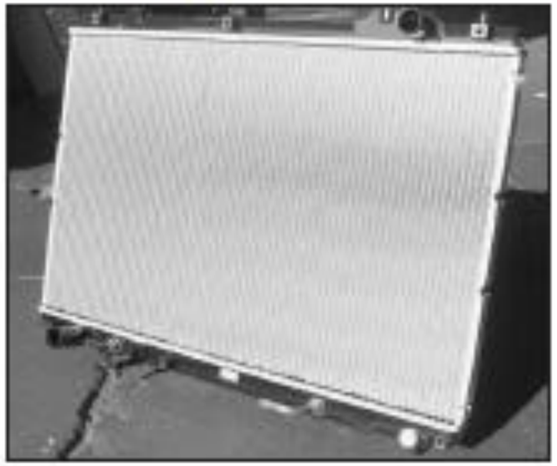
- The chemical engineer deals with many chemical species, and experimental data are often lacking.
- This has led to development of "generalized correlations“ that provide property estimates in the absence of data.
- The application of thermodynamics to any real problem starts with the identification of a particular body of matter as the focus of attention.
- This body of matter is called the *system*, and its thermodynamic state is defined by a few measurable macroscopic properties.
- These depend on the fundamental *dimensions* of science, of which length, time, mass, temperature, and amount of substance are of interest here.
- The following figures illustrate the common applications of Thermodynamics

Applications of Thermodynamics

The human body

Air conditioning systems

Airplanes



Car radiators

Power plants

Refrigeration systems

1/ MEASURES OF AMOUNT OR SIZE

Three measures of amount or size are in common use:

-Mass, ***m*** -Number of moles, ***n*** -Total volume, ***Vt***

These measures for a specific system are in direct proportion to one another. Mass, *a primitive* without definition, may be divided by the molar mass M, commonly called the molecular weight, to yield number of moles:

$$n = \frac{m}{M} \qquad \text{or} \qquad m = Mn$$

Total volume, representing the size of a system, is a defined quantity given as the product of three lengths. It may be divided by the mass or number of moles of the system to yield *specific* or *molar volume:*

- Specific volume: $V \equiv \dfrac{V^t}{m}$ or $V^t = mV$
- Molar volume: $V \equiv \dfrac{V^t}{n}$ or $V^t = n\,V$

2/ FORCE

- The SI unit of force is the *newton*, symbol N, derived from Newton's second law, which expresses force *F* as the product of mass *m* and acceleration *a:*

$$F = ma$$

- The newton is defined as the force which when applied to a mass of 1 kg produces an acceleration of 1 m s^{-2}; thus the newton is a *derived* unit representing *1* kg m s^{-2}.

- Since force and mass are different concepts, a kilogram *force* and a kilogram *mass* are different quantities, and their units do not cancel one another. When an equation contains both units, ***kgf*** and kg, the dimensional constant *g*, must also appear in the equation to make it dimensionally correct.

3/ TEMPERATURE

Although we are familiar with temperature as a measure of "hotness" or "coldness," it is not easy to give an exact definition for it. Based on our physiological sensations, we express the level of temperature qualitatively with words like *freezing cold*, *cold*, *warm*, *hot*, and *red-hot*. However, we cannot assign numerical values to temperatures based on our sensations alone.

Furthermore, our senses may be misleading. A metal chair, for example, will feel much colder than a wooden one even when both are at the same temperature.

Fortunately, several properties of materials change with temperature in a *repeatable* and *predictable* way, and this forms the basis for accurate temperature measurement. The commonly used mercury-in-glass thermometer, for example, is based on the expansion of mercury with temperature. Temperature is also measured by using several other temperature-dependent properties.

3.1. Temperature Scales

Temperature scales enable us to use a common basis for temperature measurements, and several have been introduced throughout history. All temperature scales are based on some easily reproducible states such as the freezing and boiling points of water, which are also called the *ice point* and the steam point, respectively. The following equations are commonly used to temperature conversion

Celsius scale: For the Celsius scale, the ice point (freezing point of water saturated with air at standard atmospheric pressure) is zero, and the steam point (boiling point of pure water at standard atmospheric pressure) is 100.

