MECHANICAL ENGINEERING HANDBOOK

FOR FORMULAS

(GATE, ESE, SSC JE AND OTHER COMPETITIVE EXAMS)

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ABOUT

“ Mechanical Engineering Formulas - all subjects formulas with concepts and course outlines are given here. Select your desired course and you can revise all the Formulas within an hour only. When you are a mechanical engineer, you need to know the important formulas during the competitive exams like GATE, ESE and other exams to solve the answers easily using the formula. So, you must know the all-important formulas in the mechanical engineering Subjects. This book is specially prepared for the mechanical engineers”.

PREFACE

In order to ignite your preparations for your Exams. This book providing the list of Important formulas for all subject of mechanical engineering, which was quite in demand and useful for all learners. Providing all the formulas in the single book will help the candidates for their preparation.

This combined formula book will help you to learn the all mechanical engineering formulas for GATE, ESE, SSC JE and other mechanical engineering exams.

TABLE OF CONTENT

SI MULTIPLES

Metric System

VALUE	EXPONENT	SYMBOL	PREFIX
1 000 000 000 000	10^{12}	T	tera
1 000 0S00 000	10^{9}	G	giga
1 000 000	10^{6}	M	mega
1 000	10^{3}	k	kilo
100	10^{2}	h	hecto
10	10^{1}	da	deca
0.1	10^{-1}	d	deci
0.01	10^{-2}	c	centi
0.001	10^{-3}	m	milli
0.000 001	10^{-6}	µ	micro
0.000 000 001	10^{-9}	n	nano
0.000 000 000 001	10^{-12}	p	pico

Conversion Chart for Metric Units

		To Milli-	To Centi-	To Deci-	To Metre, Gram, Litre	To Deca-	To Hecto-	To Kilo-
To Convert	Kilo-	x 10^{6}	x 10^{5}	x 10^{4}	x 10^{3}	x 10^{2}	x 10^{1}	
	Hecto-	x 10^{5}	x 10^{4}	x 10^{3}	x 10^{2}	x 10^{1}		x 10^{-1}
	Deca-	x 10^{4}	x 10^{3}	x 10^{2}	x 10^{1}		x 10^{-1}	x 10^{-2}
	Metre, Gram, Litre	x 10^{3}	x 10^{2}	x 10^{1}		x 10^{-1}	x 10^{-2}	x 10^{-3}
	Deci-	x 10^{2}	x 10^{1}		x 10^{-1}	x 10^{-2}	x 10^{-3}	x 10^{-4}

	Centi-	x 10^{1}		x 10^{-1}	x 10^{-2}	x 10^{-3}	x 10^{-4}	x 10^{-5}
	Milli-		x 10^{-1}	x 10^{-2}	x 10^{-3}	x 10^{-4}	x 10^{-5}	x 10^{-6}

BASIC UNITS (DISTANCE, AREA, VOLUME, MASS, DENSITY)

BASIC UNITS

SI	IMPERIAL
DISTANCE 1 metre (1 m) = 10 decimetres (10 dm) =100 centimetres (100 cm) =1000 millimetres (1000 mm) 1 decametre (1 dam) = 10 m 1 hectometre (1 hm) = 100 m 1 kilometre (1 km) = 1000 m	12in.=1ft 3 ft = 1yd 5280 ft = 1 mile 1760 yd = 1 mile

Conversions:

1 in. = 25.4 mm
1 ft = 30.48 cm
1 mile = 1.61 km
1 yd = 0.914 m
1 m = 3.28 ft

AREA

1 sq metre (1 m^2) = 10 000 cm^2 = 1 000 000 mm^2 1 sq hectometre (1 hm^2) = 10 000 m^2 = 1 hectare (1 ha) 1 sq km (1 km^2) = 1 000 000 m^2	1 ft^2 = 144 in.^{2} 1 yd^2 = 9 ft^2 1 sq mile = 640 acre = 1 section

Conversions:

1 in.^{2} = 6.45 cm^2 =645 mm^2
1 m^2 = 10.8 ft^2
1 acre = 0.405 ha
1 sq mile = 2.59 km^2

SI	IMPERIAL
VOLUME 1 m^3 = 1000000 cm^3	1ft^3 = 1728 in.^{3}

= 1×10^9 mm^3 1 dm^3 = 1 litre 1 litre = 1000 cm^3 1 mL = 1cm^3 1 m^3 = 1000 litres	1 yd^3 = 27 ft^3 1(liquid) U.S. gallon = 231 in.^{3} = 4 (liquid) quarts 1 U.S. barrel (bbl) = 42 U.S. gal. 1 imperial gallon = 1.2 U.S. gal.

