Design for Manufacture

3. Thermodynamics

Thermodynamics

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- Thermodynamics – study of heat related matter in motion.
- Major developments during 1650-1850
- Engineering thermodynamics mainly concerned with work producing or utilising machines such as
  - Engines,
  - Turbines and
  - Compressors

together with the working substances used in the machines.

- Working substance – fluids: capable of deformation, energy transfer
- Air and steam are common working substance

Pressure

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

Force per unit area. Unit: Pascal (Pa) N / m^2

$1\ Bar = 10^5\ Pa$

1 standard atmosphere = 1.01325 *Bar*

1 *Bar* =14.504 *Psi* *(pound force / square inch,* 1*N*= 0.2248 *pound force)*

1 *Psi*= 6894.76 *Pa*

Phase

Nature of substance. Matter can exists in three phases: solid, liquid and gas

Cycle

If a substance undergoes a series of processes and return to its original state, then it is said to have been taken through a cycle.

Process

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A substance is undergone a process if the state is changed by operation carried out on it

Isothermal process - Constant temperature process

Isobaric process - Constant pressure process

Isometric process or isochoric process - Constant volume process

Adiabatic Process

No heat is transferred, if a process happens so quickly that there is no time to transfer heat, or the system is very well insulated from its surroundings.

Polytropic process

Occurs with an interchange of both heat and work between the system and its surroundings

E.g. Nonadiabatic expansion or compression

Energy, Work and Power

Energy - Capacity of doing work

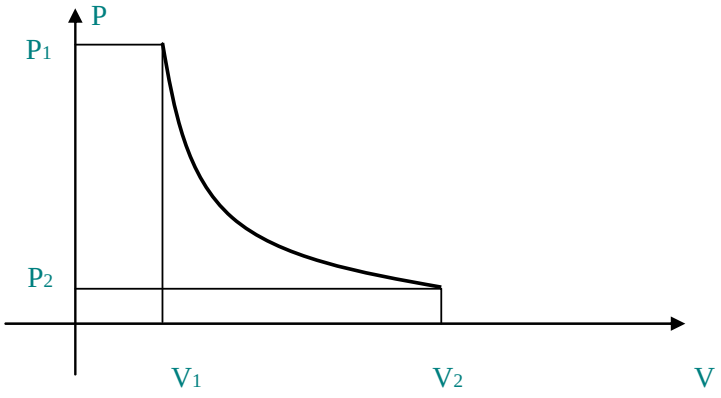
Work - A force is moved through a distance

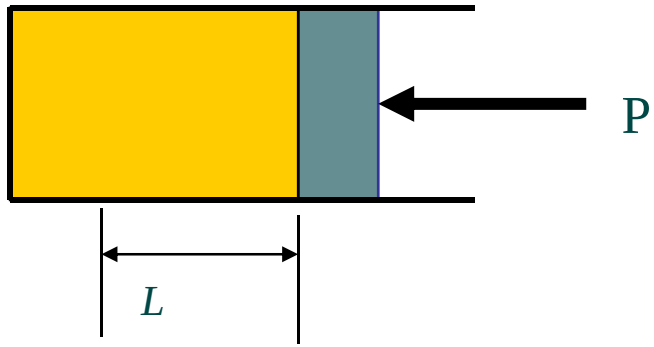
In a piston, if pressure is constant

$$work\ \ done = PA \times L = P \times AL = P(V_2 - V_1) \quad Nm\ \ (Joule)$$

In variable pressure case

$$work\ \ done = \int_{V_1}^{V_2} P\, dV$$





Power - Rate of doing work ***J/s = Watt***

Work done in polytropic process

$$workdone$$

$$= \int_{V_1}^{V_2} P\,dV$$

$$= C\int_{V_1}^{V_2} V^{-n}\,dV$$

$$= \frac{C}{-n+1}\left(V_2^{-n+1} - V_1^{-n+1}\right)$$

$$= \frac{P_1V_1 - P_2V_2}{n-1}$$

Heat

Temperature t (Celsius) = T-273.15 (Kelvin)

Q – heat energy joules/kg

Specific heat capacity:
heat transfer per unit temperature:

$$c = \frac{dQ}{dt}$$

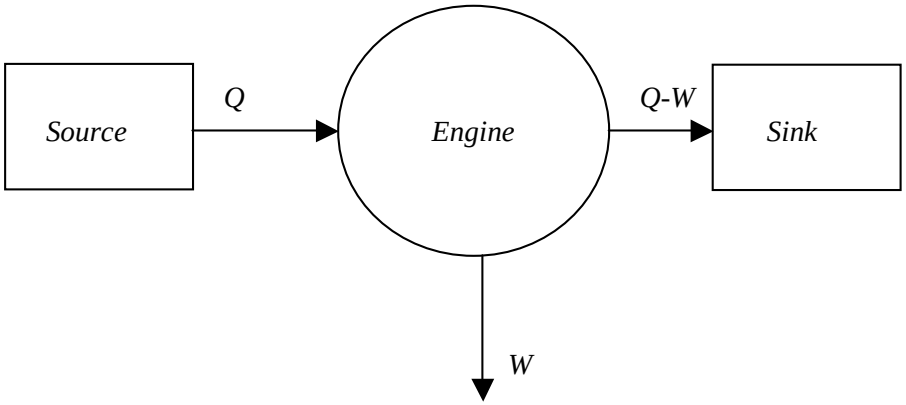
Unit: joules/kg K (joules per kg per K)

Calorific value

The heat liberated by burning unit mass or volume of a fuel.

e.g. petrol: 43MJ/kg

Principle of the thermodynamic engine



The Conservation of Energy

For a system

Initial Energy + Energy Entering = Final Energy +Energy Leaving

Thermal efficiency

$$\eta = \frac{Work\ \ done}{Heat\ \ received} = \frac{W}{Q}$$

Heat Engines

An engine in which transfers energy results from difference in temperature.