Kelvin scale temperatures are given the symbol T; Celsius temperatures, given the symbol t, are defined in relation to Kelvin temperatures:

$$t\,°\mathrm{C} = T\ \mathrm{K} - 273.15$$

Rankine scale and the Fahrenheit scale. The Rankine scale is an absolute scale directly related to the Kelvin scale by:

$$T(\mathrm{R}) = 1.8\,T\ \mathrm{K}$$

Basic concepts

The Fahrenheit scale is related to the Rankine scale by an equation analogous to the relation between the Celsius and Kelvin scales:

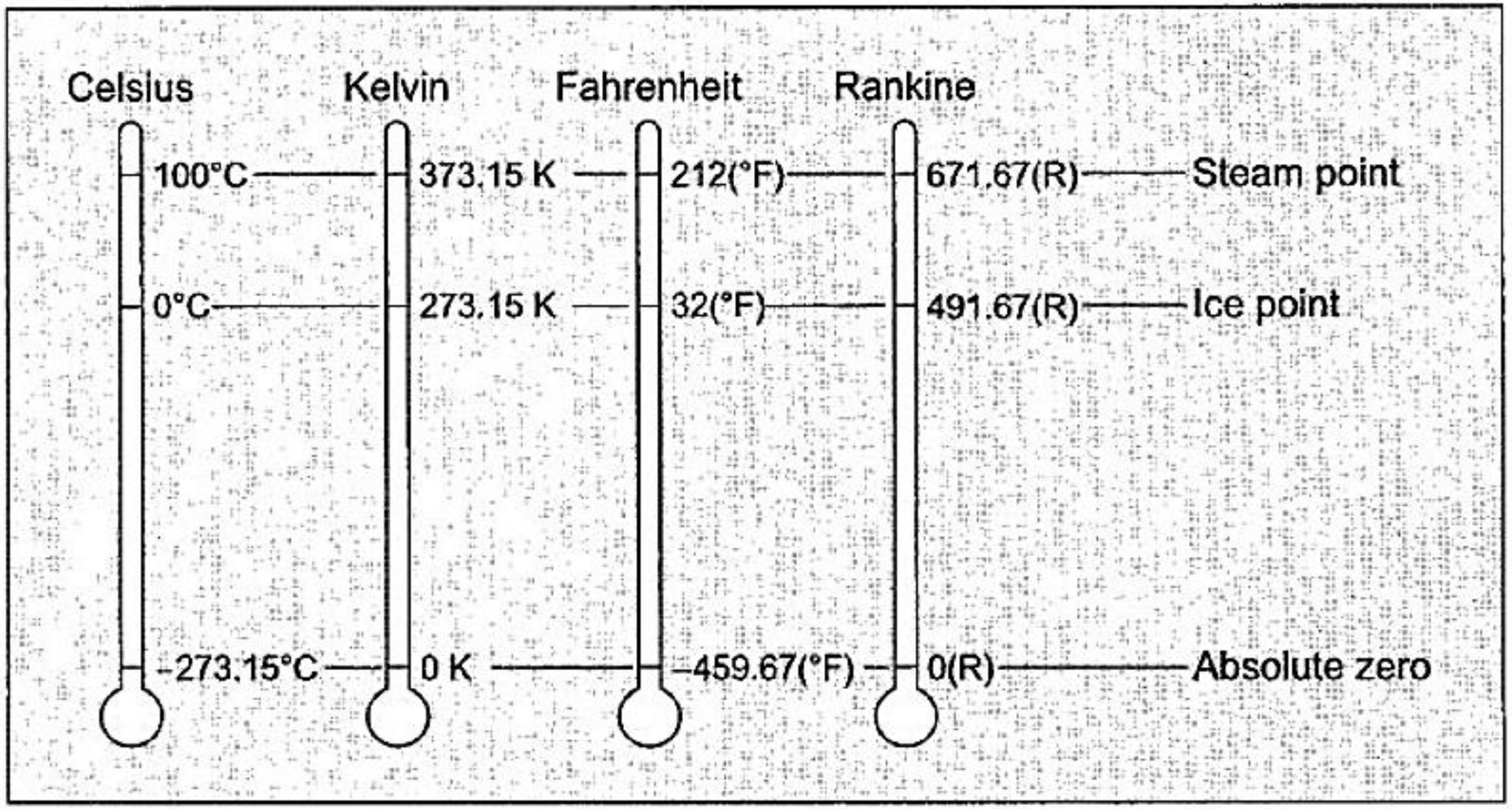
$$t(°F) = T(R) - 459.67$$

The lower limit of temperature on the Fahrenheit scale is -459.67CF). The relation between the Fahrenheit and Celsius scales is:

$$t(°F) = 1.8\,t°C + 32$$

The relationships among the four temperature scales are shown in the following figure . In thermodynamics, absolute temperature is implied by an unqualified reference to temperature.

