

MECHANICAL ENGINEERING FORMULAS AND REVIEW MANUAL

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SECTION



MATHEMATICS
ENGINEERING
ECONOMICS
AND BASIC
ENGINEERING
SCIENCES

UNITS OF MEASUREMENT

QUALITY	ENGLISH	METRUC	SI
Length (L)	Feet (ft) Inches (in)	Meter (m) Centimeter (cm) Millimeter (mm) Kilometer (km)	Meter (m)
Area (A)	ft ² , in ²	m ² , cm ² , mm ²	m ²
Volume (V)	ft ³ , in ³ , gallons (gal)	m ³ , cm ³ , liters	m ³
Mass (m)	Slugs, pound-mass (lb _m)	kilogram-mass (kg _m)	kilogram
Weight, Force (W, F)	pound (lb)	kilogram-force (kg _f , kilopond)	Newton (N) Kilonewton (KN)
Density (ρ)	lb _m /ft ³	kg _m /m ³	kg/m ³
Specific Weight (δ)	lb/ft ³	kg _f /m ³ kg _f /li	kN/m ³ N/m ³
Specific Volume (V)	ft ³ /lb	m ³ /kg, li/kg	m ³ /kg
Temperature (t, T)	Degrees Fahrenheit(°F) Degrees Rankine (°R)	Degrees Celsius (°C) Kelvin (K)	Degrees Celsius (°C) Kelvin (K)
Angle (θ)	Degrees (°)	Gradient (grad)	Radians (rad)
Time (t, T)	Seconds (sec, s) Minutes (min, m) Hours (hr, h)	sec, min, hr	sec
Velocity, Speed, Rate (V, v, r)	ft/sec ft/min	m/sec km/hr	m/sec
Volume Flow Rate (V, Q)	ft ³ /sec gal/min (gpm)	m ³ /sec li/sec	m ³ /sec
Pressure, Stress (P, p, s)	lb/in ² (psi) lb/ft ² (psf)	kg/m ² kg/cm ²	Pascal (Pa) Kilopascal(Kpa) Megapascal(Mpa)
Work, Energy, Torque (W, E, T)	ft-lbs in-lbs	kg _f -m	Joules (J) Kilojoules(KJ)
Heat (Q, q)	Btu	calorie (cal) kilocalorie (kcal)	J, KJ

Power (P)	Horsepower (HP)	Metric Hp (MHP)	Watt (W) Kilowatt(KW) Megawatt(MW)
Specific Heat (c)	$\frac{\text{Btu}}{\text{lb} \cdot ^\circ\text{F}}$	$\frac{\text{kcal}}{\text{kg} \cdot ^\circ\text{C}}$	$\frac{\text{kJ}}{\text{kg} \cdot \text{K}}$
Specific Enthalpy (h)	$\frac{\text{Btu}}{\text{Lb}}$	$\frac{\text{kcal}}{\text{kg}}$	$\frac{\text{kJ}}{\text{kg}}$
Thermal Conductivity (k)	$\frac{\text{Btu} - \text{in}}{\text{ft}^2 \cdot ^\circ\text{F}}$	$\frac{\text{kcal}}{\text{m} \cdot ^\circ\text{C}}$	$\frac{\text{W}}{\text{m} \cdot \text{K}}$

RELATIONS OF UNITS

12 $\frac{\text{in}}{\text{ft}}$	5280 $\frac{\text{ft}}{\text{mi}}$	1.609 $\frac{\text{km}}{\text{mi}}$	100 $\frac{\text{cm}}{\text{m}}$
3 $\frac{\text{ft}}{\text{yd}}$	39.37 $\frac{\text{in}}{\text{m}}$	6080 $\frac{\text{ft}}{\text{naut. mi}}$	1000 $\frac{\text{mm}}{\text{m}}$
3.28 $\frac{\text{ft}}{\text{m}}$	25.4 $\frac{\text{mm}}{\text{in}}$	10 ⁴ $\frac{\text{microns}}{\text{cm}}$	1000 $\frac{\text{m}}{\text{km}}$

AREA

144 $\frac{\text{in}^2}{\text{ft}^2}$	10000 $\frac{\text{cm}^2}{\text{m}^2}$	10.76 $\frac{\text{ft}^2}{\text{m}^2}$	10000 $\frac{\text{m}^2}{\text{ha}}$	2.471 $\frac{\text{acres}}{\text{ha}}$
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VOLUME

1728 $\frac{\text{in}^3}{\text{ft}^3}$	7.481 $\frac{\text{gal}}{\text{ft}^3}$	4 $\frac{\text{qts}}{\text{gal}}$	3.7854 $\frac{\text{li}}{\text{gal}}$
231 $\frac{\text{in}^3}{\text{gal}}$	35.31 $\frac{\text{ft}^3}{\text{m}^3}$	2 $\frac{\text{pts}}{\text{qt}}$	1000 $\frac{\text{li}}{\text{m}^3}$

FORCE, MASS

16 $\frac{\text{oz}}{\text{lb}}$	32.174 $\frac{\text{lb}}{\text{slug}}$	2.205 $\frac{\text{lb}}{\text{kg}}$	1000 $\frac{\text{gr}}{\text{kg}}$
1000 $\frac{\text{lb}}{\text{kip}}$	7000 $\frac{\text{grains}}{\text{lb}}$	9.81 $\frac{\text{N}}{\text{kg}}$	2205 $\frac{\text{lbs}}{\text{MTon}}$
2000 $\frac{\text{lb}}{\text{ton}}$	1000 $\frac{\text{kg}}{\text{MTon}}$	0.00981 $\frac{\text{kN}}{\text{kg}}$	1000 $\frac{\text{N}}{\text{kN}}$

ANGLE

$\frac{\pi \text{ rad}}{180 \text{ deg}}$	$\frac{2\pi \text{ rad}}{\text{rev}}$	$\frac{360 \text{ deg}}{\text{rev}}$	$\frac{90 \text{ deg}}{100 \text{ grad}}$	$\frac{60 \text{ min}}{\text{deg}}$	$\frac{60 \text{ sec}}{\text{min}}$
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TIME

60 $\frac{\text{sec}}{\text{min}}$	60 $\frac{\text{min}}{\text{hr}}$	3600 $\frac{\text{sec}}{\text{hr}}$	24 $\frac{\text{hrs}}{\text{day}}$	8760 $\frac{\text{hrs}}{\text{year}}$
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PRESSURE

14.696 $\frac{\text{psi}}{\text{atm}}$	760 $\frac{\text{mm Hg}}{\text{atm}}$	101.325 $\frac{\text{KPa}}{\text{atm}}$	1 $\frac{\text{N/m}^2}{\text{Pa}}$
29.921 $\frac{\text{in.Hg}}{\text{atm}}$	1.033 $\frac{\text{kg/cm}^2}{\text{atm}}$	100 $\frac{\text{KPa}}{\text{bar}}$	1 $\frac{\text{kN/m}^2}{\text{KPa}}$

ENERGY

778 $\frac{\text{ft-lb}}{\text{Btu}}$	252 $\frac{\text{cal}}{\text{Btu}}$	4.187 $\frac{\text{kJ}}{\text{kcal}}$	1 $\frac{\text{kN-m}}{\text{kJ}}$
1.055 $\frac{\text{kJ}}{\text{Btu}}$	0.252 $\frac{\text{kcal}}{\text{Bt}}$	1 $\frac{\text{N-m}}{\text{J}}$	1000 $\frac{\text{K}}{\text{kJ}}$

POWER

550 $\frac{\text{ft-lbs/sec}}{\text{hp}}$	42.4 $\frac{\text{Btu/min}}{\text{hp}}$	1 $\frac{\text{kJ/sec}}{\text{KW}}$	1.014 $\frac{\text{MHP}}{\text{Hp}}$
33,000 $\frac{\text{ft-lbs/min}}{\text{hp}}$	3413 $\frac{\text{Btu/hr}}{\text{kw}}$	0.746 $\frac{\text{KW}}{\text{HP}}$	33,480 $\frac{\text{Btu/hr}}{\text{Boiler Hp}}$
2545 $\frac{\text{Btu/hr}}{\text{hp}}$	1 $\frac{\text{J/sec}}{\text{W}}$	0.736 $\frac{\text{KW}}{\text{MHP}}$	35,322 $\frac{\text{kJ/hr}}{\text{Boiler Hp}}$

TEMPERATURE

$^{\circ}\text{C} = 5/9 (^{\circ}\text{F}-32)$	$^{\circ}\text{F} = 9/5 ^{\circ}\text{C} + 32$	$^{\circ}\text{R} = ^{\circ}\text{F} + 460$	$\text{K} = ^{\circ}\text{C} + 273$
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TEMPERATURE DIFFERENCE

$^{\circ}\text{C} = 5/9 ^{\circ}\text{F}$	$^{\circ}\text{F} = 9/5 ^{\circ}\text{C}$	$^{\circ}\text{C} = \text{K}$	$^{\circ}\text{F} = ^{\circ}\text{R}$
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UNIVERSAL GAS CONSTANT

$\frac{\text{ft-lb}}{\text{p mole} - ^{\circ}\text{R}}$	$\frac{\text{kJ}}{\text{kg mole} - \text{K}}$
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PROPERTIES OF AIR

$c_p = 0.24 \frac{\text{Btu}}{\text{lb-}^{\circ}\text{F}}$	$= 0.24 \frac{\text{kcal}}{\text{kg-}^{\circ}\text{C}}$	$= 1.0 \frac{\text{kJ}}{\text{kg-}^{\circ}\text{C}}$
$c_v = 0.171 \frac{\text{Btu}}{\text{lb-}^{\circ}\text{F}}$	$= 0.171 \frac{\text{kcal}}{\text{kg-}^{\circ}\text{C}}$	$= 0.716 \frac{\text{kJ}}{\text{kg-}^{\circ}\text{C}}$
$R = 53.3 \frac{\text{ft-lb}}{\text{lb-}^{\circ}\text{R}}$	$= 0.287 \frac{\text{kJ}}{\text{kg-KC}}$	

PROPERTIES OF WATER

$$c_p = \text{specific heat (sensible heat) of liquid} = 4.187 \frac{\text{kJ}}{\text{kg} \cdot ^\circ\text{C}}$$

$$= 1 \frac{\text{Btu}}{\text{lb} \cdot ^\circ\text{F}}$$

$$L = \text{latent heat of fusion} = 335 \frac{\text{kJ}}{\text{kg}} = 144 \frac{\text{Btu}}{\text{lb}}$$

$$\text{Specific (sensible) heat of ice} = 2.093 \frac{\text{kJ}}{\text{kg} \cdot ^\circ\text{C}} = 0.5 \frac{\text{Btu}}{\text{lb} \cdot ^\circ\text{F}}$$

$$\text{Latent heat of vaporization (from and at } 100^\circ\text{C)} = 2257 \frac{\text{kJ}}{\text{kg}}$$

$$= 970.3 \frac{\text{Btu}}{\text{lb}}$$

Latent of water vapor in air and flue gases (average)

$$= 2442 \frac{\text{kJ}}{\text{kg}} = 1050 \frac{\text{Btu}}{\text{lb}}$$

ALGEBRA

EXPONENTS AND RADICALS

$$a^0 = 1$$

$$\frac{a^m}{a^n} = a^{m-n}$$

$$\frac{1}{a^m} = a^{-m} \quad (ab)^m = a^m b^m$$

$$a^m \cdot a^{m+n}$$

$$(a^m)^n = a^{mn}$$

$$a^{m/n} = \sqrt[n]{a^m}$$

$$(a/b)^m = a^m/b^m$$

FACTORS AND PRODUCTS

$$a(x + y) = ax + ay$$

$$(x + y)(x - y) = x^2 - y^2$$

$$(x + y)^2 = x^2 + 2xy + y^2$$

$$(x^3 + y^3) = (x + y)(x^2 - xy + y^2)$$

$$(x - y)^2 = x^2 - 2xy + y^2$$

$$(x^3 - y^3) = (x - y)(x^2 + xy + y^2)$$

TYPES OF EQUATIONS AND HOW THE UNKNOWNNS ARE SOLVED

1. Linear Equation in one unknown
Simple Transposition
2. Linear Equations in two or more unknowns
 - a. Substitution
 - b. Elimination
 - c. Determinants
3. Quadratic Equation in one unknown
Standard Form: $ax^2 + bx + c = 0$
 - a. Factoring (if factorable)
 - b. Quadratic Formula:

$$x = \frac{-b \pm \sqrt{b^2 - 4a}}{2a}$$

- c. Completing the Square
4. Quadratic Equations in two more unknowns
 - a. Substitution
 - b. Elimination
 - c. Determinants

5. Cubic Equation
Synthetic division, trial and error
(Possible roots are the factors of the constant)
6. Quadric Equation
Synthetic division, trial and error
7. Equations solvable only by trial and error

WORDED PROBLEMS IN ALGEBRA AND HINTS ON THEIR SOLUTIONS

1. Age Problem
The difference in the ages of the two persons always remains the same.
2. Clock Problem
The minute hand travels 12 times faster than the hour hand.
3. Motion Problem
Distance = rate x time
4. Mixture Problem
Percentage of a component in the mixture = $\frac{\text{Amount of the component}}{\text{Total amount of the mixture}}$
5. Percentage Problem
Percentage of a Part = $\frac{\text{Amount of the Part}}{\text{Total amount of the whole}}$
6. Work Problem
Part of work accomplished by a team = $\frac{\text{Number of days worked}}{\text{Number of days the team alone can do the entire work}}$

7. Number Problem
Two consecutive numbers have a difference of 1; two consecutive odd (and even) numbers have a difference of 2.
8. Interest Problem
Interest = Principal x Period x Interest Rate/Period
9. Lever Problem
Force A x Lever Arm A = Force b Lever Arm B
10. Miscellaneous Problems

VARIATION

- a. Direct Variation: x varies directly as y

$$x \propto y$$

$$x = ky$$

- b. Inverse Variation: x varies inversely as y

$$x \propto \frac{1}{y}$$

- c. Joint Variation: x varies directly as y and inversely as z

$$\propto \frac{y}{z} \quad x$$

$$x = k(y/z)$$

PROGRESSIONS

Arithmetic Progression – a series of numbers having a common difference

$$L = a + (n-1)d$$

$$S = \frac{(a + L)}{2} n$$

$$= n/2 [2a + (n-1)d]$$

Geometric Progression with infinite number of terms

$$S = \frac{a}{1-r}$$

Harmonic Progression – a series of numbers whose reciprocals form an Arithmetic Progression

where: a = first term

b = common difference

c = number of terms

L = the n^{th} term

S = sum

PERMUTATION, COMBINATION AND PROBABILITY

Permutation - an ordered arrangement of a group of things

The number of permutations of “n” things taken “r” at a time

$$= \frac{n!}{(n-r)!}$$

where: $n!$ = n factorial
 $= 1 \times 2 \times 3 \times 4 \times \dots \times n$

Combination – a part or all of a set of things

The number of combinations of “n” things taken “r” at a time

$$= \frac{n!}{r! (n-r)!}$$

Probability = $\frac{\text{Number of occurrences of a certain event}}{\text{Total number of occurrences}}$

Set – a collection of things each of which is called an element of the set

Venn Diagram – a diagram, drawn with circles, which portrays the relations of sets

TRIGONOMETRY

THE RIGHT TRIANGLE

Basic Trigonometric Functions:

$$\sin A = a/c = \cos (90-A)$$

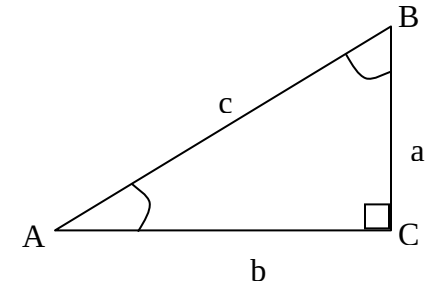
$$\cos A = b/c = \sin (90-A)$$

$$\tan A = a/b = \cot (90-A)$$

$$\cot A = b/a = 1/\tan A$$

$$\sec A = c/b = 1/\cos A$$

$$\csc A = c/a = 1/\sin A$$



Sum of Angles: $A + B + C = 180^\circ$

Pythagorean Theorem:

$$a^2 + b^2 = c^2$$

RELATIONS AMONG TRIGONOMETRIC FUNCTIONS

$$\tan A = \frac{\sin A}{\cos A}$$

$$\sin^2 A + \cos^2 A = 1$$

MEASUREMENT OF ANGLE: Degrees, Gradients, Radians

$$1 \text{ deg} = 60 \text{ min or } 60'$$

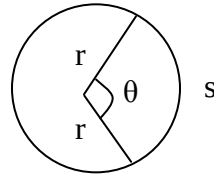
$$1 \text{ min} = 60 \text{ sec or } 60''$$

$$90 \text{ deg} = 100 \text{ grad}$$

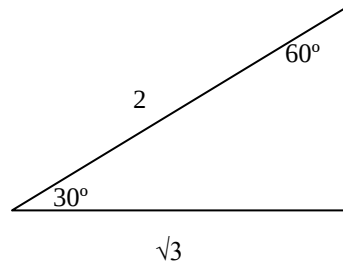
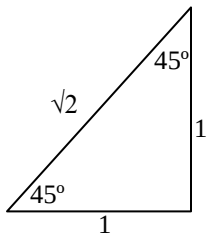
$$\pi \text{ rad} = 180 \text{ deg}$$

Radian Measure of an Angle:

$$\frac{s}{r} = \theta \text{ rad}$$



FUNCTIONS OF COMMON TRIANGLES



$$\sin 45^\circ = 1/\sqrt{2} = 0.707$$

$$\cos 45^\circ = 1/\sqrt{2} = 0.707$$

$$\tan 45^\circ = 1$$

$$\sin 30^\circ = \frac{1}{2} = 0.5$$

$$\cos 30^\circ = \sqrt{3}/2 = 0.866$$

$$\tan 30^\circ = 1/\sqrt{3} = 0.577$$

$$\sin 60^\circ = \sqrt{3}/2 = 0.866$$

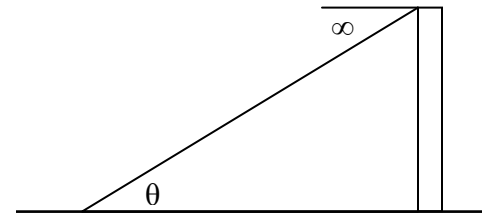
$$\cos 60^\circ = \frac{1}{2} = 0.5$$

$$\tan 60^\circ = \sqrt{3}/1 = 1.732$$

ANGLE OF ELEVATION AND ANGLE OF DEPRESSION

Angle of Elevation (θ) – angle between the horizontal and the line of sight which is above the horizontal.

Angle of Depression (ϕ) – angle between the horizontal and the line of sight which is below the horizontal



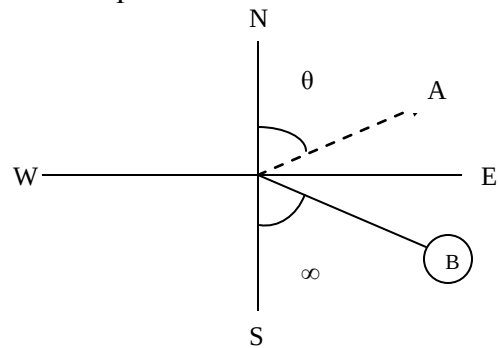
DIRECTION AND BEARING

Direction – the angle of the path of a moving object referred from the standard directions

Example: Direction of A: N θ° E or θ° E of N

Bearing – the angle of the line of sight on a stationary object referred from the standard directions

Example: Bearing of B: S ∞° E



FUNCTIONS OF SUM AND DIFFERENCE OF TWO ANGLES

$$\sin (x+y) = \sin x \cos y + \cos x \sin y$$

$$\sin (x-y) = \sin x \cos y - \cos x \sin y$$

$$\cos (x+y) = \cos x \cos y - \sin x \sin y$$

$$\cos (x-y) = \cos x \cos y + \sin x \sin y$$

$$\tan (x+y) = \frac{\tan x + \tan y}{1 - \tan x \tan y}$$

$$\tan (x-y) = \frac{\tan x - \tan y}{1 + \tan x \tan y}$$

FUNCTIONS OF DOUBLE ANGLES

$$\sin 2x = 2 \sin x \cos x$$

$$\cos 2x = \cos^2 x - \sin^2 x$$

$$\tan 2x = \frac{2 \tan x}{1 - \tan^2 x}$$

FUNCTIONS OF HALF ANGLES

$$\sin \frac{x}{2} = \sqrt{\frac{1 - \cos x}{2}}$$

$$\cos \frac{x}{2} = \sqrt{\frac{1 + \cos x}{2}}$$

$$\tan \frac{x}{2} = \frac{1 - \cos x}{2}$$

OBLIQUE TRIANGLES

Sine Law:

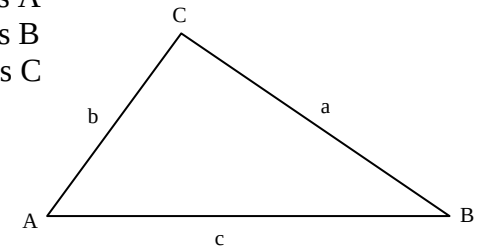
$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

Cosine Law:

$$a^2 = b^2 + c^2 - 2bc \cos A$$

$$b^2 = a^2 + c^2 - 2ac \cos B$$

$$c^2 = a^2 + b^2 - 2ab \cos C$$



LOGARITHM

Definition:

If $M^x = Y$ then $\log_M Y = x$

The logarithm of a number Y to the M is the number that will raise M to get Y

There is no logarithm of a negative number.

Rules of Logarithm

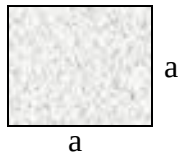
1. $\log M^x = x \log M$
2. $\log MN = \log M + \log N$
3. $\log M/N = \log M - \log N$

$\ln$ = natural logarithm
= $\log_e$
where: $e = 2.7182818$

SOLID MENSURATION

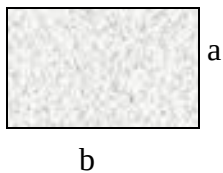
PLANE AREAS

Square



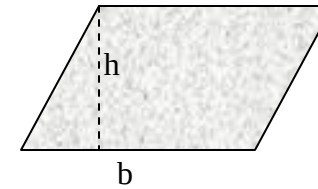
$$A = a^2$$
$$P = 4a$$

Rectangle



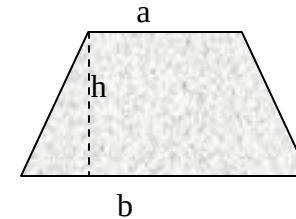
$$A = ab$$
$$P = 2a + 2b$$

Parallelogram



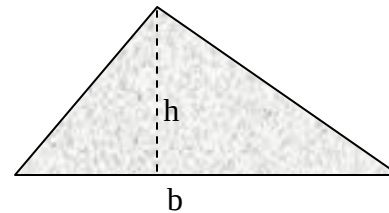
$$A = bh$$

Trapezoid

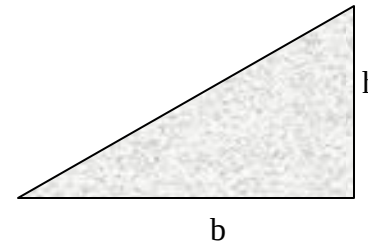


$$A = [(a+b)/2]h$$

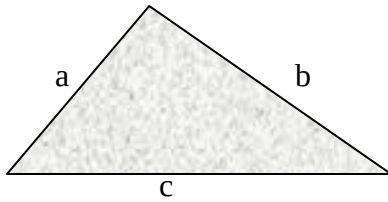
Triangle



$$A = bh/2$$



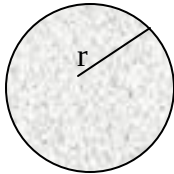
**Three sides known:
Here's formula**



$$s = \text{semi-perimeter} = (a + b + c)/2$$

$$A = \sqrt{s(s-a)(s-b)(s-c)}$$

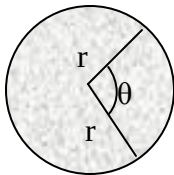
Circle



$$A = \pi r^2 = \pi/4(d^2)$$

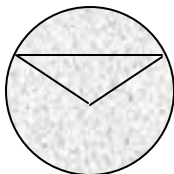
$$C = 2\pi r = \pi d$$

Circular Sector



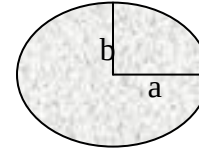
$$A = \frac{1}{2} r^2 \theta$$

Circular Segment



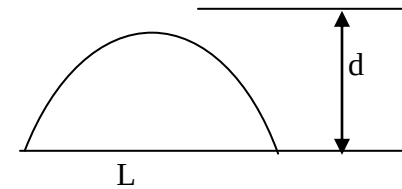
$$A = A_{\text{sector}} - A_{\text{triangle}}$$

Ellipse



$$A = \pi ab$$

Parabolic Segment



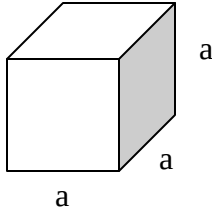
$$A = \frac{2}{3} Ld$$

Symbols:

A	= area
P	= perimeter
C	= circumference
V	= volume
SA	= surface area
LSA	= lateral surface area
L	= slant height

SOLIDS

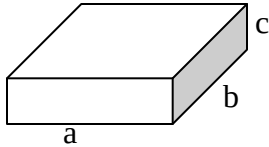
Cube



$$V = a^3$$

$$SA = 6a^2$$

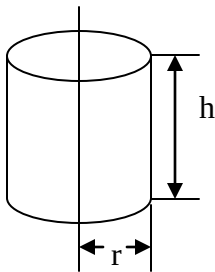
Rectangular Parallelopiped



$$V = abc$$

$$SA = 2ab + 2ac + 2bc$$

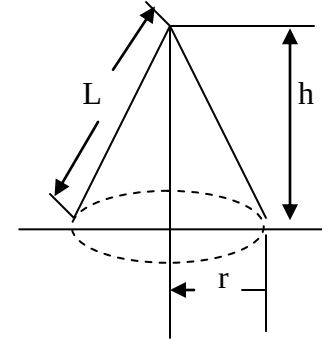
Cylinder



$$V = Ah = \pi r^2 h = (\pi/4)d^2 h$$

$$LSA = 2\pi r h$$

Cone

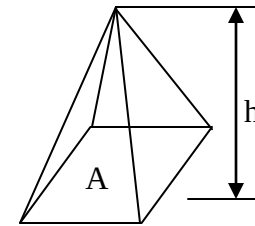


$$V = \frac{1}{3} \pi r^2 h$$

$$LSA = \frac{1}{2} CL$$

$$= \frac{1}{2} (2\pi r) \sqrt{r^2 + h^2}$$

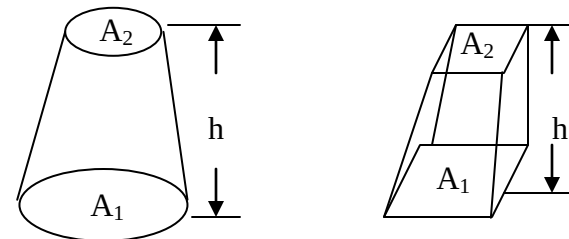
Pyramid



$$V = \frac{1}{3} Ah$$

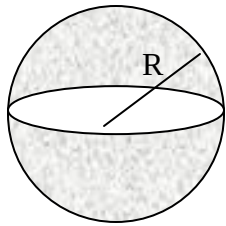
$A = \text{area of base}$

Frustrums



$$V = \frac{h}{3} (A_1 + A_2 + \sqrt{A_1 A_2})$$

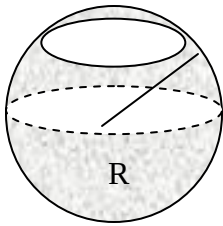
Sphere



$$V = \frac{4}{3}\pi R^3$$

$$SA = 4\pi R^2$$

Spherical Segment

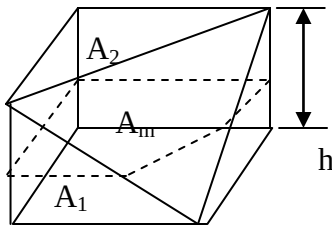


$$V = \frac{\pi h^2}{3} (3R - h)$$

$$Z = \text{area of zone}$$

$$= 2\pi R h$$

Prismatoid



$$V = \frac{h}{6}(A_1 + 4A_m + A_2)$$

$$A_m = \text{area of mid-section}$$

Pappus Theorem

I. Surface Area of Revolution

$$SA = 2\pi \bar{x} L$$

where: L = length of line that is rotated

$\bar{x}$ = distance of centroid of line from axis of rotation

II. Volume of Solid of Revolution

$$V = 2\pi \bar{x} A$$

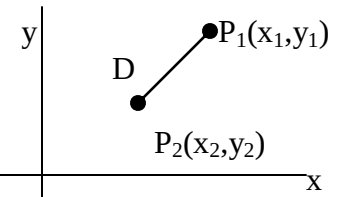
where: A = area of figure that is rotated

$\bar{x}$ = distance of centroid of figure from axis of rotation

ANALYTIC GEOMETRY

DISTANCE BETWEEN TWO POINTS

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$



THE STRAIGHT LINE

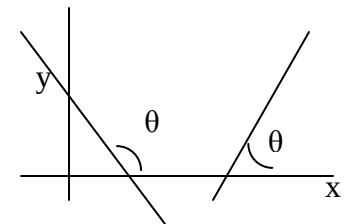
$$\text{General Equation: } Ax + By + C = 0$$

$$\text{or } x + by + c = 0$$

$$\text{Slope of line : } \tan \theta = m$$

$$\text{Parallel of lines : } m_2 = m_1$$

$$\text{Perpendicular lines : } m_2 = -1/m_1$$



Standard Equations of Straight Line

1. Point-Slope Form

$$y - y_1 = m(x - x_1)$$

where : m = slope

x_1, y_1 are the coordinates of a point on the line

If two points are given: $m = y_2 - y_1 / x_2 - x_1$

2. Slope-Intercept Form

$$y = mx + b$$

where: m = slope

b = intercept on the y-axis

3. Intercept Form

$$(x / a) + (y / b) = 1$$

where: a = intercept on x-axis

b = intercept on y-axis

DISTANCE OF A POINT FROM A LINE

Equation of Line: $AX + By + C = 0$

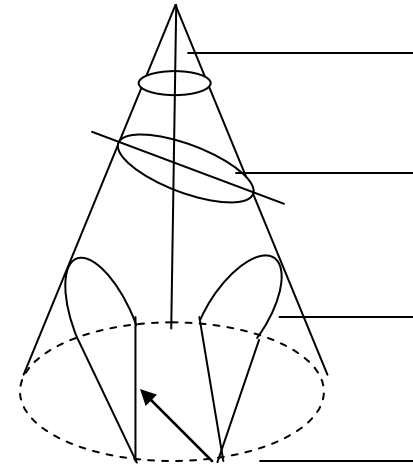
Coordinates of the point: (x_1, y_1)

$$d = \frac{Ax_1 + By_1 + C}{\pm \sqrt{A^2 + B^2}}$$

CONICS

General Equation of a Conic:

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0$$



Circle (formed by a plane perpendicular to the axis of the cone)

Ellipse (formed by a plane oblique to the axis of the cone)

Parabola (formed by a plane to the lateral side of the cone)

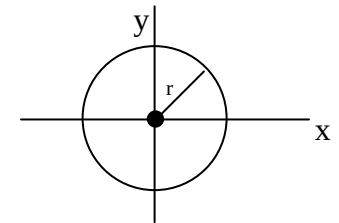
Hyperbola (formed by a plane parallel to the axis of the cone)

CIRCLE

Definition : Locus of points which are equidistant from a point called the center.

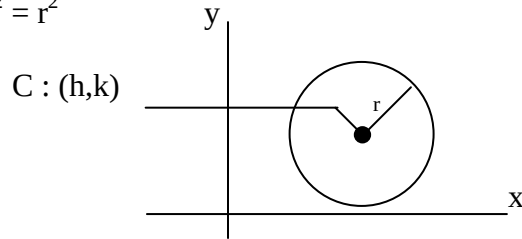
General Equation:

$$x^2 + y^2 = r^2$$



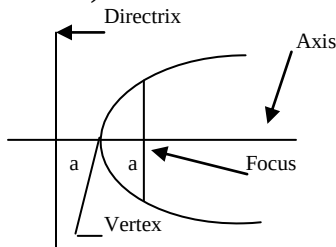
Standard equation with the center at (h,k) and radius of r:

$$(x-h)^2 + (y-k)^2 = r^2$$



PARABOLA

Definition : Locus of points whose distance from a fixed point (called the focus) is equal to the distance from a fixed line (called the directrix).



Standard equations, vertex at origin:

Opening upward: $x^2 = 4ay$

Opening downward: $x^2 = -4ay$

Opening to the right: $y^2 = 4ax$

Opening to the left: $y^2 = -4ax$

Standard Equations, vertex at (h,k):

Opening upward: $(x-h)^2 = 4a(y-k)$

Opening downward: $(x-h)^2 = -4a(y-k)$

Opening to the right: $(y-k)^2 = 4a(x-h)$

Opening to the left: $(y-k)^2 = -4a(x-h)$

ELLIPSE

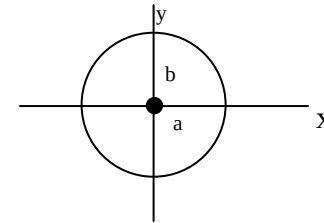
Definition: Locus of points whose distance from a fixed point is less than the distance from a fixed line.

e = eccentricity < 1

$$CF = ae = \sqrt{a^2 - b^2}$$

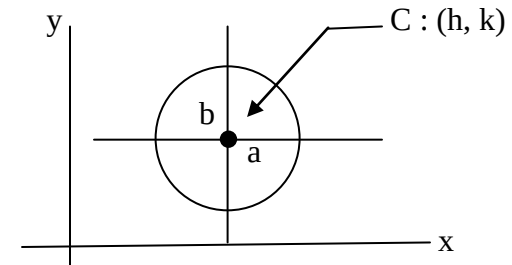
Standard Equation, center at origin:

$$(x^2/a^2) + (y^2/b^2) = 1$$



Standard Equation, center at (h, k):

$$\frac{(x-h)^2}{a^2} + \frac{(y-k)^2}{b^2} = 1$$



HYPERBOLA

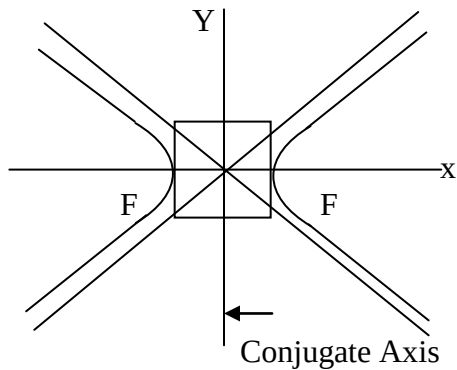
Definition: Locus of points whose distance from a fixed point is more than the distance from a fixed line.

e = eccentricity > 1

$$CF = ae = \sqrt{a^2 + b^2}$$

Standard Equation, center at origin, vertical conjugate axis:

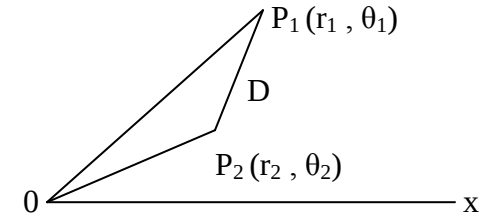
$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$$



POLAR COORDINATES

Distance Between Two Points in Polar Coordinates:

$$D = \sqrt{r_1^2 + r_2^2 - 2r_1r_2\cos(\theta_1 - \theta_2)}$$

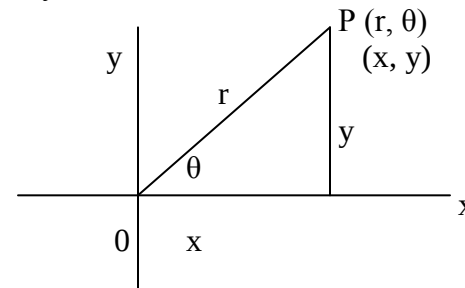


Relation of Polar Coordinates and Cartesian Coordinates:

$$x^2 + y^2 = r^2$$

$$x = r \cos \theta$$

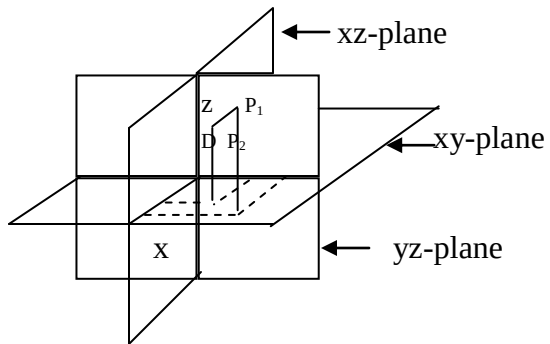
$$y = r \sin \theta$$



SOLID ANALYTIC GEOMETRY

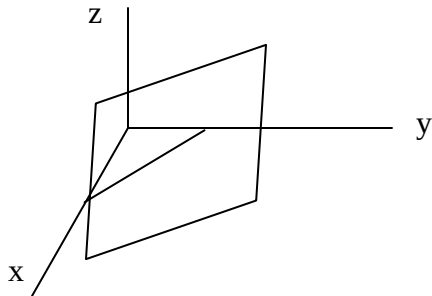
Distance Between Two Points in Space:

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$



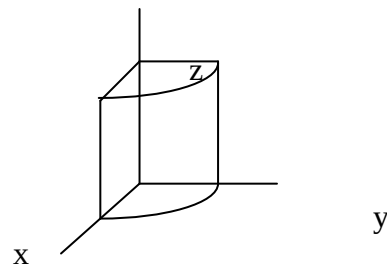
Planes

$$ax + by = k$$



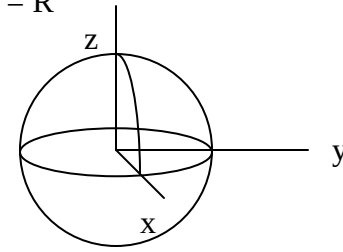
Cylinder

$$x^2 + y^2 = R^2$$



Sphere

$$x^2 + y^2 + z^2 = R^2$$



DIFFERENTIAL CALCULUS

DEFINITIONS

Let x = any variable (representing any physical quantity such as pressure, temperature, area, etc.)

dx = infinitely small change of x , which is called differential of x

dy = differential of another variable y

dy/dx = derivative of y with respect to x

Differentiation – the process of determining the derivative or differential

DIFFERENTIATION OF FORMULAS

$$\frac{d}{dx} c = 0$$

$$\frac{d}{dx} cu = c \frac{du}{dx}$$

$$\frac{d}{dx} (u+v) = \frac{du}{dx} + \frac{dv}{dx}$$

$$\frac{d}{dx} (uv) = u \left(\frac{dv}{dx} \right) + v \left(\frac{du}{dx} \right)$$

$$\frac{d}{dx} (u/v) = [v \left(\frac{du}{dx} \right) - u \left(\frac{dv}{dx} \right)] / v^2$$

$$\frac{d}{dx} u^n = n u^{n-1} \frac{du}{dx}$$

$$\frac{d}{dx} \sqrt[n]{u} = \left(\frac{du}{dx} \right) / 2 \sqrt[n]{u}$$

$$\frac{d}{dx} \sin u = \cos u \frac{du}{dx}$$

$$\frac{d}{dx} \cos u = -\sin u \frac{du}{dx}$$

$$\frac{d}{dx} \tan u = \sec^2 u \frac{du}{dx}$$

$$\frac{d}{dx} \cot u = -\csc^2 u \frac{du}{dx}$$

$$\frac{d}{dx} \sec u = \sec u \tan u \frac{du}{dx}$$

$$\frac{d}{dx} \csc u = -\csc u \cot u \frac{du}{dx}$$

$$\frac{d}{dx} \sin^{-1} u = \left(\frac{du}{dx} \right) / \sqrt{1-u^2}$$

$$\frac{d}{dx} \cos^{-1} u = \left(\frac{du}{dx} \right) / -\sqrt{1-u^2}$$

$$\frac{d}{dx} \tan^{-1} u = \left(\frac{du}{dx} \right) / 1+u^2$$

$$\frac{d}{dx} \ln u = \left(\frac{du}{dx} \right) / u$$

$$\frac{d}{dx} \log_a u = \log_a e \left(\frac{du}{dx} \right) / u$$

$$\frac{d}{dx} e^u = e^u \frac{du}{dx}$$

$$\frac{d}{dx} a^u = a^u \ln a \frac{du}{dx}$$

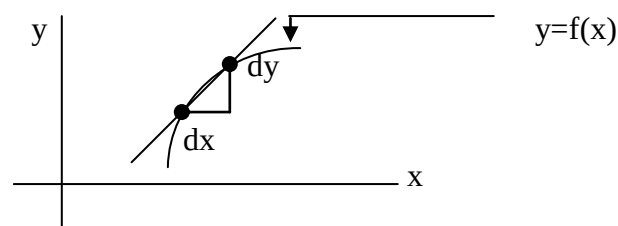
APPLICATIONS OF DIFFERENTIAL CALCULUS

1. Slope of Curve

Consider a curve whose equation is

$$y = f(x), \text{ then}$$

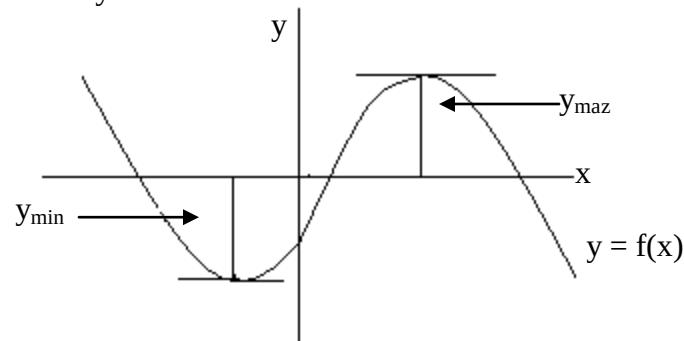
$$\text{slope} = m = \frac{dy}{dx}$$



2. Critical Points (Maximum and Minimum Points) of a Curve

At the critical points of a curve

$$\frac{dy}{dx} = 0$$



3. Points of Inflection of a Curve

At the points inflection

$$\frac{d^2y}{dx^2} = y'' = 0$$

4. Maxima-Minima

To obtain the maximum or minimum value of a certain variable, differentiate the variable and equate the derivative to zero.

