DATA SHEETS FOR MACE63081

1 Work

- **positive work:** is done by a system on the surroundings (a system does positive work if it can raise a weight)
- **negative work:** is done by the surroundings on a system.

Incremental piston, or displacement work , is $\delta W = p\mathrm{d}V$, and for a process in which the pressure varies with volume the work is $W = \int p\mathrm{d}V$

Constant pressure (isobaric) process: $pV^0 = c$

$$W_{12} = \int_1^2 pdV = p(V_2 - V_1)$$

Constant volume (isochoric) process: $pV^\infty = c$

$$W_{13} = \int_1^3 pdV = 0, \text{ because } dV = 0$$

Process defined by $pV = c$

$$W_{14} = p_1V_1 \, ln\frac{V_4}{V_1} = p_1V_1 \, ln\frac{p_1}{p_4} = etc$$

Process defined by $pV^n = c$

$$W_{15} = \frac{p_1V_1 - p_5V_5}{n-1} = \frac{p_5V_5 - p_1V_1}{1-n}$$

2 First Law of Thermodynamics - closed systems

$$Q - W_s = m\left(u_2 + \frac{V_2^2}{2} + gz_2\right) - m\left(u_1 + \frac{V_1^2}{2} + gz_1\right)$$

First Law for a closed system in the absence of kinetic and potential energy

$$\delta Q = dU + \delta W$$

Specific heat at constant volume

$$c_v = \left(\frac{\partial u}{\partial T}\right)_v = \left(\frac{\partial u}{\partial t}\right)_v = \left(\frac{\partial Q}{\partial T}\right)_v$$

Enthalpy, H

$$H = U + pV$$

Specific enthalpy, h

$$h = \frac{H}{m} = \frac{U + pV}{m} = \frac{U}{m} + \frac{pV}{m} = u + pv$$

Specific heat at constant pressure

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p = \left(\frac{\partial h}{\partial t}\right)_p = \left(\frac{\partial q}{\partial T}\right)_p$$

3 Steady flow energy equation

$$\dot{Q} - \dot{W} = \dot{m}\left(h_e - h_i + \frac{V_e^2 - V_i^2}{2} + g(z_e - z_i) \right)$$

Stagnation enthalpy

$$h_0 = h + \frac{V^2}{2}$$

Velocity at exit to a nozzle

$$V_2 = \sqrt{2\left\{ (h_1 - h_2) + \frac{V_1^2}{2} \right\}}$$

Work from an adiabatic machine

$$-\dot{W}_s = \dot{m}(h_e - h_i) = \dot{m}(h_2 - h_1).$$

4 Second Law of Thermodynamics

Efficiency

$$\textit{Thermal efficiency},\ \eta_{th} = \frac{\text{Useful work output}}{\text{Thermal energy input}},$$

for a heat engine operating in a cycle .

Thermal efficiency of heat engine

$$\text{Thermal efficiency},\ \eta_{th} = \frac{\text{Net work}}{\text{Heat supplied}} \qquad \eta_{th} = \frac{W_s}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

Coefficient of performance of refrigerator

$$\text{Coefficient of performance},\ \beta = \frac{\text{Heat transferred from cold reservoir}}{\text{Work done}}, = \frac{Q_2}{W_s} = \frac{Q_2}{Q_1 - Q_2}.$$

Coefficient of performance of heat pump

$$\text{Coefficient of performance},\ \beta' = \frac{\text{Heat transferred to hot reservoir}}{\text{Work done}}, = \frac{Q_1}{W_s} = \frac{Q_1}{Q_1 - Q_2}.$$

Relationship between coefficients of performance

$$\beta' = 1 + \frac{Q_2}{W_s} = 1 + \beta$$

Entropy

Entropy is denoted by the symbol - S; specific entropy is denoted by - s.