Basic concepts

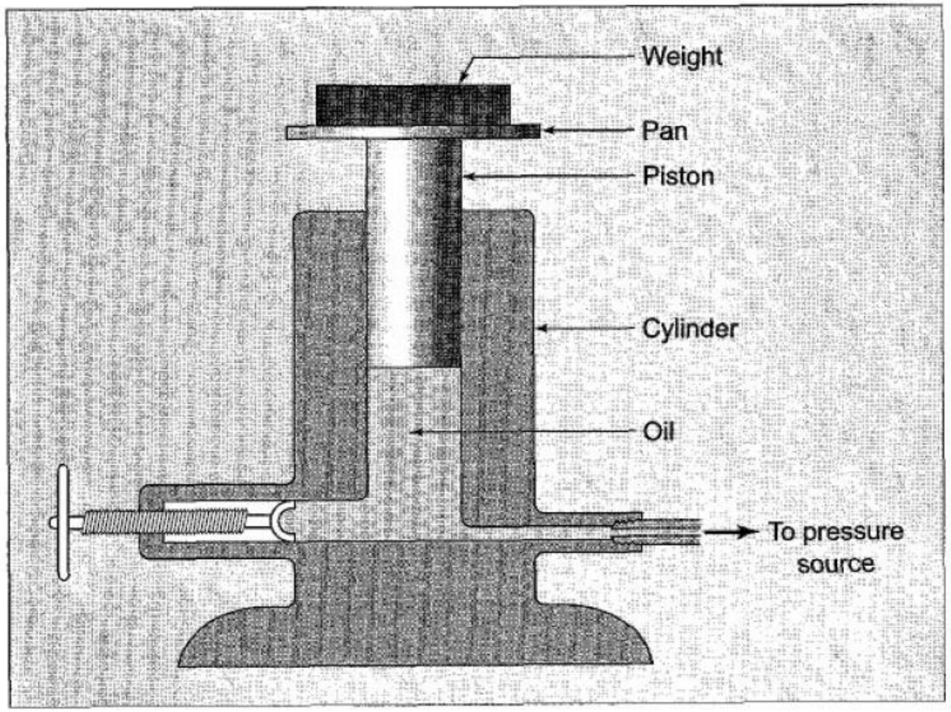


Relations among temperature scales

Basic concepts

4/ Pressure

is defined as *a normal force exerted by a fluid per unit area*. We speak of pressure only when we deal with a gas or a liquid. The counterpart of pressure in solids is *normal stress*. Since pressure is defined as force per unit area, it has the unit of newtons per square meter (N/m^2), which is called a **pascal** (Pa). That is, $1\ \text{Pa}\ \ 1\ \text{N/m}^2$



The pressure unit pascal is too small for pressures encountered in practice. Therefore, its multiples *kilopascal* ($1\ \text{kPa}\ \ 10^3\ \text{Pa}$) and *megapascal* ($1\ \text{MPa}\ \ 10^6\ \text{Pa}$) are commonly used. Three other pressure units commonly used in practice, especially in Europe, are *bar*, *standard atmosphere*, and *kilogram-force per square centimeter:*

Basic concepts

$$P = \frac{F}{A} = \frac{mg}{A}$$

where m is the mass of the piston, pan, and weights; *g* is the local acceleration of gravity; and *A* is the cross-sectional area of the piston. Gauges in common use, such as Bourdon gauges, are calibrated by comparison with dead-weight gauges.