Conversions:

1 in.^{3} = 16.4 cm^3
1 m^3 = 35.3 ft^3
1 litre = 61 in.^{3}
1 U.S. gal. = 3.78 litres
1 U.S. bbl. = 159 litres
1 litre/s = 15.9 U.S. gal/min

Mass and Weight

1 kilogram (1 kg) = 1000 grams 1000 kg = 1 tonne	2000 lb = 1 ton (short) 1 long ton = 2240 lb

Conversions:

1 kg (on Earth) results in a weight of 2.2 lb

Density

$\text{Mass density} = \frac{\text{mass}}{\text{volume}}$ $\rho = \frac{m}{v}\left(\frac{kg}{m^3}\right)$	$\text{Weight density} = \frac{\text{weight}}{\text{volume}}$ $\rho = \frac{w}{v}\left(\frac{lb}{ft^3}\right)$

Conversions:

(on Earth) a mass density of 1 Kg/m^3
results in a weight density of 0.0623 lb/ft^3

S.I	IMPERIAL
RELATIVE DENSITY In SI R.D. is a comparison of mass density to a standard. For solids and liquids the standard is fresh water.	In Imperial the corresponding quantity is **specific gravity** ; for solids and liquids a comparison of weight density to that of water.

Conversion

In both systems the same numbers hold for R.D. as for S.G. since these are equivalent ratios.

RELATIVE DENSITY (SPECIFIC GRAVITY) OF VARIOUS SUBSTANCE	
Water (Fresh)………1.00	Mica……………………2.9
Water (Sea Average)….1.03	Nickel…………………8.6
Aluminum…….2.56	Oil (linseed)…………0.94
Antimony………6.70	Oil (olive)…………….0.92
Bismuth………..9.80	Oil (petroleum)……0.76-0.86
Brass……….8.40	Oil (turpentine)……0.87
Brick…………2.1	Paraffin ……………….0.86
Calcium………1.58	Platinum……………..21.5
Carbon (Diamond)…….3.4	Sand (dry)……………1.42
Carbon (Graphite)……..2.3	Silicon…………………2.6
Carbon (Charcoal)……..1.8	Silver……………………10.57
Chromium……….6.5	Slate……………………2.1-2.8
Clay……………..1.9	Sodium………………..0.97
Coal…………1.36-1.4	Steel (mild)…………7.87
Cobalt………..8.6	Sulphur……………….2.07
Copper……….8.77	Tin………………………7.3
Cork…………0.24	Tungsten…………….19.1
Glass (Crown)……2.5	Wood (ash)…………0.75
Glass (Flint)………3.5	Wood (beech)…….0.7-0.8
Gold………………19.3	Wood (ebony)…….1.1-1.2
Iron (Cast)………..7.21	Wood (elm)…………0.66
Iron (Wrought)…...7.78	Wood (lignum-vitae)…….1.3
Lead………………11.4	Wood (oak)…………………..0.7-1.0
Magnesium……….1.74	Wood (pine)……………………0.56
Manganese………..8.0	Wood (teak)…………………..0.8
Mercury…………..13.6	Zinc………………………………7.0

Greek Alphabet

Alpha Beta Gamm a Delta	α β γ Δ	Iota Kappa Lambd a Mu	ι κ λ μ	Rho Sigma Tau Upsilon	ρ Σ, σ τ υ
Epsilon	ε	Nu	ν	Phi	Φ, ϕ
Zeta	ζ	Xi	ξ	Kai	χ
Eta	η	Omicron	Ο	Psi	ψ
Theta	θ	Pi	π	Omega	Ω, ω