5. Time Rates

Time rate is the rate at which a variable changes with time, such as:

$$\frac{dx}{dt} \text{ m/sec, } \frac{dV}{dt} \text{ m}^3/\text{sec, etc}$$

6. Approximation of Change Using Differential

The Differential can be used to approximate a measurable change, if the change is small.

7. Newton's Method of Solving Equations

Consider the equation $f(x) = 0$ in which the value of x is solvable only by trial and error

Let $y = f(x)$, then obtain $y' = f'(x)$

Let x_1 = first trial value, then

$$x_2 = x_1 - \frac{f(x_1)}{f'(x_1)}$$

$$x_3 = x_2 - \frac{f(x_2)}{f'(x_2)} \quad \text{etc.}$$

PARTIAL DIFFERENTIATION

Consider the function: $M = f(x, y)$

When obtaining $\frac{\partial M}{\partial x}$, consider y as a constant

$\frac{\partial M}{\partial y}$, consider x as a constant

INTEGRAL CALCULUS

DEFINITION

$\int$ - the integral sign, representing the sum of infinitely small quantities

INTEGRATION FORMULAS

$$\int du = u + C$$

$$\int a du = a \int du = au + C$$

$$\int u^n du = \frac{u^{n+1}}{n+1} + C$$

$$\int du/u = \ln u + C$$

$$\int e^u du = e^u + C$$

$$\int a^u du = \frac{a^u}{\ln a} + C$$

$$\int \cos u du = \sin u + C$$

$$\int \sin u du = -\cos u + C$$

$$\int \sec^2 u du = \tan u + C$$

$$\int \csc^2 u du = -\cot u + C$$

$$\int \sec u \tan u du = \sec u + C$$

$$\int \csc u \cot u du = -\csc u + C$$

$$\int du / \sqrt{a^2 - u^2} = \sin^{-1} u/a + C$$

$$\int du / a^2 + u^2 = 1/a \tan^{-1} u/a + C$$

Special Methods of Integration

1. Integration by Parts

$$\int u \, dv = uv - \int v \, du$$

2. Integration by Algebraic Substitution

A new variable is used to substitute the original variable to make the integrand integrable.

3. Integration by Trigonometric Substitution

Let $x = a \sin \theta$ for $\sqrt{a^2 - x^2}$

$x = a \tan \theta$ for $\sqrt{a^2 + x^2}$

$x = a \sec \theta$ for $\sqrt{x^2 - a^2}$

4. Integration by Partial Fractions

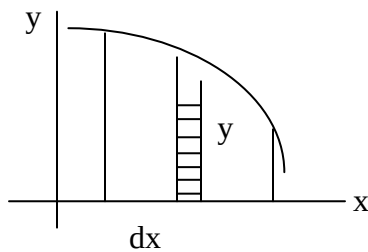
This is applied when the integrand becomes integrable when expressed into its partial functions.

5. Integration by Series

APPLICATIONS OF INTEGRATION

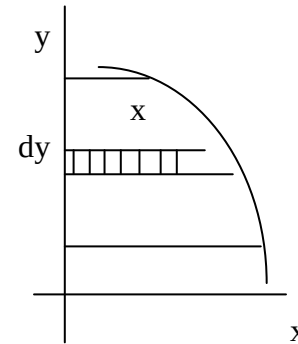
1. Plane Areas

Using Vertical Strip:



$$A = \int_{x_1}^{x_2} y \, dx$$

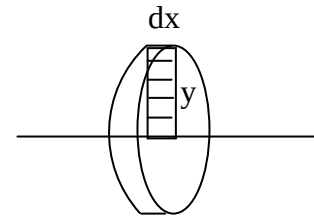
Using Horizontal Strip:



$$A = \int_{y_1}^{y_2} x \, dy$$

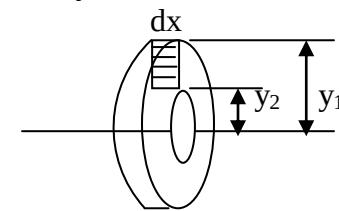
2. Volume of Solid Revolution

Cylindrical Disk



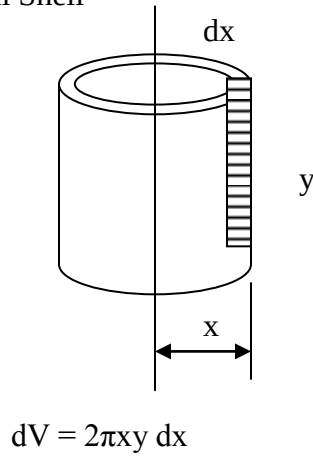
$$dV = \pi y^2 dx$$

Hollow Cylindrical Disk



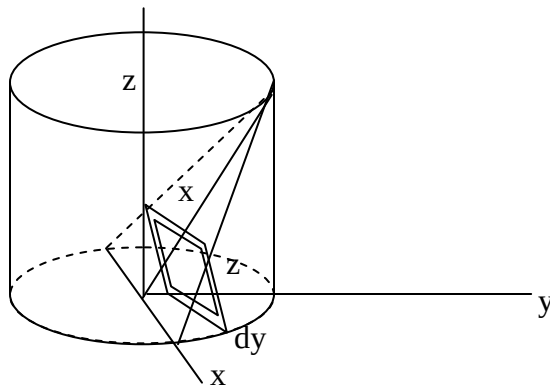
$$dV = \pi(y_1^2 - y_2^2) dx$$

Cylindrical Shell



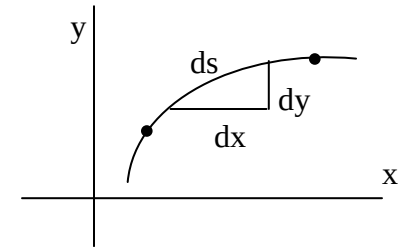
3. Volume of Miscellaneous Solids Example: Volume of Wedge

$$V = 2 \int xz \, dy$$



4. Length of Curve

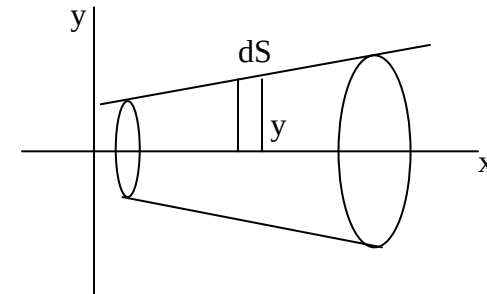
$$dS = \sqrt{1 + (dy/dx)^2} dx$$



5. Area of Surface of Revolution

$$SA = \int 2\pi y \, dS$$

$$= \int 2\pi y \sqrt{1 + (dy/dx)^2} dx$$



6. Work

$$\text{Work} = \text{Force} \times \text{Distance} = \int dV \times \text{density} \times \text{distance}$$

7. Fluid Pressure

$$F = \text{force on submerged area} = \int dA \times \text{depth} \times \text{density}$$

8. Centroid

Centroid of Plane Area:

$$\begin{aligned} A \bar{x} &= \int dA x \\ A \bar{y} &= \int dA y \end{aligned}$$

Centroid of Solid:

$$\begin{aligned} V \bar{x} &= \int dV x \\ V \bar{y} &= \int dV y \end{aligned}$$

9. Moment of Inertia

Moment of Inertia of Plane Area:

$$\begin{aligned} I_x &= \int dA y^2 \\ I_y &= \int dA x^2 \end{aligned}$$

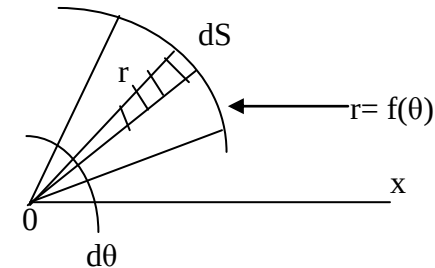
Moment of Inertia of Solid of Revolution:

$$\begin{aligned} I_x &= \int dV y^2 \\ I_y &= \int dV x^2 \end{aligned}$$

INTEGRATION IN POLAR COORDINATES

$$A = \text{Area} = \int_{\theta_1}^{\theta_2} \frac{1}{2} r^2 d\theta$$

$$S = \text{Length of Curve} = \int_{\theta_1}^{\theta_2} r d\theta$$



DIFFERENTIAL EQUATIONS

DEFINITIONS

Differential Equation – an equation containing derivatives or differentials.

Ordinary differential equation – a differential equation involving only one independent variable and therefore containing only ordinary derivatives.

Order of differential equation – the order of the highest derivative that occurs in the equation.

Degree of a differential equation – the algebraic degree in the highest-ordered derivative present in the equation.

Solution of a differential equation – an expression, free from derivatives, which is consistent with the given differential equation.

a. General Solution – solution that contains arbitrary constants.

b. Particular Solution – solution that does not contain any more arbitrary constants.

I. VARIABLE SEPARABLE

This is a type of differential equation which can be put in the form

$$A(x) dx + B(y) dy = 0$$

that is, the variables can be separated.

II. HOMOGENEOUS DIFFERENTIAL EQUATION

This is a type of differential equation in which all the terms are of the same degree.

Solution: Let $y = vx$

The substitution will make the equation variable separable.

III. EXACT DIFFERENTIAL EQUATION

This is a type of differential equation which when put in the form

$$M(x,y) dx + N(x,y) dy = 0$$

a function can be found which has for its total differential the expression $M dx + N dy$.

A differential equation is exact if $\frac{\partial M}{\partial y} = \frac{\partial N}{\partial x}$

IV. LINEAR DIFFERENTIAL EQUATION

A type of differential equation which can be put in the standard form:

$$dy + P(x) y dx = Q(x) dx$$

Solution:

1. Put the given equation into the standard form;
2. Obtain the Integrating Factor $\int P dx$
3. Apply the integrating factor to the equation in its standard form.
4. Solve the resulting exact equation.

ENGINEERING MECHANICS

DEFINITIONS

Engineering Mechanics – a science which deals with the study of forces and motion of rigid bodies.

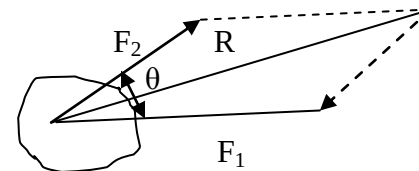
- I. Statics – branch of Mechanics which studies forces on rigid bodies that remain at rest.
- II. Dynamics – branch of Mechanics which considers the motion of rigid bodies caused by the forces acting upon them.
 1. Elinematics: deals with pure motion
 2. Kinetics: relates motion to the applied forces

FORCES

Coplanar forces – forces that lie on one plane

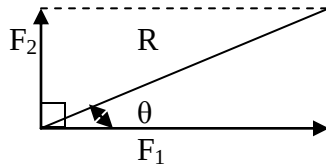
Non-coplanar forces – forces that do not lie on one plane

Resultant of Forces:



Parallelogram Method:

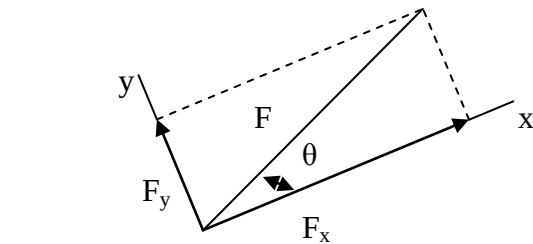
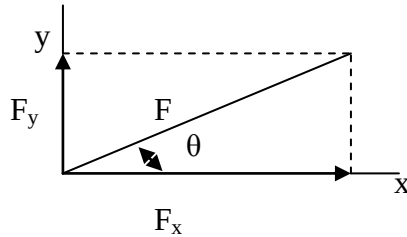
$$R = \sqrt{F_1^2 + F_2^2 - F_1 F_2 \cos(180 - \theta)}$$



$$R = \sqrt{F_1^2 + F_2^2}$$

$$\theta = \tan^{-1} F_2/F_1$$

Components of a Force:



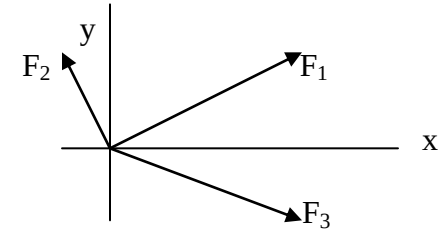
$$F_x = F \cos \theta$$

$$F_y = F \sin \theta$$

Resultant of Three or More Concurrent Forces:

$$R = \sqrt{\Sigma F_x^2 + \Sigma F_y^2}$$

$$\theta = \tan^{-1} \frac{\Sigma F_y}{\Sigma F_x}$$



Moment of Force = Force x Perpendicular distance from the axis to the line of action of the force

“Free Body” Diagram – diagram of an isolated body at which shows only the forces acting on the body

STATICS

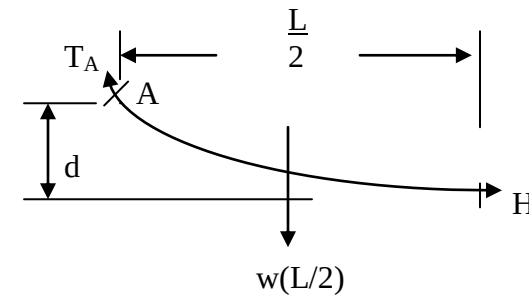
Forces in Equilibrium (Condition of Statics)

$$\Sigma F_x = 0$$

$$\Sigma F_y = 0$$

$$\Sigma M = 0$$

PARABOLIC CABLES



$$\Sigma M_A = 0:$$

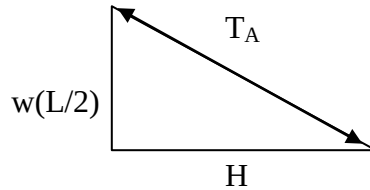
$$H(d) - w(L/2)(L/4) = 0$$

$$H = \frac{wL^2}{8d}$$

From force triangle:

$$T_A = \sqrt{H^2 + [w(L/2)]^2}$$

$$\text{Length of Cable} = L + \frac{8d^2}{3L} - \frac{32d^4}{5L^3}$$



CATENARY

$$T_A = T_B = wy$$

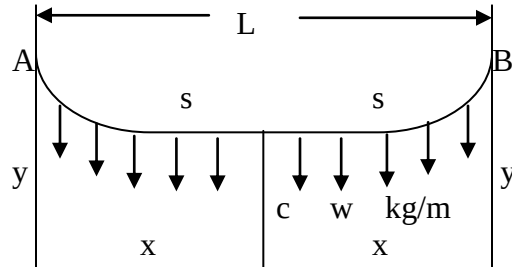
H = tension at lowest point

$$= wc$$

$$y^2 = s^2 + c^2$$

$$x = c \ln \frac{s+y}{c}$$

$$L = 2x$$



FRICTION

$$F = fN$$

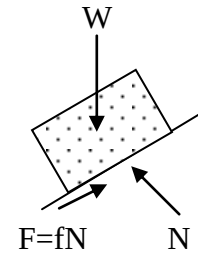
where: F = frictional force

N = normal force (reaction normal to the surface of contact)

f = coefficient of static friction

a. coefficient of static friction
(for bodies that are not moving)

b. coefficient of kinetic friction
(for bodies that are moving)



KINEMATICS: RECTILINEAR MOTION

$$1. a = \frac{V_2 - V_1}{t}$$

a = acceleration, m/sec²
+ when accelerating
- when decelerating

$$2. S = V_1 t + 1/2 a t^2$$

V = velocity, m/sec

S = distance, m

$$3. V_2^2 = V_1^2 + 2aS$$

t = time, sec

$$a = dV/dt$$

$$y = dS/dt$$

FALLING BODIES

$$1. g = \frac{V_2 - V_1}{t}$$

g = acceleration of gravity
= 9.81 m/sec² = 32.2 ft/sec²
+ when going down
- when going up

$$2. S = V_1 t + 1/2 g t^2$$

$$3. V_2^2 = V_1^2 + 2gS$$

PROJECTILE

V_o = initial velocity

t = time of flight

Horizontal displacement:

$$x = V_o \cos \theta t$$

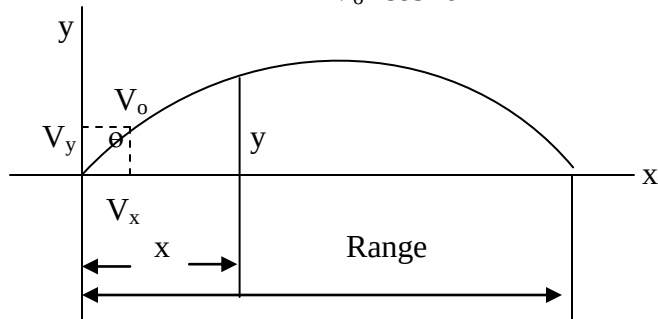
Vertical displacement:

$$y = V_o \sin \theta t - \frac{1}{2} g t^2$$

Equation of path of projectile:

(Parabola)

$$y = x \tan \theta - \frac{g x^2}{2 V_o^2 \cos^2 \theta}$$



$$V_x = V_o \cos \theta$$

$$V_y = V_o \sin \theta$$

ROTATION (ANGULAR MOTION)

1. $\alpha = \omega_2 - \omega_1$
2. $\theta = \omega_1 t + \frac{1}{2} \alpha t^2$
3. $\omega_2^2 = \omega_1^2 + 2 \alpha \theta$

α = angular acceleration, rad/sec² or rev/sec²

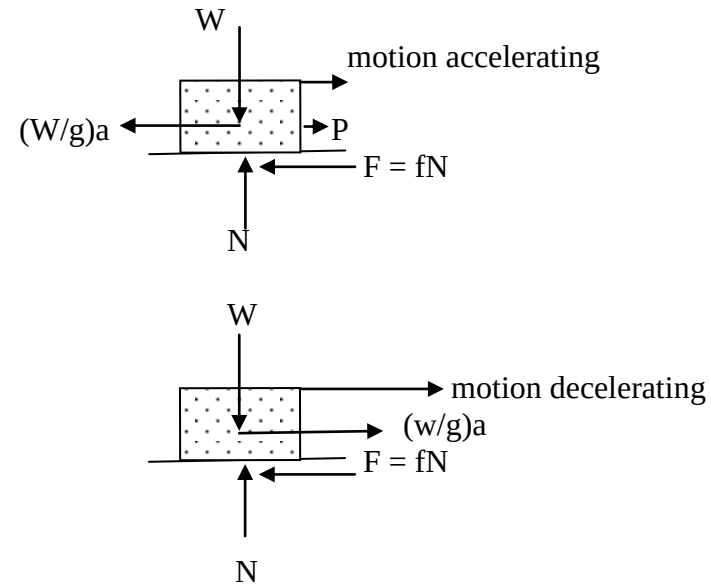
ω = angular velocity, rad/sec or rev/sec

θ = angular displacement, rad or rev

t = time, sec

KINETICS

REVERSED EFFECTIVE FORCE



$(w/g)a$ = reversed effective force (acceleration force)

a = acceleration

WORK-ENERGY METHOD

$$KE_1 + PW - NW = KE_2$$

KE_1 = initial kinetic energy

PW = positive work

NW = negative work

KE_2 = final kinetic energy

$$= \frac{W V_2^2}{2g}$$

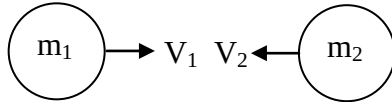
WORK, ENERGY AND POWER

Work = Force x Distance

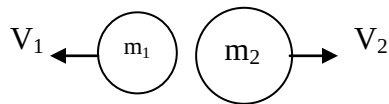
Power = $\frac{\text{Force} \times \text{Distance}}{\text{Time}}$ = Force x Velocity

MOMENTUM

Before Impact:



After Impact:



Conservation of Momentum:

$$m_1 V_1 + m_2 V_2 = m_1 V_1' + m_2 V_2'$$

e = coefficient of restitution

$$e = \frac{V_2' - V_1'}{V_1 - V_2}$$

CENTRIFUGAL FORCE

$$F_c = \frac{W V^2}{g r}$$

F_c = centrifugal force

W = weight of body being rotated

V = peripheral velocity = $\pi D N$

r = radius of rotation

STRENGTH OF MATERIALS

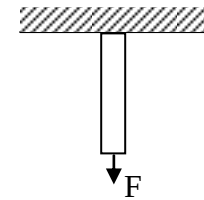
STRESSES

Stress = Force/Area

Ultimate Stress = the stress that will cause failure

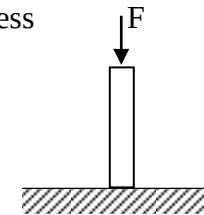
Allowable Stress (or Safe Stress) = $\frac{\text{Ultimate Stress}}{\text{Factor of Safety}}$

1) Tensile Stress



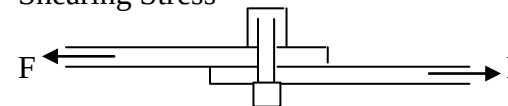
$$s_t = F/A$$

2) Compressive Stress



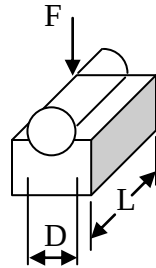
$$s_c = F/A$$

3) Shearing Stress



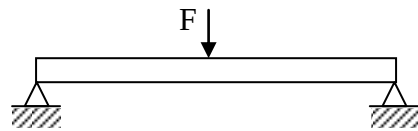
$$s_s = F/A$$

4) Bearing Stress

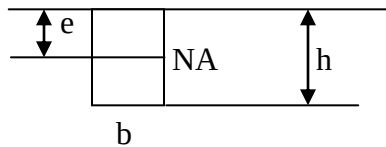


$$s_b = F/DL$$

5) Bending (Flexural) Stress



$$s_f = Mc/I$$



where: M = moment
 c = distance of farthest fiber neutral axis (NA)
 I = moment of inertia about the neutral axis
 = $bh^3/12$ for rectangular section

6) Torsional Stress

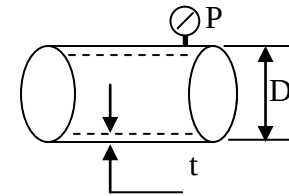
$$s_s = Tc/J \quad T = \text{torque}$$

$$s_s = 16T/\pi D^3 \quad J = \text{polar moment of inertia}$$

(for circular section where D = diameter)

7) Stresses in Thin Pressure Vessels

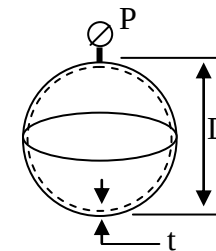
Cylinder:



$$s_t = \text{tangential stress}$$

$$= PD/2t$$

Sphere:



$$s = PD/4t$$

8) Strain; Elongation

$$\text{Strain} = Y/L$$

$$\text{Stress} = F/A$$

E = Modulus of Elasticity
 (Young's Modulus)

$$= \frac{F/A}{Y/L}$$

$$Y = FL/AE = s(L/E)$$

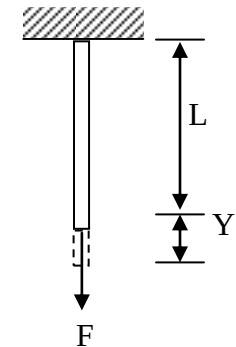
Y = elongation (or shortening)

L = length

F = force

A = area

s = stress



9) Thermal Elongation; Stress

$$Y = k L (t_2 - t_1)$$

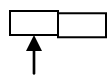
Y = elongation due to temperature change, m

k = coefficient of thermal expansion, m/m-°C

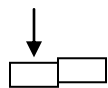
t₁ = initial temperature, °C

t₂ = final temperature, °C

SHEAR AND MOMENT IN BEAMS



Positive Shear



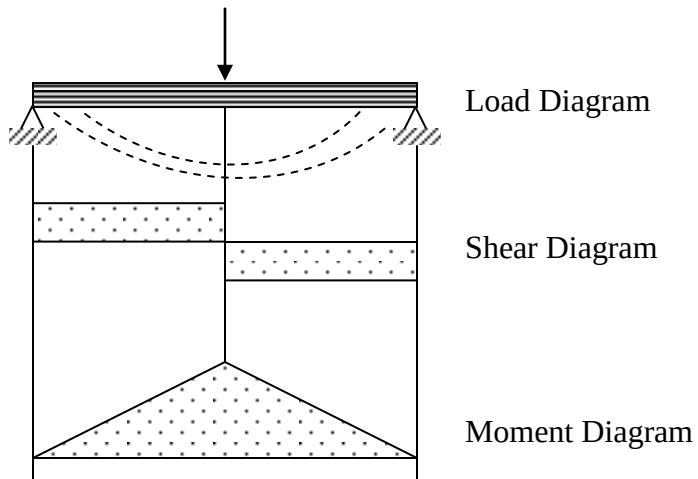
Negative Shear



Positive Bending Moment

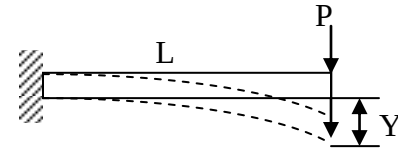


Negative Bending Moment

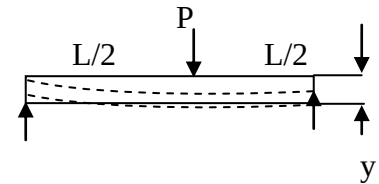


DEFLECTION OF BEAMS

$$\frac{d^2y}{dx^2} = \frac{M}{EI}$$



$$y = \frac{PL^3}{3EI}$$



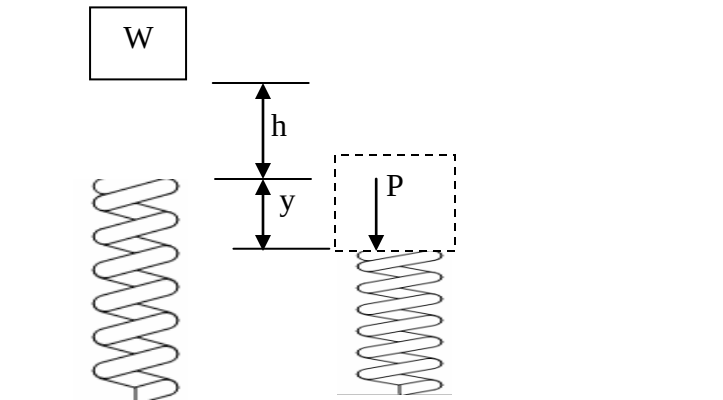
$$y = \frac{PL^3}{48EI}$$

IMPACT LOAD

$$w(h+y) = P(y/2)$$

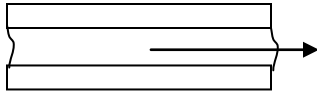
where P = maximum force (on the spring)

y = deflection of spring



FLUID MECHANICS

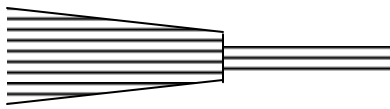
GENERAL FLOW EQUATION



where: A = area, m^2
 V = velocity, m/sec

$$Q = A \times V \text{ m}^3/\text{sec}$$

FLOW THROUGH NOZZLE



where: A = area of nozzle
 C_d = coefficient of discharge
 h = height of liquid above nozzle

$$Q = C_d A \sqrt{2gh} \text{ m}^3/\text{sec}$$

HYDROSTATIC PRESSURE: PRESSURE HEAD

Pressure = Height x Density or $h = \text{Pressure}/\text{Density}$

VELOCITY HEAD

$$V = \sqrt{2gh} \text{ or } h = V^2/2g$$

FRICTION HEAD LOSS IN PIPES

$$h_f = f L V^2 / 2 g D \text{ (Darcy Formula)}$$

$$= 2 f L V^2 / g d \text{ (Morse Formula, and } f \text{ should be taken from Morse's table)}$$

where: h_f = friction head loss, m
 f = coefficient of friction
 L = length of pipe, m
 V = velocity, m/sec
 $g = 9.81 \text{ m/sec}^2$
 D = internal diameter, m

BUOYANCY

Archimedes Principle:

A body partly or wholly submerged in a liquid is buoyed up by a force equal to the weight of the liquid displaced.

FORCE EXERTED BY A JET (HYDRODYNAMICS)

$$F = m V = (w/g)V$$

where: W = flow rate, kg/sec
 $g = 9.81 \text{ m/sec}^2$
 V = velocity of jet, m/sec

PERIPHERAL COEFFICIENT

$$\text{Peripheral Coefficient} = \frac{\text{Peripheral Velocity}}{\text{Velocity of Jet}}$$

$$= \frac{\pi D N}{\sqrt{2gh}}$$

ENGINEERING ECONOMICS

DEFINITIONS

Engineering Economics – the study of the cost factors involved in engineering projects, and using the results of such study in employing the most efficient cost-saving techniques without affecting the safety and soundness of the project.

Investment – the sum of total of first cost (fixed capital) and working capital which is being put up in a project with the aim of getting a profit.

Fixed Capital – part of the investment which is required to acquire or set up the business.

Working Capital – the amount of money set aside as part of the investment to keep the project or business continuously operating.

Demand – the quantity of a certain commodity that is bought at a certain price at a given place and time.

Supply – the quantity of a certain commodity that is offered for sale at a certain place at a given place and time.

Perfect Competition – a business condition in which a product or service is supplied by a number of vendors and there is no restriction against additional vendors entering the market.

Monopoly – a business condition in which unique product or service is available from only one supplier and that supplier can prevent the entry of all others into the market.

Oligopoly – a condition in which there are so few suppliers of a product or service that action by one will almost result in similar action by the others.

Law of Supply and Demand: “Under conditions of perfect competition, the price of a product will be such that the supply and demand are equal.”

Law of Diminishing Returns: “When the use of one of the factors of production is limited, either in increasing cost or by absolute quantity, a point will be reached beyond which an increase in the variable factors will result in a less than proportionate increase in output.”

INTEREST

Interest – money paid for the use of borrowed money

SIMPLE INTEREST

$$I = Pni$$

$$S = P + I = P + Pni$$

where: P = principal or present value

n = number of interest periods

i = interest rate per period (if not specified, consider per year)

I = interest

S = sum or future value

Ordinary Simple Interest:

$$1 \text{ year} = 12 \text{ months} = 360 \text{ days}$$

Exact Simple Interest:

$$1 \text{ year} = 12 \text{ months} = 365 \text{ days}$$

COMPOUND INTEREST

$$S = P(1+i)^n$$

$$P = \frac{S}{(1+i)^n}$$

where: S = compound amount or future worth

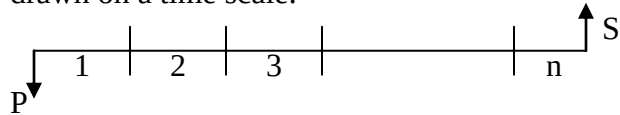
P = original sum or principal

i = interest rate per period

n = number of interest periods

$(1+i)^n$ is called single payment compound amount factor

Cash Flow Diagram – a graphical representation of cash flows drawn on a time scale.



Discount = $S - P$

Rate of Discount = $d = \frac{S - P}{S}$

Nominal and Effective Interest Rates

Examples:	<u>Nominal Rate</u>	<u>Effective Rate</u>
	12% compounded semi-annually	$\frac{12}{2} = 6\%$ per semi-annual
	12% compounded quarterly	$\frac{12}{4} = 3\%$ per quarter
	12% compounded monthly	$\frac{12}{12} = 1\%$ per month

To find effective rate per year:

$$i = (1 + (i_n/m))^m - 1$$

where: i_n = nominal rate
 m = periods per year

ANNUITY

Annuity – a series of equal payments occurring at equal intervals of time

Applications of annuity:

1. installment purchase
2. amortization of loan
 (amortization – payment of debt by installment usually by equal amounts and at equal intervals of time)
3. depreciation
4. payment of insurance premiums

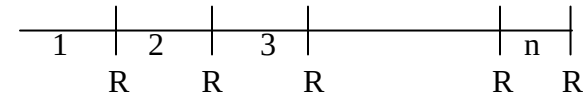
Types of Annuity:

Ordinary Annuity: payments occur at the end of each period

Annuity Due: payments occur at the beginning of each period

Deferred Annuity: first payment occurs later than at the end of the first period

Ordinary Annuity:



$$P = R [(1+i)^n - 1 / i(1+i)^n]$$

R = periodic payments

i = interest rate per period

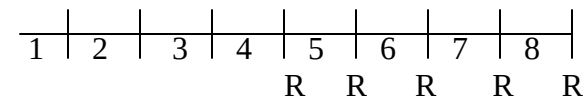
n = number of periods

P = present value of the periodic payments

S = value of the periodic payments at the end of n periods

$$S = R [(1+i)^n - 1 / i]$$

Annuity Due, Example:



$$P = \frac{R [(1+i)^5 - 1 / i(1+i)^5]}{(1+i)^3}$$

Perpetuity – an annuity that continues indefinitely

$$P = R/i$$

where: P = present value of the perpetuity

R = periodic payments

i = interest rate per period

DEPRECIATION AND VALUATION

Depreciation – the decrease in value of a physical property due to the passage of time

1. Physical Depreciation – type of depreciation caused by the lessening of the physical ability of the property to produce results, such as physical damage, wear and tear.
2. Functional Depreciation – type of depreciation caused by lessening in the demand for which the property is designed to render, such as obsolescence and inadequacy.

Valuation (Appraisal) – the process of determining the value or worth of a physical property for specific reasons.

Purposes of Depreciation:

1. To provide for the recovery of capital which has been invested in the property.
2. To enable the cost of depreciation to be charged to the cost of producing the products that are turned out by the property.

First Cost (FC) – the total amount invested on the property until the property is put into operation.

Economic Life – the length of time at which a property can be operated at a profit.

Value – the present worth of all the future profits that are to be received through ownership of the property.

1. market value – the price that will be paid by a willing buyer to a willing seller for a property where each has equal advantage and is under no compulsion to buy or sell
2. book value – the worth of a property as shown in the accounting records.
3. salvage or resale value – the price of a property when sold second-hand; also called trade-in value.

4. scrap value – the price of a property when sold for junk
5. fair value – the worth of a property as determined by a disinterested party which is fair to both seller and buyer
6. use value – the worth of a property as an operating unit
7. face or par value of a bond – the amount that appears on the bond which is the price at which the bond is first bought

Depletion – the decrease in value of a property due to the gradual extraction of its contents, such as mining properties, oil wells, timber lands and other consumable resources.

METHODS OF COMPUTING DEPRECIATION

1. Straight Line Method

$$\text{Annual Depreciation} = (\text{FC} - \text{SV}) / n$$

FC = first cost

SV = salvage or scrap value

n = useful life

$$\begin{aligned} \text{Book Value after } m \text{ years} \\ = \text{FC} - m((\text{FC} - \text{SV})/n) \end{aligned}$$

2. Sinking Fund Method

$$\text{Annual Dep} = \frac{\text{FC} - \text{SV}}{[(1+i)^n - 1 / i]}$$

i = interest rate or worth of money

$$\begin{aligned} \text{Book Value after } m \text{ years} \\ = \text{FC} - (\text{annual Dep}) \frac{[(1+i)^m - 1]}{i} \end{aligned}$$

3. Declining-Balance Method (also called Diminishing-Balance Method, Matheson Method, Constant-Percentage or Constant-Ratio Method)

$$k = \text{constant ratio} = 1 - \sqrt[n]{\text{SV}/\text{FC}}$$

$$\begin{aligned} \text{Dep}_1 &= k(\text{FC}) \\ \text{Dep}_2 &= k(\text{FC}) (1-k) \\ \text{Dep}_3 &= k(\text{FC}) (1-k)^2 \\ \text{Dep}_4 &= k(\text{FC}) (1-k)^3 \\ &\vdots \\ \text{Dep}_n &= k(\text{FC}) (1-k)^{n-1} \end{aligned}$$

$$\begin{aligned} \text{Book Value after } m \text{ years} \\ &= \text{FC}(1-k)^m \end{aligned}$$

4. Sum-of-the-Years-Digits Method

$$\text{SYD} = 1 + 2 + 3 + \dots + n \text{ where: } n = \text{useful life}$$

$$\begin{aligned} \text{Dep}_1 &= (\text{FC}-\text{SV})(n/\text{SYD}) \\ \text{Dep}_2 &= (\text{FC}-\text{SV})(n-1/\text{SYD}) \\ \text{Dep}_3 &= (\text{FC}-\text{SV})(n-2/\text{SYD}) \\ &\text{etc} \end{aligned}$$

$$\begin{aligned} \text{Book Value after } m \text{ years} \\ &= \text{FC} (\text{Dep}_1 + \text{Dep}_2 + \text{Dep}_3 \dots + \text{Dep}_m) \end{aligned}$$

5. Service Output or Production Units Method

$$\text{Depreciation (Per Unit)} = \frac{\text{FC}-\text{SV}}{\text{No. of Units Capacity}}$$

6. Working Hours or Machine Hours Method

$$\text{Depreciation (Per Hour)} = \frac{\text{FC}-\text{SV}}{\text{No. of Hours Capacity}}$$

CAPITAL RECOVERY: FACTORS OF ANNUAL COST

1. Using Sinking Fund Method:

$$\text{Annual Depreciation} = \frac{\text{FC} - \text{SV}}{[(i+i)^n - 1 / i]}$$

$$\text{Interest on Investment} = i(\text{FC})$$

2. Using Straight Line Method:

$$\text{Annual Depreciation} = \frac{\text{FC} - \text{SV}}{n}$$

$$\text{Average Interest} = i/2 ((n+1)/n) (\text{FC}-\text{SV}) + i(\text{SV})$$

CAPITALIZED COST

Capitalized Cost – the sum of the first cost and the present worth of all cost of replacement, operation and maintenance for a long time.