The change of entropy between states 1 and 2 is $S_2 - S_1 = \int_1^2 \frac{\delta Q_R}{T}$

Central Equation of Thermodynamics

$$Tds = du + pdv = dh - vdp$$

Steady flow entropy equation for an adiabatic machine

$$\dot{S}_i = \dot{m}(s_e - s_i) \geq 0$$

5 Properties of pure substances

Dryness fraction, or quality

$$\text{Dryness fraction, } x = \frac{\text{Mass of dry vapour}}{\text{Total mass of liquid } + \text{ vapour}}$$

$$v = xv_g + (1-x)v_f = v_f + xv_{fg}$$

$$u = xu_g + (1-x)u_f = u_f + xu_{fg}$$

$$h = xh_g + (1-x)h_f = h_f + xh_{fg}$$

$$s = xs_g + (1-x)s_f = s_f + xs_{fg}$$

6 Perfect gases, and mixtures of perfect gases

Ideal gas $\frac{pv}{T} = const, R$

Universal Gas Constant $\Re = MR$

S.I. units $\Re$ = 8.3145 kJ/kmol K

Imperial $\Re$ = 1545 ft.lbf/lb mol °R

= 1.986 Btu/lb mol °R

Molar Masses for Common Gases/Elements

Gas/Element	**M** (kg/kmol)
H_2	2
O_2	32
N_2	28
CO	28
CO_2	44
H_2O	18
C	12

Internal energy $u = \int_{T_o}^{T} c_v dT + u_o$, where u_0 is the value of u at temperature T_0

Enthalpy $h = u + pv = u + RT$

$h = \int_{T_0}^{T} c_p dT + h_0$, where h_0 is the enthalpy at temperature T_0.

Relationship between c_p and c_v

$$c_p = c_v + R \qquad \gamma = c_p/c_v$$

Entropy change

$$ds = \frac{c_v dT + pdv}{T} = c_v \frac{dT}{T} + \frac{p}{T} dv$$

$$s_2 - s_1 = \int_{T_1}^{T_2} \frac{c_v}{T} dT + R\ell n \frac{v_2}{v_1}$$

$$s_2 - s_1 = \int_{T_1}^{T_2} \frac{c_p}{T} dT - R\ell n \frac{p_2}{p_1}$$

7 Isentropic or process efficiencies

For compressors: $\eta_c = \dfrac{h_{2i} - h_1}{h_2 - h_1}$

For turbines: $$\eta_t = \frac{h_1 - h_2}{h_1 - h_{2i}}$$

where the process is from state 1 to state 2 and subscript *i* denotes ideal (isentropic) values

8 Ideal cycle efficiencies

Otto cycle: $\eta = 1 - r_v^{-(\gamma-1)}$

Diesel cycle: $$\eta = 1 - r_v^{-(\gamma-1)} \frac{(r_c^\gamma - 1)}{\gamma(r_c - 1)}$$

Dual cycle: $$\eta = 1 - r_v^{-(\gamma-1)} \frac{(r_p r_c^\gamma - 1)}{(r_p - 1) + \gamma r_p (r_c - 1)}$$

where r_v is the volumetric compression ratio
r_c is the volumetric cut-off ratio
r_p is the constant-volume heat input pressure ratio
γ is the ratio of specific heats

9 Mean effective pressures of reciprocating engine cycles

The indicated mean effective pressure (imep)

$$p_m = \frac{W_{net}}{V_s}$$

where W_{net} is the net cycle work, V_s is the swept volume

The brake mean effective pressure (bmep)

$$p_b = \frac{W_{net} - W_f}{V_s}$$

where W_f is the work lost to friction.

The friction mean effective pressure (fmep)

$$p_f = p_m - p_b$$

10 Specific and Relative Humidity

Absolute Humidity

$$\omega = \frac{m_v}{m_a} \quad (\text{kg water vapor / kg dry air})$$

$$\omega = \frac{m_v}{m_a} = \frac{P_v V / R_v T}{P_a V / R_a T} = \frac{P_v / R_v}{P_a / R_a} = 0.622 \frac{P_v}{P_a}$$

$$\omega = \frac{0.622 P_v}{P - P_v} \quad (\text{kg water vapor / kg dry air})$$

Relative Humidity

$$\phi = \frac{m_v}{m_g} = \frac{P_v V / R_v T}{P_g V / R_v T} = \frac{P_v}{P_g}$$

$$\phi = \frac{\omega P}{(0.622 + \omega) P_g} \quad \text{and} \quad \omega = \frac{0.622 \phi P_g}{P - \phi P_g}$$

Enthalpy

$$h = h_a + \omega h_g \quad (\text{kJ / kg dry air})$$

Adiabatic Saturation and Wet-bulb Temperatures

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg_2}}{h_{g_1} - h_{f_2}}$$

$$\omega_2 = \frac{0.622 P_{g_2}}{P_2 - P_{g_2}}$$