THERMODYNAMICS

Symbol/Formula	Parameter
M	Molar mass (M/μ)
m	Mass (M)
$n = \frac{m}{M}$	Number of moles (μ)
E	Energy or general extensive property
$e = \frac{E}{m}$	Specific molar energy (energy per unit mass) or general extensive property per unit mass
$\bar{e} = \frac{E}{n} = eM$	Specific energy (energy per unit mole) or general extensive property per unit mole
P	Pressure ($ML^{-1}T^{-2}$)
V	Volume (L^3); Specific volume or volume per unit mass, v (L^3M^{-1}) and the volume per unit mole v ($L^3\mu^{-1}$)
T	Temperature (Θ)
ρ	Density (ML^{-3});ρ= 1/v.
X	Quality
U	Thermodynamic internal energy (ML^2T^{-2}); Internal energy per unit mass, u (L^2T^{-2}), and the internal energy per unit mole, u ($ML^2T^{-2}\mu^{-1}$)
H=U+PV	Thermodynamic enthalpy (ML^2T^{-2}); Enthalpy per unit mass, h = u + Pv (dimensions: L^2T^{-2}) and the internal energy per unit mole h ($ML^2T^{-2}\mu^{-1}$)
S	Entropy ($ML^2T^{-2}\Theta^{-1}$); Entropy per unit mass, s($L^2T^{-2}\Theta^{-1}$) and the internal energy per unit mole s ($ML^2T^{-2}\Theta^{-1}\mu^{-1}$)
W	Work (ML^2T^{-2})
Q	Heat transfer (ML^2T^{-2})
W_u	The useful work rate or mechanical power (ML^2T^{-3})
M	The mass flow rate (MT^{-1})
$\frac{\vec{V}^2}{2}$	The kinetic energy per unit mass (L^2T^{-2})
Gz	The potential energy per unit mass (L^2T^{-2})
E_{tot}	The total energy $= m\left(u + \frac{\vec{V}^2}{2} + gz\right)$($ML^2T^{-2}$)
$\dot{Q}$	The heat transfer rate (ML^2T^{-3})
$\frac{dE_{cv}}{dt}$	The rate of change of energy for the control volume. (ml^2t^{-3})

UNIT CONVERSION FACTOR

For metric units

Basic:

- $1\ N = 1\ kg \cdot m/s^2$;
- $1\ J = 1\ N \cdot m$;
- $1\ W = 1\ J/s$;
- $1\ Pa = 1\ N/m^2$.

Others:

- $1\ kPa \cdot m^3 = 1\ kJ$;
- $T(K) = T(^{o}C) + 273.15$;
- 1 L (liter) = $0.001\ m^3$;
- $1\ m^2/s^2 = 1\ J/kg$.

Prefixes (and abbreviations):

- nano(n) – 10^{-9};
- micro (μ) – 10^{-6};
- milli(m) – 10^{-3};
- kilo(k) – 10^{3};
- mega(M) – 10^{6};
- giga(G) – 10^{9}.
- A metric ton (European word: tonne) is 1000 kg

For engineering units

Energy:

- 1 Btu = $5.40395\ psia \cdot ft^3 = 778.169\ ft \cdot lb_f$ = (1 kWh)/3412.14 = (1 hp·h)/2544.5 = $25{,}037\ lb_m \cdot ft^2/s^2$.

Pressure:

- $1\ psia = 1\ lb_f/in^2 = 144\ psfa = 144\ lb_f/ft^2$.

Others:

- $T(R) = T(^{o}F) + 459.67$;
- $1\ lb_f = 32.174\ lb_m \cdot ft/s^2$;
- 1 ton of refrigeration = 200 Btu/min.

Concepts & Definitions

	Formula	Units
Pressure	$P = \frac{F}{A}$	Pa
Units	$1\ Pa = 1\ N/m^2$ $1\ bar = 10^5\ Pa = 0.1\ Mpa$ $1\ atm = 101325\ Pa$	
Specific Volume	$v = V/m$	m^3/kg
Density	$\rho = \frac{m}{V} \to \rho = \frac{1}{v}$	kg/m^3
Static Pressure Variation	$\Delta P = \rho g h$ $\quad \uparrow = -, \downarrow = +$	Pa
Absolute Temperature	$T\ (K) = T\ (°C) + 273.15$	