Since a vertical column of a given fluid under the influence of gravity exerts a pressure at its base in direct proportion to its height, pressure is also expressed as the equivalent height of a fluid column. This is the basis for the use of manometers for pressure measurement. Conversion of height to force per unit area follows from Newton's law applied to the force of gravity acting on the mass of fluid in the column. The mass is given by:

$$m = A.h\ .\rho$$

where A is the cross-sectional area of the column, h is its height, and ρ is the fluid density. Therefore,

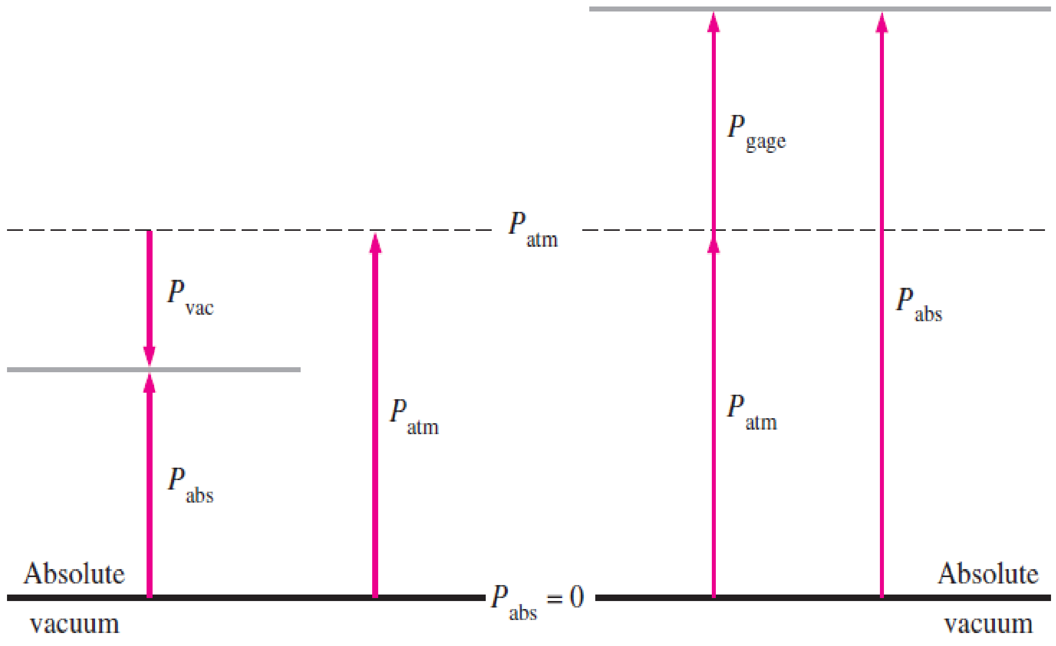
$$P = \frac{F}{A} = \frac{mg}{A} = \frac{Ah\rho g}{A} = h\rho g$$

Basic concepts

The actual pressure at a given position is called the **absolute pressure,** and it is measured relative to absolute vacuum (i.e., absolute zero pressure). Most pressure-measuring devices, however, are calibrated to read zero in the atmosphere, and so they indicate the difference between the absolute pressure and the local atmospheric pressure. This difference is called the **gage pressure.** Pressures below atmospheric pressure are called **vacuum pressures** and are measured by vacuum gages that indicate the difference between the atmospheric pressure and the absolute pressure. Absolute, gage, and vacuum pressures are all positive quantities and are related to each other by

Gauge Pressure: $P_{gage} = P_{abs} - P_{atm}$

Vacuum Pressure: $P_{vac} = P_{atm} - P_{abs}$



Basic concepts

5/ Units

Factor	*Prefix*	*Symbol*	*Factor*	*Prefix*	*Symbol*
10^{12}	tera	T	10^{-1}	deci	d
10^{9}	giga	G	10^{-2}	centi	c
10^{6}	mega	M	10^{-3}	milli	m
10^{3}	kilo	k	10^{-6}	micro	µ
10^{2}	hecto	h	10^{-9}	nano	n
10^{1}	deca	da	10^{-12}	pico	p
			10^{-15}	fasnto	f
			10^{-18}	atto	a

Quantity	*Name*	*Symbol*
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
luminous intensity	candela	cd
amount of substance	mole	mol