1. For life n:

$$\text{Capitalized Cost} = \text{FC} + \text{OM}/i + \frac{\text{FC} - \text{SV}}{(1+i)^n - 1}$$

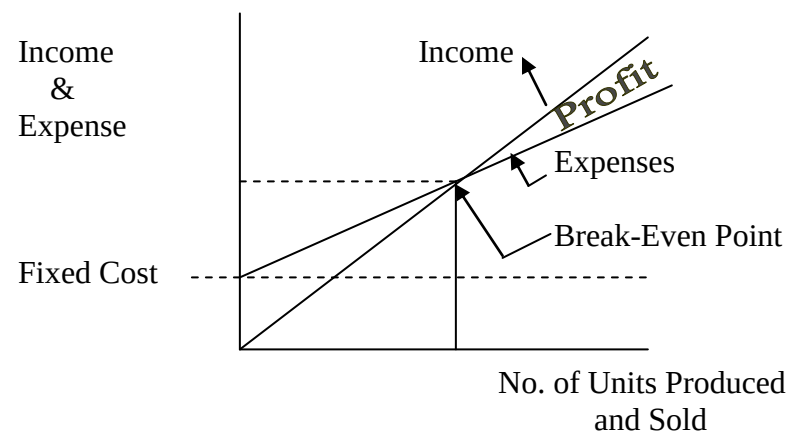
where: OM = annual operation and maintenance cost

2. For perpetual life:

$$\text{Capitalized Cost} = \text{FC} + \text{OM}/i$$

BREAK-EVEN ANALYSIS

Break-Even Point – the value of a certain variable for which the costs of two alternatives are equal.



$$\text{INCOME} = P(x)$$

$$\text{EXPENSES} = M(x) + L(x) + V(x) + FC$$

To break even:

$$\text{INCOME} = \text{EXPENSES}$$

x = no. of units produced and sold

P = selling price per unit

M = material cost per unit

L = labor cost per unit

V = variable cost per unit

FC = fixed cost

BUSINESS ORGANIZATIONS; CAPITAL FINANCING

Types of Business Organizations

1. Individual Ownership
2. Partnership
3. Corporation
 - a. Private Corporation
 - b. Public Corporation
 - c. Semi-Public Corporation
 - d. Quasi-Public Corporation
 - e. Non-Profit Corporation

Stock – certificate of ownership of corporation

- a. common stock
- b. preferred stock

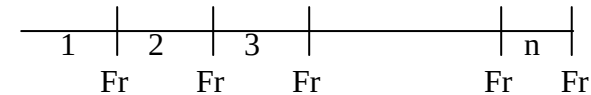
Bond – a certificate of indebtedness of a corporation usually for a period of not less than 10 years and guaranteed by a mortgage on certain assets of the corporation or its subsidiaries

Types of bond according to security behind:

- a. Mortgage bond – type of bond in which the security behind are the asset of the corporation
- b. Collateral bond – type of bond in which the security behind are the assets of a well known subsidiary.

c. Debenture bond – a type of bond in which there is no security behind except a promise to pay

Bond Value:



$$P = Fr \left[\frac{(1+i)^n - 1}{I(1+i)^n} \right] + \frac{C}{(1+i)^n}$$

P = value of bond n periods before maturity

F = face or par value

r = bond rate

Fr = periodic dividend

n = no. of periods

C = redeemable value (usually equal to par)

I = investment rate

BASIC INVESTMENT STUDIES

Basic investment studies are made to determine whether an investment should be made or not, based on the following criteria:

1. Rate of Return

$$\text{Rate of Return} = \frac{\text{Net Profit}}{\text{Total Investment}}$$

2. Payout Period

Payout Period = length of time that the investment can be recovered

$$= \frac{\text{Total Investment} - \text{Salvage Value}}{\text{Net Annual Cash Flow}}$$

SELECTION OF ALTERNATIVES

Studies on selection of alternatives are made to determine in what manner an investment should be undertaken, based on any of the following criteria:

1. Present Economy

This involves selection of alternatives in which interest or time value of money is not a factor. Studies usually involve the selection between alternative designs, material or methods.

2. Rate of Return

$$\text{Rate of Return} = \frac{\text{Net Profit}}{\text{Total Investment}}$$

The alternative which gives a higher rate of return on investment is then the favorable choice.

3. Payout Period

$$\text{Payout Period} = \frac{\text{Total Investment} - \text{Salvage Value}}{\text{Net Annual Cash Flow}}$$

The alternative which has a shorter payout period will be the choice.

4. Annual Cost

$$\text{Annual Cost} = \text{Depreciation} + \text{Interest on Capital} + \text{Operation and Maintenance} + \text{Other Out-of-Pocket Expenses}$$

The alternative with a lower annual cost is then the more economical alternative.

5. Present Worth

This is applicable when the alternatives involve future expenses whose present value can be easily determined.

6. Future Worth

This is applicable when the alternatives involve expenses whose future worth is the more suitable basis of comparison.

REPLACEMENT STUDIES

This is an application of selection of alternatives in which the alternatives are: to replace the old equipment with a new one or to continue using the old equipment. Two criteria commonly used are:

1. Rate of return

$$\text{Rate of Return} = \frac{\text{Savings Incurred by Replacement}}{\text{Additional Capital Required}}$$

The computed rate of return is then compared with the given interest rate or worth of money.

2. Annual Cost

$$\text{Annual Cost} = \text{Depreciation} + \text{Interest on capital} + \text{Operation and Maintenance} + \text{Other Out-Of-Pocket-Expenses}$$

In computing the depreciation and interest of the old equipment in either method, actual present realizable values and not historical values should be used.

BENEFIT-TO COST RATIO IN PUBLIC PROJECTS

Consider a public project which has the following:

FC = first cost

SV = salvage value at the end of life

n = useful life

OM = annual operation and maintenance cost

i = interest rate or worth of money per year

i = interest rate or worth of money per year
 B = annual benefits, that is, the annual worth of benefits incurred because of the existence of the project

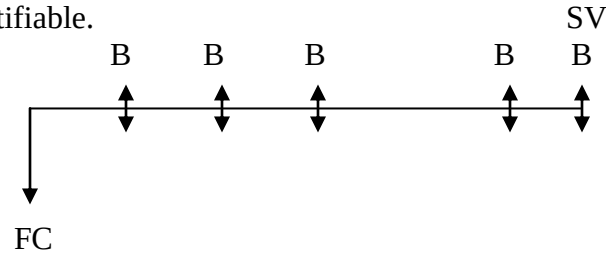
C = annual equivalent of the cost

$$C = \frac{FC}{\frac{(1+i)^n - 1}{i(1+i)^n}} - \frac{SV}{\frac{(1+i)^n - 1}{i}}$$

B/C = Benefit-to-cost ratio

$$= \frac{B - OM}{C}$$

B/C should be greater than 1 for the project to be justifiable.



THERMODYNAMICS

DEFINITIONS

Thermodynamics – study of heat and work and those properties of substances that bear a relation to heat and work.

Working Substance – a substance to which heat can be stored and from which heat can be extracted.

- Pure Substance – a working substance whose chemical composition remains the same even if there is a change in phase; water, ammonia, Freon-12 are pure substances.
- Ideal Gas – a working substance which remains in gaseous state during its operating cycle (and whose equation of state is $PV = mRT$); air, O_2 , N_2 , CO_2 are ideal gases.

PROPERTIES OF WORKING SUBSTANCE

$$1. \text{ Pressure} = \frac{\text{Force}}{\text{Area}} \quad \text{KN/m}^2 \text{ or KPa}$$

$$\text{Absolute Pressure} = \text{Gauge Pressure} + \text{Atmospheric Pressure}$$

$$\text{KPa} = \text{KPag} + 101.325$$

$$1 \text{ Atm} = 0 \text{ KPag}$$

$$= 101.325 \text{ KPa}$$

$$= 29.92 \text{ in.Hg}$$

$$= 760 \text{ mm Hg}$$

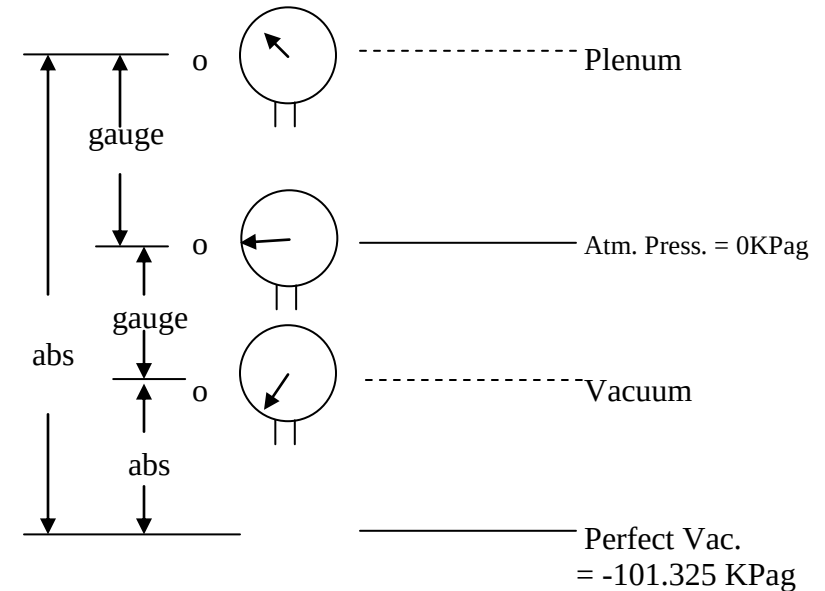
$$= 14.7 \text{ psia}$$

$$= 1.033 \text{ kg/cm}^2$$

$$\text{Pressure of Perfect Vacuum}$$

$$= -101.325 \text{ KPag}$$

$$1 \text{ Bar} = 100 \text{ KPa}$$



2. Temperature – the degree of hotness or coldness of a substance.

Relation of Temperature

Scales, °C and °F:

$$^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$$

$$^{\circ}\text{F} = 9/5 ^{\circ}\text{C} + 32$$

x2

Temperature at which molecules stop moving

$$= -273^{\circ}\text{C} = -460^{\circ}\text{F}$$

Absolute Temperatures:

$$\text{K} = ^{\circ}\text{C} + 273$$

$$^{\circ}\text{R} = ^{\circ}\text{F} + 460$$

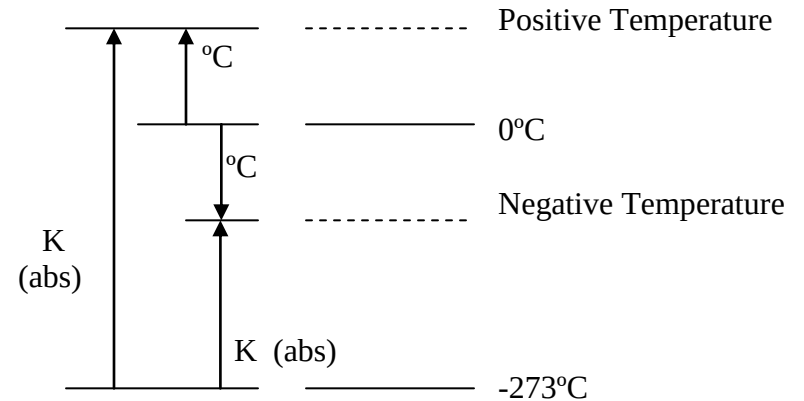
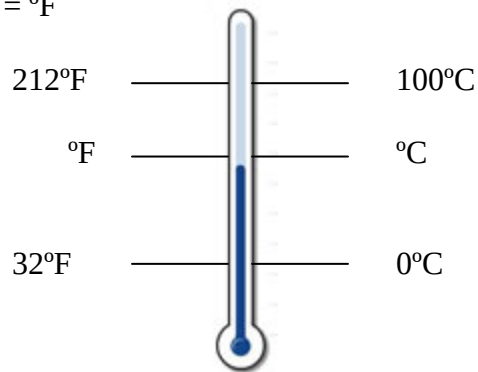
Temperature Difference:

$$^{\circ}\text{C} = 5/9 ^{\circ}\text{F}$$

$$^{\circ}\text{F} = 9/5 ^{\circ}\text{C}$$

$$\text{K} = ^{\circ}\text{C}$$

$$^{\circ}\text{R} = ^{\circ}\text{F}$$



3. Specific Volume and Density

$$v = \text{specific volume} = \frac{\text{volume}}{\text{Mass}} \text{ m}^3/\text{kg}$$

$$f = \text{density} = \frac{\text{Mass}}{\text{Volume}} \text{ kg/m}^3$$

4. Internal Energy, u , kJ/kg

– heat energy due to the movement of the molecules within the substance brought about by its temperature.

5. Flow Work = work due to the change in volume

$$= pv \text{ kJ/kg} \quad \text{where: } P = \text{pressure, KPa} \\ v = \text{specific volume, m}^3/\text{kg}$$

6. Enthalpy = Internal Energy + Flow Work

$$h = u + Pv \text{ kJ/kg}$$

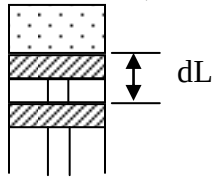
7. Entropy, s , $\frac{\text{kJ}}{\text{kg} \cdot ^{\circ}\text{K}}$

$$s = \int dQ/T$$

WORK AND HEAT

Work = Force x Distance

$$W = \int F dL = \int F dv/A = \int_{v_1}^{v_2} P dV$$



Heat – form of energy due to temperature difference

Mechanical Equivalent of Heat:

$$1 \text{ J} = 1 \text{ N-m}$$

$$1 \text{ kJ} = 1 \text{ kN-m}$$

Specific Heat – the heat required to change the temperature of 1kg of a substance 1°C

$$c_p = \text{specific heat at constant pressure, } \frac{\text{kJ}}{\text{kg} \cdot ^\circ\text{C}} \quad \text{or} \quad \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

$$c_v = \text{specific heat at constant volume, } \frac{\text{kJ}}{\text{kg} \cdot ^\circ\text{C}} \quad \text{or} \quad \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

$$\text{Power} = \text{time rate of doing work} = \frac{\text{Work}}{\text{Time}}$$

$$1 \text{ W} = 1 \text{ J/sec}$$

$$1 \text{ HP} = 0.746 \text{ KW}$$

$$1 \text{ KW} = 1 \text{ kJ/sec}$$

$$1 \text{ Metric HP} = 0.736 \text{ KW}$$

FIRST LAW OF THERMODYNAMICS

Total Energy Entering a System

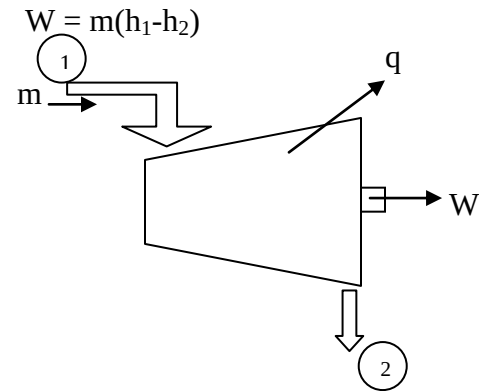
= Total Energy Leaving

$$H_1 + KE_1 + PE_1 = H_2 + KE_2 + PE_2 + q + W$$

From which:

$$W = m(h_1 - h_2) + \frac{1}{2} m(V_1^2 - V_2^2) + m(z_1 - z_2) - q$$

So that if KE, PE and q are negligible:



SECOND LAW OF THERMODYNAMICS

Kelvin-Planck statement applied to the heat engine:

“It is a cycle and receives a given amount of heat engine which operates temperature body and does an equal amount of work”

Clausius statement applied to the heat pump:

“It is impossible to construct a heat pump that operates without an input of work”.

The most efficient operating cycle is the Carnot Cycle.

IDEAL GAS

Definition: An ideal gas is a substance that has the equation of state:

$$PV = mRT \quad \text{where: } P = \text{absolute pressure, KPa}$$

$$V = \text{volume, m}^3 \text{ or m}^3/\text{sec}$$

$$m = \text{mass, kg or kg/sec}$$

$$R = \text{gas constant, kJ/kg-K}$$

$$T = \text{absolute temperature, K}$$

Basis Properties of an Ideal Gas:

$$R = 8.3143 / M$$

where: R = gas constant

M = molecular weight

$$c_p - c_v = R$$

c_p = specific heat at constant pressure

c_v = specific heat at constant volume

$$k = c_p / c_v$$

k = specific heat ratio

Properties of Air:

M	R	c_p	c_v	k
28.97	0.287	1.0 (1.003)	0.716	1.4

Processes Involving Ideal Gases

Any Process:

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

$$U_2 - U_1 = m c_v (T_2 - T_1)$$

$$H_2 - H_1 = m c_p (T_2 - T_1)$$

$$S_2 - S_1 = m c_p \ln \frac{T_2}{T_1} - m R \ln \frac{P_2}{P_1}$$

Reversible Process: No friction loss

Adiabatic Process: No heat loss, no heat gain, that is, completely insulated system

Adiabatic Throttling Process: constant enthalpy or isenthalpic process, that is, $h_2 = h_1$ and $t_2 = t_1$

Constant Pressure or Isobaric Process: $P_1 = P_2$

Constant Volume or Isovolumic Process: $V_1 = V_2$

Constant Temperature or Isothermal Process: $T_1 = T_2$

Constant entropy or Isentropic Process: adiabatic and reversible, $s_1 = s_2$

Polytropic Process: non-adiabatic process

Process	P, V & T Relations	Work Done	Heat Added	Entropy Change
Constant Pressure (Charles' Law)	$P_1 = P_2$ $\frac{V_1}{T_1} = \frac{V_2}{T_2}$	$P_1(V_2 - V_1)$	$m c_p (T_2 - T_1)$	$m c_p \ln \frac{T_2}{T_1}$
	$V_1 = V_2$ $\frac{P_1}{T_1} = \frac{P_2}{T_2}$	0	$m c_v (T_2 - T_1)$	$m c_v \ln \frac{T_2}{T_1}$
Constant Temperature (Boyles' Law)	$T_1 = T_2$ $P_1 V_1 = P_2 V_2$	$P_1 V_1 \ln \frac{V_2}{V_1}$	$m R T_1 \ln \frac{V_2}{V_1}$	$m R \ln \frac{V_2}{V_1}$
Constant Entropy	$P V^k = C$ $P_1 V_1^k = P_2 V_2^k$ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{k-1/k}$ $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{k-1}$	$\frac{P_1 V_1 - P_2 V_2}{k-1}$	0	0
Polytropic	$P V^n = C$ $P_1 V_1^n = P_2 V_2^n$ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{n-1/n}$ $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{n-1}$	$\frac{P_1 V_1 - P_2 V_2}{n-1}$	$\frac{m c_v (n-k)(T_2 - T_1)}{n-1}$	$\frac{m c_v (n-k)}{n-1} \ln \frac{T_2}{T_1}$

Mixtures Involving Ideal Gases

Consider a mixture of three gases, a, b and c at a pressure P and a temperature T, and having a volume V.

1. Mass or Gravimetric Analysis:

$$m_T = m_a + m_b + m_c$$

$$\frac{m_a}{m_T} + \frac{m_b}{m_T} + \frac{m_c}{m_T} = 1$$

2. Volumetric or Molar Analysis:

$$V = V_a + V_b + V_c$$

$$\frac{V_a}{V} + \frac{V_b}{V} + \frac{V_c}{V} = 1$$

V_a = volume that gas a would occupy at pressure P and temperature T

V_b = volume that gas b would occupy at pressure P and temperature T

V_c = volume that gas c would occupy at pressure P and temperature T

3. Dalton's Law of Partial Pressures:

$$P = P_a + P_b + P_c$$

P_a = partial pressure of gas a, that is, the pressure that gas a will exert if it alone occupies the volume occupied by the mixture, etc.

$$P_a = (V_a/V)P \quad P_b = (V_b/V)P \quad P_c = (V_c/V)P$$

4. Specific Heat of the Mixture:

$$C_p = m_a/m_t(C_{pa}) + m_b/m_t(C_{pb}) + m_c/m_t(C_{pc})$$

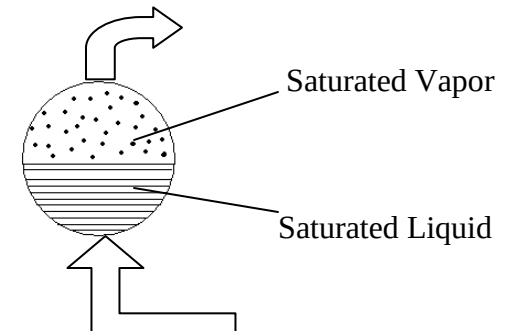
$$C_v = m_a/m_t(C_{va}) + m_b/m_t(C_{vb}) + m_c/m_t(C_{vc})$$

PURE SUBSTANCE

Definition: A pure substance is a working substance that has a homogeneous and invariable chemical composition even though there is a change of phase.

Saturated Liquid and Saturated Vapor

Saturation temperature – the temperature at which vaporization takes place at a given pressure, this pressure being called the saturation pressure for the given temperature



Examples of saturation temperature at various pressures for three common pure substances:

	Saturation Temperature		
Pressure	Water	Ammonia	Freon-12
50 KPa	81.33°C	-46.73°C	-45.19°C
101.325 KPa	100°C	-33.52°C	-29.79°C
500 KPa	151.86°C	4.08°C	15.59°C

Properties of saturated liquid and saturated vapor at various temperatures and pressure are found in tables (Table 1 and Table 2 for steam) with the following typical construction:

<u>Temp.</u>	<u>Press.</u>	Specific Volume		Internal Energy			Enthalpy			Entropy		
		v_f	v_g	u_f	u_{fg}	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
		$v_{fg} = v_g - v_f$		$h_{fg} = h_g - h_f$								
		$u_{fg} = u_g - u_f$		$s_{fg} = s_g - s_f$								

Mixture

x = quality or dryness factor

= ratio of mass of saturated vapor to the total mass of the mixture, expressed in decimal or percent

$1-x$ = wetness

Properties of Mixture:

$$v = v_f + x v_{fg} \quad h = h_f + x h_{fg}$$

$$u = u_f + x u_{fg} \quad s = s_f + x s_{fg}$$

Since a mixture consists of saturated vapor and saturated liquid, the properties of each component are also found in the saturated tables.

Superheated vapor – vapor whose temperature is higher than the saturation temperature at the given pressure

Degrees Superheat = difference between actual temperature and saturation temperature

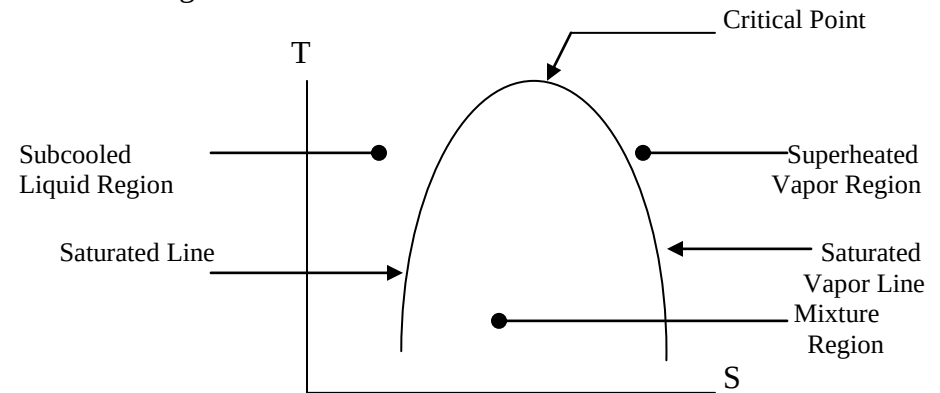
Properties of superheated steam are found in Table 3.

Subcooled or Compressed Liquid – liquid whose temperature is lower than the saturation temperature at the given pressure (or liquid whose pressure is higher than the saturation pressure at the given temperature)

Degrees Subcooling = difference between saturation temperature and actual temperature)

Properties of compressed liquid water are found in Table 4.

The T-S Diagram of a Pure Substance



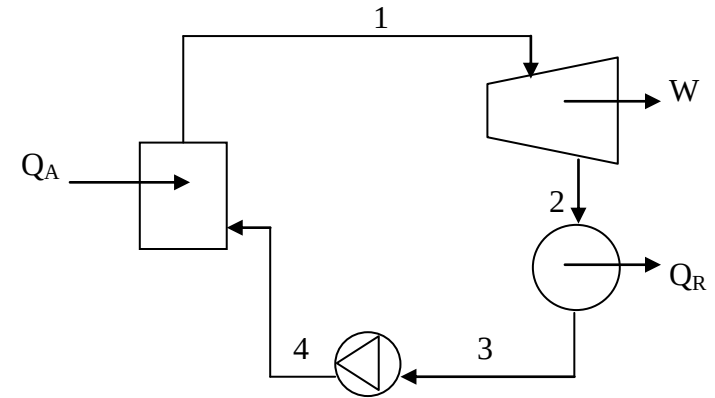
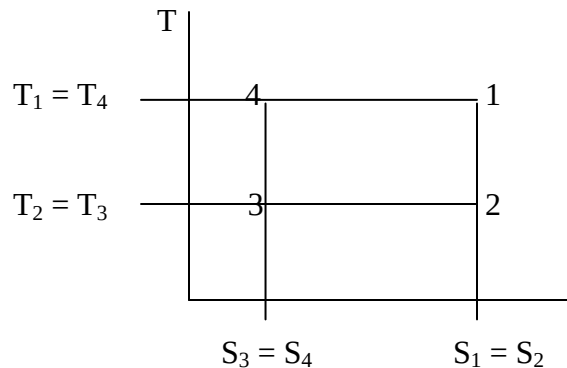
The Mollier (h-s) Diagram of Steam is usually useful in determining the final enthalpy of steam after an isentropic process.

Processes Involving Pure Substance

1. Isobaric or constant pressure process: $P_1 = P_2$
2. Isothermal or constant temperature process: $T_1 = T_2$
Evaporation and condensation processes occur at constant pressure and constant temperature.
3. Isovolumic or constant volume process: $V_1 = V_2$
For constant mass: $V_1 = V_2$
If the final state is a mixture: $V_1 = (v_f + x v_{fg})_2$
4. Isentropic or constant entropy process: $s_1 = s_2$
Isentropic process is reversible (no friction loss) and adiabatic (no heat loss, that is, completely insulated system).
If the final state is a mixture: $s_1 = (s_f + x s_{fg})_2$
5. Throttling or isenthalpic (constant enthalpy) process: $h_1 = h_2$
If the final state is a mixture: $h_1 = (h_f + x h_{fg})_2$
If the initial state is a mixture, such as in steam calorimeter: $(h_f + x h_{fg})_1 = h_2$

<u>Process</u>	<u>Heat Added or Rejected</u>
Constant Pressure Heating or Cooling of Liquid	$m c_p (T_2 - T_1)$ For water: $c_p = 4.187 \text{ kJ/kg-K}$
Evaporation or Condensation	$m (h_{fg})$ (latent heat)
Constant Volume	$m (u_2 - u_1)$
Constant Entropy (Isentropic)	$m (h_2 - h_1)$
Constant Enthalpy (Throttling)	0

THE CARNOT CYCLE



$$Q_A = T_1 (S_1 - S_4)$$

$$Q_R = T_2 (S_2 - S_3) = T_2 (S_1 - S_4)$$

$$W = Q_A - Q_R = T_1 (S_1 - S_4) - T_2 (S_1 - S_4)$$

$$n_T = W/Q_A = \frac{T_1 (S_1 - S_4) - T_2 (S_1 - S_4)}{T_1 (S_1 - S_4)} = \frac{T_1 - T_2}{T_1}$$

Basic Working Cycles for Various Applications

<u>Application</u>	<u>Basic Working Cycle</u>
Steam Power Plant	Rankine Cycle
Spark-Ignition (Gasoline) Engine	Otto Cycle
Combustion-Ignition (Diesel Engine)	Diesel Cycle
Gas Turbine	Brayton Cycle
Refrigeration System	Refrigeration Cycle

PRACTICE PROBLEMS

ALGEBRA

1. Simplify:

$$\sqrt{\frac{ab}{\sqrt[3]{ab}}} \quad (\text{ANS. } \sqrt[3]{ab})$$

2. Combine into a single fraction:

$$\frac{3x-1}{x^2-1} - \frac{x+3}{x^2+3x+2} - \frac{1}{x+2} \quad \text{ANS. } \frac{1}{x-1}$$

3. Two cars start at the same time from two nearby towns 200km apart and travel towards each other. One travels at 60km/hr and the other 40km/hr. After how many hours will they meet on the road and how many km each car has traveled when they meet?

(ANS. 2 hrs; 120 km, 80 km)

4. A Cessna single engine airplane has an airspeed (speed in still air) of 125 KPH. A west wind of 25 KPH is blowing. The plane is to patrol due to east and then return to its base. How far east can it go if the round trip is to consume 4 hours?

(ANS. 240km)

5. A car travels from A to B, a distance of 100 km, at an average speed of 30 km per hour. At what speed must it travel back from B to A in order to average 45 km per hour for the round trip of 200 km?

(ANS. 90km/hr)

6. Two trains A and B having average speed of 75 mi/hr and 90 km/hr respectively. Leave the same point and travel in opposite directions. In how many minutes would they be 1600 miles apart?

(ANS. 733.2 min)

7. The gasoline tank of a car contains 50 liters of gasoline and alcohol; the alcohol comprising 25%. How much of the mixture must be drawn off and replaced by alcohol so that the tank will contain a mixture of which 50% is alcohol?

(ANS. 16 2/3 liters)

8. It takes Butch twice as long as it takes Dan to do a certain piece of work. Working together, they can do the work in 6 days? How long would it take Dan to do it alone?

(ANS. 9days)

9. Maria is 36 years old. Maria was twice as old as Ana was Maria was when Maria was as old as Ana is now. How old is Ana now?

(ANS. 24)

10. A man leaving his office one afternoon noticed the clock at past two o'clock. Between two to three hours, he returned to his office noticing the hands of the clock interchanged. At what time did he leave the office and the time that he returned to the office?

(ANS. 2:26.01; 5:12.17)

11. When two times a certain number is added to thrice its reciprocal, the sum is 7. Find the number.

(ANS. 1/2 and 3)

12. A company has a certain number of machines of equal capacity that produced a total of 180 pieces each working day. If two machines breakdown, the workload of the remaining machines is increased by three pieces per day to maintain production. Find the number of machines.

(ANS. 12)

13. A rectangular field is surrounded by a fence 548 meters long. The diagonal distance from a corner to corner is 194 meters. Determine the area of the rectangular field.

(ANS. 18,720 m²)

14. A machine foundation has a trapezoidal cross-section whose area is 21 square feet. The shorter base of the trapezoid must be twice its height and the longer base must exceed the height by 5 feet. Find the height and the two base lengths (the bases are the parallel sides of the trapezoid).

(ANS. $h=3'$, $b=8'$, $a=6'$)

15. Solve for x:

$$\sqrt{x+2} + \sqrt{3x-2} = 4$$

16. Solve for x:

$$\frac{1}{x} + \frac{2}{x^2} = \frac{3}{x^3}$$

(ANS. $x=1$, $x=-3$)

17. Solve for x:

$$\frac{x^{2/3} + x^{-2/3}}{4} = \frac{17}{4}$$

(ANS. $x=8$, $x=1/8$)

18. A rectangular lot has a perimeter of 120 meters and an area of 800 square meters. Find the length and width of the lot.

(ANS. 40m and 20m)

19. A 24-meter pole is held by three guy wires in its vertical position. Two of the guy wires are equal length. The third wire is 5 meters longer than the other two and is attached to the ground 11 meters farther from the foot of the pole than the other two equal wires. Find the length of the wires.

(ANS. 25m and 30m)

20. From a point inside a square, the distance to three corners are 4, 5 and 6 meters, respectively. Find the length of the side of the square.

(ANS. 7.07m)

21. A man bought 20 calculators for P20,000.00. There are three types of calculators bought, business type costs P3,000 each, scientific type costs P1,500 each and basic type costs P500 each. How many calculators of each type were purchased?

(ANS. 2, 5, 13)

22. A production supervisor submitted the following report on the average rate of production of printed circuit boards (PCB) in an assembly line:

“1.5 workers produce 12 PCB's in 2 hours”

How many workers are employed in the assembly line working 40 hours each per week with a weekly production of P8000 PCB's?

(ANS. 50 workers)

23. A pile of boiler pipes contains 1275 pipes in layers so that the top layer contains one pipe and each lower layer has one more pipe than the layer above. How many layers are there in the pile?

(ANS. 50)

24. In a racing contest, there are 240 cars which will have fuel provisions that will last for 15 hours. Assuming a constant hourly consumption for each car, how long will the fuel provisions last if 8 cars withdraw from the race every hour after the first?

(ANS. 25 hours)

TRIGONOMETRY

1. Two points lie on a horizontal line directly south of a building 35 meters high. The angles of depression to the points are $29^\circ 10'$ and $45^\circ 50'$ respectively. Determine:
 - a. The distance between the points.
 - b. The distance between the building and the nearest point.

- c. The distance between the building and the farthest point.
(ANS. 25 hours)
2. A pole which leans $10^{\circ}15'$ from the vertical towards the sun casts a shadow 9.43 meters long on the ground when the angle of elevation of the sun is $54^{\circ}50'$. Find the length of the pole.
(ANS. 18.3 m)
3. Given a triangle ABC with sides $AB=210\text{m}$, $BC=205\text{m}$ and $AC=110$. Find the largest angle.
(ANS. $C=77.157^{\circ}$)
4. Given: Triangle ABC whose angle A is 32° and opposite side of A is 75 meters. The opposite side of angle B is 100 meters. Find: Angle C and opposite side of Angle C.
(ANS. 103.44° ; 137.879 m)
5. Using trigonometric function and not using calculator, find $\tan 105^{\circ}$.
(ANS. -3.732)
6. Solve for x:
 $\arcsin - \arcsin x = 15^{\circ}$
(ANS. 0.2428)
7. A quadrilateral ABCD is inscribed in a semi-circle such that one of the sides coincides with the diameter AD. $AB=10$ meters, $BC=20$ meters. If the diameter AD of the semi-circle is 40 meters, find the area of the quadrilateral.
(ANS. 470m^2)
8. Two ships started sailing from the same point. One traveled $N20^{\circ}E$ at 30 miles per hour. After 3 hours, how far apart are the ships?
(ANS. 124.07 miles)

9. Solve for the value of "x" in the equation
 $\ln(2x+7) - \ln(x-1) = \ln 5$
(ANS. $x=4$)
10. Solve for x:
 $2^x + 4^x = 8^x$
(ANS. $x = 0.694242$)
11. A point P within an equilateral triangle has a distance of 4m, 5m and 6m respectively from the vertices. Find the side of the triangle.
(ANS. 8.53 m)
12. Ship "A" started sailing $N40^{\circ}32'E$ at the rate of 3mph. after 2 hours, ship "B" started from the same port going $S45^{\circ}18'E$ at the rate of 4mph. after how many hours will the second ship be exactly south of ship "A"?
(ANS. 4.37 hours)

SOLID MENSURATION

1. A right circular conical vessel is constructed to have a volume of 100,000 liters. Find the diameter and the depth of the depth is to be 1.25 times the diameter. Give the answers in meters.
(ANS $D=6.736\text{m}$, $H=8.42\text{m}$)
2. The three sides of a triangle are given as $a=68$ meters, $b=52$ meters and $c=32$ meters. Find the area of the triangle. (Hint: Use Hero's formula)
(ANS. 801.28m^2)
3. A hollow sphere with an outer radius of 32cm is made of a metal weighing 8 grams per cubic cm. The weight of the sphere is 150 kg so that the volume of the metal is 24,000 cubic cm. Find the inner radius.
(ANS. 30.014cm)

4. A circular cylindrical tank, axis horizontal, diameter 1 meter, and length 2 meters, is filled with water to a depth of 0.75 meter. How much water is in the tank?

(ANS. 1.2638m^3)

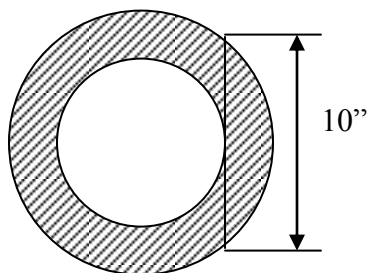
5. A machine foundation has the shape of a frustrum of a pyramid with lower base $6\text{m} \times 2\text{m}$, upper base $5.5\text{m} \times 1.8\text{m}$ and altitude of 1.5m. Find the volume of the foundation.

(ANS. 16.4m^3)

6. An elevated water tank is in the form of a circular cylinder with diameter of 3 meters and a hemispherical bottom. The total height of the tank is 5 meters. Water is pumped into the tank at the rate of 30 gallons per minute. How long will it take to full fill the tank starting from empty?

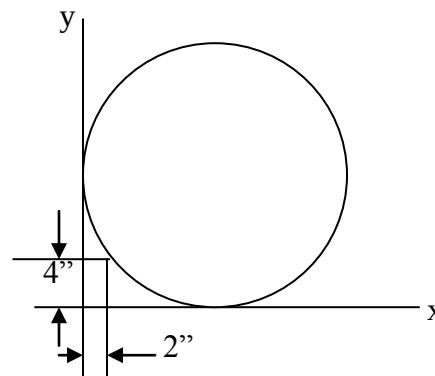
(ANS. 5.663 hrs)

7. Find the area of the shaded portion:



(ANS. 78.54 in^2)

8. Find the area of the circle shown:



(ANS. 314 in^2)

ANALYTIC GEOMETRY

1. Find the area of the polygon which is enclosed by the straight lines $x-y=0$, $x+y=0$, $x-y=2a$ and $x+y=2a$.

(ANS. $2a^2$)

2. A straight line passes through (2,2) such that the length of the line segment intercepted between the coordinate axes is equal to the square root of 5. Find the equation of the straight line.

(ANS. $x-2y+2=0$, $2xy-2=0$)

3. Find the equation of the circle with center at (2,-3) and radius of 4.

(ANS. $x^2+y^2-4x+6y-3=0$)

4. Find the area of the circle whose equation is

$$2x^2 - 8x + 2y^2 + 12y = 1$$

(ANS. 42.41sq. units)

5. A cable supporting a pipeline has a span of 1740 feet. The difference in elevation of the supports is 190 feet and the lowest point of the cable is 45 feet below the lower support. If the curve formed by the cable is parabolic, find the equation of the parabola using the lowest point of the cable as origin.
(ANS. $x^2 = 6234y$)
6. Find the area of an ellipse whose equation is $9x^2 - 36x + 25y^2 = 189$
(ANS. 47.12 sq. units)
7. Given the curve $Ax^2 + By^2 + F = 0$. It passes through points (4,0) and (0,3). Find the value of A, B and F and give the specific equation of the given curve.
(ANS. A=9, B=16, F=144; $9x^2 + 16y^2 - 144 = 0$)
8. Find the volume of the solid which is formed by revolving the area enclosed by $\frac{(x-2)^2}{9} + \frac{(y-1)^2}{4} = 1$
About the line $3x+4y-24=0$
(Hint: Use Pappua theorem)
(ANS. V = 331.6 cu.units)
9. When a load is uniformly distributed horizontally, a suspension bridge cable hangs in parabolic arc. If the bridge is 200m long and the towers 40m high and the cable is 15m above the floor of the bridge at the mid-point, find the equation of the parabola using mid-point of the bridge as origin.
(ANS. $x^2 = 400y - 6000$)
2. Find the equations of the tangents to the graph $y = x^3 + 3x^2 - 15x - 20$ at the points of the graph where the tangents to the graph have slope of 9.
3. A rectangular field to contain a given area is to be fenced off along a straight river. If no fencing is needed along the river, show that the least amount of fencing will be required when the length of the field is twice its width.
(ANS. L = 2W)
4. Find the shape of the largest rectangle that can be inscribed in a given circle.
(ANS. Square)
5. Divide the number 60 into two parts so that the product P of one part and the square of the other is a maximum.
(ANS. 40 and 20)
6. What is the maximum volume of a box that is constructed from a piece of cardboard 16 inches square by cutting equal squared out of the corners and turning up the sides.
(ANS. 303.41 in³)
7. A square sheet of galvanized iron, 100 cm x 100 cm will be used in making an open-top container by cutting a small square from each corner and bending up the sides. Determine how large the square should be cut from each corner in order to obtain the largest possible volume.
(ANS. 16 2/3 cm x a6 2/3 cm)
8. The sum of two positive numbers is 36. What are the numbers if their product is to be the largest possible?
(ANS. 18 and 18)

DIFFERENTIAL CALCULUS

1. Find the equation of the tangent and normal to the ellipse $4x^2 + 9y^2 = 40$ at point (1,-2)
(ANS. $2x-9y-20=0$; $9x+2y-5=0$)

9. A bus company charges P85.00 per passenger from Manila to Baguio for 100 or less passengers. For group tours, the company allows for P0.50 discount of the ticket price for every passenger in excess of 100. How many passengers will give the maximum income?

(ANS. 135)

10. A tinsmith wishes to make a gutter of maximum cross-section (carrying capacity) whose bottom and sides are each 6 inches wide and whose sides have the same slope. What will be the width at the top?

(ANS. 12 in.)

11. A lot is in the shape of a quadrant of a circle of radius 100 meters. Find the area of the largest rectangular building that can be constructed inside the lot.

(ANS. $5,000 \text{ m}^2$)

12. The cost of setting up a geothermal plant is P10M for the first MW, P11M for the second MW, P12M for the third MW, etc. other expenses (Land rights, design fee, etc.) amount to P50M. if the expected annual income per MW is P2M, find the plant capacity that will yield a maximum rate of return of investment.

(ANS. 10 MW)

13. If the fuel cost to run a boat is proportional to the square of her speed and is P25.00 per hour for a speed of 30 KPH, find the most economical speed to run a boat, other expenses independent from the speed amount to P100.00 per hour and the distance is 200m.

(ANS. 60 KPH)

14. The strength of a rectangular beam is proportional to the breadth and the square of the depth. Find the dimensions of the strongest beam that can be cut from a log 30cm in diameter.

(ANS. $b=17.32\text{cm}$, $h=24.29\text{cm}$)

15. Two posts, one 8 meters high and the other 12 meters high, stand 15 meters apart. They are to be stayed by wires attached to a single stake at ground level, the wires running to the tops of the posts. How far from the shorter post should the stake be placed, to use the least amount of wire?

(ANS. 6m)

16. A cylindrical glass jar has a metal top. If the metal costs three times as much as the glass per unit area, find the proportions of the least costly jar that holds a given amount.

(ANS. Height = $2 \times \text{Diameter}$)

17. The parcel post regulations limit the size of a package to such a size that the length plus the girth equals 6 feet. Determine the dimensions and the volume of the largest cylindrical package that can be sent by the parcel post.