Properties of a Pure Substance

	Formula	Units
Quality	$x = \frac{m_{vapor}}{m_{tot}}$ (Vapour mass fraction) $1 - x = \frac{m_{liquid}}{m_{tot}}$ (Liquid mass fraction)	
Specific Volume	$v = v_f + x v_{fg}$	m^3/kg
Average Specific Volume	$v = (1-x)v_f + x v_g$ (only two phase mixture)	m^3/kg
Ideal –gas law	$P << P_c T << T_c$ $\quad Z = 1$	
• Equations	$Pv = RT \quad PV = mRT = n\bar{R}T$	
• Universal Gas Constant	$\bar{R} = 8.3145$	kJ / kmol K
• Gas Constant	$R = \frac{\bar{R}}{M}$ $\quad$ M = molecular mass	kJ / kg K
Compressibility Factor Z	$Pv = ZRT$	
Reduced Properties	$P_r = P/P_c\ ,\ \ T_r = T/T_c$	

Work & Heat

	Formula	Units
Displacement Work	$W = \int_1^2 Fdx = \int_1^2 PdV$	J
Integration	$W = \int_1^2 PdV = P(V_2 - V_1)$	J
Specific Work	$w = \frac{W}{m}$ (work per unit mass)	J/kg
Power (rate of work)	$\dot{W} = F\overline{V} = P\dot{V} = T\omega$	W
• Velocity	$\overline{V} = r\omega$	Rad/s
• Torque	T=Fr	Nm
Polytropic Process $(n \neq 1)$	$PV^n = const = P_1V_1^n = P_2V_2^n$	
• Polytropic Exponent	$n = \frac{\ln\left(\frac{P_2}{P_1}\right)}{\ln\left(\frac{V_1}{V_2}\right)}$	
• n=1	$PV = Const = P_1V_1 = P_2V_2$	
Polytropic Process Work	$W_2 = \frac{1}{1-n}(P_2V_2 - P_1V_1)\ n \neq 1$	J
• n=1	$W_2 = P_2V_2 \ln\left(\frac{V_2}{V_1}\right)$	J
Adiabatic Process	$Q = 0$	
Conduction Heat Transfer	$\dot{Q} = -KA\frac{dT}{dx}, K = \text{conductivity}$	W
Convection Heat Transfer	$\dot{Q} = hA\Delta T$, h = convection coefficient	W
Radiation Heat Transfer	$\dot{Q} = \varepsilon\sigma A(T_S^4 - T_{amb}^4)$	W

Terminology

Q1 = heat

Q2 = heat transferred during the process between state 1 and state 2

Q = rate of heat transfer

W = work

	Formula	Units
Total Energy	$E = U + KE + PE \rightarrow dE = dU + d\,(KE) + d\,(PE)$	J
Energy	$dE = \delta Q - \delta W \rightarrow E_2 - E_1 = {}_1Q_2 - {}_1W_2$	J
Kinetic Energy	$KE = 0.5m\bar{V}^2$	J
Potential Energy	$PE = mgZ \rightarrow PE_2 - PE_1 = mg(Z_2 - Z_1)$	J
Internal Energy	$U = U_{liq} + U_{vap} \rightarrow mu = m_{liq}u_f + m_{vap}u_g$	
Specific Internal Energy of Saturated Steam (two-phase mass average)	$u = (1-x)u_f + xu_g$ $u = u_f + xu_{fg}$	kJ / kg
Total Energy	$U_2 - U_1 + \frac{m(\bar{V}^2{}_2 - \bar{V}^2{}_1)}{2} + mg(Z_2 - Z_1) = Q_2 - W_1$	J
Specific Energy	$e = u + 0.5\bar{V}^2 + gZ$	
Enthalpy	$H = U + PV$	
Specific Enthalpy	$h = u + Pv$	kJ / kg
For Ideal Gasses	$Pv = RT$ and $u = f\,(T)$	
• Enthalpy	$h = u + Pv = u + RT$	
• R Constant	$u = f\,(t) \rightarrow h = f\,(T)$	
Specific Enthalpy for Saturation State (two-phase mass average)	$h = (1-x)h_f + xh_g$ $h = h_f + xh_{fg}$	kJ / kg
Specific Heat at Constant Pressure	$C_v = \frac{1}{m}\left(\frac{\delta Q}{\delta T}\right)_v = \frac{1}{m}\left(\frac{\delta U}{\delta T}\right)_v = \left(\frac{\delta u}{\delta T}\right)_v$ $(u_e - u_i) = C_v(T_e - T_i)$	
Specific Heat at Constant Pressure	$C_p = \frac{1}{m}\left(\frac{\delta Q}{\delta T}\right)_p = \frac{1}{m}\left(\frac{\delta H}{\delta T}\right)_p = \left(\frac{\delta h}{\delta T}\right)_p$ $(h_e - h_i) = C_p(T_e - T_i)$	
Solids & Liquids	Incompressible, so v=constant $C = C_c = C_p$ (Tables A.3 & A.4) $u_2 - u_1 = C(T_2 - T_1)$ $h_2 - h_1 = u_2 - u_1 + v(P_2 - P_1)$	