Mechanical Power

$$Power = \frac{Work\ \ done}{Time\ \ Taken}$$

Unit: $J/s = watt$

Electrical Power

$$W = I\,V$$

Unit: $J/s = Watt$

Laws of Thermodynamics

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The zeroth Law

If body A and B are in thermal equilibrium, and A and C are in thermal equilibrium,
then, B and C must in thermal equilibrium.

The first law

$W=Q$

Means if some work W is converted to heat Q or some heat Q is converted to work W, $W=Q$*. It does not mean all work can convert to heat in a particular process.*

The second law

Nature heat transfer will occur down a temperature gradient.

The third law

At the absolute zero of temperature the entropy of a perfect crystal of a substance is zero.

Gas laws

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Boyle's law (1662)

For perfect gas

PV=C *-constant*
Temperature remains constant.

or
$P_1V_1 = P_2V_2$ - constant T (Isothermal process)

Charle's Law (work by 1780, Gay-Lussac 1802 published)

$\frac{V}{T} = \text{constant}$ **- constant *P* (Isobaric process)**

Gay-Lussac's law (Actually by Guillaume Amontons 1700)

$\frac{P}{T} = \text{constant}$ -- constant V (Isometric process)

Combined gas law (1834 by Clapeyron, 1856 by Kronig, 1857 by Causius)

Let $PV = c_1, \frac{V}{T} = c_2$ *and* $\frac{P}{T} = c_3$

$PV \cdot \frac{V}{T} \cdot \frac{P}{T} = c_1 c_2 c_3$ *or* $\frac{PV}{T} = \sqrt{c_1 c_2 c_3}$

$$\frac{PV}{T} = a \quad \text{(constant)}$$

or

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Let $mR=a$, where m is the mass,

R - specific gas constant (air: $R=287\ J/kgK$)

$\frac{PV}{T} = mR$ - characteristic equation of gas (adiabatic with surroundings)

Joule's law

Internal energy of gas is the function of temperature only and independent of changes in volume and pressure.

The specific heat capacity at constant volume

c_v

$$U_2 - U_1 = mc_v(T_2 - T_1)$$ (change in internal energy)

The specific heat capacity at constant pressure

c_p

$$U_2 - U_1 + P(V_2 - V_1) = mc_p(T_2 - T_1)$$

Polytropic Process

$$PV^n = C$$

When n=1, isothermal process;
When $n = c_p / c_v = \gamma$, it is an adiabatic process

From

$$P_1 V_1^{\,n} = P_2 V_2^{\,n}$$

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^n = \left(\frac{V_1}{V_2}\right)^{-n} \qquad \textit{and} \qquad \frac{V_1}{V_2} = \left(\frac{P_1}{P_2}\right)^{-1/n}$$

From the gas characteristic equation

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{T_1}{T_2} = \frac{P_1V_1}{P_2V_2} = \left(\frac{V_2}{V_1}\right)^n \frac{V_1}{V_2} = \left(\frac{V_2}{V_1}\right)^{n-1}$$

and

$$\frac{T_1}{T_2} = \frac{P_1V_1}{P_2V_2} = \frac{P_1}{P_2}\left(\frac{P_1}{P_2}\right)^{-1/n} = \left(\frac{P_1}{P_2}\right)^{\frac{n-1}{n}}$$

i.e.

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{n-1}$$

$$\frac{T_1}{T_2} = \left(\frac{P_1}{P_2}\right)^{\frac{n-1}{n}}$$

Enthalpy

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- To describe total energy in gas

$H = U + P V$

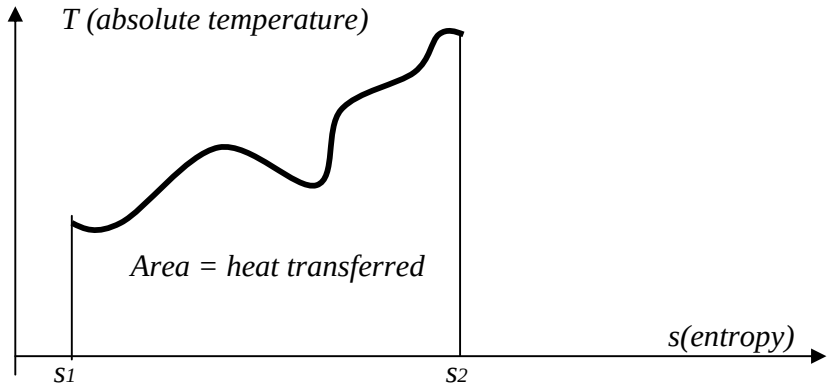
U – internal energy

P – pressure
v – volume

Specific Enthalpy

$h = U/m = u + P v$

Entropy



Entropy is a quantity s that associates with the temperature T and heat transfer Q_{rev} in the following way:

$$\Delta s = \frac{\Delta Q_{rev}}{T}$$

$$ds = \frac{dQ_{rev}}{T} \qquad or \qquad dQ_{rev} = Tds$$

where Q_{rev} - reversi*ble heat transfer:*

$$Q_{rev} = \int_{s_1}^{s_2} T\, ds$$

Entropy describes the availability of thermal energy. An isolated system can only change to states of equal or greater entropy.