(ANS. $D=1.273 \text{ ft}$, $L=2 \text{ ft}$, $V=2.546 \text{ ft}^3$)

18. A cylindrical steam boiler is to be constructed having a capacity of 30 cubic meters. The material for the sides costs P430 per square meter and for the ends P645 per square meter. Find the radius when the cost is least.

(ANS. 1.47m)

19. A boat is towed toward a pier which is 20 feet above the water. The rope is pulled in at the rate of 6ft/sec. How fast is the boat approaching the base of the pier when 25 feet of rope remain to be pulled in?

(ANS. 10ft/sec)

20. A water tank is in the form of a right circular cone with vertex down, 12 feet deep and 6 feet across the top. Water is being pumped into the tank at the rate of 10 cu ft/min. How fast is the surface of the water in the tank rising when the water is 5 feet deep?

(ANS. 2.037 ft/min)

INTEGRAL CALCULUS

21. Water is flowing out a conical funnel at the rate of $1 \text{ in}^3/\text{sec}$. If the radius of the funnel is 2 inches and the altitude is 6 inches, find the rate at which the water level is dropping when it is 2 inches from the top.
(ANS. 0.179 in/sec)
22. A helicopter is rising vertically from the ground at a constant rate of 25 ft per second. When it is 250 feet of the ground, a jeep passed beneath the helicopter traveling in a straight line at a constant speed of 50 miles per hour. Determine how fast is the distance between them changing after one second.
(ANS. 34.015 ft/sec)
23. An elevated light rail transit on a track 4.27 meters above ground crosses a street station at 6.1 m/sec at the instant that a car approaching at 9.15 m/sec is 12.2 meters up the street. How fast are the train and the car separating one second later?
(ANS. 1.16 km/hr)
24. A plane flying north at 640 km per hour passes over a certain town at noon and a second plane going east at 600 km per hour is directly over the same town 15 minutes later. If the planes are flying at the same altitude, how fast will they be separating at 1:15 PM?
(ANS. 872 km/hr)
25. The height of a cylindrical cone is measured to be four (4) meters which is equal to its radius with a possible error of 0.04. Determine the percentage error in computing the volume.
(ANS. 3%)
26. Divide 94 into three parts such that one-half the product of one pair, plus one-third the product of another pair, plus one-fourth the product of the third pair may seem to be a maximum value. (Clue: use partial differentiation)
(ANS. 42, 40, 12)

1. Find the area bounded by the parabola $y=x^2$, the x-axis and the lines $x=1$, $x=3$.
(ANS. $A=8\frac{2}{3} \text{ sq. units}$)
2. An ellipsoidal tank measuring 6 ft by 12 ft has its axis vertical, the axis of rotation being the major axis. It is filled with water to a depth of 7 feet. Find the amount of water in the tank.
(ANS. 141.11 ft^3)
3. Find the volume common to the two cylinders $x^2 + y^2 = a^2$, $y^2 + z^2 = a^2$. (Work with the part of the volume lying in the first octant. Since the curve of the intersection lie on the cylinder, it will project into $x^2 + y^2 = a^2$ in the xy plane).
(ANS. $V= \frac{16}{3} a^3$)
4. Find the area enclosed by the curves $y^2 = 8x - 24$ and $5y^2 = 16x$.
(ANS. 16 sq. units)
5. An open cylindrical tank 3 feet in diameter and 4.5 feet high is full of water. It is then tilted until one-half of its bottom is exposed. How many gallons of water was spilled out?
(ANS. 187.45 gal)
6. The parabolic reflector of an automobile headlight is 12 inches in diameter and 4 inches depth. What is the surface area in square inches?
(ANS. 153.94 sq.in)
7. A cistern in the form of an inverted right circular cone is 20 meters deep and 12 meters diameter at the top. If the kilojoules in pumping out the water to a height of 10 meters above the top of the cistern.
(ANS. 68, 167 kJ)

8. A flour bag originally weighing 60 kilograms is lifted through a vertical distance of 9 meters. While the bag is being lifted, flour is leaking from the bag at such rate that the weight lost is proportional to the square root of the distance traveled. If the total loss is 12 kilograms, find the amount of work in kilojoules done in lifting the bag.
(ANS. 4.59 KJ)

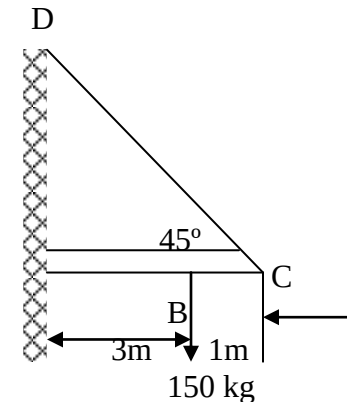
DIFFERENTIAL EQUATIONS

- Solve the differential equation
 $(x^2-1)dx + xy dy = 0$
 (ANS. $x^2 + y^2 = 2 \ln(cx)$)
- The rate of population growth of a country is proportional to the number of inhabitants. If the population of a certain country now is 40 million and 50 million in 10 years, what will be its population 20 years from now?
 (ANS. 62.5 million)
- In drying copra by a certain process, the moisture is removed at a rate proportional to the actual moisture present. If the 50% of the moisture content is removed in 10 hours, how long will it take to remove 90% of the moisture?
 (ANS. 33.37 hours)
- Solve the differential equation
 $(x^2-xy+y^2)dx - xy dy = 0$
 (ANS. $(y-x)e^{y/x} = C$)
- Solve for $P = f(x)$ from the differential equation
 $\frac{dP}{dx} - \frac{P}{x} = 2P^2$

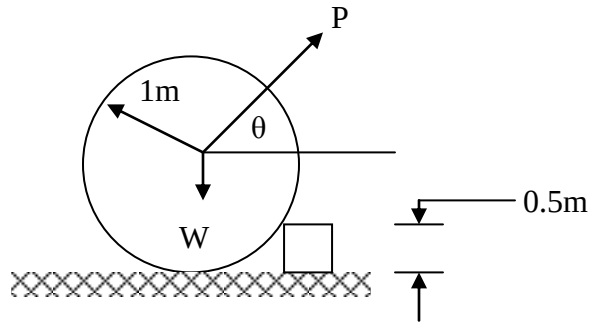
6. Pure water at 3gal/min enters a tank initially containing 100 gal of brine wherein 200 lbs of salt are dissolved. If the solution is kept uniform by stirring, flows out at 2 gal/min, determine the amount of salt in the tank at the end of 100 minutes.
(ANS. 50 lbs)

ENGINEERING MECHANICS

- A body weighing 2000 kilos is suspended by a cable 20 meters long and pulled 5 meters to one side by a horizontal force. Find the tension in the cable and the value of the horizontal force.
 (ANS. $T = 2066 \text{ kg}$; $F_h = 516 \text{ kg}$)
- The arm ABC, weighing 60 kg per meter carries a load of 15kg at B, is hinged to the wall at A and supported by the cable CD making an angle of 45° with the horizontal. Compute the reaction at A.
 (ANS. 280.82 kg ; $\theta = 34.11^\circ$)

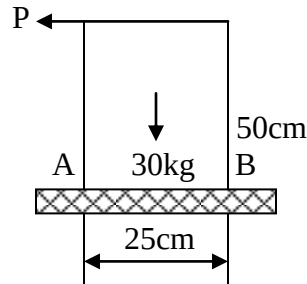


- Find the minimum force P required to roll the 1000 kg wheel over the block shown in the figure.
 (ANS. 866 kg)



4. A force P on top of the 30 kg block as shown in the figure. If the coefficient of friction between the block and the plane is 0.33, what is the value of the force P for motion to impend?

(ANS. 7.5 kg)



5. A body weighing 350 kg rests on a plane inclined 30° with the horizontal. The angle of static friction between the body and the plane is 15 degrees. What horizontal force P is necessary to hold the body from sliding down the plane?

(ANS. 93.782 kg)

6. A 200-kg crate is on a 30° ramp. The coefficient of friction between the crate horizontally, calculate the force F to:

- Just prevent the crate from sliding down the inclined ramp.
- Start the crate moving up the ramp.

(ANS. a. 37.83kg b. 232.44kg)

7. A 600-n block rests on a 30° inclined plane. The coefficient of static friction is 0.30 and the coefficient of kinetic friction is 0.20. if a force P is applied to the block horizontally, find the value of P needed to

- Prevent the block from sliding down the plane. (141.84 N)
- start the block moving up the plane (636.69 N)
- keep the block moving up the plane (527.30 N)

8. A steam pipe weighing 200 kg per meter will cross a road by suspension on a cable anchored between supports 6 meters apart. The maximum allowable sag of the cable is 50cm.

- Calculate the tension in the cable
- Calculate the length of the cable.

(ANS. a. 1,897.37kg b. 6.109m)

9. A parabolic cable has a span of 400 feet. The difference in elevation of the supports is 10 feet and the lowest point of the cable is 5 feet below the lower support. If the load supported by the cable is 12 lbs per horizontal foot, find the maximum tension in the cable.

(ANS. 25,902.5 lbs)

10. A tripod whose legs are each 4 meters long supports of 1000 kilograms. The feet of the tripod are vertices of a horizontal equilateral triangle whose side is 3.5 meters. Determine the load on each leg.

(ANS. 386.19kg)

11. Two cars A and B accelerate from a stationary start. The acceleration of A is 4 ft/sec^2 and that of B is 5 ft/sec^2 . If B was originally 20 feet behind A, how long will it take B to overtake A?

(ANS. 6.32 sec)

12. Two cars, A and B are traveling at the same speed of 80 km/hr in the same direction on a level road, with car A 100 meters ahead of car B. Car A slows down to make a turn, decelerating at 7ft/sec^2 .
- In how many seconds will B overtake A?
 - How far will each car have traveled before coming abreast with each other?
- (ANS. a. 9.69 sec b. 115.12 m, 215.12 m)
13. In a 25 storey office building, the elevator starting from rest at first floor, is accelerated at 0.8 m/sec^2 for 5 seconds then continues at constant velocity for 10 seconds more and is stopped in 3 seconds with constant deceleration. If the floors are 4 meters apart, at what floor does the elevator stop?
- (ANS. 15th floor)
14. A stone is dropped from a cliff into the ocean. The sound of the impact of the stone on the ocean surface is heard 5 seconds after it is dropped. The velocity of sound is 1,100 fps. How high is the cliff?
- (ANS. 352.55 ft)
15. Water drips from a faucet at the rate of 8 drops per second. The faucet is 18 cm above the sink. When one drop strikes the sink, how far is the next drop above the sink?
- (ANS. 15.82 cm)
16. Bombs from a plane drop at a rate of one (1) per second. Calculate the vertical distance between two (2) bombs after the first had dropped for 7 seconds. Assume freely falling body with $g=9.7\text{m/sec}^2$.
- (ANS. 63.7m)

17. A weight is dropped from a helicopter that is rising vertically with a velocity of 6m/sec. if the weight reaches the ground in 15 seconds, how high above the ground was the helicopter when the weight was dropped and what velocity does the weight strike the ground?
- (ANS. H = 1.013 m; V=141.15 m/sec)
18. A bomber flying at a horizontal speed of 800 km/hr drops a bomb. If the bomb hits the ground in 20 seconds, calculate:
- The vertical height of the bomber when it released the bomb, in meters.
 - The horizontal distance traveled by the bomb before it hit the ground, in meters.
 - The vertical velocity of the bomb as it hit the ground, in meters per second.
- (ANS. a. 1962m b. 4,444m c. 196.2 m/sec)
19. A flywheel starting from rest develops a speed of 400 RPM in 30 seconds.
- What is the angular acceleration?
 - How many revolutions did the flywheel make in 30 seconds it took to attain 400 RPM?
- (ANS. a. 0.222 rev/sec^2 b. 100 rev)
20. A 100-kg block of ice is released at the top of a 30° incline 10 meters above the ground. If the slight melting of the ice renders the surfaces frictionless, calculate the velocity at the foot of the incline.
- (ANS. 14.01 m/sec)
21. What drawbar pull is required to change the speed of a 120,000 lb car from 15 miles/hr to 30 miles/hr on a half mile while the car is going up a 1.5% grade? Car resistance is 10 lb/ton.
- (ANS. 3425 lbs)

22. A body weighing 200 kg is being dragged along a rough horizontal plane by a force of 45 kg. if the coefficient of friction is assumed to be $1/12$ and the line of pull makes an angle of 18° with the horizontal, what are the velocities acquired from the rest in the first 3 meters and in the first 5 meters?

(ANS. 2.834 m/sec; 3.66 m/sec)

23. A 50-KN Diesel Electric Locomotive (DEL) has its speed increased from 30 km/hr in a distance of 1km while ascending a 3% grade. What constant thrust (drawbar pull) parallel to the surface of the railway must be exerted by the wheel? The total frictional resistance is 30 N/KN of DEL weight.

(ANS. 5.655 KN)

STRENGTH OF MATERIALS

1. A reactor weighing 1,000 metric tons is placed on a 10 sq.in. platform. Find the pressure in kg/sq m exerted on the platform floor.

(ANS. $1.55 \times 10^8 \text{ kg/m}^2$)

2. A spherical tank is supported by four steel pipes each having an outside diameter of 400 mm and inside diameter of 375 mm. if the maximum allowable stress for the pipe is 104 MPa, what maximum weight of tank, in KN, can be supported?

(ANS. 6334 KPN)

3. A cylindrical strut, $\frac{1}{2}$ meter high and 10 cm diameter is loaded axially with 1000 kg. Calculate the compressive stress in kg/sq cm.

(ANS. 12.732 kg/sq cm)

4. A tank with its content weighs 5000 kg. It will be supported by four concrete posts equally spaced and with outer edges flushed with the perimeter of the tank. The compressive strength of the concrete posts is 1000 psi and a factor of safety of 4 is required. Calculate the diameter of each post in centimeters.

(ANS. 9.52 cm)

5. Determine the diameter of a steel rod that will carry a tensile load of 50,000 kg at a stress of 1400 kg per sq.cm

(ANS. 6.743 cm)

6. A steel wire 20 feet long, hanging vertically supports a load of 500 lbs. Neglecting the weight of the wire, determine the required diameter if the stress is not to exceed 20,000 psi and the total elongation is not to exceed 0.13 inch. Assume modulus of elasticity $E = 30 \times 10^6$ psi.

(ANS. 0.198 in)

7. A copper-rolled wire 10 meters long and 1.5 mm in diameter when supporting a weight of 35.7 kilograms elongates 1.86 cm. Compute the stress (kg/cm^2) strain, and the value of the Young's modulus of elasticity for this wire.

(ANS. 2020.1 kg/cm^2 ; 0.00186 cm/cm ; $1,086,132 \text{ kg/cm}^2$)

8. Determine the maximum thickness of metal plate in which a 7.5 centimeter diameter hole can be punched, if the plate has an ultimate shearing strength of 4245 kg/cm^2 and the punch can exert a maximum force of 200 metric tons.

(ANS $t = 2 \text{ cm}$)

9. A single bolt is used to lap join two steel bars together. Tensile force on the bars is 4,400 lbs. Determine the diameter of the bolt if the allowable shearing stress in it is 10,000 psi.

(ANS. $d = 0.748 \text{ in}$)

10. A rectangular beam with a span of 20 feet is simply supported at both ends. The maximum flexural stress for the beam is 1,200 psi and the dimensions of its cross-section are: $b=4$ inches and $h=10$ inches. If the beam is to be loaded at mid-span with a concentrated load of 2,000 lbs, will beam collapse?
(ANS. $s_f = 1,800$ psi, the beam will collapse)
11. What horsepower can be transmitted by a $\frac{1}{2}$ inch diameter solid shaft at 1800 rpm if the allowance torsional shearing stress is 6,000 psi?
(ANS. 4.2 hp)
12. A cantilever beam 3 meters long by 30 centimeters depth by 10 centimeters breadth has a single 45 kg load at the unsupported end.
- Draw the shear and moment diagram
 - Determine the maximum moment
 - Determine the maximum flexural stress
- (ANS. b. 135 kg-m c. 9 kg/cm²)

ENGINEERING ECONOMICS

- A young engineer buys a television set from a merchant who asks P1,250.00 at the end of 60 days (Cash in 60 days). The engineer wishes to pay immediately and the merchant offers to compute the cash price on the assumption that money is worth 8% simple interest. What is the cash price today?
(ANS. P1,233.55)
- Five years ago you paid P340,000 for a house and lot. If you sold it today for P500,000 what would be the interest rate of your investment?
(ANS. 8.0185%)
- The amount of P52,000 was deposited in a fund earning interest at 8% compounded quarterly. What is the amount in the fund at the end of three years?
(ANS. P65,948.58)
- An engineering student borrowed P5,000.00 to meet college expenses during his senior year. He promised to repay the loan with interest 12% in 5 equal annual installments, the first payment to be made 3 years after the date of the loan. How much will this payment be?
(ANS. P1,739.91)
- A savings and loan association requires that loans be repaid by uniform monthly payments which include monthly interest calculated on the basis of a nominal 5.4% per annum. If P5,000 is borrowed to be repaid in 10 years, what must be the monthly payment?
(ANS. P54.02)
- You want to start saving for your 10-year old son's college education. If you were guaranteed 6% interest compounded quarterly, how much would you have to save per month to amass P24,000.00 by the time he is 18?
(ANS. P195.64)
- A man will buy a house and lot worth P300,000.00 in a subdivision in Metro Manila. His year-end installments is P34,200.00 for a period of 20 years. Through his monthly amortizations does not look much as a burden to his income, what is the annual interest rate?
(ANS. 9.56%)
- Which method is the best for an investor, to invest at 5% compounded monthly, or at 5.5% compounded semi-annually? Prove your answer by the mathematical solution.
(ANS. 5.5% compounded semi-annually)

9. A firm plans to market a new minicomputer that will sell for P200, 000.00. The required down payment is 20% and the balance to be settled by equal monthly payments for 5 years. If the interest rate is 24% compounded monthly, what is the monthly payment?

(ANS. P4,602.87)

10. A P10, 000.00 mortgage is being amortized by means of 20 equal yearly installments at an interest of 10%. The agreement provides for paying of the mortgage in a lump sum at any time with an amount equal to the unpaid balance including interest. What single amount have to be paid to discharge the mortgage after 10 payments have been made?

(ANS. P7, 217.38)

11. A manufacturing firm has just installed standby power generating unit at a first cost of P400, 000.00. The projected useful life is 15 years and the estimated salvage value is 10% of first cost. Determine the following:

- Annual depreciation charges using straight line method
- Annual depreciation charges using sinking fund method assuming cost of money to be 12%

(ANS. a. P24, 000 b. P8, 656.73)

12. A machine which cost P10, 000.00 was sold as scrap after being used for 10 years. If the scrap value was P500.00, determine:

- Total depreciation at the end of the 5th year.
- Book value at the end of the 5th year.

(ANS. a. P4,750.00 b. P5,250.00)

13. The direct labor cost and material cost of a certain product are P300 and P400 per unit, respectively. Fixed charges are P100,000 per month and the other variable costs are P100 per unit. If the product is sold at P1200 per unit, how many units must be produced and sold to break even?

(ANS. 250 units per month)

14. The RST Company manufactures electric-gas stoves at a labor cost of P200 per unit, material cost of P300 per unit, fixed charges of P220, 000 per month and variable cost of P160 per unit. The net selling price of each stove is P1, 260, wholesale. Determine the monthly break even sales volume in pesos.

(ANS. 420,840)

15. A total of P62, 092 is donated by a wealthy man to provide an annual scholarship to deserving students. It is proposed that an annual grant of P10, 000 will be drawn from this fund. Worth of money is 10%. How many years from today should be the scholarship grant given so that the scholarship will last forever?

(ANS. 6 years)

16. You purchased a P5,000 bond for P5,100. The bond pays P200 per year. It is redeemable for P5,050 after 10 years. What is the net rate of interest on your investment?

(ANS. 3.84%)

17. A man wants to make 14% nominal interest compounded semi-annually on a bond investment. How much should the man be willing to pay now for a 12%, P10, 000 bond that will mature in 10 years and pays interest semiannually?

(ANS. P8, 940)

18. An air compressor has been purchased at a cost of P18,000. The compressor will be retired at the end of 5 years, at which time it is expected to have a salvage value of P2, 000 based on current prices. The compressor will then be replaced with an exact duplicate. The firm plans to establish a reserve fund to accumulate the capital needed to replace the compressor. If an average annual rate of inflation of 3 percent is anticipated, how much capital must be accumulated?

(ANS. P18, 548)

19. In the manufacture of a certain product, two processes are available. Process A will produce 80 units of the finished product per P100 worth of raw materials and will cost P0.42 per unit of the finished product. Process B will produce 87 units of the finished product per P100 worth of raw materials and will cost P0.56 per unit of the finished product. If the selling price per unit of the finished product is P2.50, which process is more profitable?

(ANS. Process B)

20. A chemical plant needs a generating set. After evaluating several offers, the choice was narrowed down to two offers, a Diesel engine and a gasoline engine. The engineering staff made estimates of life, salvage value, operating cost and maintenance cost as follows:

	Diesel Model	Gasoline Model
Purchase price	P360, 000	P205, 000
Annual fuel cost	40, 000	60, 000
Maintenance cost	10, 000	15, 000
Salvage Value	30, 000	5, 000
Useful life, years	12	8

If money is worth 10%, which model is preferable? Show your computations with the itemized cost.

(ANS. Diesel Model)

21. A manufacturing company is faced with the choice of repairing an old machine at a cost of P12, 000 or replaces it with a new one at P50, 000. It is estimated that the repaired machine will last for 5 years after which replacement will be necessary. Present salvage value of the old machine is P10, 000 and its salvage value after 5 years will be P5,000. It is estimated that the new machine will last for 20 years and will have a salvage value of P15, 000. The yearly maintenance of the new machine will be P500 less than the old. At 6% interest, which is more economical, repair or replace? Use uniform annual cost.

(ANS. Annual cost, repair = P4, 835.74

Annual cost, new = P3, 961.45

Therefore: Replace)

22. A contain heat exchanger costs P30, 000 installed and has an estimated life of 6 years. By the addition of certain auxiliary equipment when the heat exchanger is initially purchased, an annual saving of P1, 000 in operating cost can be obtained and the estimated life of the heat exchanger can be doubled. Neglecting any salvage value for either plan, and with effective annual interest at 8% what present expenditure can be justified for the auxiliary equipment?

(ANS. P26, 442)

THERMODYNAMICS

1. A boiler installed where the atmospheric pressure is 752 mm Hg has a pressure of 12 kg per sq cm. What is the absolute pressure in MPa?

(ANS. 1.277 MPa)

2. An oil storage tank contains oil specific gravity of 0.88 and depth of 20 meters. What is the hydrostatic pressure at the bottom of the tank in kg/cm²? What is the absolute pressure in KPa?

(ANS. 1.76 kg/cm², 274 KPa)

3. A pressure tank for a water pump system contains 2/3 water by volume when the pressure is 10 kg/cm² gauge. What is the absolute pressure at the bottom of the tank if the water is 2 meters deep? Express in KPa?
(ANS. 1102 KPa)
4. Convert 36°F temperature difference to °C and to K.
(ANS. 20°C, 20K)
5. At what temperature are the two temperature scales °C and to °F equal?
(ANS. -40°C)
6. The temperature inside a furnace is 320°C and the temperature of the outside is -10°C. What is the temperature difference in °F?
(ANS. 594°F)
7. Convert 60 lbs/cu ft to kg/cu m; to kN/cu m.
(ANS. 960.8 kg/cu m, 9.426 kN/cu m)
8. Determine the specific volume, enthalpy and entropy of water (or steam) in the given states:
 - a. 2.34 MPa, dry and saturated
 - b. 3.40 MPa, 90% quality
 - c. 4.23 MPa, 277°C
 - d. 3.00 MPa, 150°C
9. Determine the quality (if saturated) or temperature (if superheated) of steam in the given states:
 - a. 3.0 MPa, 0.1 m³/kg
 - b. 2.5 MPa, 0.5 m³/kg
 - c. 3.4 MPa, h = 2900 kJ/kg

10. A boiler feed pump delivers 200,000 kg of water per hour at 10MPa and 230°C. What is the volume rate of flow in m³/sec?
(ANS. 0.0666 m³/sec)
11. The radiator of a heating system was filled with dry and saturated steam at 0.15 MPa after which the valves on the radiator were closed. As a result of heat transfer to the room, the pressure drops to 0.10 MPa. What percentage of steam has condensed?
(ANS. 31.63%)
12. A throttling calorimeter receives a sample of steam from a steam main in which the pressure is 1 MPa. After throttling, the steam is at 100 KPa and 120°C. What is the quality of steam in the steam main?
(ANS. 96.95%)
13. Steam at 2.5 MPa and 320°C expands through a nozzle to 1.5 MPa at the rate of 10, 000 kg/hr. If the process occurs isentropically and the initial velocity is low, calculate
 - a. The velocity leaving the nozzle
 - b. The exit area of the nozzle
(ANS. a. 499 m/sec b. 853x10⁻⁶m²)
14. Water at a pressure of 10 MPa and temperature of 230°C is throttled to a pressure of 1 MPa in an adiabatic process. What is the quality after throttling?
(ANS. 11.36%)
15. Steam at 5 MPa and 320°C enters a turbine and expands isentropically to 0.01 MPa. If the steam flow rate is 100, 000 kg per hour, determine
 - a. The enthalpy after expansion
 - b. The turbine power
(ANS. a. 2042.0 kJ/kg b. 28,511 KW)

16. An air compressor delivers air to an air receiver having a volume of 2 m^3 . At the start, the air in the receiver is at atmospheric condition of 25°C and 100 KPa . After 5 minutes, the pressure of the air in the tank is 1500 KPa and the temperature is 60°C . What is the capacity of the compressor in m^3/min of free air?

(ANS. $4.97 \text{ m}^3/\text{min}$)

17. At the suction of an air compressor, in which the conditions are 97.9 KPa and 27°C , the air flow rate is $10.3 \text{ m}^3/\text{min}$. What is the volume flow rate at free air conditions of 100 KPa and 20°C ?

(ANS. $9.848 \text{ m}^3/\text{min}$)

ADDENDA

PLANE TRIGONOMETRY

DEFINITIONS

- Axiom – a statement accepted as true
Postulate – a statement assumed to be true, as a basis for argument
Hypothesis – an unapproved theory tentatively accepted to explain certain facts
Theorem – a proposition that can be proven from accepted premises
Corollary – a proposition that follows from one already proved
- Altitude of a Triangle – a perpendicular from any vertex of a triangle to the side opposite
- Angle – the opening between two straight lines drawn from the same point
- Apothem – the radius of the inscribed circle of a polygon
- Area – the number of unit squares of a plane figure.
- Center of Polygon – the common center of the inscribed and circumscribed circles of a regular polygon

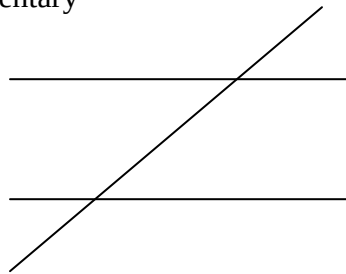
- Circle – a closed plane curve every point of which is equally distant from a point in the plane of the curve
- Complementary Angles – two angles whose sum is equal to a right angle (or 90°)
- Concurrent Lines – three or more lines which have one point in common
- Diagonal – a line joining any two nonconsecutive vertices of a polygon
- Hypotenuse – the side opposite the right angle of a right triangle.
- Isosceles triangle – a triangle which has two equal sides.
- Locus – a figure containing all the points, and only those points, which fulfill a given requirement
- Parallel Lines – lines that lie in the same plane and do not meet however far extended.
- Parallelogram – a quadrilateral whose opposite sides are parallel
- Perpendicular – a line which cuts another line so as to make two adjacent angles equal
- Polygon – a closed plane figure bounded by straight lines (Triangle, quadrilateral, pentagon, hexagon, etc)
- Quadrilateral – a polygon with four sides (square, rectangle, parallelogram, trapezoid)
- Rectangle – a parallelogram whose angles are right angles
- Regular Polygon – a polygon all of whose angles are equal and all of whose sides are equal
- Rhomboid – a parallelogram with oblique angles and only the opposite sides equal
- Rhombus – an equilateral parallelogram,
- Similar Polygons – polygons whose corresponding angles are equal and whose corresponding sides are proportional
- Supplementary Angles – two angles whose sum is equal to two right angles (or 180°)
- Tangent – a straight line which meets a curve only at one point
- Trapezoid – a quadrilateral two and only two of whose sides are parallel
- Triangle – a plane figure bounded by three straight lines; a polygon with three sides

- 28. Vertical Angles – opposite angles of two intersecting lines
- 29. π (pi) – the ratio of circumference of a circle to its diameter
- 30. Right Isosceles Triangle – a right triangle whose legs are equal

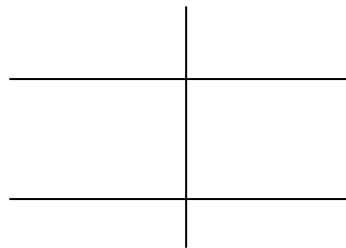
THEOREMS

LINES

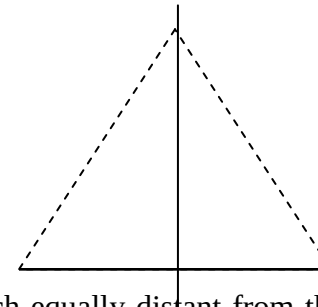
1. If two parallel lines are cut by a transversal:
 - a. Alternate interior angles are equal
 - b. Exterior-interior angles are equal
 - c. Angles on the same side of the transversal are supplementary



2. If a line is perpendicular to one of two parallel lines, it is perpendicular to the other also



3. Any point in the perpendicular bisector of a line is equally distant from the extremities of a line determines the perpendicular bisector of the line



4. Two points each equally distant from the extremities of a line determines the perpendicular bisector of the line.

PROPERTIES OF TRIANGLES

1. The sum of the three angles of a triangle is equal to two right angles (or 180°).
2. The sum of two sides of a triangle is greater than the third side, and their difference is less than the third side.
3. If two sides of a triangle are unequal, the angles opposite are unequal, and the greater angle is opposite the greater side; and conversely.
4. If two sides of a triangle are equal (an isosceles triangle), the angles opposite these sides are equal; and conversely.
5. The bisectors of the angles of a triangle meet at a point which is the center of the inscribed circle.
6. The perpendicular bisectors of the sides of a triangle meet at a point which is the center of the circumscribed circle.
7. The medians of a triangle are concurrent at a point which is two-thirds of the distance from any vertex to the midpoint of the opposite side.
8. Two triangles are congruent if two angles and the included side of one are equal, respectively, to two angles and the included side of the other.
9. Two triangles are congruent if two sides and the included angle of one are equal, respectively, to two sides and the included angle of the other.

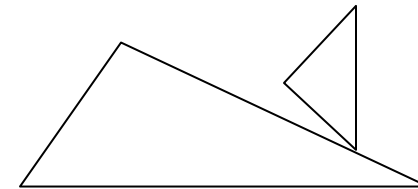
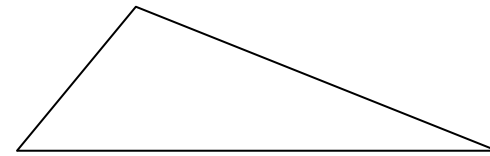
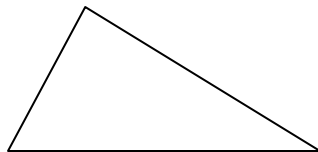
10. Two triangles are congruent if the three sides of one are equal, respectively, to the three sides of the other.

RIGHT ANGLES

1. Theorem of Pythagoras: In any right triangle the square of the hypotenuse is equal to the sum of the squares of the other two sides.
2. Two right angles are equal if a side and the hypotenuse of one are equal, respectively, to a side and the hypotenuse of the other.
3. Two right triangles are equal if the hypotenuse and an adjacent angle of one are equal, respectively, to the hypotenuse and an adjacent angle of the other.
4. If a perpendicular is drawn from the vertex of the right angle to the hypotenuse of a right triangle, the two triangles formed are similar to each other and to the given triangle.

SIMILAR TRIANGLES

1. Two triangles are similar if the angles of one are respectively equal to the angles of the other; or if two angles of one are respectively equal to two angles of the other.
2. Two triangles are similar if their sides are in the same ratio.
3. Two triangles are similar if their sides are respectively parallel each to each.
4. Two triangles are similar if their sides are respectively perpendicular each to each.



POLYGONS

1. The sum of the interior angles of a polygon of “n” sides is equal to $(n-2)180^\circ$.
2. Each interior angle of a regular polygon of “n” sides is equal to $(n-2)180^\circ / n$
3. Corresponding parts of congruent figures are equal.

CIRCLES

1. Through three points not in a straight line one circle and only one can be drawn.
2. A tangent to a circle is perpendicular to the radius at the point of tangency; and conversely.
3. The tangents to a circle drawn from an external point are equal, and make equal angles with the line joining the point to the center.
4. An inscribed angle is measured by one-half the intercepted arc.
5. An angle inscribed in a semicircle is a right angle.
6. If two chords intersect in a circle, the product of the segments of one is equal to the product of the segments of the other.
7. The circumference of two circles are in the same ratio as their radii, and the arcs of two circles subtended by equal central angles are in the same ratio as their radii.

SECTION

2

POWER AND
INDUSTRIAL
PLANT
ENGINEERING

FUELS AND COMBUSTION

Classifications of Fuels:

Solid Fuels (principal component: carbon, C):

Coal, Coke, wood, charcoal, bagasse, coconut shells and husks, briquetted fuels.

Liquid Fuels (principal component: Hydrocarbon, C_nH_m):

Gasoline, alcohol, kerosene, diesel, bunker, other fuel oils

Gaseous Fuels (principal component: Hydrocarbon, C_nH_m):

Natural gas, producer gas, blast furnace gas, liquefied petroleum gas (LPG), methane, ethane, acetylene, propane

Properties of Fuels and Lubricants:

1. Analysis of composition:

- Proximate analysis – analysis of the composition of fuel which gives, on mass basis, the relative amounts of Moisture Content, Volatile Matter, Fixed Carbon and Ash.
- Ultimate (chemical) analysis – analysis of the composition of fuel which gives, on mass basis, the relative amounts of Carbon, Hydrogen, Oxygen, Nitrogen, Sulfur, Ash and Moisture

2. Specific Gravity; Density

$$\text{Specific Gravity} = \frac{\text{Density}}{\text{Density of Water}} \quad (\text{for liquids})$$

$$= \frac{\text{Density}}{\text{Density of Water}} \quad (\text{for gases})$$

Instruments used for measuring specific gravity:

Hydrometer, pycnometer, Westphal balance

API and Baume Gravity Units:

$$^{\circ}\text{API} = \frac{141.5}{\text{SG at } 15.6^{\circ}\text{C}} - 131.5 \quad (\text{Petroleum products})$$

$$^{\circ}\text{Baume} = \frac{140}{\text{SG at } 15.6^{\circ}\text{C}} - 130 \quad (\text{brine})$$

Specific gravity at temperature t, applying correction factor:

$$\text{SG}_t = \text{SG}_{15.6^{\circ}\text{C}} [1 - 0.0007(t - 15.6)]$$

3. Heating Value or Calorific Value, kJ/kg

- Higher heating value (gross calorific value) – the heating value obtained when the water in the products of combustion is in the liquid state.
- Lower heating value (net calorific value) – the heating value obtained when the water in the products of combustion is in the vapor state.