Ideal Gas	$h = u + Pv = u + RT$ $u_2 - u_1 \cong C_v\,(T_2 - T_1)$ $h_2 - h_1 \cong C_p\,(T_2 - T_1)$	
Energy Rate	$E = Q - W$(rate = +in − out) $E_2 - E_1 = {}_1Q_2 - {}_1W_2$(change = +in − out)	

W2 = work done during the change from state 1 to state 2

W = rate of work = Power. 1 W=1 J/s

The First Law of Thermodynamics

First-Law Analysis for Control Volume

	Formula	Units
Volume Flow Rate	$\dot{V} = \int \bar{V} dA = A\bar{V}$ (using average velocity)	
Mass Flow Rate	$\dot{m} = \int \rho \bar{V} dA = \rho A \bar{V} = A\frac{\bar{V}}{v}$ (using average values)	kg / s
Power	$\dot{W} = \dot{m} C_p \Delta T$ $\quad \dot{W} = \dot{m} C_v \Delta T$ $\quad \dot{m} = \dot{V}/v$	W
Flow Work Rate	$\dot{W}_{flow} = P\dot{V} = \dot{m}Pv$	
Flow Direction	From higher P to lower P unless significant KE or PE	
• **Total Enthalpy**	$h_{tot} = h + \frac{1}{2}\bar{V}^2 + gZ$	
Instantaneous Process		
• **Continuity Equation**	$\dot{m}_{C.V.} = \sum \dot{m}_i - \sum \dot{m}_e$	
• **Energy Equation**	$\dot{E}_{C.V.} = \dot{Q}_{C.V.} - \dot{W}_{C.V.} + \sum \dot{m}_i h_{tot\,i} - \sum \dot{m}_e h_{tot\,e}$ → First Law $\rightarrow \dot{Q} + \sum \dot{m}_i (h_i + \frac{1}{2}\bar{V}^2 + gZ_i) = \frac{dE}{dt} + \sum \dot{m}_e \left(h_e + \frac{1}{2}\bar{V}^2 + gZ_e\right) - \dot{W}$	
Steady State Process	A steady-state has no storage effects, with all properties constant with time	
• **No Storage**	$\dot{m}_{C.V.} = 0, \quad \dot{E}_{C.V.} = 0$	
• **Continuity Equation**	$\sum \dot{m}_i = \sum \dot{m}_e$ (in = out)	
• **Energy Equation**	$\dot{Q}_{C.V.} + \sum \dot{m}_i h_{tot\,i} = \dot{W}_{C.V.} + \sum \dot{m}_e h_{tot\,e}$ (in = out) → First Law $\rightarrow \dot{Q} + \sum \dot{m}_i (h_i + \frac{1}{2}\bar{V}^2 + gZ_i) = \dot{W} + \sum \dot{m}_e \left(h_e + \frac{1}{2}\bar{V}^2 + gZ_e\right)$	
• **Specific Heat Transfer**	$q = \frac{\dot{Q}_{C.V.}}{\dot{m}}$	kJ / kg
• **Specific Work**	$w = \frac{\dot{W}_{C.V.}}{\dot{m}}$	kJ / kg
• **SS Single Flow Eq.**	$q + h_{tot\,i} = w + h_{tot\,e}$ (in = out)	
Transient Process	Change in mass (storage) such as filling or emptying of a container.	