Basic concepts

Quantity	*SI Units*	
	Name	*Symbol*
area	square metre	m^2
volume	cubic metre	m^3
speed, velocity	metre per second	m/s
acceleration	metre per second squared	m/s^2
wave number	1 per metre	m^{-1}
density, mass density	kilogram per cubic metre	kg/m^3
concentration (of amount of substance)	mole per cubic metre	mol/m^3
activity (radioactive)	1 per second	s^{-1}
specific volume	cubic metre per kilogram	m^3/kg
luminance	candela per square metre	cd/m^2

Basic concepts

Quantity	*SI Units*			
	Name	*Symbol*	*Expression in terms of other units*	*Expression in terms of SI base units*
frequency	hertz	Hz	—	s^{-1}
force	newton	N	—	$m.kg.s^{-2}$
pressure	pascal	Pa	N/m^2	$m^{-1}.kg.s^{-2}$
energy, work, quantity of heat power	joule	J	N.m	$m^2.kg.s^{-2}$
radiant flux quantity of electricity	watt	W	J/S	$m^2.kg.s^{-3}$
electric charge	coloumb	C	A.s	s.A
electric tension, electric potential	volt	V	W/A	$m^2.kg.s^{-3}.A^{-1}$
capacitance	farad	F	C/V	$m^{-2}.kg^{-1}.s^4$
electric resistance	ohm	Ω	V/A	$m^2.kg.s^{-3}.A^{-2}$
conductance	siemens	S	A/V	$m^{-2}.kg^{-1}.s^3.A^2$
magnetic flux	weber	Wb	V.S.	$m^2.kg.s^{-2}.A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg.s^{-2}.A^{-1}$
inductance	henry	H	Wb/A	$m^2.kg.s^{-2}.A^{-2}$
luminous flux	lumen	lm	—	cd.sr
illuminance	lux	lx	—	$m^{-2}.cd.sr$

Basic concepts

Quantity	*SI Units*		
	Name	*Symbol*	*Expression in terms of SI base units*
dynamic viscosity	pascal second	Pa-s	$m^{-1}.kg.s^{-1}$
moment of force	metre newton	N.m	$m^2.kg.s^{-2}$
surface tension	newton per metre	N/m	$kg.s^{-2}$
heat flux density, irradiance	watt per square metre	W/m^2	$kg.s^{-2}$
heat capacity, entropy	joule per kelvin	J/K	$m^2.kg.s^{-2}.K^{-1}$
specific heat capacity, specific entropy	joule per kilogram kelvin	J/(kg.K)	$m^2.s^{-2}.K^{-1}$
specific energy	joule per kilogram	J/kg	$m^2.s^{-2}$
thermal conductivity	watt per metre kelvin	W/(m.K)	$m.kg.s^{-3}.K^{-1}$
energy density	joule per cubic metre	J/m^3	$m^{-1}.kg.s^{-2}$
electric field strength	volt per metre	V/m	$m.kg.s^{-3}.A^{-1}$
electric charge density	coloumb per cubic metre	C/m^3	$m^{-3}.s.A$
electric flux density	coloumb per square metre	C/m^2	$m^{-2}.s.A$
permitivity	farad per metre	F/m	$m^{-3}.kg^{-1}.s^4.A^4$
current density	ampere per square metre	A/m^2	—
magnetic field strength	ampere per metre	A/m	—
permeability	henry per metre	H/m	$m.kg.s^{-2}.A^{-2}$
molar energy	joule per mole	J/mol	$m^2.kg.s^{-2}mol^{-1}$
molar heat capacity	joule per mole kelvin	J/(mol.K)	$m^2.kg.s^{-2}.K^{-1}.mol^{-1}$

Basic concepts

$$1 \text{ bar} = 10^5 \text{ Pa} = 0.1 \text{ MPa} = 100 \text{ kPa}$$

$$1 \text{ atm} = 101{,}325 \text{ Pa} = 101.325 \text{ kPa} = 1.01325 \text{ bars}$$

$$1 \text{ kgf/cm}^2 = 9.807 \text{ N/cm}^2 = 9.807 \times 10^4 \text{ N/m}^2 = 9.807 \times 10^4 \text{ Pa}$$

$$= 0.9807 \text{ bar}$$

$$= 0.9679 \text{ atm}$$

End