Instruments used in measuring heating value of fuels:

- Oxygen bomb calorimeter: for solid and liquid fuels
- Gas calorimeter: for gaseous fuels

Calculating heating value by formulas:

- Dulong's formula, used for solid fuels of known ultimate analysis:

$$Q_h = 33,820 C + 144,212(H - 0/8) + 9,304 S \text{ kJ/kg}$$

- ASME formula, for petroleum products:

$$Q_h = 41,130 + 139.6 \times ^{\circ}\text{API} \text{ kJ/kg}$$

- Bureau of Standards formula:

$$Q_h = 51,716 - 8,793.8(\text{SG})^2 \text{ kJ/kg}$$

4. Viscosity of Lubricants

Viscosity – resistance to flow or the property which resists shearing of the lubricant

Absolute viscosity – viscosity which is determined by direct measurement of shear resistance

Kinematic Viscosity – absolute viscosity divided by the density

Viscosity Index – the rate at which viscosity changes with temperature

Units of viscosity:

$$1 \text{ reyn} = 1 \text{ lb-sec/in}^2$$

$$1 \text{ stoke} = 1 \text{ cm}^2/\text{sec}$$

$$1 \text{ poise} = 1 \text{ dyne-sec/cm}^2$$

Viscosimeter – an instrument, consisting of standard orifice, used for measuring viscosity (in SSU and SSF)

SSU (Saybolt Second Universal) – number of seconds required for 60ml of oil (at 37.8°C) to pass through a standard orifice

Relations of Viscosity Units:

$$\text{Centistokes} = 0.308 (\text{SSU} - 26)$$

$$62 \text{ SSF} = 660 \text{ SSU}$$

5. Other Properties of fuels and lubricants:

Flash Point – the temperature at which oil gives off vapor that burns temporarily when ignited

Fire Point – the temperature at which oil gives off vapor that burns continuously when ignited

Pour Point – the temperature at which oil will no longer pour freely

Dropping Point – the temperature at which grease melts

Conradson number (carbon residue) – the percentage by weight of the carbonaceous residue remaining after destructive distillation

Octane Number – the ignition quality rating of gasoline, which is the percentage by volume of iso-octane in a mixture of iso-octane and heptane that matches the gasoline in anti-knock quality

Cetane number – the ignition quality rating of diesel, which is the percentage by volume of iso-octane in the standard fuel

Combustion

Combustion – chemical reaction, between fuel and oxygen, which is accompanied by heat and light

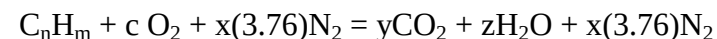
Theoretical air-fuel ratio – the exact theoretical amount, as determined from the combustion reaction, of air needed to burn a unit amount of fuel, kg air per kg of fuel

Actual air-fuel ratio – theoretical air-fuel ratio plus excess air

Air by volume consists of 21% oxygen and 79% nitrogen, thus there are 3.76 mols of N₂ per mol of O₂

Typical combustion reaction of a fuel with known chemical formula:

Fuel + Air = Products of Combustion



Where: x, y and z represent number of mols

Combustion of Solid fuel with known ultimate analysis:

$$\text{Theo. A/F} = 11.5C + 34.5(H - O/8) + 4.3S \text{ Kg air/ kg fuel}$$

Molecular Weights:

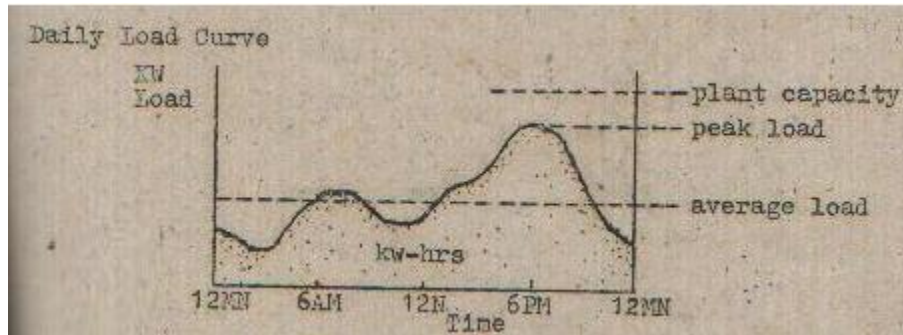
C : 12 N₂ : 28

H₂ : 2 S : 32

C₂ : 32

VARIABLE LOAD PROBLEM

Daily Load Curve



Reserve over peak = plant capacity – peak load

Average load = kw-hrs energy / number of hours

1. Load factor = average load / peak load

2. Capacity factor = $\frac{\text{actual energy produced}}{\text{maximum possible energy that might have been produced during the same period}}$

Annual capacity factor = $\frac{\text{annual kw-hrs}}{\text{kw plant cap} \times 8760}$

3. Use factor = $\frac{\text{annual kw-hrs}}{\text{kw plant cap} \times \text{no. of hours operation}}$

4. Demand factor = $\frac{\text{actual maximum}}{\text{Connected loan}}$

5. Diversity factor = $\frac{\text{sum of individual maximum demands}}{\text{maximum simultaneous demand}}$

6. Plant factor = $\frac{\text{average load}}{\text{rating of equipment supplying the load}}$

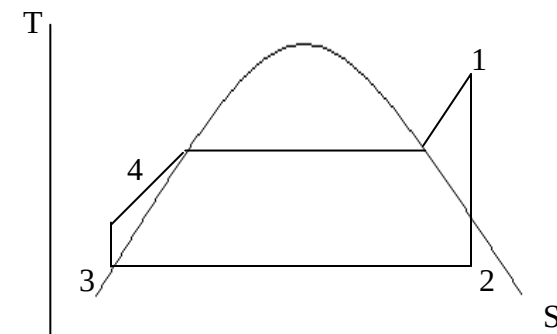
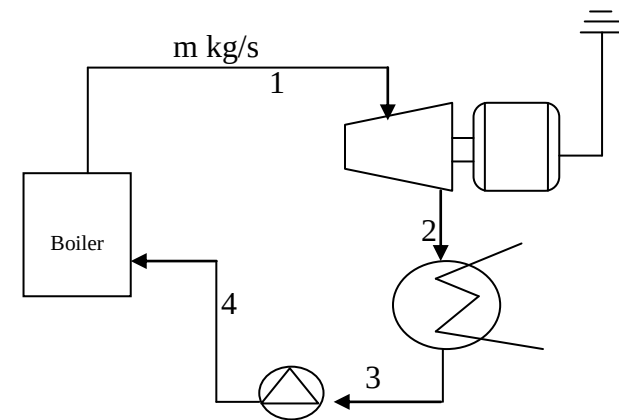
7. Utilization factor = $\frac{\text{maximum demand of system}}{\text{Rated capacity of system}}$

8. Operation factor = $\frac{\text{duration of actual service}}{\text{Total duration of the period of time considered}}$

STEAM POWER PLANT

STEAM CYCLES

1. Rankine Cycle



$$\begin{aligned}\text{Turbine Work} &= h_1 - h_2 \text{ kJ/kg} \\ &= m(h_1 - h_2) \text{ kW}\end{aligned}$$

$$\begin{aligned}\text{Heat Rejected in Condenser} &= h_2 - h_3 \text{ kJ/kg} \\ &= m(h_2 - h_3) \text{ kW}\end{aligned}$$

$$\begin{aligned}\text{Pump Work} &= h_4 - h_3 \text{ kJ/kg} \\ &= v_3(P_4 - P_3) \text{ kJ/kg} \\ &= m(h_4 - h_3) \text{ kW}\end{aligned}$$

$$\begin{aligned}\text{Rankine Cycle Efficiency} &= \frac{\text{Net Turbine Work}}{\text{Heat Added}} \\ &= \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)}\end{aligned}$$

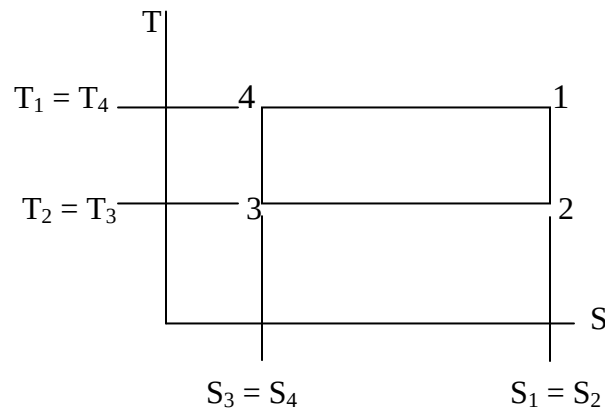
2. Carnot Cycle Applied to Steam Power

$$\begin{aligned}Q_A &= \text{heat added (in boiler)} \\ &= T_1 (S_1 - S_4)\end{aligned}$$

$$\begin{aligned}Q_R &= \text{heat rejected (in condenser)} \\ &= T_2 (S_2 - S_3) = T_2 (S_1 - S_4)\end{aligned}$$

$$\begin{aligned}W &= \text{work} = Q_A - Q_R \\ &= T_1 (S_1 - S_4) - T_2 (S_1 - S_4)\end{aligned}$$

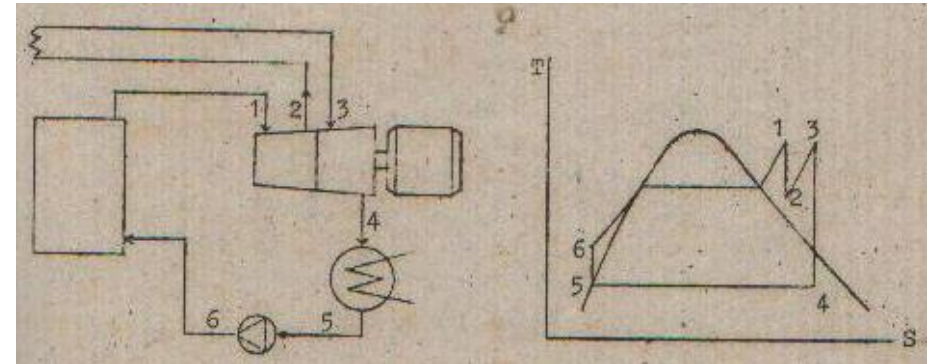
$$\begin{aligned}\text{Carnot Cycle Efficiency} &= W/Q_A \\ &= \frac{T_1 (S_1 - S_4) - T_2 (S_1 - S_4)}{T_1 (S_1 - S_4)} \\ &= \frac{T_1 - T_2}{T_1}\end{aligned}$$



3. Reheat Cycle

$$\text{Turbine Work} = (h_1 - h_2) + (h_3 - h_4) \text{ kJ/kg}$$

$$\text{Heat Added} = (h_1 - h_6) + (h_3 - h_2) \text{ kJ/kg}$$

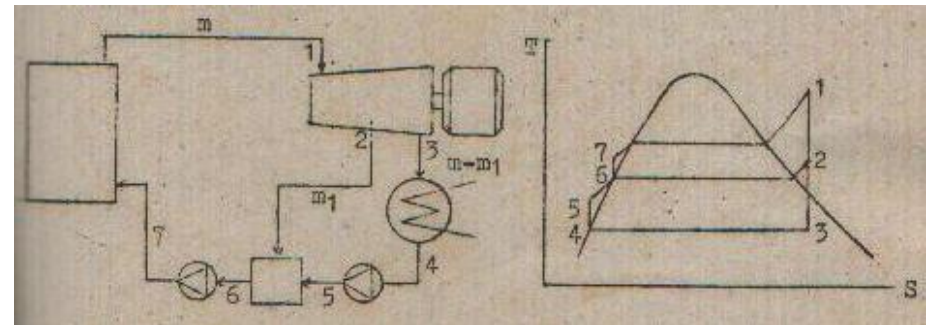


4. Regenerative Cycle

$$\text{Turbine Work} = m(h_1 - h_2) + (m - m_1)(h_2 - h_3) \text{ kJ/kg}$$

$$\text{Heat Balance in regenerative heater:}$$

$$m_1 h_2 + (m - m_1) h_5 = m h_6$$

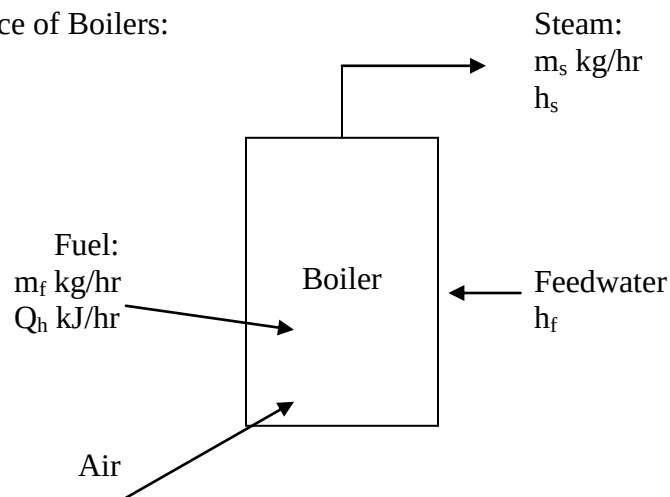


STEAM GENERATORS (BOILERS)

Primary classification of boilers (based on relative position of heated water and hot gases):

- Water Tube (Tubulous) Boiler – type of boiler in which the water is inside the tubes while the hot gases surround the tubes.
- Fire Tube (Tubular) Boiler – type of boiler in which the hot gases pass inside the tubes while the water is outside the tubes.

Performance of Boilers:



- m_s = rate of evaporation, kg/hr
- HS = heating surface, m^2
= total surface area through which the heated water and hot gases exchange heat
- Q_s = heat supplied or heat generated by fuel
= $m_f Q_h$
- Rated Boiler Horsepower = $HS/0.91$ (for water tube)
= $HS/1.1$ (for fire tube)
- Developed boiler Horsepower = $\frac{m_s(h_s - h_f)}{35,322}$
(1 boiler hp = 35,322 kJ/hr)
- Percent Rating = $\frac{\text{Developed Boiler Hp}}{\text{Rated Boiler Hp}}$

7. ASME Evaporation Units (rate at which heat is transformed)

$$= m_s (h_s - h_f) \text{ kJ/hr}$$

8. Factor of Evaporation (FE) = $\frac{h_s - h_f}{2257}$

9. Boiler Efficiency = $\frac{m_s (h_s - h_f)}{m_f Q_h}$
(Thermal Eff.)

$$\text{Net Boiler eff.} = \frac{m_s (h_s - h_f) - \text{Energy consumed by boiler accessories}}{m_f Q_h}$$

10. Actual Specific Evaporation = $\frac{m_s}{m_f} \frac{\text{kg steam}}{\text{kg fuel}}$

11. Equivalent Evaporation = $m_s \times \text{FE}$ kg/hr from and at 100°C

12. Equivalent Specific Evaporation = $m_s/m_f \times \text{FE} \frac{\text{kg steam}}{\text{kg fuel}}$ from and at 100°C

Boiler Auxiliaries and Accessories:

Stoker – combustion equipment for firing solid fuels

Burner – combustion equipment for firing liquid and gaseous fuels

Feedwater Pump – delivers water into the boiler

Economizer – feedwater pre-heating device which utilizes the heat of the flue gases

Feedwater Heater – pre-heating device which utilizes steam mixed with the feedwater

Water Walls – water tubes installed in the furnace to protect the furnace against high temperature and also serve as extension of heat transfer area for the feedwater

Safety Valve – a safety device which automatically releases the steam in case of over-pressure

Gage Glass (Water Column) – indicated the water level existing in the boiler

Pressure Gauge – indicates the temperature of the steam in the boiler

Temperature Gauge – indicates the temperature of the steam in the boiler

Fusible Plug – a metal plug with a definite melting point through which the steam is released in case of excessive temperature which is usually caused by low water level

Baffles – direct the flow of the hot gases to effect efficient heat transfer between the hot gases and the heated water

Furnace – encloses the combustion equipment so that the heat generated will be utilized effectively

Soot Blower – device which uses steam or compresses air to remove the soot that has accumulated in the boiler tubes and drums

Draft Fans (forced draft and induced draft fans) – supply air needed for combustion and create the draft required for the flow of gases in the boiler

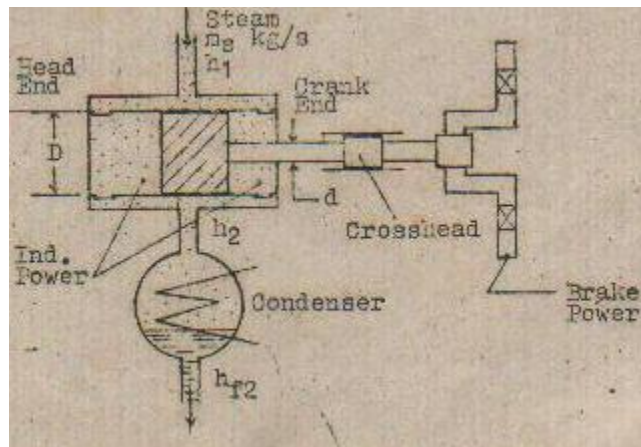
Blowdown Valve – valve through which the impurities that settle in the mud drum are removed

Breeching – the duct that connects the boiler and the chimney

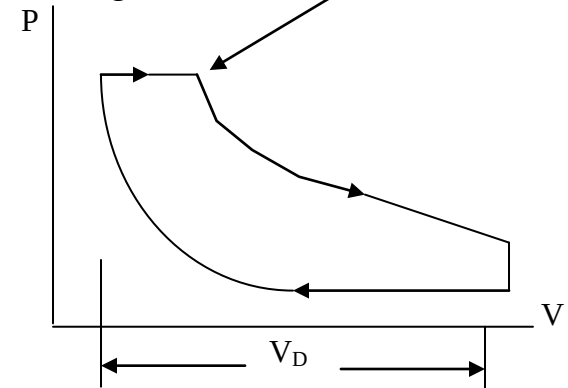
Air Preheater – heat exchanger which utilizes the heat of the flue gases to preheat the air needed for combustion

STEAM ENGINES

Performance of Steam Engines:
(Steam Engines are double-acting)



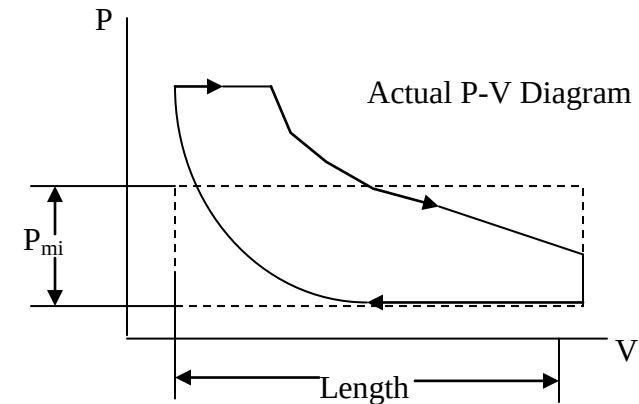
1. Ideal P-V Diagram



2. $V_D = \text{piston displacement}$
 $= 2 (\pi/4 D^2 L N)$, m^3/s (piston rod neglected)
 $= \pi/4 D^2 L N + \pi/4 (D^2 - d^2) L N$, m^3/s (piston rod considered)

3. Indicated Power

Measuring instruments used: Engine Indicator traces actual P-V diagram; Planimeter measures area of P-V diagram; Tachometer measures speed



$P_{mi} = \text{indicated mean effective pressure}$
 $= \frac{\text{area of diagram}}{\text{Length of diagram}} \times \text{spring scale. KPa}$

$$\text{Indicated Power} = P_{mi} V_D, \text{ KW}$$

4. Brake Power

Measuring instruments used: Dynamometer measures the torque; Tachometer measures the speed

$$\text{Brake Power} = 2\pi TN, \text{ KW} \quad \text{where: } T = \text{torque, kN-m} \\ N = \text{speed, rev/s}$$

$$P_{mb} = \text{brake mean effective pressure, KPa} \\ = \frac{\text{Brake Power}}{V_D}$$

$$\text{Therefore: Brake Power} = P_{mb} V_D$$

$$5. \text{ Friction Power} = \text{Indicated Power} - \text{Brake Power}$$

$$6. n_m = \text{mechanical efficiency} = \frac{\text{Brake Power}}{\text{Indicated Power}}$$

7. Thermal Efficiency

$$a. n_{ti} = \text{indicated thermal efficiency} = \frac{\text{Ind. Power}}{m_s (h_1 - h_{f2})}$$

$$b. n_{tb} = \text{brake thermal efficiency} = \frac{\text{Brake Power}}{m_s (h_1 - h_{f2})}$$

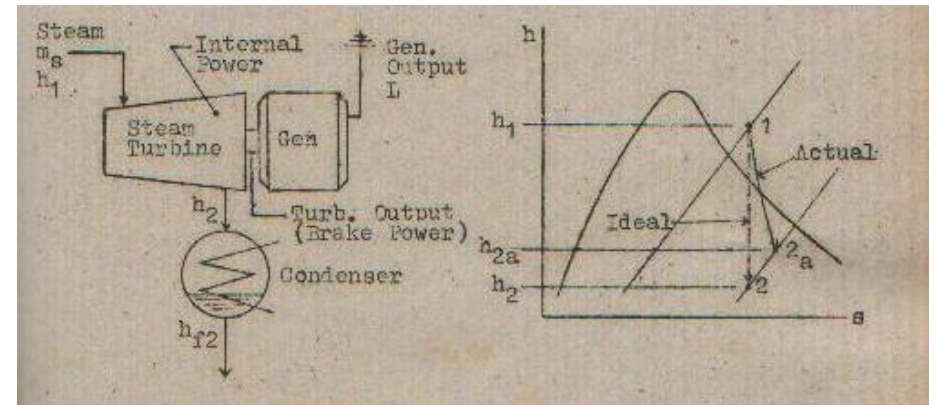
8. Engine Efficiency

$$a. n_{ei} = \text{indicated engine efficiency} = \frac{\text{Ind. Power}}{m_s (h_1 - h_2)}$$

$$b. n_{eb} = \text{brake engine efficiency} = \frac{\text{Brake Power}}{m_s (h_1 - h_2)}$$

STEAM TURBINES

Performance of Steam Turbines:



1. Ideal Turbine Work = $m_s(h_1 - h_2)$
where: h_1 = enthalpy of steam entering
 h_2 = enthalpy after ideal (isentropic) expansion
2. Actual Turbine Work = $m_s(h_1 - h_{2a}) = m_s(h_1 - h_2)n_{st}$
where: h_{2a} = enthalpy after actual expansion
 n_{st} = stage efficiency
3. Turbine Power Output = $m_s(h_1 - h_2)n_T$
where: n_T = turbine efficiency
4. n_e = electrical or generator efficiency = $\frac{\text{Generator Output}}{\text{Turbine Output}}$
5. Thermal Efficiency
 - a. n_{tb} = brake thermal efficiency = $\frac{\text{Turbine Output}}{m_s (h_1 - h_{f2})}$
 - b. n_{tc} = combined or overall thermal efficiency = $\frac{\text{Generator Output}}{m_s(h_1 - h_{f2})}$

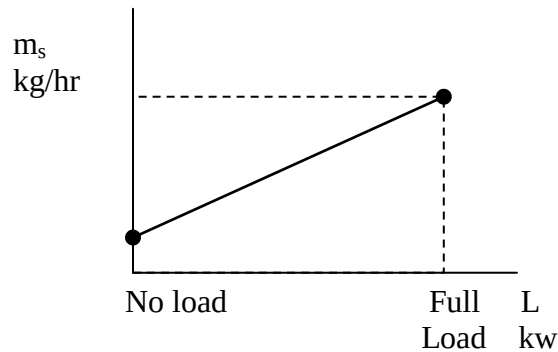
6. Engine Efficiency of Turbine

a. n_{eb} = brake engine efficiency = $\frac{\text{Brake Power}}{m_s (h_1 - h_2)}$

b. n_{ec} = combined or overall engine efficiency = $\frac{\text{Gen. Output}}{m_s (h_1 - h_2)}$

7. Willian's Line:

Willian's Line is a straight line which show's the relation between the steam consumption (m_s , kg/hr) and the load (L , kw) of a steam turbine generator unit.



STEAM CONDENSERS

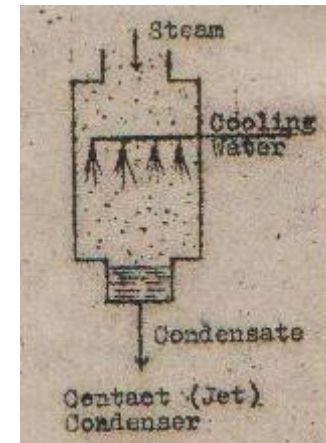
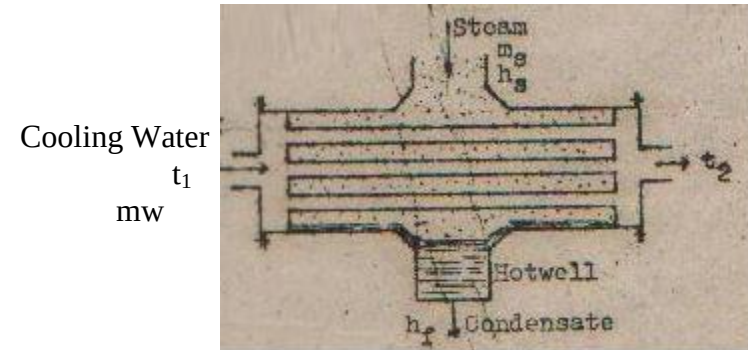
Classification of steam condensers:

1. Surface Condenser

- type of condenser in which the steam and cooling water do not mix; commonly used design is the shell-and-tube.

2. Contact (Jet) Condenser

- type of condenser in which the steam and cooling water are mixed.



By heat balance:

$$m_w c_p (t_2 - t_1) = m_s (h_s - h_f) E$$

where: $c_p = 4.187 \text{ kJ/kg}^\circ\text{C}$

E = heat extraction factor

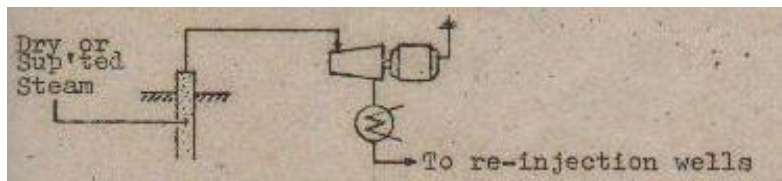
GEOHERMAL POWER PLANT

Definitions:

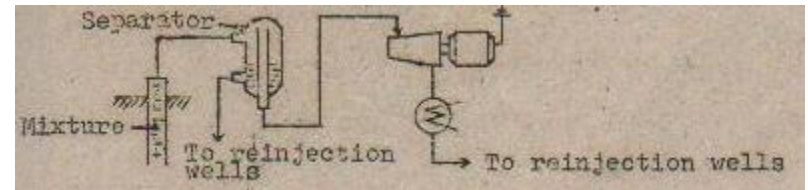
1. Magma – molten metal within the earth which is basically nickel-iron in composition whose stored energy heats the surrounding water thereby producing steam or hot water.
2. Well-bore product – the effluent coming out from the geothermal well as produced after drilling. This can be purely steam or hot water, or a mixture of both.
3. Steam-dominated geothermal field – refers to a geothermal plant with its well producing all steam, as the well-bore product.
4. Liquid-dominated geothermal field – the well-bore product for this type of field is practically all hot water pressurized.
5. Sources of geothermal energy:
 - a. Hot spring
 - b. Steam vent
 - c. Geyser
6. Fumarole – a crack in the earth through which geothermal substance passes.

Types of Geothermal Plants:

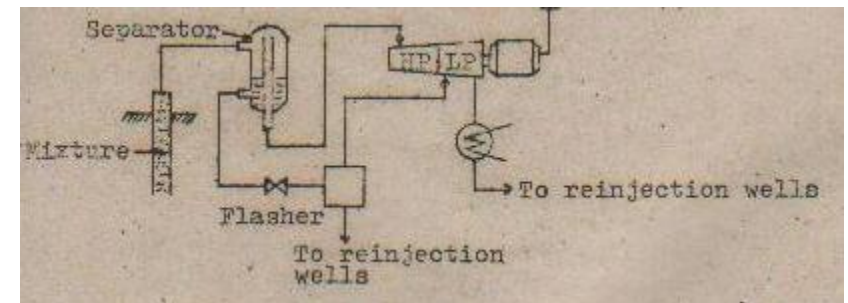
1. Dry or Superheated Geothermal Plant



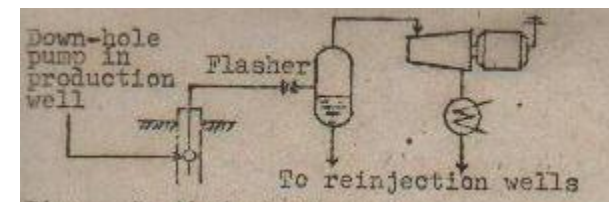
2. Separated Steam or “Single Flash” Geothermal Plant



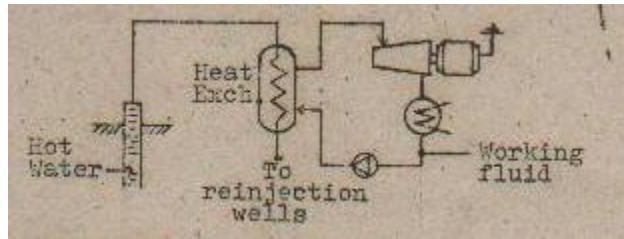
3. Separated Steam/Hot-Water-Flash or “Double Flash” Geothermal Plant



4. Single Flash Plant with Pumped Wells



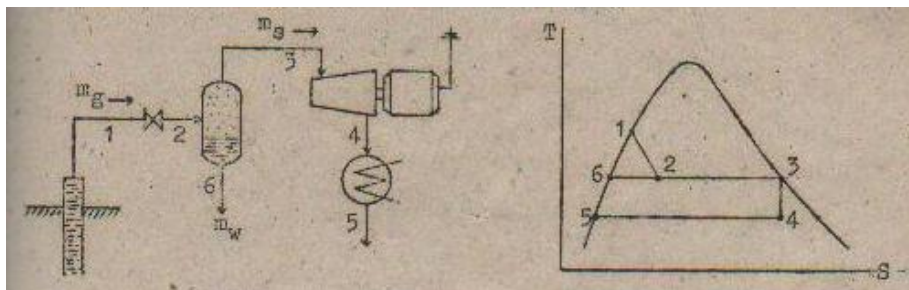
5. Binary Geothermal Plant



Geothermal Plants in the Philippines:

1. Tiwi-Albay Geothermal Plant
Albay (330 MW)
2. Makiling-Banahaw Geothermal Plant
Los Baños, Laguna (300 MW)
3. Tongonan Geothermal Plant
Leyte (112.5 MW)
4. Palimpinon-Dauin Geothermal Plant
Negros Oriental (112.5 MW)

Performance of Flashed-Steam Geothermal Plant



m_g = mass flow rate of ground water
 m_s = mass flow rate of steam entering turbine

Throttling Process (1 – 2):

$$h_1 = h_2 = (h_f + x h_{fg})_2$$

where x : quality after throttling

Mass flow rate of steam entering turbine

$$m_s = x (m_g)$$

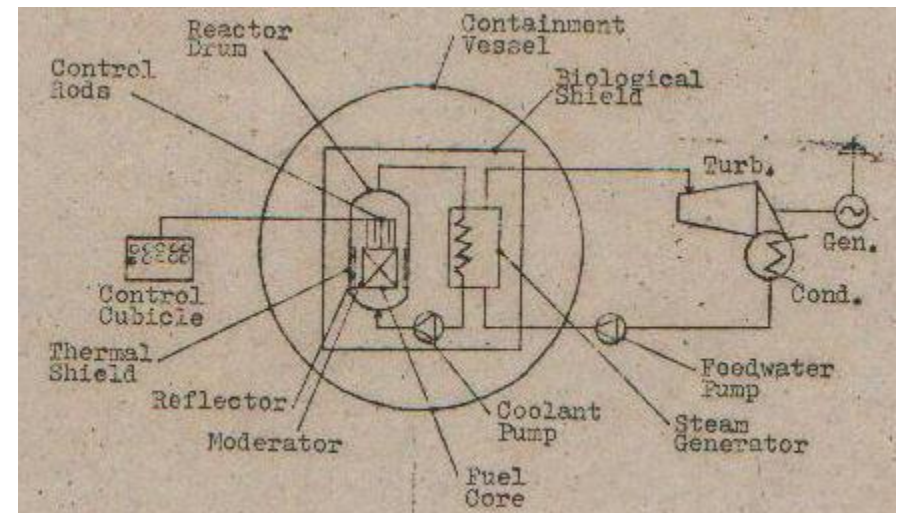
Turbine Output = $m_s(h_3 - h_4)n_T$

where: n_T = turbine efficiency

Heat Rejected in Condenser = $m_s (h_4 - h_5)$

NUCLEAR POWER PLANT

Typical Nuclear Power Plant:



Fuel Core – radioactive material, U^{235} with U^{238} , which is the source of energy

Moderator – slows down the neutrons to thermal energy, made of Carbon and Beryllium

Control Rods – Boron-coated steel rods used to control the reactor

Reflector – made of lead or carbon which surrounds the core to bounce back any leakage of neutrons

Thermal Shield – prevents escape of radiation from reactor vessel

Reactor Drum – encloses the fuel core and components

Biological Shield – concrete or lead which absorbs any leakage of radiation and protects operators from exposure to radioactivity

Control Cubicle – contains the meters that show the operating quantities in the reactor

Containment Vessel – prevents spread of radiation in case of a major explosion; made of concrete

Coolants – absorbs the heat from the fuel core and then release the heat to the water in the steam generator

Coolant Pump – circulates the coolant

Turbine-Generator – generates the electric power

Condenser – converts steam coming from the turbine into liquid

Feedwater Pump – delivers the feedwater to the steam generator

Commercial Types of Nuclear Power Reactors:

1. Pressurized Water Reactor (PWR)

This type of reactor uses high pressure light or heavy water as both moderator and coolant. This is the type which is constructed in Morong, Bataan with capacity of 620 MW and intended to supply power to the Luzon area. In 1986 the Philippine government decided to stop the completion of the plant because of the controversy regarding its safety and economic features.

2. Boiling Water reactor (BWR)

This is the simplest form of nuclear reactor. The feedwater from the power turbine goes directly into the reactor and picks up the heat from the fuel core. Thus the feedwater also serves as the coolant. The first experimental reactor installed in Diliman, Quezon City is of this type. It has a capacity of 1 MW.

3. Heavy Water Reactor (HWR)

This type of reactor uses heavy water Deteriu, D_2O as coolant.

4. Gas-Cooled Power Reactor (GCPR)

The gas coolant used in this type of reactor is carbon dioxide.

Nuclear power plants in the Philippines:

1. Pressurized Water reactor

Location: Morong, Bataan

Capacity: 620 MW

Purpose: To supply power to the Luzon area

(The Philippine government stopped the completion of the plant in 1986 due to controversy regarding its safety and economic features)

2. Boiling Water Reactor
Location: Diliman, Quezon City
Capacity: 1 MW
Purpose: Experimental

DIESEL (I.C.E) POWER PLANT

Basic Classification of Common Internal Combustion Engines:

Type of Engine	Fuel Used	Method of Ignition	Operating Cycle
Gasoline Engine	Gasoline	Spark	Otto
Kerosene Engine	Kerosene	Spark	Otto
Gas Engine	Gaseous Fuel	Spark	Otto
Diesel Engine	Diesel	Heat of Compression	Diesel
Oil-Diesel Engine	Fuel Oils	Heat of Compression	Diesel

Other Methods of Classification:

Number of Strokes per cycle:

- Two-stroke
- Four-stroke

Number of Cylinders:

- Single-cylinder
- Two-cylinder
- Three-cylinder, etc

Position of cylinders:

- Vertical
- Horizontal
- Incline

Arrangement of cylinders:

- In-line
- V
- Radial
- Opposed cylinder
- Opposed piston

Method of Starting:

- Manual: crank, rope, kick
- Electric (battery)
- Compressed air
- Using another engine

Application:

- Automotive
- Marine
- Industrial
- Stationary Power
- Locomotive
- Aircraft

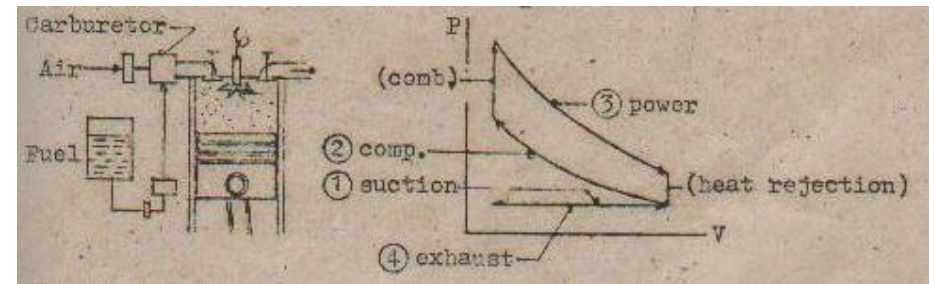
Number of Piston sides working:

- Single-acting
- Double-acting

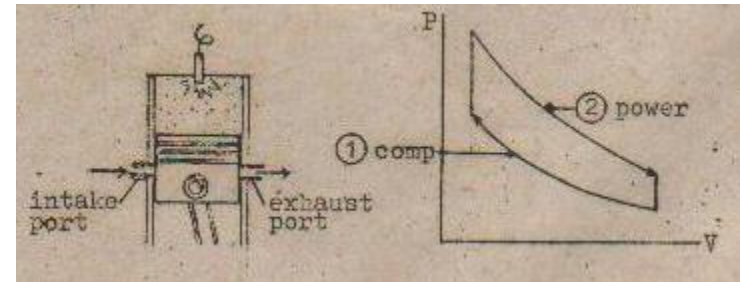
Method of Cooling
Air cooled
Water cooled

Intake Pressure:
Naturally aspirated
Supercharged

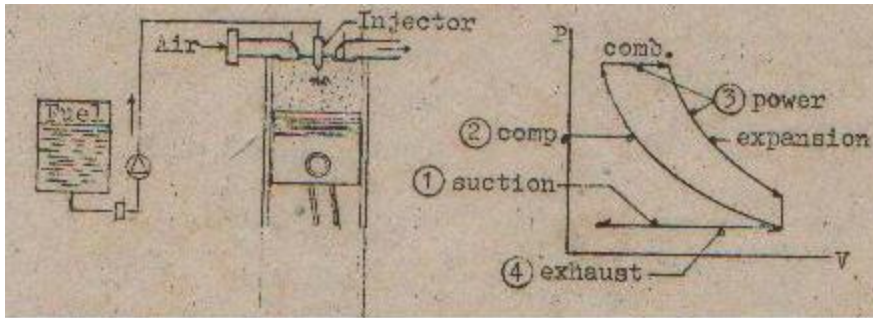
Cycle Analysis of 4-stroke Gasoline Engine:



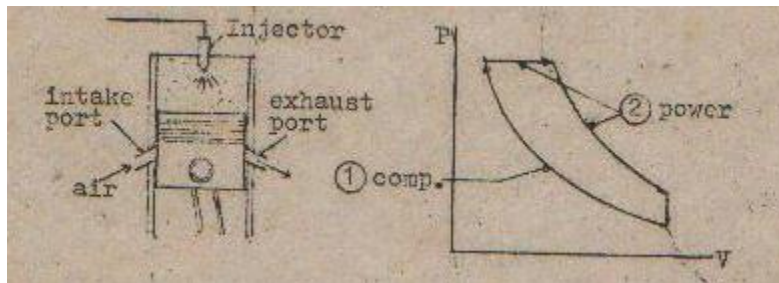
Cycle Analysis of 2-stroke Gasoline Engine:



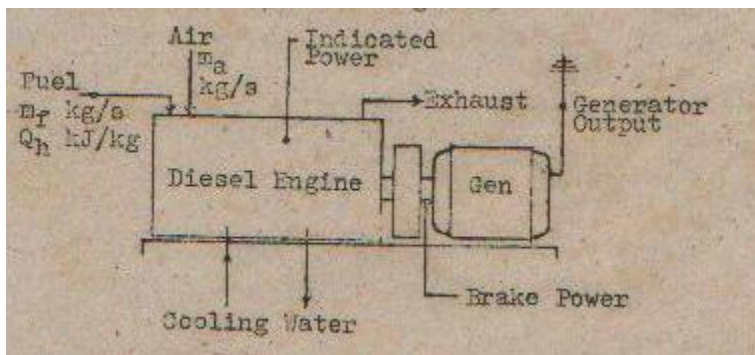
Cycle Analysis of 4-stroke Diesel Engine:



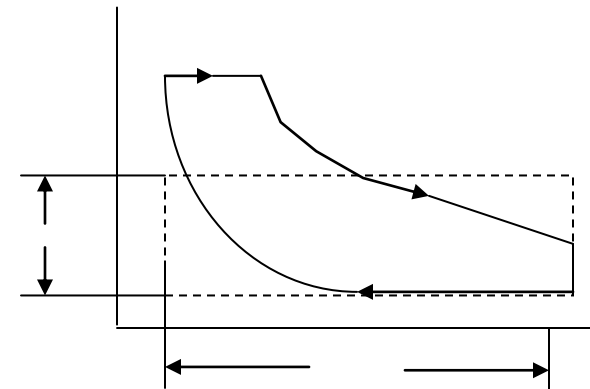
Cycle Analysis of 2-stroke Diesel Engine:



Performance of Diesel Generating Set



- Heat Generated (Fuel) = $m_f Q_h$ KW
where: m_f = fuel consumption, kg/sec
 Q_h = heating value, kJ/kg
- A/F = air-fuel ratio = $\frac{m_a}{m_f} \frac{\text{kg air}}{\text{kg fuel}}$ $m_a = \frac{PV}{RT}$ kg/sec
- VD = piston displacement, m^3/sec
 $= \pi/4 D^2 L N C$
where: D = bore, m
L = stroke, m
N = speed, rev/sec (for 2-stroke)
= speed/2, rev/sec (for 4-stroke)
C = number of cylinders
- Piston Speed = $2LN$, m/sec
- Indicated Power
Measuring instruments used: Engine indicator traces actual P-V diagram; Planimeter measures area of p-V diagram; Tachometer measures speed



$$P_{mi} = \text{indicated mean effective pressure}$$

$$= \frac{\text{area of diagram}}{\text{length of diagram}} \times \text{spring scale, kPa}$$

$$\text{Indicated Power} = P_{mi} V_D \text{ KW}$$

6. Brake Power

Measuring instruments used: Dynamometer measures the torque; Tachometer measures the speed

$$\text{Brake Power} = 2\pi TN, \text{ KW} \quad \text{where: } T = \text{torque, kN-m} \\ N = \text{speed, rev/sec}$$

Calculation of brake Power using brake mean effective pressure:

$$\text{Brake Power} = P_{mb} V_D \text{ KW} \quad \text{where: } P_{mb} = \text{brake mean effective pressure, kPa}$$

$$7. \text{ Friction Power} = \text{Indicated Power} - \text{Brake Power}$$

$$8. \quad n_m = \text{mechanical efficiency} = \frac{\text{Brake Power}}{\text{Ind. Power}}$$

$$9. \quad n_e = \text{electrical or generator efficiency} = \frac{\text{Generator Output}}{\text{Brake Power}}$$

10. Thermal Efficiency

$$a. \quad n_{ti} = \text{indicated thermal efficiency} = \frac{\text{Ind. Power}}{m_f Q_h}$$

$$b. \quad n_{tb} = \text{brake thermal efficiency} = \frac{\text{Brake Power}}{m_f Q_h}$$

$$c. \quad n_{tc} = \text{combined or overall thermal eff.} = \frac{\text{Generator Output}}{m_f Q_h}$$

11. Volumetric Efficiency (air only)

$$= \frac{\text{Actual vol. of air entering}}{\text{Piston displacement}} = \frac{V_a}{V_D}$$

$$V_a = m_a RT/P$$

12. Specific Fuel Consumption

$$a. \quad m_i = \text{ind. spec. fuel consumption} = \frac{m_f \times 3600}{\text{Ind. Power}} \frac{\text{kg}}{\text{kw-hr}}$$

$$b. \quad m_b = \text{brake spec. fuel consumption} = \frac{m_f \times 3600}{\text{Brake Power}} \frac{\text{kg}}{\text{kw-hr}}$$

$$c. \quad m_c = \text{comb. or overall spec fuel consumption} = \frac{m_f \times 3600}{\text{Gen. Output}} \frac{\text{kg}}{\text{kw-hr}}$$

13. Heat rate

$$a. \quad \text{Indicated Heat Rate} = \frac{m_f (3600)(Q_h)}{\text{Ind. Power}} \frac{\text{kJ}}{\text{kw-hr}}$$

$$b. \quad \text{Engine Heat Rate} = \frac{m_f (3600)(Q_h)}{\text{Brake Power}} \frac{\text{kJ}}{\text{kw-hr}}$$

$$c. \quad \text{Engine-Generator Heat Rate} = \frac{m_f (3600)(Q_h)}{\text{Gen. Output}} \frac{\text{kJ}}{\text{kw-hr}}$$

14. Generator Speed

$$N = 120f/p$$

where: N = speed, rpm

f = frequency (usually 60hz)

p = no. of poles (even)

Typical Heat Balance of Diesel Engine:

Useful Output (Brake Power)..... 34%

Cooling Loss..... 30%

Exhaust Loss..... 26%

Friction, Radiation, Etc..... 10%

Heat Input (Fuel)..... 100%

Supercharging:

Supercharging – admittance into the cylinder of an air charge with density higher than that of the surrounding air

Reasons for supercharging:

1. to reduce the weight-to-power ratio
2. to compensate for power loss due to high altitude

Types of superchargers:

1. Engine-driven compressor
2. Exhaust-driven compressor (turbo-charger)
3. Separately-driven compressor

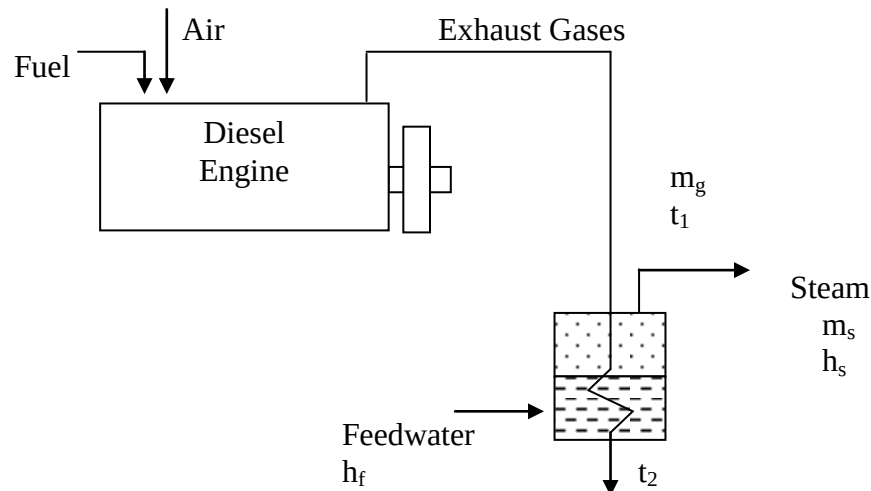
Five Auxiliary Systems of Diesel Engine:

1. Fuel System:
Fuel Storage tank, fuel filter, transfer pump, day tank, fuel pump
2. Cooling System:
Cooling water pump, heat exchanger, surge tank, cooling tower, raw water pump
3. Lubrication System:
Lub oil tank, lub-oil pump, oil filter, oil cooler, lubricators
4. Intake and Exhaust System:
Air filter, intake pipe, exhaust pipe, silencer
5. Starting System:
Air compressor, air storage tank

Advantages of Diesel engine over other I.C.E. engines:

1. Low fuel cost
2. High Efficiency
3. Needs no large water supply
4. No long warm-up period
5. Simple plant layout

Waste Heat Recovery Boiler Utilizing Diesel Engine Exhaust:



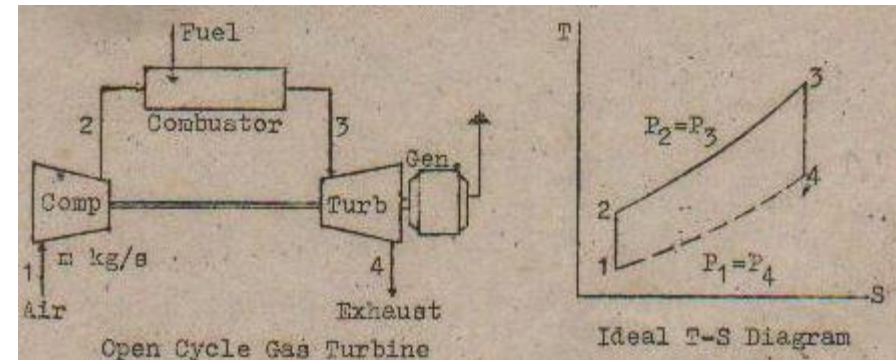
By heat balance in boiler:

$$m_g c_p (t_1 - t_2) = m_s (h_s - h_f)$$

where: c_p = specific heat of exhaust gas

GAS TURBINE POWER PLANT

Air Standard, Ideal (Brayton) Cycle:



Compression (Isentropic) Process:

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

$$W_C = \text{compressor work} = m c_p (T_2 - T_1)$$

Where: $c_p = 1.0 \text{ kJ/kg}^\circ\text{C}$ for air

Heat added in Combustor

$$Q_A = m_{cp} (T_3 - T_2)$$

Turbine Expansion (Isentropic) Process:

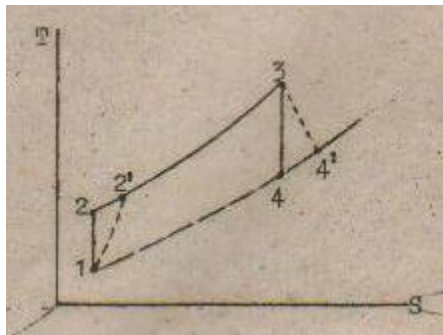
$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4} \right)^{k-1/k}$$

$$W_T = \text{turbine work} = m c_p (T_3 - T_4)$$

$$W_N = \text{net turbine work} = W_T - W_C$$

$$\text{Cycle efficiency} = \frac{W_N}{Q_A} = \frac{W_T - W_C}{Q_A}$$

Gas Turbine Cycle Considering Fluid Friction:



n_c = compressor efficiency

n_t = turbine efficiency

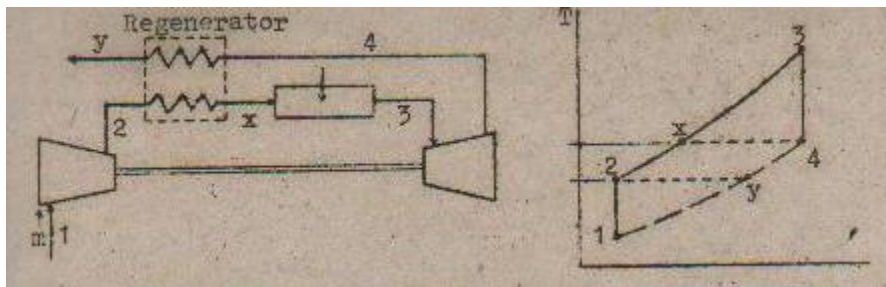
$$n_c = \text{ideal work/actual work} = W_C / W_{C'}$$

$$= \frac{m c_p (T_2 - T_1)}{m c_p (T_2' - T_1)} = \frac{T_2 - T_1}{T_2' - T_1}$$

$$n_t = \text{actual work/ideal work} = W_T' / W_T$$

$$= \frac{m c_p (T_3 - T_4')}{m c_p (T_3 - T_4)} = \frac{T_3 - T_4'}{T_3 - T_4}$$

Ideal Gas Turbine Cycle with Regenerator:



$$Q_A = \text{heat added in combustor} = m c_p (T_3 - T_x)$$

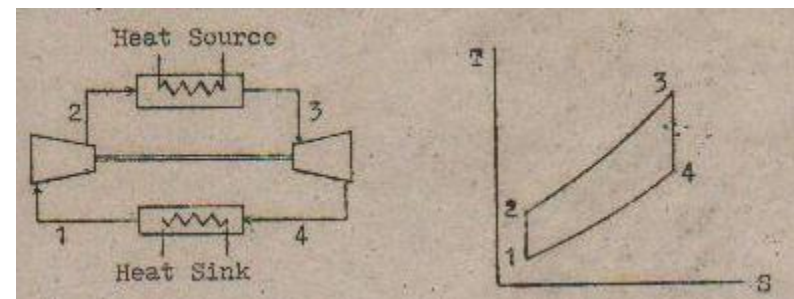
Heat balance in regenerator:

$$m c_p (T_x - T_2) = m c_p (T_4 - T_y)$$

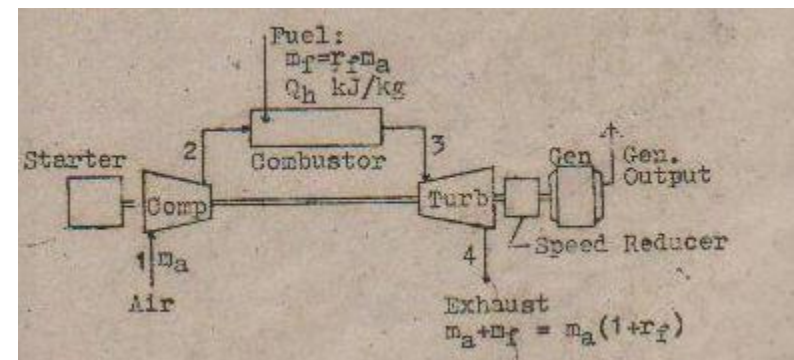
$$T_x - T_2 = T_4 - T_y$$

Effectiveness of Regenerator = $\frac{\text{actual amount of heat transferred}}{\text{Amount of heat that could be transferred reversibly}}$

Closed Cycle Gas Turbine:



Performance of Actual Cycle:



$$W_C' = \text{actual compressor work} = \frac{\text{ideal compressor work}}{\text{Compressor efficiency}}$$

$$= \frac{m_a c_{pa} (T_2 - T_1)}{n_c}$$

where: c_{pa} = specific heat of air = 1.0 kJ/kg-°C

W_T = actual turbine work = (ideal work) x turbine efficiency
 $= m + a + (1 + r_f)c_{pg}(T_3 - T_4)n_t$
 where: Q_h = heating value of fuel kJ/kg

Thermal Efficiency = $\frac{W_T - W_C - W_{aux}}{Q_f}$
 (Gas Turbine)

where: W_{aux} = work consumed by auxiliaries

Overall thermal Efficiency = $\frac{\text{Generator Output}}{Q_f}$

Gas Turbine Power Plants in the Philippines (completed Aug. 1989):

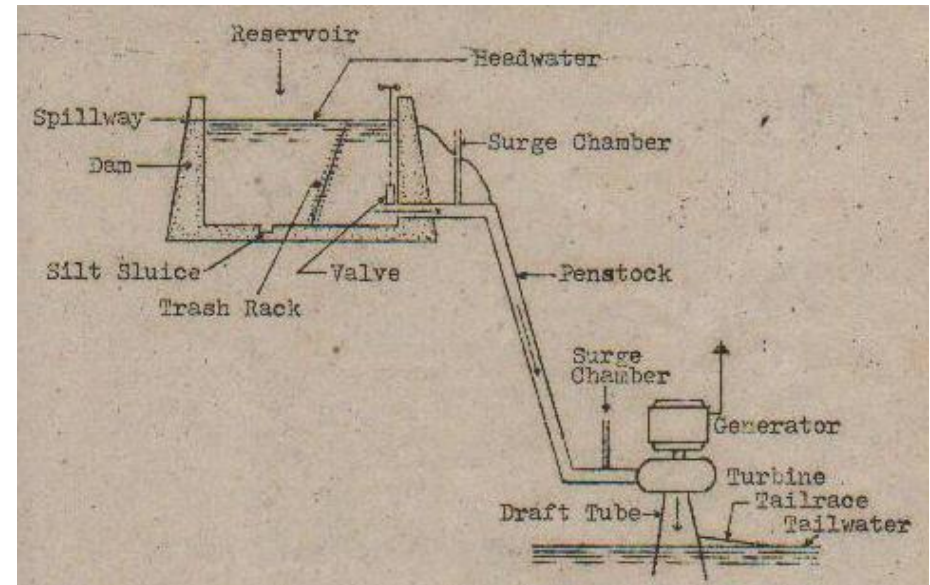
<u>Location</u>	<u>Capacity</u>
1. Limay, Bataan	4 x 30 = 120 MW
2. Malaya, Pililia, rizal	3 x 30 = 90 MW

Additional capacities expected to be operational by mid-1990:

Land-based gas turbines with total capacity of 285 MW
 Barge-mounted gas turbines with total capacity of 270 MW

HYDROELECTRIC POWER PLANT

Basic Parts of High-Head Hydro-Electric Plant:



Reservoir – stores the water coming from the upper river or water falls

Headwater – the water in the reservoir

Spillway – a weir in the reservoir which discharges excess water so that the head of the plant will be maintained

Dam – the concrete structure that encloses the reservoir

Silt Sluice – a chamber which collects the mud and through which the mud is discharged

Trash Rack – a screen which prevents the leaves, branches and other water contaminants to enter into the penstock

Valve – opens or closes the entrance of the water into the penstock

Super Chamber – a standpipe connected to the atmosphere and attached to the penstock so that the water will be at atmospheric pressure

Penstock – the channel that leads the water from the reservoir to the turbine

Turbine – converts the energy of the water into mechanical energy

Generator – converts the mechanical energy of the turbine into electrical energy output

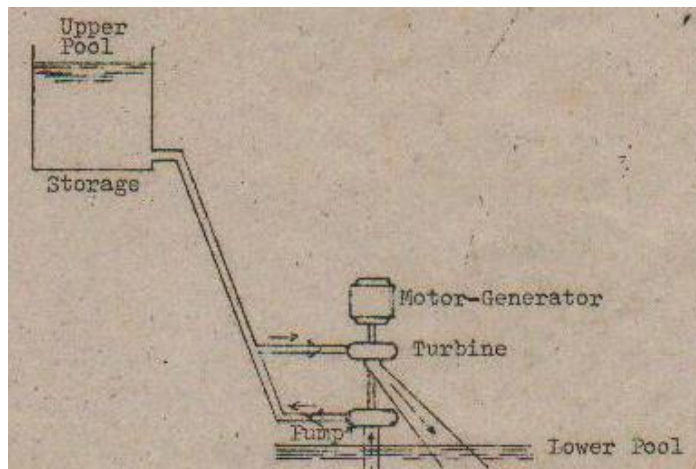
Draft tube – connects the turbine outlet to the tailwater so that the turbine can be set above the tailwater level

Tailrace – a channel which leads the water from the turbine to the tailwater

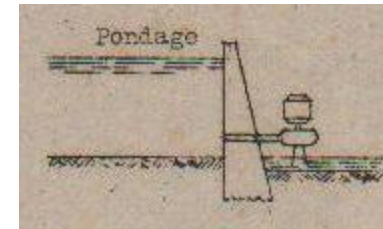
Tailwater – the water that is discharged from the turbine

Pumped Storage Hydro-Electric Plant or Hydraulic Accumulator:

Pumped Storage Plant is a hydro-electric plant which involves the use of off-peak energy to store water and to use the stored water to generate extra energy to cope with the peak load.



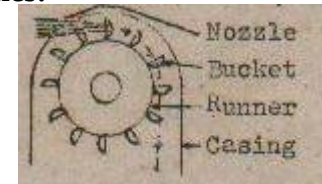
Run-of-the-River (Low head) Hydro-Electric Power Plant:



Pondage – the water behind the dam of a run-of-the-river hydro-electric plant

Classification of Hydraulic Turbines:

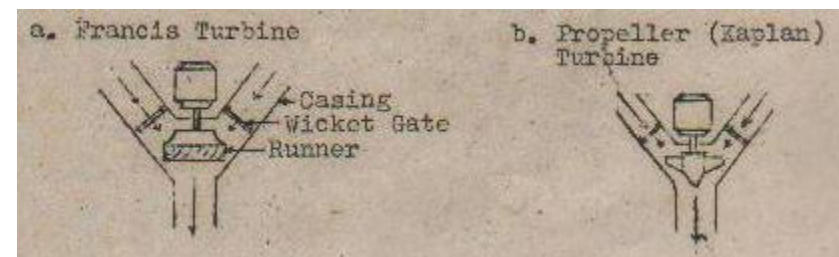
1. Impulse (Pelton) Turbine



2. Reaction turbine

a. Francis turbine

b. Propeller (Kaplan) Turbine



Selection of turbine type based on head:

Net Head
Up to 70 ft
70 ft to 110 ft
110 ft to 800 ft
800 ft to 1300 ft
1300 ft and above

Type of Turbine
Propeller type
Propeller type or Francis
Francis
Francis or impulse
Impulse

Performance:

1. h_g = gross head = difference between headwater and tailwater elevation
2. h_f = friction loss = $\frac{f L V^2}{2 g D}$ (Darcy eq.), meters
 $= \frac{2 F L V^2}{g D}$ (Morse eq.)

where: f = coefficient of friction

L = total length, meters

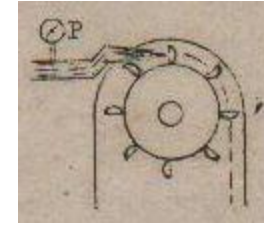
V = velocity, m/sec

$g = 9.81 \text{ m/sec}^2$

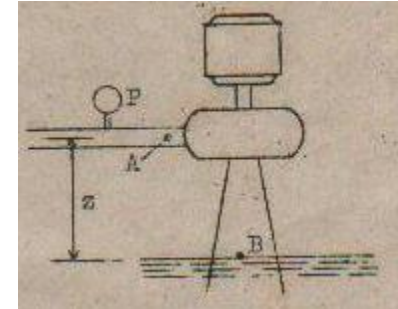
D = inside diameter, meters

(Friction head loss is usually expressed as a percentage of the gross head)

3. h = net head or effective head = $h_g - h_f$
4. penstock efficiency = h/h_g
5. General flow equation: $Q = A V$
 where: Q = flow rate, m^3/sec
 A = cross-sectional area, m^2
 V = velocity, m/sec
6. Water Power = $Q w h$ KW
 where: w = density = 9.81 kN/m^3
 $= 1000 \text{ kg/m}^3$
7. Turbine Output = $Q w h (n_t)$
 where: n_t = turbine efficiency
8. Generator Output = $Q w h n_t n_e$
 where: n_e = electrical or generator efficiency
9. Generator Speed = $N = 120f/p$
 where: N = speed, rpm
 f = frequency (usually 60 hz)
 p = number of poles (even number)
10. h_w = utilized head = $h(n_h)$
 Where: n_h = hydraulic efficiency
11. Head of Pelton (Impluse) Turbine:



12. Head of Reaction (Francis and Kaplan) Turbine:



13. Peripheral coefficient = $\phi = \frac{\text{peripheral velocity}}{\text{Velocity of jet}} = \frac{\pi D N}{\sqrt{2gh}}$

where: D = diameter of runner, meters

N = speed of runner, rev/sec

$g = 9.81 \text{ m/sec}^2$

h = net head, meters

14. Specific speed of hydraulic turbine:

$$N_s = \frac{N \sqrt{HP}}{h^{5/4}} \quad \text{rpm} \quad \text{where: } N = \text{speed, rpm} \\ h = \text{head, feet}$$

In metric units:

$$N_s = \frac{0.2623 N \sqrt{KW}}{h^{5/4}} \quad \text{rpm} \quad \text{where: } N = \text{speed, rpm} \\ h = \text{head, feet}$$

15. Specific Speed Vs. Head Curve:

Page 165, ME Tables and Charts (MRII)

Fig. 10, page 5-30 Kent's (Power) Handbook

16. $e_t = e_h e_m e_v$

where: e_t = total efficiency of turbine

e_h = hydraulic efficiency

e_m = mechanical efficiency

e_v = volumetric efficiency

NON-CONVENTIONAL POWER SOURCES

Solar Power

Types of Solar Collectors:

1. Flat Rate
2. Concentrating
3. Focusing

Photovoltaic Cell – a device which converts solar energy to electric energy

Solar Energy received at earth's surface = $Q_s (1-i)A$ kcal/hr

where: Q_s = solar energy without atmospheric interference, ($= 1200 \text{ kcal.hr-m}^2$)

i = atmospheric interference, usually expressed in percent

A = surface area of solar collector, m^2

Wind Power

Typical uses of wind power:

1. to drive water pumps
2. to drive rice and corn mills
3. to charge batteries
4. to generate power

Types of windmills:

1. Turbine type
2. Rotor type
3. Propeller Type
4. Dutch sail type
5. Panemone type

Tidal Power

Tidal power is basically hydro-electric power utilizing the difference in elevation between the high and low tide to produce energy. A basin is required to catch the sea water during high tide while the water drives a turbine. During low tide, the water in the basin discharges back to the sea while driving the turbine.

Low Thermal Head Plant

Low thermal head plant, otherwise known as Ocean Thermal energy Conversion, makes use of the temperature difference between the ocean surface water and the water at the sea bottom. Surface water which is at relatively high temperature is pumped to an evaporator where the water evaporates into saturated steam. This steam drives a single stage turbine thereby producing electricity, and exhausts to a jet condenser maintained at the saturation pressure of the subsurface water temperature pumped from the sea bottom.

Magneto Hydro Dynamic Plant

In a magnetohydrodynamic generator, combustion gases produced in a combustion chamber at high pressure and temperature and seeded with metal vapor to increase its electrical conductivity, is passed through an expansion tube lined with a strong magnetic field. This induces an electric voltage in the gas conductor and effects the flow of electrons through the electrodes along the magnetic field, thereby generating electricity.

Thermionic Converter

Thermionic converter is a device which converts heat energy directly to electrical energy.

Fuel Cell

Fuel Cell is a device which converts chemical energy to electrical energy.

INSTRUMENTATION

<u>Physical Quantity Measured</u>	<u>Instruments Used</u>
Pressure	Bourdon pressure gauge Compound gauge Vacuum gauge Manometer Draft Gauge Barometer
Temperature	Mercurial thermometer Bi-metallic thermometer Thermocouple Radiation pyrometer Optical pyrometer
Weight	Platform balance, spring balance, analytical balance, beam balance, pendulum scale
Density; specific gravity	Hydrometer, pycnometer, Westphal Balance
Heating Value of fuel	Bomb calorimeter (for solid and liquid fuels) Gas calorimeter (for gaseous fuels)
Viscosity	Viscosimeter
Area of irregular plane figures	Planimeter

Rotational speed	Tachometer centrifugal, vibration electric Stroboscope
Vibration intensity and frequency	Vibrometer
Linear Speed	Speedometer
Distance traveled by a vehicle	Odometer
Velocity of flow	Velometer
Flow (rate)	Rotameter, anemometer, flowmeter
Indicated power	Engine indicator
Brake power	Dynamometer a. absorption dynamometer: prony brake, water brake b. transmission dynamometer: electric dynamometer, electrical cradle dynamometer
Analysis of flue gas	Orsat apparatus (Gas Analyzer)
Quality of Steam	Steam calorimeter Throttling, separating, condensing, barrel, electric
Dry bulb and wet bulb temperature of air	Psychrometer sling, aspiration
Relative humidity of air	Humeter

Hardness of metal	Brinell hardness tester Rockwell hardness tester Vickers hardness tester
Surface roughness	Profilometer
Angle	Protractor
Linear distance (thickness, depth, etc)	Rule, depth gauge, Vernier caliper, micrometer caliper
Inaccuracy in alignments, eccentricities	Dial indicator
Space clearance, gap	Feeler gauge

MACHINE FOUNDATION

Functions of Machine Foundation:

1. To support the weight of the machine, and to distribute the weight of the machine and its own over a safe sub-soil area.
2. To absorb the vibrations produced by the machine.
3. To maintain the alignment of the machine

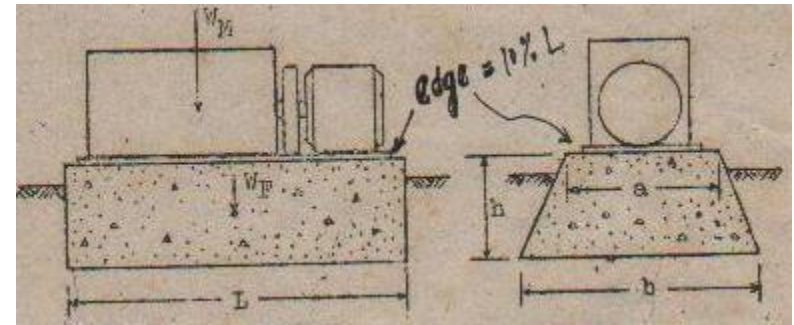
Monolithic Foundation – concrete foundation which is formed by pouring the entire concrete mixture continuously at one time and allowing the structure to harden as whole unit

Grouting – process of filling a small clearance between machine and foundation, after the machine is aligned and leveled, by using a special hardening mixture.

Design Procedure in Machine Foundation:

Manufacturer's manual supplies foundation drawings, but in the absence of such drawings, the following guide can be used.

Refer: PSME Code, pp 9-11; Morse, pp 101-113



1. Knowing the bedplate dimensions of the machine, determine the upper dimensions of the foundation “a” and “L”. Allow a clearance from the edge of about one foot or about 10% of the length of the bedplate.
2. Knowing the weight of the machine, W_M , determine the required weight of the foundation, W_F , by any of the following methods:
 - a. $W_F = 3 \text{ to } 5 \text{ times } W_M$
(Sec. 2.4.1.2, PSME Code)
 - b. $W_F = e \times W_e \times \sqrt{N}$
where: W_F = weight of the foundation, kg
 W_e = weight of engine, kg
 N = engine speed, rpm
 e = an empirical coefficient, Table 2.4.2.3(4), PSME Code
 - c. Volume of foundation can be computed based on HP of the engine, Table 2.4.2.3(5), PSME Code
 - d. Weight of foundation can be computed based on the HP of the engine, Morse, Table 4-5, p. 108

- Knowing the bearing capacity of the soil, solve for the base width “b”. For machine foundation use only ½ of the given safe soil bearing capacity. The safe bearing capacity is computed using a factor of safety of 5.

$$\frac{S_b}{2} = \frac{W_M + W_F}{bL}$$

where: S_b = safe soil bearing capacity

Note: If “b” will come out less than “a”, then make $b=a$, that is, the foundation has a rectangular cross-section.

- Using a density of 2406 kg/m^3 for concrete, determine the volume of the foundation.

$$V_F = W_F / 2406 \text{ m}^3$$

- Compute the depth of the foundation “h”:

$$V_F = ((a+b)/2)hL$$

- Finalize the design; make adjustments in the dimensions if necessary provided the required volume is maintained and without reducing the required base area.

Other data and information:

- Use Class A (1:2:4) mixture, that is, 1 part cement, 2 parts sand and 4 parts stone.
- Determine the quantity of cement, sand and stone using the following data:

To produce 1 cu yd of concrete using 1:2:4 mixture, the following are needed: 6 sacks cement, 0.44 cu yd sand and 0.88 cu yd stone.

- Weight of steel bar reinforcements needed should be about 1/2% to 1% of the weight of the foundation.
- Anchor bolts should be imbedded in the concrete at least 30

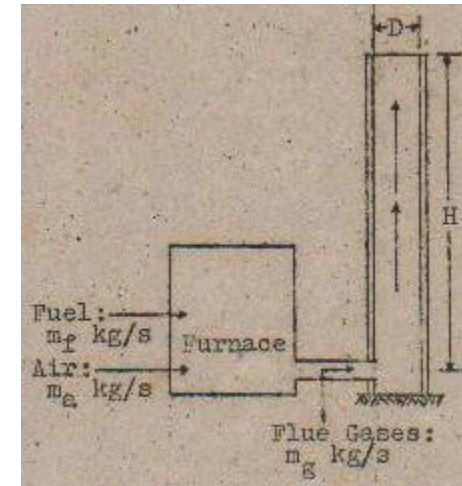
CHIMNEY

Functions of Chimney:

- To dispose the exhaust gases at suitable height so that no pollution will occur in the vicinity.
- To produce the necessary draft required for the flow of the gases.

Stack – name given to steel chimney

Calculation of Chimney Diameter and Height Using Gas Laws:



D = internal diameter of chimney, meters (for a tapering chimney, D is the internal diameter at the top)

H = height of chimney, meters

T_a = temperature of air, K

T_g = temperature of flue gas, K

R_a = gas constant of air

R_g = gas constant of flue gas

P = barometric pressure, KPa

d_a = density of air = $P / R_a T_a$

$$h_w = \text{draft} = H(d_a - d_g) \text{ KPa}$$

$$Q_g = \text{gas flow } m_g R_g T_g / P \text{ m}^3/\text{s}$$

$$V = \text{velocity (theo.) of flue gas in chimney} = \sqrt{2g(h_w/d_g)}$$

Actual velocity of flue gas in chimney is only 30% to 50% of theoretical velocity, thus to get the actual velocity, multiply the theoretical velocity by a velocity coefficient of 0.30 to 0.50.

$$Q_g = \text{Area} \times \text{Vel} = \pi/4 D^2 v$$

HEAT TRANSFER AND HEAT EXCHANGERS

Heat Exchanger – any device which affects a transfer of heat from one substance to another. Examples: condenser, superheater, evaporator, economizer, etc.

Modes of Heat Transfer:

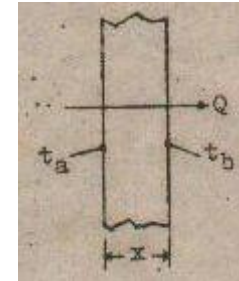
Conduction – mode of heat transfer by molecular communication through solid materials or stagnant fluids

Convection – mode of heat transfer in which the heat is carried from one point to another by actual movement of the substance

- Free Convection: the substance moves because of the decrease in its density which is caused by increase in temperature
- Forced convection: the substance moves because of the application of mechanical power such as that of a fan

Radiation – mode of heat transfer in which invisible electromagnetic waves are passed from one body to another through a space.

Conduction Through a Plane Wall



$$Q = kA (t_a - t_b) / x$$

where: Q = heat transmitted, W

A = heat transfer area, m²

t_a = surface temperature on hot side, °C (or K)

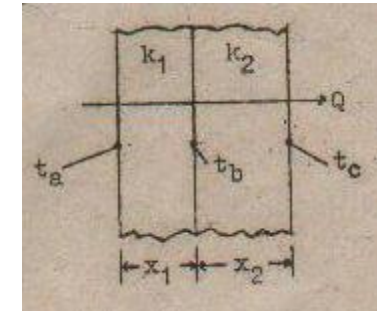
t_b = surface temperature on cold side, °C

x = thickness of wall, m

k = thermal conductivity, W / m·°C

Conduction Through Composite Plane Wall

$$\begin{aligned} Q &= k_1 A (t_a - t_b) / x_1 \\ &= k_2 A (t_b - t_c) / x_2 \\ &= \frac{A(t_a - t_c)}{\frac{x_1}{k_1} + \frac{x_2}{k_2}} \end{aligned}$$



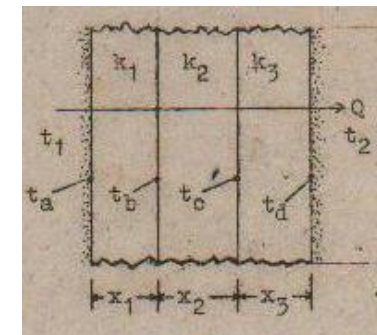
where: k₁ = thermal conductivity of first layer

k₂ = thermal conductivity of second layer

A = heat transfer area which is common to both layers

Conduction from Fluid to Fluid

$$\begin{aligned} Q &= h_1 A (t_1 - t_a) \\ &= h_2 A (t_d - t_2) \end{aligned}$$



where: h_1 = surface film conductance on the hot side $W/m^2\text{-}^\circ\text{C}$
 h_2 = surface film conductance on the cold side

$$Q = \frac{A (t_1 - t_2)}{\frac{1}{h_1} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{h_2}}$$

$$\text{Let } \frac{1}{\frac{1}{h_1} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{h_2}} = U$$

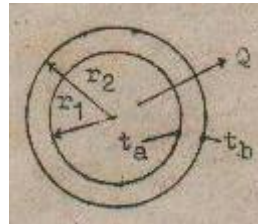
$$\text{Then: } Q = UA \Delta t$$

where: U = overall conductance or overall coefficient of heat transfer, $W/m^2\text{-}^\circ\text{C}$

Conduction Through Pipe

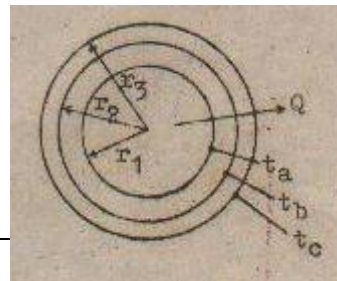
$$Q = \frac{2\pi kL (t_a - t_b)}{\ln(r_2/r_1)} = \frac{2\pi kL (t_a - t_b)}{\ln(D_2/D_1)}$$

where: L = length of the pipe



Conduction Through Composite Pipe

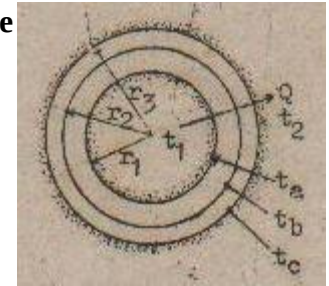
$$Q = \frac{2\pi k_1 L (t_a - t_b)}{\ln(r_2/r_1)} = \frac{2\pi k_2 L (t_b - t_c)}{\ln(r_3/r_2)} = \frac{2\pi L (t_a - t_c)}{\frac{\ln(r_2/r_1)}{k_1} + \frac{\ln(r_3/r_2)}{k_2}}$$



where: k_1 = thermal conductivity of inner pipe
 k_2 = thermal conductivity of outer pipe
 L = common length of the pipes

Conduction from Fluid to Fluid Through Pipe

$$Q = h_i A_i (t_1 - t_a) = h_o A_o (t_c - t_2)$$



where: h_i = surface conductance on inside surface
 h_o = surface conductance on outside surface
 $A_i = 2\pi r_1 L$
 $A_o = 2\pi r_3 L$

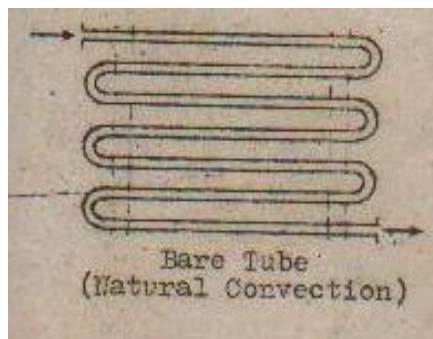
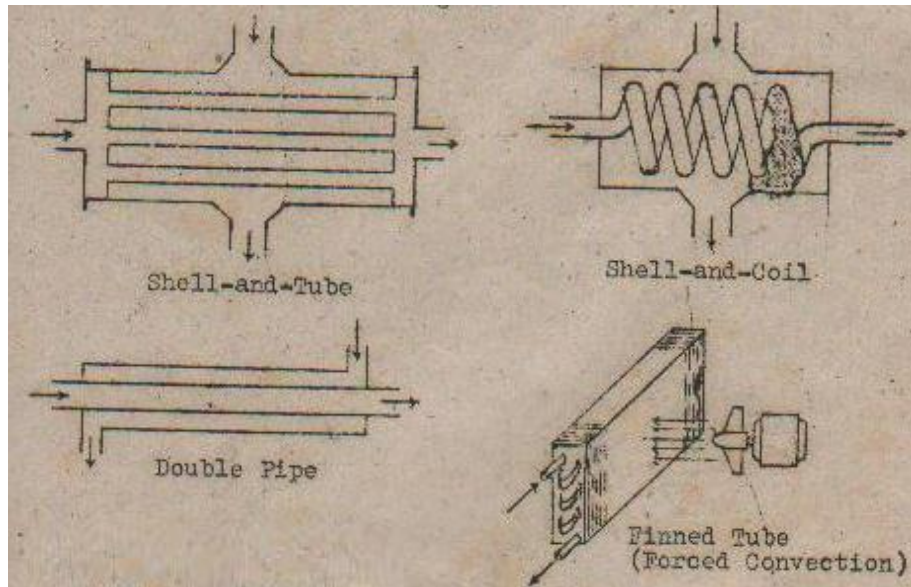
$$Q = \frac{(t_1 - t_2)}{\frac{1}{A_i h_i} + \frac{\ln(r_2/r_1)}{2\pi k_1 L} + \frac{\ln(r_3/r_2)}{2\pi k_2 L} + \frac{1}{A_o h_o}}$$

Simplified Equation:

$$Q = U_i A_i \Delta t = U_o A_o \Delta t$$

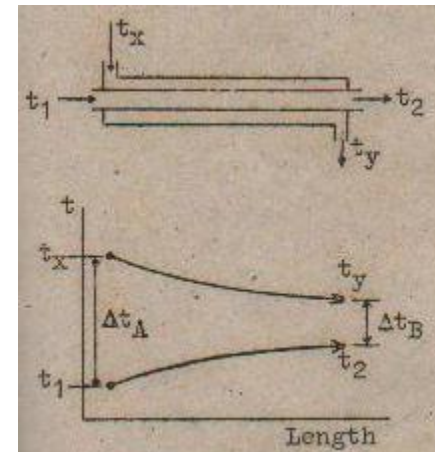
where: U_i = overall conductance based on inside area
 U_o = overall conductance based on outside area

Typical Designs of Heat Exchangers



Mean Temperature Difference

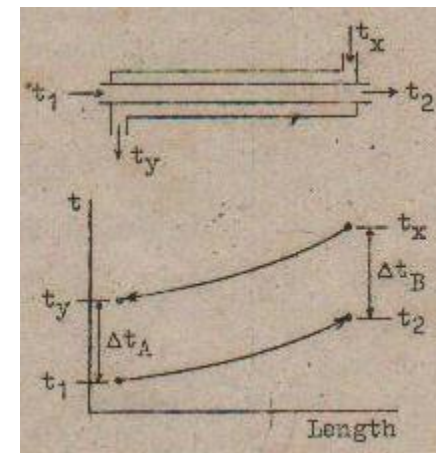
Parallel Flow Heat Transfer



$$\Delta t_A = t_x - t_1$$

$$\Delta t_B = t_y - t_2$$

Counterflow Heat Transfer



$$\Delta t_A = t_y - t_1$$

$$\Delta t_B = t_x - t_2$$

1. Arithmetic Mean Temperature Difference

$$\text{Arith } \Delta t = \frac{\Delta t_A + \Delta t_B}{2}$$

2. Logarithmic (True) Mean Temperature Difference

$$\text{Log } \Delta t = \frac{\Delta t_A - \Delta t_B}{\ln \Delta t_A / \Delta t_B}$$

Radiation

a = absorptance = the fraction of radiant heat that is absorbed

r = reflectance = the fraction of radiant heat that is reflected

t = transmittance = the fraction of radiant heat that is transmitted

$$a + r + t = 1$$

“black body” – a body which absorbs (and omits) all the impinging radiant heat

“gray body” – actual body that radiates less heat than a black body

emittance (emissivity) = e = ratio of radiation from an actual body to the radiation from a black body

Heat transmitted by radiation:

$$Q_r = 20,408.4 \times 10^{-8} F_e (T_1^4 - T_2^4) \text{ J/m}^2\text{-hr}$$

where: F_e = emissivity factor

T_1 = absolute temperature of surface radiating the heat, K

T_2 = absolute temperature of surface receiving the heat, K

Convection

a. Convective heat transfer of a fluid with known specific heat:

$$Q_C = m c_p (t_2 - t_1) \text{ J/sec}$$

where: m = mass flow, kg/sec

c_p = specific heat, J/kg-°C

$t_2 - t_1$ = temperature change, °C

b. Surface convection:

$$Q_C = h_c A (t_1 - t_f) \text{ J/sec}$$

where: h_c = surface coefficient associated with convection, J/sec-m²-°C

A = heat transfer area, m²

t_1 = temperature of hot surface, °C

t_f = temperature of fluid, °C

AIR (GAS) COMPRESSORS

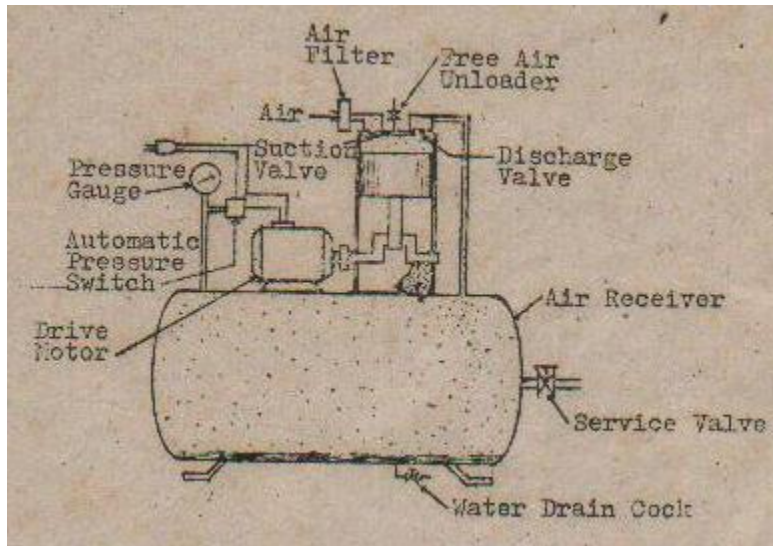
Compressor - a machine which is used to increase the pressure of a gas by decreasing its volume

Uses of compressed air:

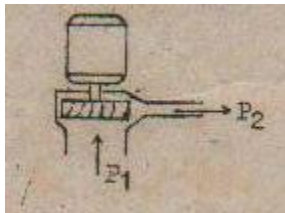
1. to drive pneumatic tools such as pneumatic hammer, air hoists, etc
2. sand blasting
3. industrial cleaning
4. spray painting
5. starting diesel engines
6. to supply air in mine tunnels
7. manufacture of plastics and other industrial products

Classification of Air Compressors:

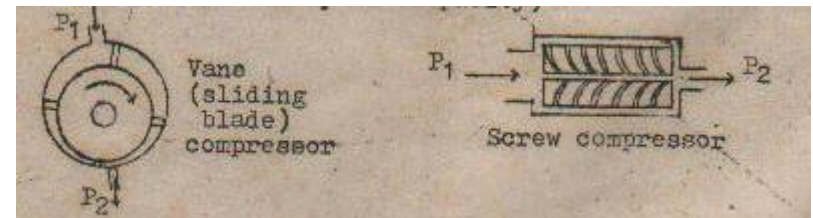
1. Reciprocating Compressor
(high pressure, low capacity)



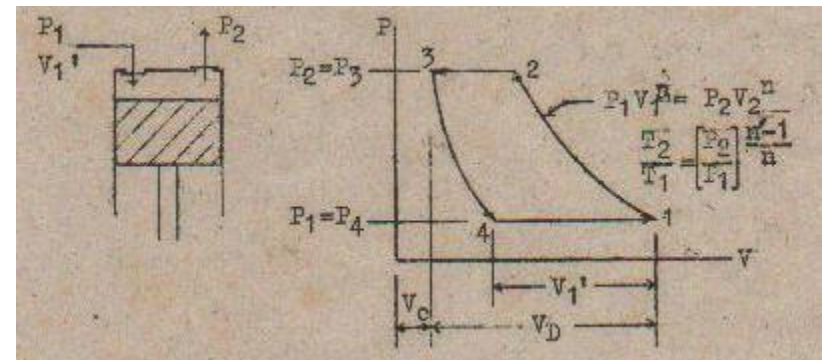
2. Centrifugal Compressor
(low pressure, high capacity)



3. Rotary Compressor
(medium pressure, low capacity)



Performance of Single-Stage, Single-Acting Reciprocating Compressor



1. Compression Process: (1-2)

$$P_1 V_1^n = P_2 V_2^n$$

$$T_2/T_1 = (P_2/P_1)^{n-1/n}$$

where: n = polytropic exponent
 $= k$ for isentropic process ($k=1.4$ for air)
 $= 1$ for isothermal process

2. Piston Displacement, V_D

$$V_D = \pi/4 D^2 L N \text{ m}^3/\text{sec}$$

where: D = bore, m

L = stroke, m

N = speed, rev/sec

3. Capacity of Compressor, V_1'

$$V_1' = \text{volume flow at suction} = \frac{mRT_1}{P_1}$$

4. Volumetric Efficiency, n_v

$$n_v = V_1' / V_D$$

Conventional volumetric efficiency:

$$n_v = 1 + c - c (P_2/P_1)^{n-1/n}$$

where: c = clearance = V_o/V_D

5. Compressor Work (Power)

$$= \frac{nP_1V_1'}{n-1} [(P_2/P_1)^{n-1/n} - 1]$$

where: P_1 = suction pressure, KPa

P_2 = discharge pressure, KPa

6. Brake Power = power required to drive the compressor

$$= \frac{\text{Compressor Power}}{\text{Compressor Efficiency}}$$

7. Piston Speed = $2LN$, m/sec

8. Adiabatic Compressor Efficiency

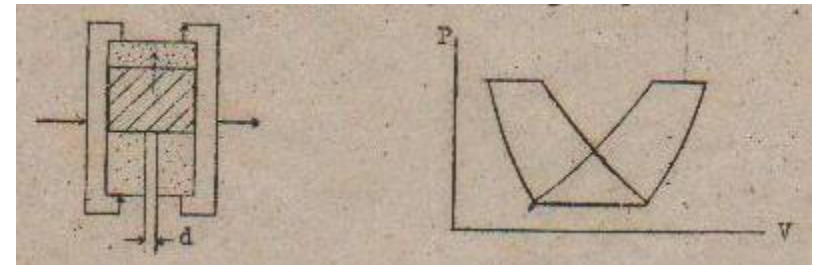
$$= \frac{\text{Isentropic work}}{\text{Actual Fluid Work}}$$

9. Ideal Indicated Power

$$= P_{mi}V_D$$

where: P_{mi} = indicated mean effective pressure

Double-Acting, Single-Stage Reciprocating Compressor



Piston Displacement

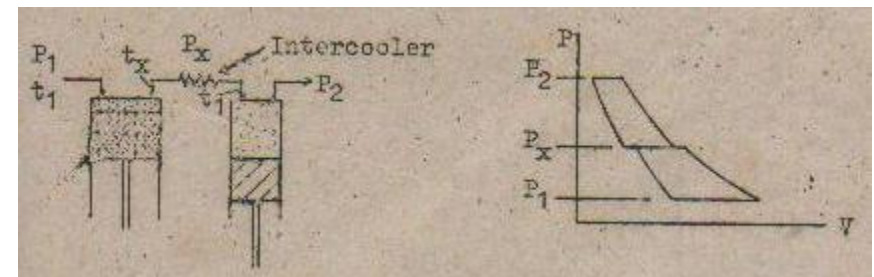
a. Piston rod neglected

$$V_D = 2 (\pi/4 D^2 LN)$$

b. Piston rod considered:

$$V_D = \pi/4 D^2 LN + \pi/4 (D^2 - d^2) LN$$

Two-stage Reciprocating Compressor



Ideal (Optimum) Conditions:

1. No pressure drop in intercooler

2. Perfect intercooling

3. Work in 1st stage = Work in 2nd stage

$$\frac{nmRT_1}{n-1} [(P_x/P_1)^{n-1/n} - 1]$$

$$\frac{nmRT_1}{n-1} [(P_2/P_1)^{n-1/n} - 1]$$

$$\text{Compressor Work} = \frac{2nP_1V_1'}{n-1} [(P_x/P_1)^{n-1/n} - 1]$$

To solve for heat rejected in intercooler:

Solve for the mass flow:

$$m = P_1 V_1' / RT_1$$

Solve for T_x :

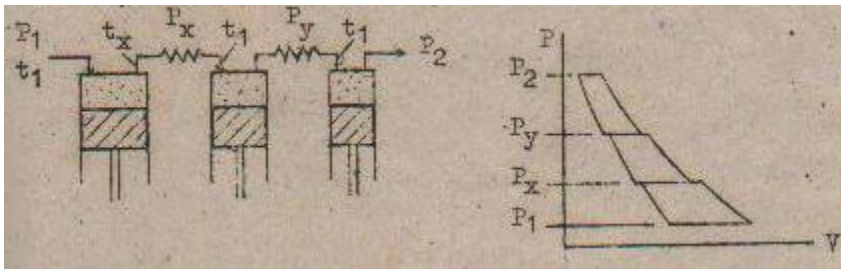
$$\frac{T_x}{T_1} = (P_x/P_1)^{n-1/n}$$

Q = heat rejected in intercooler

$$= m c_p (T_x - T_1)$$

where: c_p for air = 1.0 kJ/kg-K

Three-Stage reciprocating Compressor



For ideal conditions, pressure ratios are equal

$$\frac{P_x}{P_1} = \frac{P_y}{P_x} = \frac{P_2}{P_y} \text{ from which: } P_x = (P_1^2 P_2)^{1/3}$$

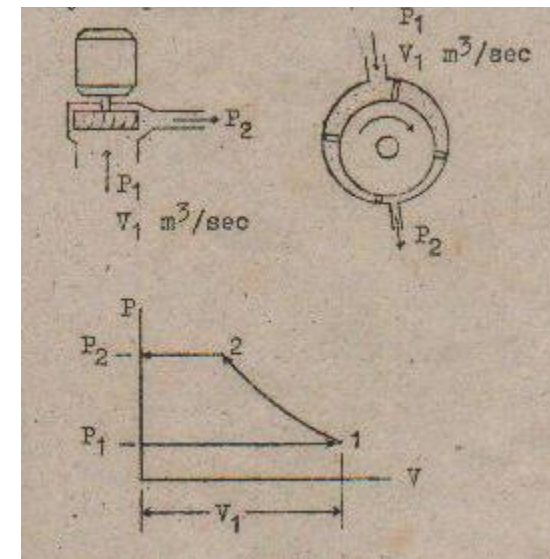
$$\text{Compressor Work} = \frac{3nP_1V_1'}{n-1} [(P_x/P_1)^{n-1/n} - 1]$$

$$\text{Heat rejected in intercoolers} = 2 m c_p (T_x - T_1)$$

Summary of Multi-Stage Reciprocating Compressor:

No. of Stages	P_x = interstage pressure after first stage	Compressor Work (Power)
2	$P_x = (P_1 P_2)^{1/2}$	$W = \frac{2nP_1V_1'}{n-1} [(P_x/P_1)^{n-1/n} - 1]$
3	$P_x = (P_1^2 P_2)^{1/3}$	$W = \frac{3nP_1V_1'}{n-1} [(P_x/P_1)^{n-1/n} - 1]$
4	$P_x = (P_1^3 P_2)^{1/4}$	$W = \frac{4nP_1V_1'}{n-1} [(P_x/P_1)^{n-1/n} - 1]$
General Formula	$P_x = (P_1^{s-1} P_2)^{1/s}$	$W = \frac{snP_1V_1'}{n-1} [(P_x/P_1)^{n-1/n} - 1]$
s		

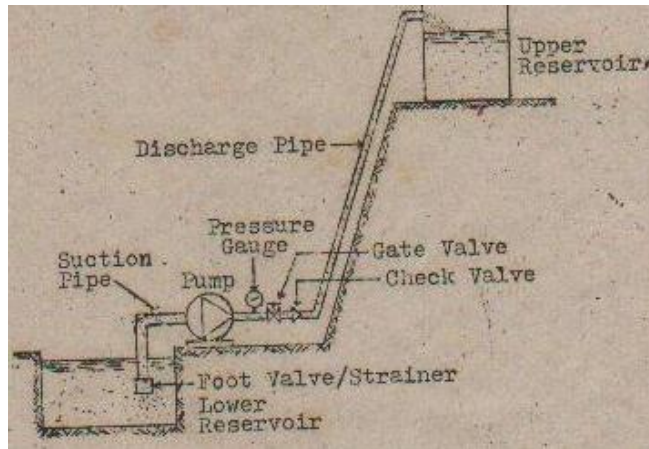
Performance of Centrifugal and Rotary Compressors



PUMPS

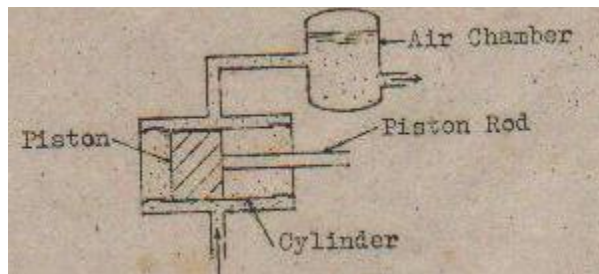
Pump – a machine which is used to add energy to a liquid in order to transfer the liquid from one point to another point of higher energy level

Typical Pumping Installation:

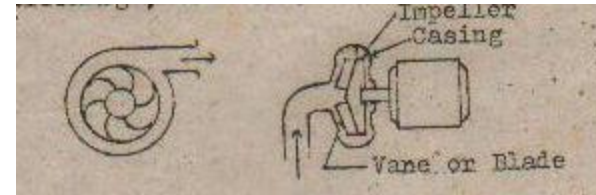


Basic Classification of Pumps

1. Reciprocating Pump
(low discharge, high head, low speed, self-priming)

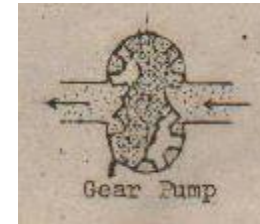


2. Centrifugal Pump
(high discharge, low head, high speed, not self-priming)



3. Rotary Pump
(low discharge, low head, used for pumping viscous liquids like oil)

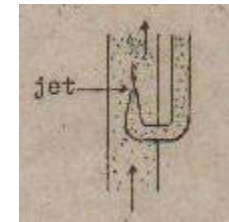
- a. Gear Pump
- b. Screw Pump
- c. Vane Pump



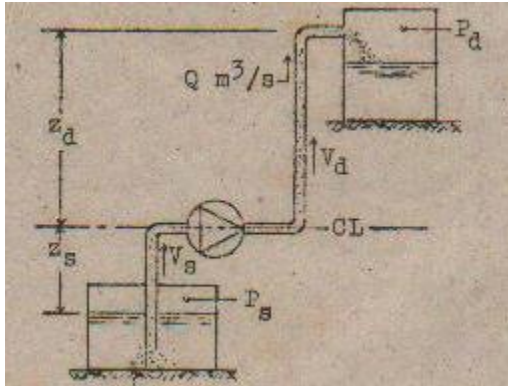
4. Turbine Pump
(for pumping water with high suction lift; for pumping condensate)



5. Jet Pump (Injector)
(for pumping boiler feedwater; used as accessory of centrifugal pump)



Head and Power Calculations



Discharge = volume flow rate of liquid handled by the pump (m^3/sec or gal/min)

Head = total energy developed by the pump, expressed in height of the liquid (meters)

Basic Principles:

General Flow Equation: $Q = Av$ or $v = Q/A$

Pressure Head: $P = zw$ or $z = v^2/2g$

H = total head or total dynamic head (TDH)

= static head + pressure head + friction head + velocity head

$$= (z_d - z_s) + \frac{P_d - P_s}{w} + (h_{fs} + h_{fd}) + \frac{V_d^2 - V_s^2}{2g}$$

Note: z_s is negative if source is below pump center line

P_s is negative if it is a vacuum

Water Power = $Q w H$, KW

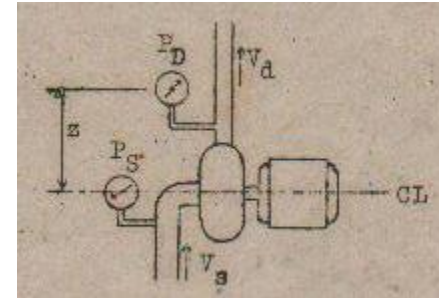
where: Q = discharge, m^3/sec

w = density, KN/m^3 ($9.81 \text{ KN}/\text{m}^3$ for water)

H = total head, m

$$\text{Brake (Input) Power} = \frac{\text{Water Power}}{\text{Pump Efficiency}}$$

Head, as determined from Readings of Pressure Gauges:



$$H = \frac{P_d - P_s}{w} + z + \frac{V_d^2 - V_s^2}{2g}$$

Note P_s is negative if a vacuum

Calculating the Friction Head:

$$h_f = fLv^2 / 2gD \text{ (Darcy Equation)}$$

$$h_f = 2fLv^2 / gD \text{ (Morse Equation)}$$

where: h_f = friction head loss, m

f = coefficient of friction (should be taken from Morse table if Morse equation is used)

L = total length, m (including equivalent lengths of the fittings)

v = velocity, m/sec

$g = 9.81 \text{ m}/\text{sec}^2$

D = inside diameter, m

Characteristics of Reciprocating Pumps:

1. Piston Displacement

a. If piston rod neglected:

$$V_D = 2 (\pi/4 D^2 LN)$$

b. If piston rod considered:

$$V_D = \pi/4 D^2 L N + \pi/4 (D^2 - d^2) L N$$

Where: d = diameter of piston rod

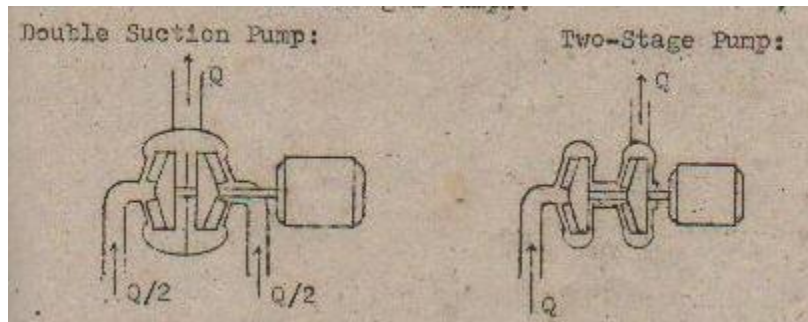
2. Q = actual discharge

3. Slip = $V_D - Q$

$$\% \text{ Slip} = \frac{V_D - Q}{V_D} \times 100$$

4. Volumetric Efficiency = Q / V_D

Characteristics of Centrifugal Pumps:



1. Specific Speed

- the speed at which a geometrically similar impeller of a pump would run to discharge 1 gpm at 1 foot head

$$n_s = \frac{N \sqrt{Q}}{H^{3/4}}$$

where: n_s = specific speed, rpm

N = speed, rpm

Q = discharge, gpm

H = head, ft

2. Similar Pumps:

$$a. \frac{N_1 \sqrt{Q_1}}{H_1^{3/4}} = \frac{N_2 \sqrt{Q_2}}{H_2^{3/4}}$$

$$b. \frac{Q_1}{N_1 D_1^3} = \frac{Q_2}{N_2 D_2^3}$$

where: D = impeller diameter

3. Same Pump:

a. Constant impeller diameter, variable speed:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \quad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2} \right)^2 \quad \frac{P_1}{P_2} = \left(\frac{N_1}{N_2} \right)^3$$

(P = power)

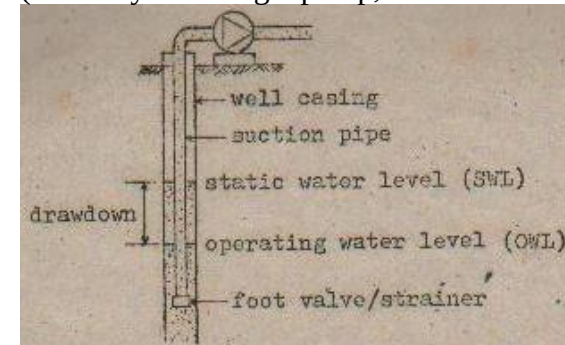
b. Constant speed, variable impeller diameter:

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \quad \frac{H_1}{H_2} = \left(\frac{D_1}{D_2} \right)^2 \quad \frac{P_1}{P_2} = \left(\frac{D_1}{D_2} \right)^3$$

Special Classification of Pumps Based on Suction Lift:

1. Shallow Well Pump

(Ordinary centrifugal pump, for suction lift up to 25 feet)

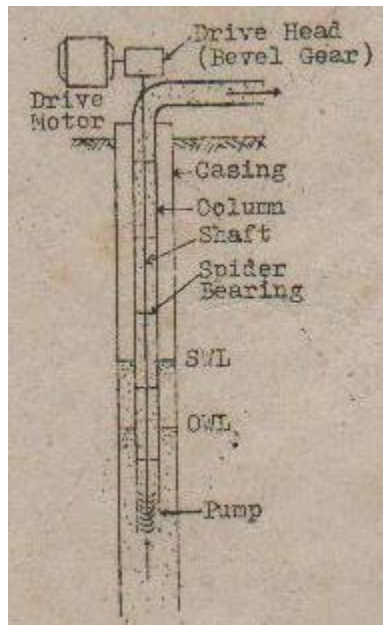


2. Deepwell Pump

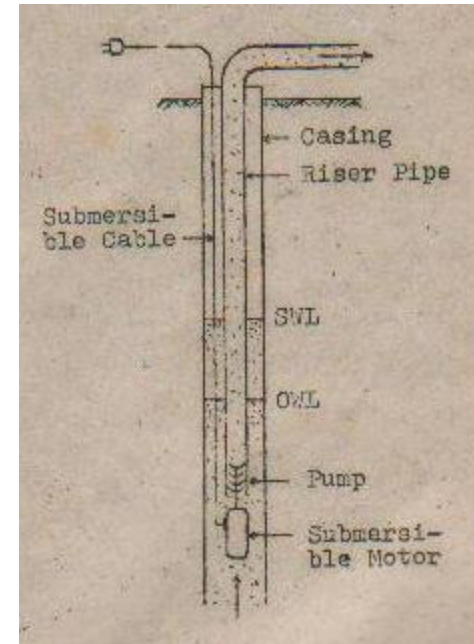
(centrifugal pump with injector for suction lift up to 120 feet)



3. Turbine Pump
(multi-stage pump, for suction lift up to 300 ft)



4. Submersible Pump
(multi-stage pump driven by submersible motor)



Cavitation; NPSH

Cavitation – the formation of cavities of water vapor in the suction side of a pump due to low suction pressure

Causes of Cavitation:

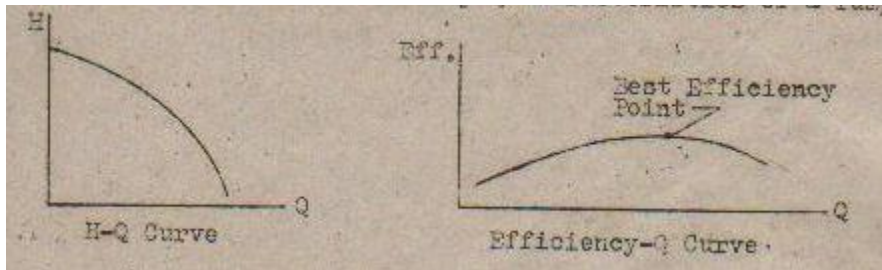
1. low suction pressure
2. low atmospheric pressure
3. high liquid temperature
4. high velocity
5. rough surfaces and edges
6. sharp bends

Bad Effects of Cavitation:

1. drop in capacity and efficiency
2. noise and vibration
3. corrosion and pitting

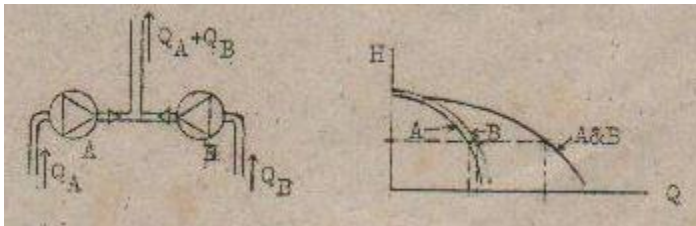
NPSH (Net Positive Suction Head) = difference between actual suction pressure and saturation vapor pressure of the liquid

H-Q Characteristics and Efficiency-Q Characteristics of a Pump:



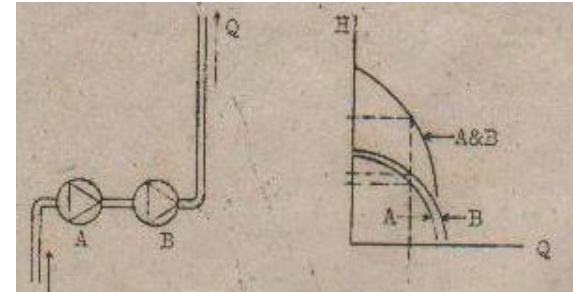
Pumps in Parallel

(to increase discharge at same head)



Pumps in Series

(to increase head with the same discharge)



FANS AND BLOWERS

Fan – a machine is used to apply power to a gas in order to cause movement of the gas

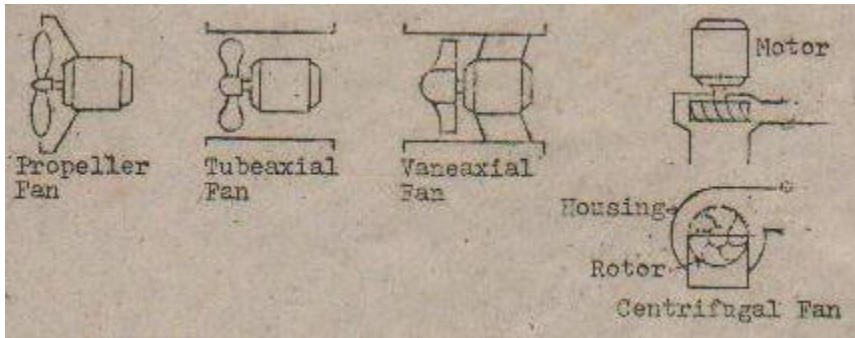
Blower – a fan which is used to force air under pressure, that is, the resistance to gas is imposed primarily upon the discharge

Exhauster – a fan which is used to withdraw air under suction that is, the resistance to gas flow is imposed primarily upon the inlet

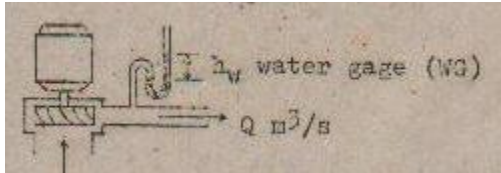
Common Uses of Fans:

Ventilation, air conditioning, forced and induced draft service for boilers, dust collection, drying and cooling of materials, cooling towers, heating, mine and tunnel ventilation, pneumatic conveying and other industrial process work

Types of Fans:



Head and Power Calculations:



Basic assumptions:

1. constant temperature
2. negligible inlet velocity

Capacity of Fan = volume flow rate measured at outlet (m^3/s)

Static Pressure Head:

$h_s = h_w d_w / d_a$ where: h_s = static pressure head, meters of air
 h_w = manometer reading, meters of water
 d_w = density of water (9.81 KN/m^3)
 d_a = density of air, KN/m^3

Velocity Head;

$$h_v = V_o^2 / 2g \quad \text{where: } h_v = \text{velocity head, meters of air}$$

$$V_o = \text{outlet velocity, m/s}$$

$$g = 9.81 \text{ m/sec}^2$$

Total Head:

$$h = h_s + h_v$$

Air Power = $Q d_a h$, KW

where: Q = fan capacity, m^3/s
 d_a = density of air KN/m^3
 h = head, m

Brake (Input) Power = $\frac{\text{Air Power}}{\text{Fan Efficiency}}$

Standard Air:

29.92" Hg (101.325 KPa)
 70°F (21.11°C)

Fan Laws:

a. Variable Speed (constant fan size, constant density)

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \quad \frac{h_1}{h_2} = (N_1/N_2)^2 \quad \frac{P_1}{P_2} = (N_1/N_2)^3$$

b. Variable Speed (constant fan size, constant density)

$$Q_1 = Q_2 \quad \frac{h_1}{h_2} = \frac{d_1}{d_2} \quad \frac{P_1}{P_2} = \frac{d_1}{d_2}$$

where: d = density
 P = power

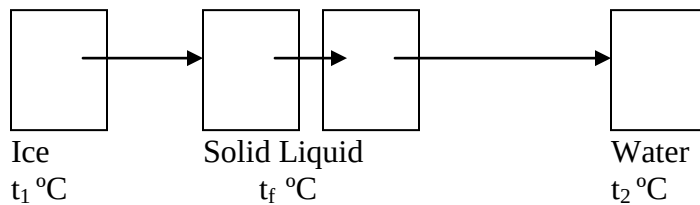
REFRIGERATION

Refrigeration – maintaining a space cooler than the surrounding

Methods of Refrigeration

1. Ice Refrigeration
2. Mechanical Refrigeration
3. Absorption Refrigeration
4. Steam Jet Refrigeration
5. Air Cycle Refrigeration

Ice Refrigeration



Amount of Cooling provided by the ice

$$= m [c_1 (t_f - t_1) + L + c_2 (t_2 - t_f)], \text{ kJ}$$

where: m = mass of ice, kg

c_1 = specific heat of ice = 2.093 kJ/ kg-°C

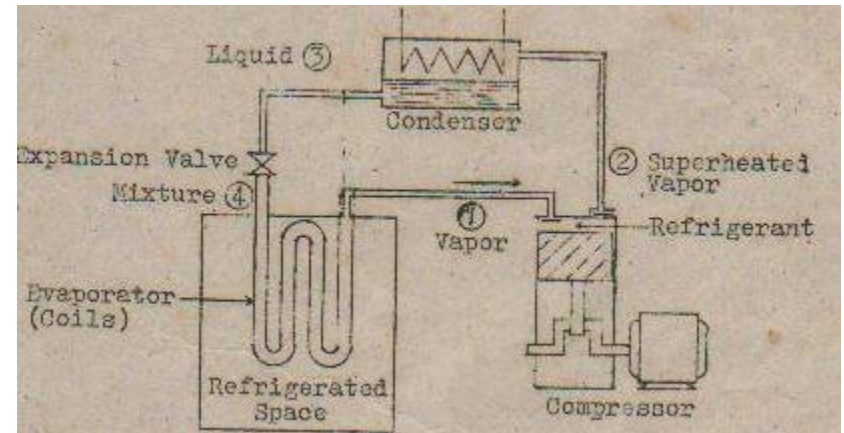
c_2 = specific heat of water = 4.187 kJ/kg-°C

L = latent heat of fusion = 335 kJ/kg

t_f = freezing temperature = 0 °C

Mechanical Refrigeration

Basic Components:



Compressor: compresses refrigerant vapor and causes it to flow in the system

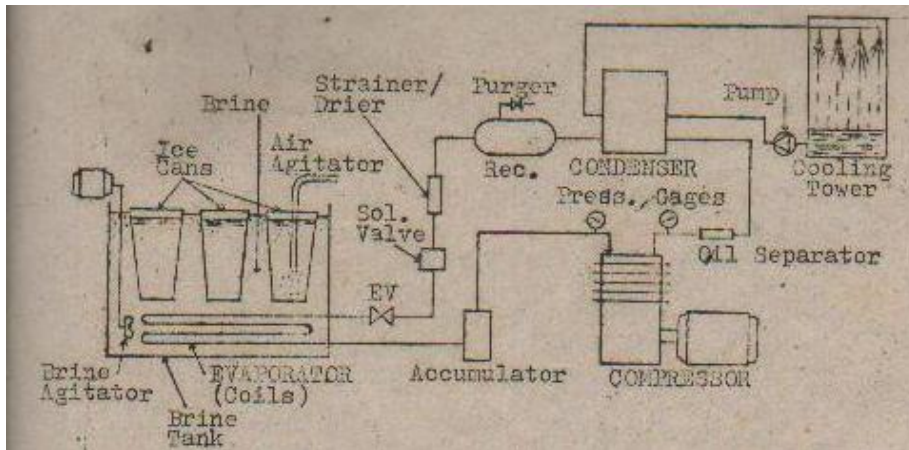
Condenser: here the refrigerant condenses while rejecting heat to the cooling medium which is either air or water

Expansion Valve: reduces the pressure of the refrigerant so that low temperature will be attained; regulates the flow of the refrigerant to the evaporator

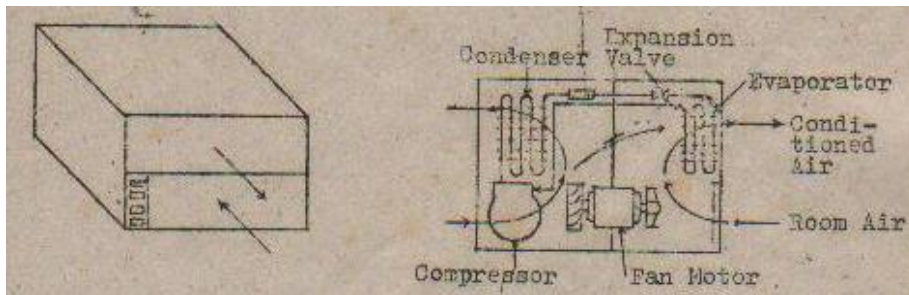
Evaporator: the liquid portion of the refrigerant evaporates while absorbing heat from the surrounding

Some Applications:

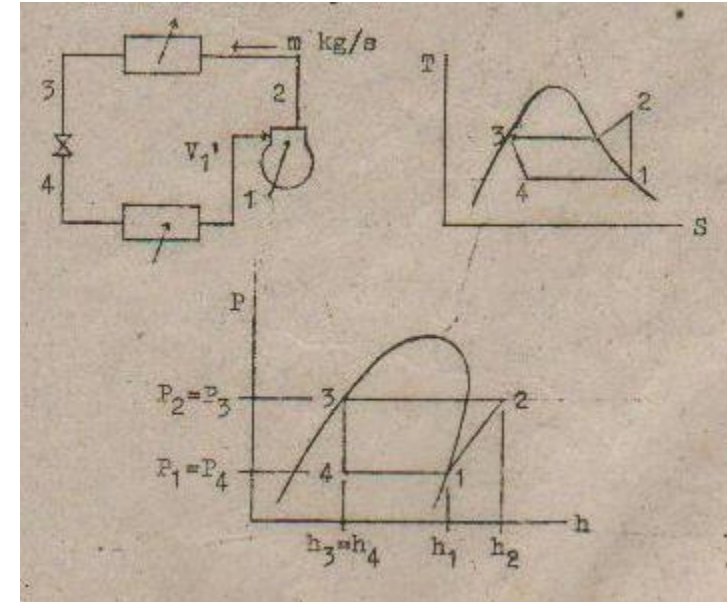
Ice Plant, showing the accessories of the refrigeration system (Refrigerant: NH_3)



Room Air Conditioner (Refrigerant: R-22)



The Vapor Compression Cycle



Compressor Work (Power)

$$= h_2 - h_1 \text{ kJ/kg}$$

$$= m (h_2 - h_1) \text{ KW}$$

Heat Rejected in Condenser

$$= h_2 - h_3 \text{ kJ/kg}$$

$$= m(h_2 - h_3) \text{ KW}$$

To find cooling water requirement of condenser, m_w :

$$m_w c_p \Delta t = (h_2 - h_3)$$

where: c_p = sp. heat of water = $4.187 \text{ kJ/kg-}^\circ\text{C}$

Δt = temperature rise of the cooling water

Expansion Valve Process

$$h_3 = h_4$$

$$h_3 = (h_f + x h_{fg})_4$$

where: x = quality or weight of flash gas per unit weight of refrigerant

Refrigerating Effect

$$= h_1 - h_4 \text{ kJ/kg}$$

$$= m(h_1 - h_4) \text{ KW}$$

$$= \frac{m(h_1 - h_4)}{3,516} \text{ Tons of Refrigeration}$$

$$3,516$$

$$(1 \text{ ton ref} = 3.516 \text{ KW} = 200 \text{ Btu/min})$$

Coefficient of Performance (COP)

$$= \frac{\text{Refrigerating Effect}}{\text{Compressor Work}} = \frac{h_1 - h_4}{h_2 - h_1}$$

Power Per Ton

$$= \frac{\text{Compressor Power}}{\text{Tons Refrigeration}}, \text{ KW/ton}$$

Volume Flow at Suction, V_1'

$$= m v_1 \text{ m}^3/\text{s} \quad \text{where: } v_1 = \text{sp. volume at suction, m}^3/\text{kg}$$

Volume Flow Per Ton

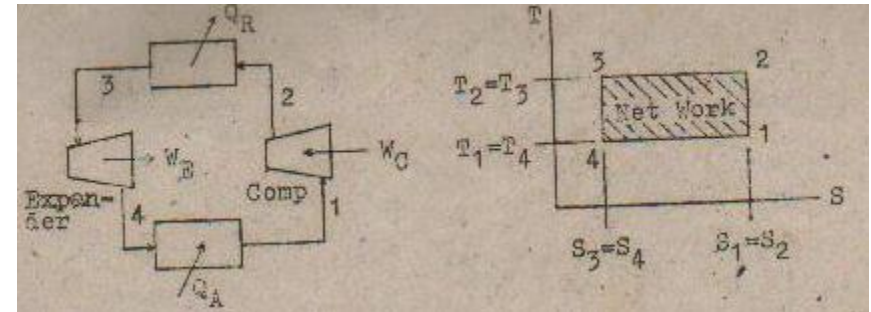
$$= \frac{V_1'}{\text{Tons Ref}} = \frac{m v_1}{\text{Tons Ref}}, \frac{\text{m}^3}{\text{s ton}}$$

Standard Refrigeration Cycle:

Evaporation Temperature: 5°F (-15°C)

Condensing Temperature: 86°F (30°C)

Reversed Carnot Cycle in Refrigeration



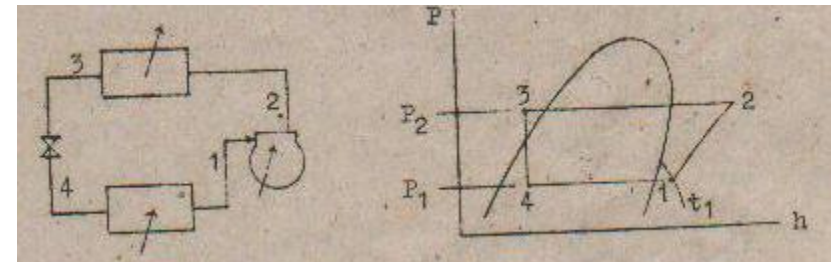
$$Q_R = \text{heat rejected in condenser} = T_2(S_2 - S_3) = T_2(S_1 - S_4)$$

$$Q_A = \text{refrigerating effect} = T_1(S_1 - S_4)$$

$$W = \text{net work} = Q_R - Q_A = T_2(S_1 - S_4) - T_1(S_1 - S_4)$$

$$\text{COP} = Q_A = \frac{T_1(S_1 - S_4)}{T_2(S_1 - S_4) - T_1(S_1 - S_4)} = \frac{T_1}{T_2 - T_1}$$

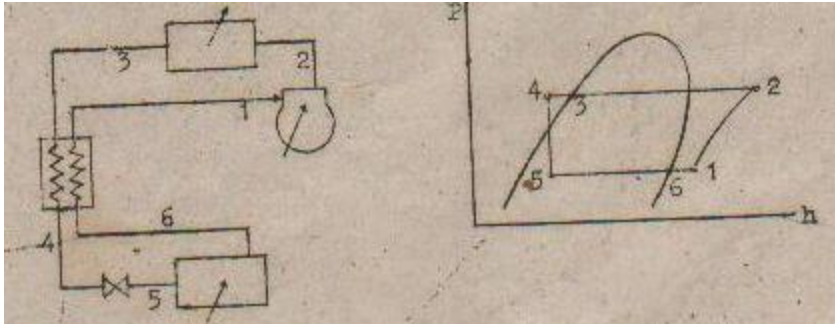
Refrigeration Cycle with Subcooling and/or Superheating



Note: $h_3 = h_f$ at t_3

h_1 will be obtained from the P-h chart at P_1 and t_1

Refrigeration System with Heat Exchanger



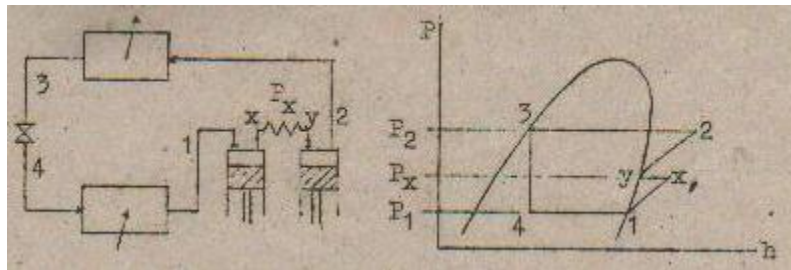
Refrigerating Effect = $h_6 - h_5$ kJ/kg

By heat balance in the heat exchanger:

$$h_1 - h_6 = h_3 - h_4$$

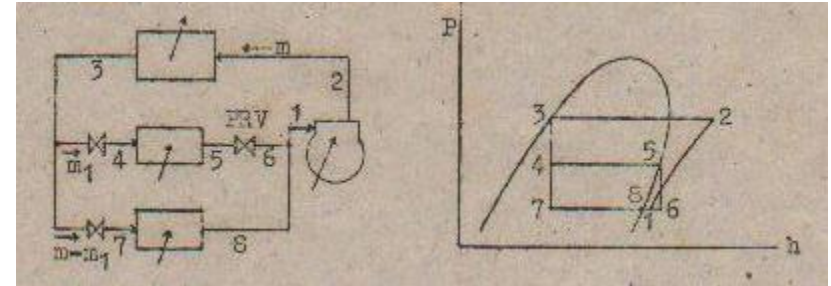
Multi-Pressure Refrigeration Systems

1. Refrigeration System with Two-Stage Compressor



$$\text{Compressor Work} = (h_x - h_1) + (h_2 - h_y)$$

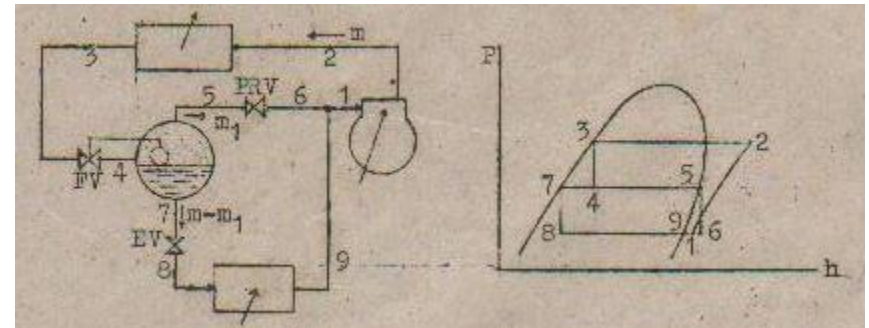
2. Refrigeration System with One Compressor Serving Two (or More) Evaporators



By heat balance at junction:

$$m_1 h_6 + (m - m_1) h_8 = m h_1$$

3. Refrigeration System with Flash Tank



By heat balance in flash tank:

$$m h_4 = m_1 h_5 + (m - m_1) h_7$$

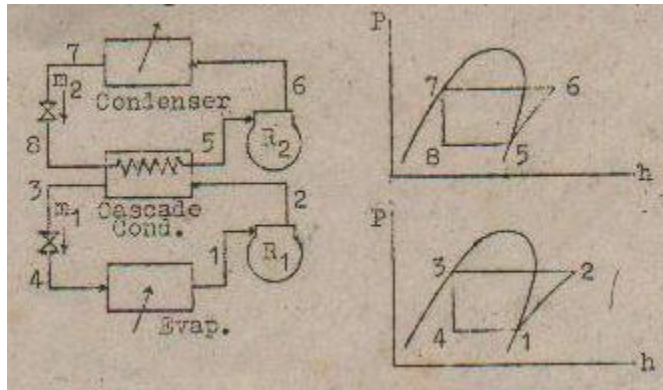
By heat balance at junction:

$$m_1 h_6 + (m - m_1) h_9 = m h_1$$

Low Temperature Refrigeration

Cryogenics – the science of low temperature

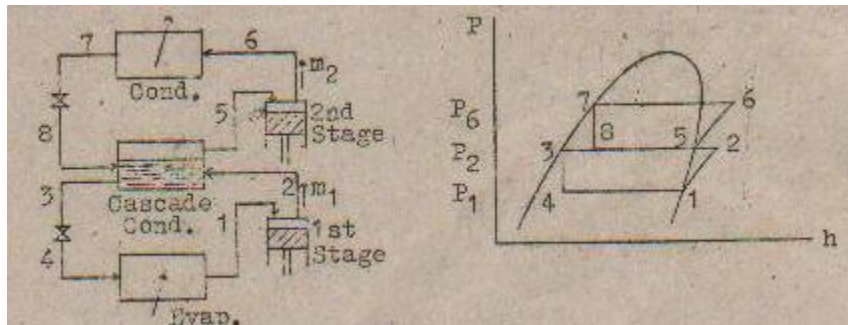
Cascade Refrigeration System:



By heat balance in the cascade condenser:

$$m_1 (h_2 - h_3) = m_2 (h_5 - h_8)$$

Cascade Refrigeration System with Direct Contact Cascade Condenser:



$$P_2 = P_3 = P_5 = P_8 = \text{pressure at the cascade condenser} \\ = \sqrt{P_1 P_6}$$

By heat balance in the cascade condenser:

$$m_1 (h_2 - h_3) = m_2 (h_5 - h_8)$$

$$\text{Total Compressor Work (power)} = m_1 (h_2 - h_1) + m_2 (h_6 - h_5)$$

Refrigeration Compressors

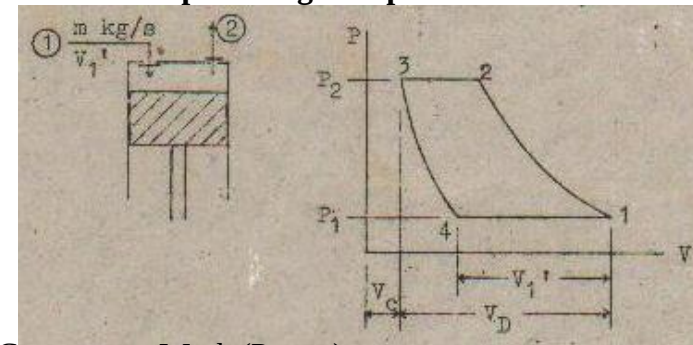
Types of Compressors:

1. Reciprocating Compressor
2. Centrifugal Compressor
3. Rotary Compressor
 - a. Vane Type
 - b. Screw Type

Classification of refrigeration compressors, based on enclosure:

1. Open-type compressor
 - compressor whose crankshaft extends through the compressor housing so that a motor can be externally coupled to the shaft
2. Hermetically sealed compressor
 - type in which the compressor and the motor are enclosed in then same housing
3. Semi-Hermetic Compressor
 - hermetically sealed compressor in which the cylinder head can be removed for servicing of the valves and pistons

Performance of Reciprocating Compressor



1. Compressor Work (Power)
 - $= h_2 - h_1$ kJ/kg
 - $= m(h_2 - h_1)$ KW
2. V_D = piston displacement $= \pi/4 D^2 L N C$, m^3/sec
 - where: D = bore, m
 - L = stroke, m
 - N = speed, rev/s

C = number of cylinders

3. V_1' = volume at suction = $m v_1$

where: v_1 = specific volume at suction, m^3/kg

4. n_v = volumetric efficiency = V_1' / V_D

Conventional (clearance) volumetric efficiency:

$$n_v = 1 + c - c (P_2/P_1)^{1/n} = 1 + c - c(v_1/v_2)$$

where: c = clearance

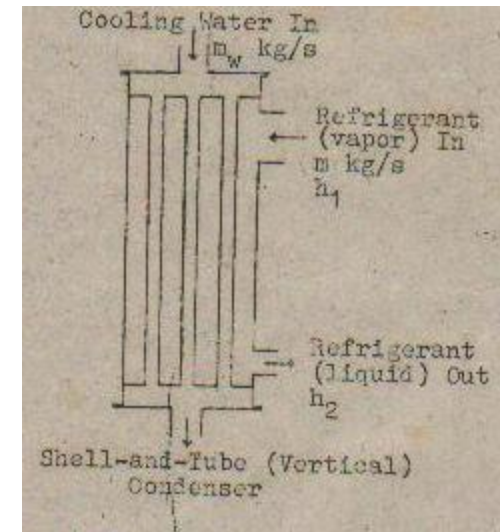
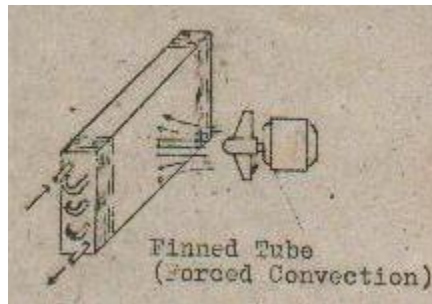
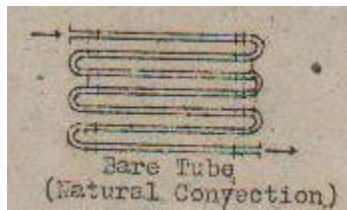
v_1 = specific volume at suction, m^3/kg

v_2 = specific volume at discharge, m^3/kg

Refrigerant Condensers

Types of Condensers use in refrigeration:

1. Air-cooled
 - a. Bare tube
 - b. Finned tube
2. Water-cooled
 - a. Shell-and-tube
 - b. Shell-and-coil



Expansion Devices

Functions of the expansion device:

1. to reduce the pressure of the liquid refrigerant from the condenser in order to attain low temperature
2. to control the flow of the refrigerant to the evaporator

Types of Expansion Devices:

1. Capillary Tube
 - Inside Dia.: 0.50mm to 2mm
 - Length: 1m to 6m
 - Capacity: up to 10KW
2. Expansion Valves
 - a. Gate Valve
 - b. Constant Pressure Expansion Valve
 - c. Thermostatic Expansion Valve
 - d. Thermostatic Expansion Valve with External Equalizer
 - e. Float Valve (used with flooded evaporator)

Refrigerants

I. Halocarbon Refrigerants:

R-12	CCl_2F_2	Dichlorodifluoromethane
R-22	CHClF_2	Monochlorodifluoromethane
R-40	CH_3Cl	Methyl Chloride

II. Inorganic Refrigerants:

R-717	NH_3	Ammonia
718	H_2O	Water
729	-	Air
744	CO_2	Carbon Dioxide

III. Hydrocarbon Refrigerants:

R-50	CH_4	Methane
170	C_2H_6	Ethane
290	C_3H_8	Propane

IV. Azeotropes:

An azeotrope is a mixture of two substances in which the components cannot be separated by distillation

R-502 (mixture of 48.8% R-22 and 51.2% R-115)

Desirable Properties of a refrigerant:

Thermodynamic properties:

1. low freezing point
2. low condensing pressure
3. low evaporating pressure
4. low power per ton
5. low volume flow per ton
6. high COP

Chemical Properties:

7. non-toxic
8. non-flammable
9. non-corrosive
10. not destructive to refrigerated products

Physical Properties:

11. low viscosity
12. high thermal conductivity
13. easy leak detection
14. miscible with oil
15. reasonable cost

Leak Detection:

R-12 and other systems using halocarbon refrigerants:

Detection: loss of cooling capacity

Location: a. soap sud

b. prestolite or alcohol torch

c. electronic leak detector

Ammonia Systems:

Detection: toxic odor

Location: a. soap sud

b. sulfur candle

Calculating the Cooling Load from Products

1. Without freezing:

$$\text{Cooling Load} = m c_p \Delta t, \text{ kJ}$$

where: m = mass of the product, kg

c_p = specific heat of the product, kJ/kg-°C

Δt = temperature change, °C

2. With Freezing:

$$\text{Cooling Load} = m[c_1(t_1 - t_f) + L + c_2(t_f - t_2)], \text{ kJ}$$

where: m = mass of the product, kg

c_1 = specific heat above freezing, kJ/kg-°C

L = latent heat of fusion, kJ/kg

c_2 = specific heat below freezing, kJ/kg-°C

t_1 = initial temperature, °C

t_f = freezing temperature, °C

t_2 = final temperature, °C

For water:

$c_1 = 4.187 \text{ kJ/kg-°C}$

$L = 335 \text{ kJ/kg}$

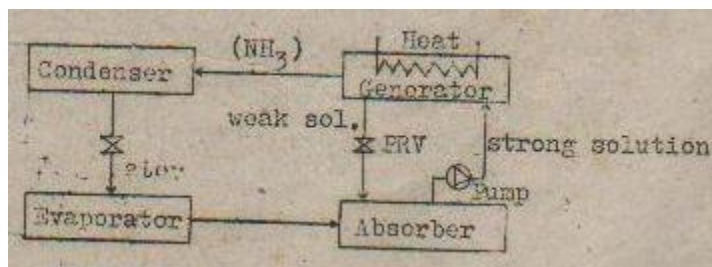
$c_2 = 2.093 \text{ kJ/kg-°C}$

Total Refrigerating Load = Cooling load from products +
Heat gain from external sources

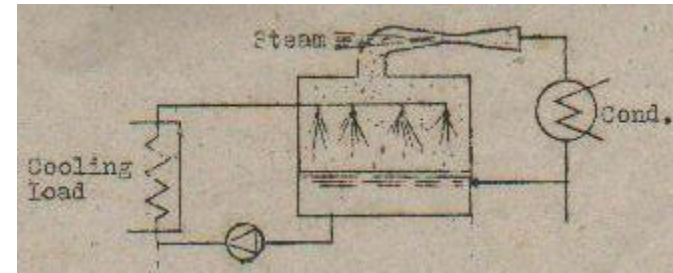
Other Methods of Refrigeration

1. Absorption Refrigeration System:

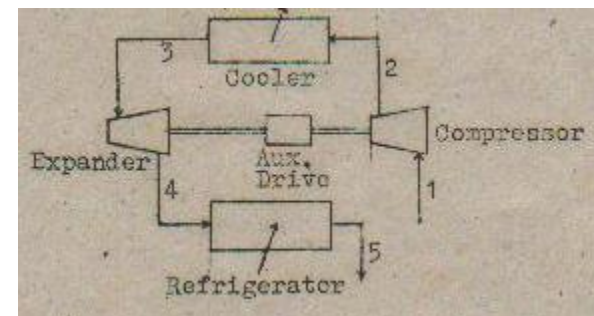
(Example: $\text{NH}_3\text{-H}_2\text{O}$ System)



2. Steam Jet Refrigeration:



3. Air Cycle Refrigeration:



AIR CONDITIONING

Air Conditioning – controlling the properties of air so that the air will be suitable for its intended use

Functions of air conditioning:

1. control of temperature
2. control of humidity
3. control of purity, that is, removal of dust and other impurities
4. control of air movement or circulation

Psychrometry – study of the properties of air and its water vapor content

Saturated Air – air whose condition is such that any decrease in temperature will result in condensation of water vapor into liquid

Properties of Air:

1. Temperature, °C

Dry Bulb Temperature – the actual temperature of the air

Wet Bulb Temperature – the temperature of the air if it is saturated

Psychrometer – is an instrument consisting of two thermometers, one to measure the dry bulb and the other to measure the wet bulb temperature of the air

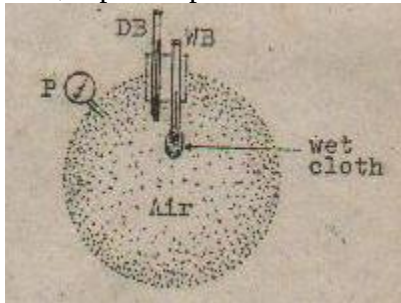
2. Pressure

$$P = P_a + P_v \text{ (Dalton's law)}$$

where: P = total pressure of air-water vapor mixture

P_a = partial pressure of dry air

P_v = partial pressure of water vapor



3. Specific Volume

From $PV = mRT$

$$v = \frac{V_a}{m_a} = \frac{R_a T}{P_a} = \frac{R_a T}{P - P_v} \text{ m}^3/\text{kg dry air}$$

4. Humidity Ratio, W, $\frac{\text{kg water vapor}}{\text{kg dry air}}$

$$W = 0.622 P_v / (P - P_v)$$

where: P = total pressure, KPa

P_v = partial pressure of water vapor, KPa

5. Enthalpy, h, kJ/kg dry air

$$h = c_p t + W h_g$$

where: c_p = specific heat of dry air = 1.0 kJ/kg- °C

t = temperature (dry bulb), °C

W = humidity ratio

h_g = enthalpy of saturated water vapor at the air temperature

6. Relative Humidity, RH, %

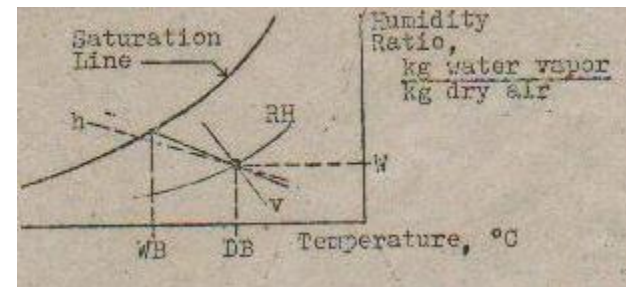
$$= \frac{\text{Actual partial pressure of water vapor}}{\text{Saturation pressure of pure water vapor at the same temperature}}$$

7. Dew Point – the temperature at which the water vapor in the air condenses when the air is cooled at constant pressure

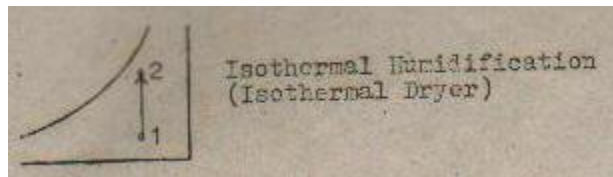
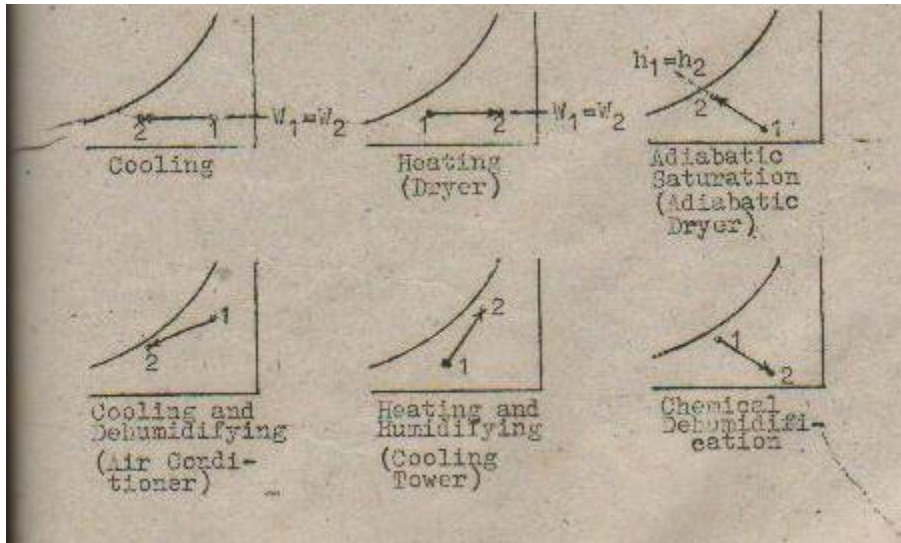
8. Percent Saturation, %

$$= \frac{\text{Actual humidity ratio}}{\text{Humidity ratio of saturated air at the dry bulb temperature}}$$

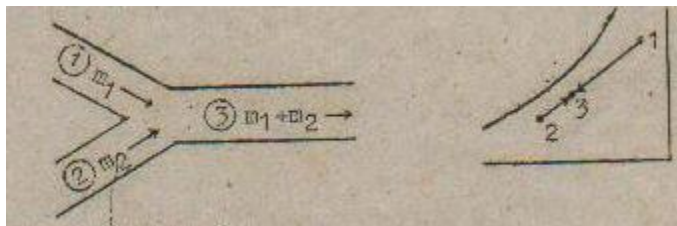
The Psychrometric Chart



Processes in the Psychrometric Chart



Air Mixing:



By heat balance:

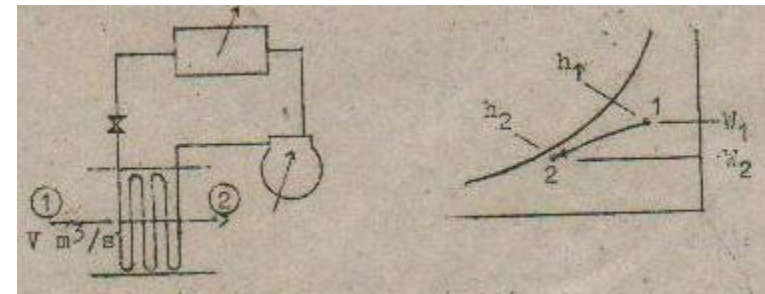
$$m_1 h_1 + m_2 h_2 = (m_1 + m_2) h_3$$

By moisture balance:

$$m_1 W_1 + m_2 W_2 = (m_1 + m_2) W_3$$

Applications of Psychrometry:

Air Conditioner

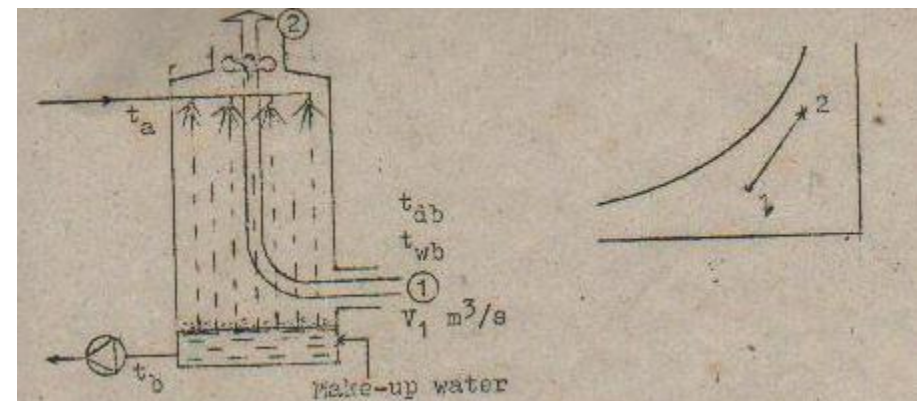


$$\begin{aligned} \text{Refrigerating Capacity} &= m(h_1 - h_2) \text{ KW} \\ &= V/v_1 (h_1 - h_2) \text{ KW} \end{aligned}$$

$$\begin{aligned} \text{Rate of moisture Removal} &= m(W_1 - W_2) \text{ kg/s} \\ &= V/v_1 (W_1 - W_2) \text{ kg/s} \end{aligned}$$

where: m = mass flow rate of air, kg/s
 v_1 = specific volume at 1

Cooling Tower

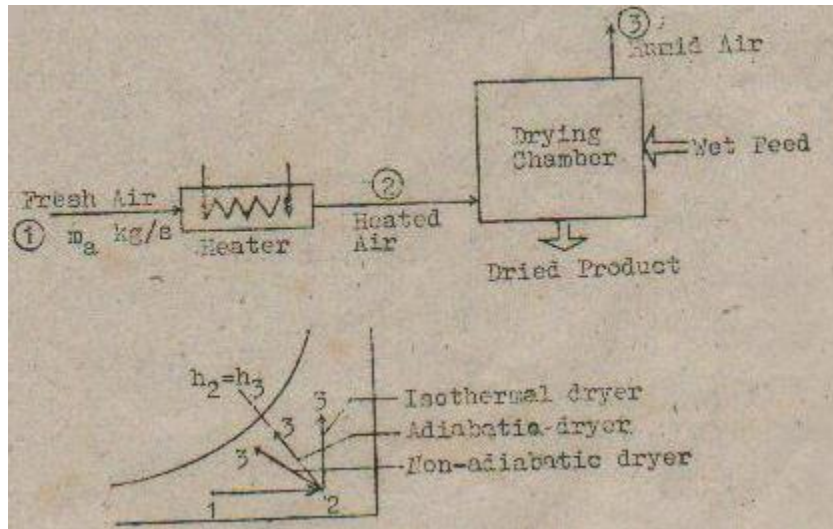


$$\text{Range} = t_a - t_b$$

$$\text{Approach} = t_b - t_{wb}$$

$$\text{Efficiency of Cooling Tower} = \frac{\text{Actual Range}}{\text{Theoretical Range}} = \frac{t_a - t_b}{t_a - t_{wb}}$$

Dryer



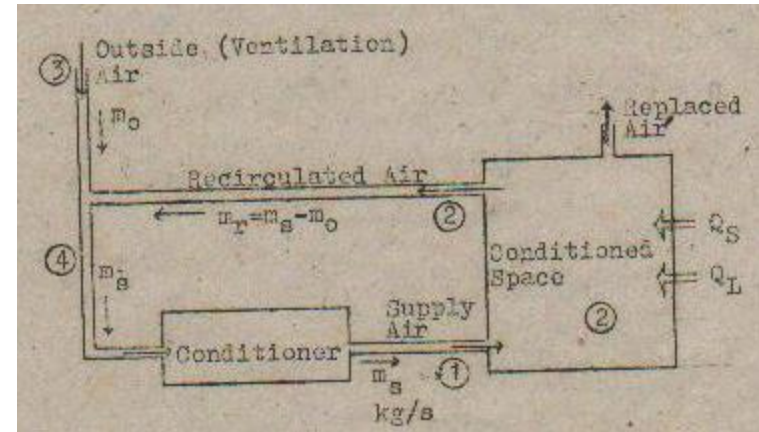
Moisture removed from materials = moisture absorbed by air
 $= m_a(W_3 - W_2) \text{ kg/s}$

Heat Supplied in heater $= m_a(h_2 - h_1) \text{ KW}$

Efficiency of dryer $= \frac{\text{Heat absorbed by materials}}{\text{Heat Supplied}}$

Air Conditioning Equipment:

1. Cooling and dehumidifying coils (of a refrigerating system)
2. Water chiller
3. Spray equipment



Q_s = Sensible Heat Load

$$= m_s c_p (t_2 - t_1) \text{ KW}$$

$$C_p = 1.0 \text{ kJ/kg} \cdot ^\circ\text{C}$$

t_1, t_2 = dry bulb temperatures

Q_L = Latent Heat Load

$$= m_s(W_2 - W_1)h_v \text{ KW}$$

$$H_v = 2442 \text{ kJ/kg (average)}$$

Q_T = Total Heat Load $= Q_s + Q_L$

$$= m_s(h_2 - h_1) \text{ KW}$$

SHR = Sensible Heat Ratio (or factor) $= Q_s / (Q_s + Q_L)$

If recirculated air and outside air are mixed before entering conditioner:

By air mixing heat balance:

$$m_o h_3 + (m_s - m_o) h_2 = m_s h_4$$

$$\text{Air Conditioner capacity} = m_s(h_4 - h_1) \text{ KW}$$

If recirculated air and outside air separately enter the conditioner:

$$\text{Air Conditioner Capacity} = m_o(h_3 - h_1) + (m_s - m_o)(h_2 - h_1) \text{ KW}$$

$$\text{Ventilation Load} = m_o(h_3 - h_1) \text{ KW}$$

INDUSTRIAL PROCESSES

Flow Diagram or Flow Sheet

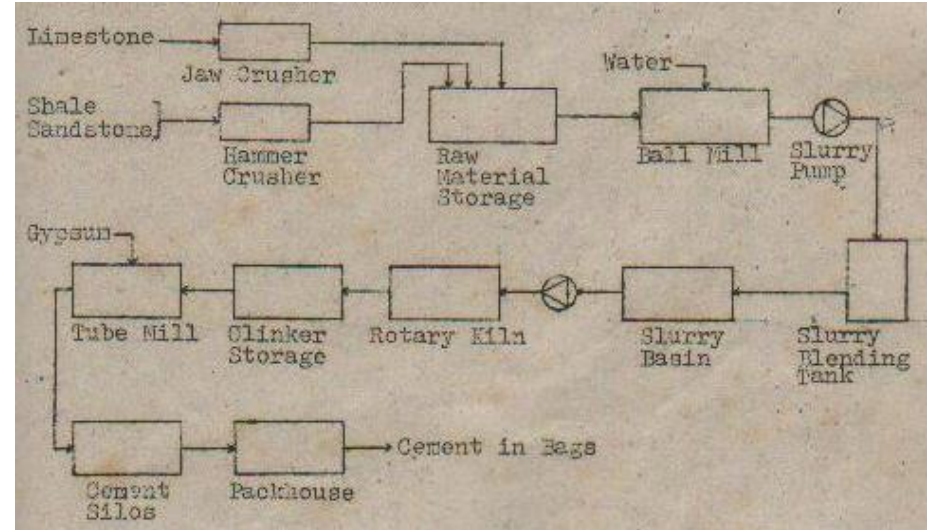
- a diagram showing the flow of the materials through the various equipment or processes involved in the manufacture of a certain product

- Process flow diagram: indicates only the processes involved, drawn in block diagrams
- Equipment flow diagram: shows the various equipment used in the processing
- Equipment-process flow diagram: combines the equipment and processes in the diagram

Some Industries in the Philippines:

1. Sugar Manufacture (Raw and refined Sugar)
2. Cement Manufacture (Wet and Dry Process)
3. Rice and Corn Milling
4. Pulp and Paper Manufacture
5. Plywood Manufacture
6. Glass Manufacture
7. Beer Manufacture
8. Copper Manufacture
9. Steel Manufacture
10. Coconut Oil Milling
11. Fertilizer Manufacture
12. Flour Milling

Example of Flow Diagram: Cement Manufacture, Wet Process:



INDUSTRIAL EQUIPMENT

A. DRYERS

Three methods of drying system based on heat transfer:

1. Direct or convection drying
2. Indirect Drying
3. Infrared or radiant heat drying

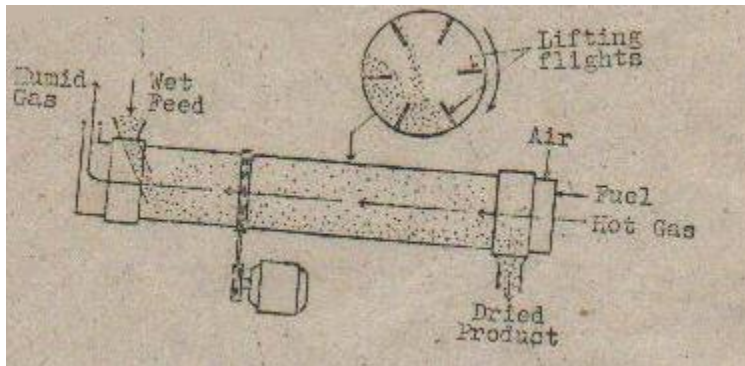
Types of Dryers, based on movement of materials:

1. Continuous dryer
2. Batch dryer

Classification of Dryers:

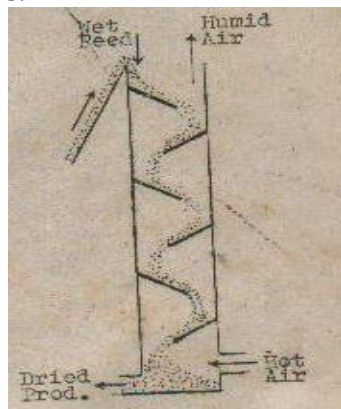
1. Rotary Dryer

- most commonly used dryer which consists of a rotating cylinder inside which the materials flow while getting in contact with the hot gases; the cylinder is tilted at a slight angle and fitted with lifting flights; used for copra, sand, wood chips.



2. Tower Dryer

- Consists of a vertical shaft in which the wet feed is introduced at the top and falls downward over baffles while coming in contact with the hot air which rises and exhausts at the top; used for palay, wheat, rains.



3. Hearth Dryer

- Type of dryer in which the material to be dried is supported on a floor through which the hot gases pass; used for copra, coal, enamel wares.

4. Centrifugal Dryer

- Consists of centrifuge revolving at high speeds causing the separation, by centrifugal force, of water from the material; used for drying fertilizer, salt, sugar.

5. Tray Dryer

- Consists of trays, carrying the materials to be dried, placed in a compartment or moving conveyor; used for ipil-ipil leaves, grains.

6. Infrared Ray Dryer

- Consists of infrared lamps in which the rays are directed to the articles to be dried; used for drying painted articles like cars.

$$\text{Efficiency of Dryer} = \frac{\text{Amount of heat absorbed by materials}}{\text{Amount of Heat Supplied}}$$

B. EVAPORATORS

Evaporators are used either to remove the water from a liquid substance, like sugar juice, or to produce distilled water by condensing the steam.

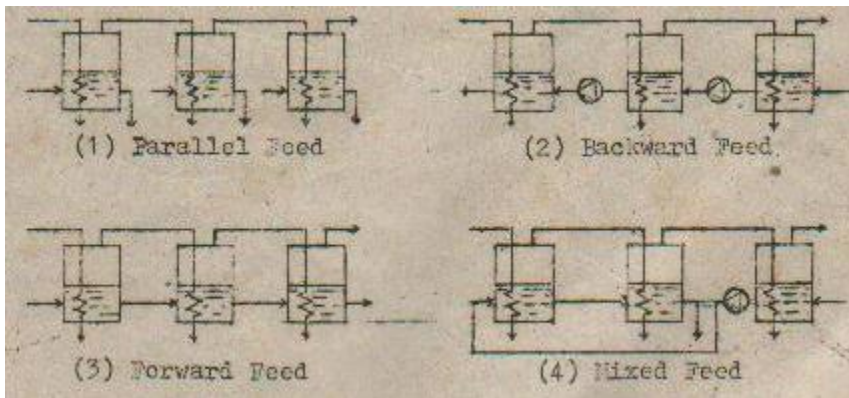
Three Principal Types of Evaporator according to construction:

1. Horizontal tube evaporator – consists of vertical cylindrical body; two rectangular steam chests in the lower section contain tube sheet; primarily suitable for non-viscous liquids that do not deposit salt or scale during evaporation.

2. Standard vertical tube evaporator – consists of vertical cylindrical shell with flat, dished or conical bottom; most widely used type; can be used for liquids that deposit salt or scale during evaporation.
3. Long-tube, natural-circulation vertical evaporator – consists of long tubes so that the liquor passes through the evaporator but once; used with non-salting or non-scaling liquids; can be used with high-viscosities; one of the cheapest types.

Multiple Effect Evaporator – series of evaporators so connected that the vapor from one body is used as the heating steam in the next.

Types of multiple effect (multi-stage) evaporator:



C. CONVEYORS

Common types of conveyors and the materials suitable for each:

1. Flat belt conveyor (coal, copra, packages)
2. Troughed belt conveyor (coal, copra, ores)
3. Screw conveyor (pulverized coal, flour grains)

4. Flight conveyor (copra, coal, grains)
5. Bucket conveyor (copra, coal, grains)
6. Pneumatic conveyor (grains, linen, match sticks)

D. GRAINS

Common Types of cranes and their applications:

1. Overhead traveling bridge crane (maintenance shops, ice plant)
2. Derrick crane (loading in ships, handling materials in piers)
3. Jib Crane (construction work, maintenance shops)
4. Gantry crane (mining, piers)
5. Pillar crane (maintenance shops, piers)

E. FOUNDRY EQUIPMENT

Melting Furnaces Used in Foundry:

1. Crucible furnace – suitable for non-ferrous metals; the metal is melted inside a crucible heated by an oil-fired burner
2. Cupola furnace – for melting iron; the heat comes from coke burning inside the cupola itself
3. Induction furnace – for ferrous and non-ferrous metals, uses electric current for melting the scraps or ingots

Methods of Casting Used in Foundry:

1. Sand casting
2. Pressure die casting
3. Metal Mold casting
4. Centrifugal casting
5. Plaster mold casting

PRACTICE PROBLEMS

FUEL AND COMBUSTION

1. A diesel power plant utilizes diesel fuel with 28° API. The plant consumes 650 liters of diesel fuel at 26.6°C in 24 hours, while the power guarantee for the same period amounts to 1,980 kw-hrs. Determine:
 - a. Density of fuel at 26°C in kg/li
 - b. Fuel rat, kg/kw-hr
 - c. Higher heating value, J/g
 - d. Overall thermal efficiency of the plant

(ANS a. 0.88 kg/li b. 0.289 kg/kw-hr, c. 45,039 J/g, d. 27.65%)

2. A steam generator burns fuel oil with 20 percent excess air. The fuel oil may be represented by $C_{14}H_{30}$. Calculate the theoretical and actual air-fuel ratio.

(ANS. 14.97 kg air/kg fuel; 17.97 kg air/kg fuel)

3. A certain coal has the following ultimate analysis:
C = 67%, H₂ = 3%, O₂ = 4%, N₂ = 6%, S=7%, Ash=5% and Moisture = 8%.

- a. Find the air-fuel ratio if this coal is burned with 50% excess air
- b. Calculate the heating value in kJ/kg
- c. If this coal is used in a boiler with steaming capacity of 100 tons per hour, factor of evaporation of 1.15 and boiler efficiency of 73%, find the fuel consumption in tons per hour.

(ANS. a. 13.3 kg air/kg coal, b. 26,916 kJ/kg, c. 13.21 tons/hr)

4. A fuel consisting of 80% $C_{12}H_{36}$ and 20% $C_{14}H_{30}$ is burned with 30% excess air. The flue gases is at atmospheric pressure. Find the minimum exhaust temperature to avoid condensation.
(ANS. 50.5°C)

VARIABLE LOAD PROBLEM

1. From a 5-MW Diesel Power Plant, the following data were obtained:

Annual gross kw-hrs generation	= 246×10^6
Annual net kw-hrs generation	= 231×10^6
Annual operating hours generation	= 7,734
Annual average load in KW	= 31,890
Annual maximum peak load in KW	= 48,000
Fuel oil consumed, gallons/year	= 18.364×10^6

Calculate:

1. Annual load factor
2. Annual plant capacity factor
3. Annual plant use factor
4. Gross fuel economy in kw-hrs per liter of fuel

(ANS. 1. 66.44% 2. 52.74% 3. 59.74% 4. 3.539 kw-hr/li)

2. A power plant is said to have a use of factor of 48.5% and a capacity factor of 42.4%. How many hours did it operate during the year?

(ANS. 7,660 hours)

STEAM POWER PLANT

1. An ideal Rankine cycle has a throttle conditions of 6 MPa and a 450°C. Exhaust pressure is at 0.005 MPa.
 - a. Determine the Rankine cycle efficiency
 - b. Determine the Carnot cycle efficiency with the same range of temperature.

(ANS. a. 39.48%, b. 57.69%)

2. A steam turbine receives 5,000 kg per hr of steam at 5 MPa and a 400°C and a velocity of 25 m/sec. It leaves the turbine at 0.006 MPa and 15% wetness and velocity of 20 m/sec. radiation loss is 10,000 kJ/hr. Find the KW power developed.

(ANS. 1373.35 KW)

3. An open feedwater heater utilizes saturated steam at 150°C which is extracted from a turbine. The feedwater to be heated enters the heater at 60°C. If the mixture leaves the heater as saturated liquid at the rate of 30,000 kg per hour, find the quantity of steam extracted from the turbine.

(ANS. 4577 kg/hr)

4. A boiler generates superheated steam at the rate of 50 tons per hour. Feedwater enters the boiler at 5 MPa and 120°C and leaves at 4.5 MPa and 320°C. If the coal used has a heating value of 5 tons per hour, calculate:

- a. Boiler efficiency
- b. Factor of evaporation
- c. ASME evaporation units in kJ/hr
- d. Actual specific evaporation
- e. Equivalent specific evaporation

(ANS. a. 83.117%, b. 1.1048, c.124675500 kJ/hr d. 10, e. 11.048)

5. A horizontal Return Tubular boiler has a steaming capacity of 4546 kg/hr of steam at 11.4 kg/cm² abs. saturated. Feedwater temperature is 80°C. it has an overall effective heating surface of 186 m². Determine:

- a. Rated boiler horsepower
- b. Developed boiler horsepower
- c. Percent rating
- d. Factor of evaporation

(ANS. a.169.09 b. 315.06 c. 186.3% d. 1.08)

6. A bunker-fired steam generating unit consumes 6 Metric Tons per hour of bunker having a heating value of 41,000 kJ/kg with a boiler efficiency of 80%. It is desired to convert this boiler to coal-fired using local having an average heating value of 29,000 kJ/kg. Using coal, however, the boiler efficiency is only 75%. What will be the coal consumption so that the boiler will maintain its steaming capacity?

(ANS. 9.048 M Tons/hr)

7. Two boilers are operating steadily on 136,500 kg of coal contained in a bunker. One boiler is producing 2,386 kg of steam per hour at 1.15 factor of evaporation and an efficiency of 75%, and the other boiler produces 2,047 kg of steam per hour at 1.10 factor of evaporation and an evaporation and an efficiency of 70%. How many hours will the coal in the bunker run the boilers if the heating value of the coal is 32, 000 kJ/kg?

(ANS. 281.89 hrs)

8. A boiler generates superheated steam at the rate of 20,000 kg per hr. Feedwater enters the boiler at 5 MPa and 200°C and the steam leaves the boiler at 5 MPa and 350°C. The coal used has a heating value of 32,000 kJ/kg and boiler efficiency is 78%. Determine:
- Developed boiler horsepower
 - Factor of evaporation
 - ASME evaporation units in kJ/hr
 - Fuel consumption in kg/hr

(ANS. a. 1254 bohp, b. 0.981, c. 44290000 kJ/hr, d. 1774 kg/hr)

9. For a 15,000 KW non-condensing geothermal steam turbine-generator operating at 4 MPa steam pressure dry and saturated and 600 mm Hg exhaust pressure, guaranteed full load steam rate is 12 kg/kw-hr. Steam rate at one-half load is 13.5 kg/kw-hr.
- Write the equation of the Willian's line.
 - Calculate the throttle steam flow at three-fourth load.

(ANS. $m_s = 10.5 L + 22,500$ kg/hr, b. 140,625 kg/hr)

GEOTHERMAL POWER PLANT

1. A flashed-steam geothermal power plant is located where underground hot water is available at 15 MPa and 300°C. To produce a steam-water mixture in the separator where the unflashed water is removed, this water is throttled to a pressure of 1 MPa. The flashed steam which is dry and saturated passes through the steam collector and enters the efficiency is 80% and the generator efficiency is 95%. For a generator output of 12 MW, calculate the ground water flow rate in kg per hour required for continuous operation.

(ANS 512,870 kg/hr)

2. A geothermal power plant has an output of 16000 KW and mech-elec. Efficiency of 80%. The pressurized ground water at 172.4 bar, 282°C leaves the wells to enter the flash chamber maintained at 13.8 bar ($h_f = 829$ kJ/kg; $h_{fg} = 1961$ kJ/kg). The flashed vapor passes through the separator and collector to enter the turbine as saturated vapor at 13.8 bar. The turbine exhausts at 1 bar. The unflashed water runs to waste. If one well discharges 195,000 kg/hr of hot water, how many wells are required?

(ANS. 4 wells)

NUCLEAR POWER PLANT

1. In a pressurized water reactor plant, the reactor releases 6.330336×10^6 kJ/hr of heat to the pressurized water coolant. Steam is generated at 4.137 MPa saturated and the condenser pressure is 0.0138 MPa. Assuming a turbine efficiency of 78%, mechanical-electrical efficiency of 90% and neglecting pipe losses and pumpwork, calculate:
- Mass flow rate of steam in kg/hr
 - KW output of generator
 - Cycle heat rate of plant in kJ/kw-hr

(ANS/ a. 2451 kg/hr, b. 404 KW, c. 15678 kJ/kw-hr)

DIESEL (I.C.E.) POWER PLANT

1. A 16-cylinder, V-type diesel engine, 4-stroke cycle, 514 rpm, 400 mm bore x 460 mm stroke is directly coupled to a 5500 KW AC generator, 13,800 volts, 3 phase, 60 cycles and 93% efficiency.
- Calculate the BHP of the diesel engine
 - Calculate the brake mean effective pressure in kg/cm²
 - The unit uses bunker oil with 17 degrees API and the fuel economy is 4.0 kw-hr per liter of fuel oil, calculate the combined heat rate in kcal/kw-hr

(ANS. a. 7927.6, b. 15.217 kg/cm², c. 2475.4 kcal/kw-hr)

2. An 8-cylinder, 450 mm x 600 mm, 4-stroke cycle diesel engine has an exhaust gas mass rate of 4.5 kg/kw-hr brake based on fuel having an air-fuel ratio of 20 to 1 and heating value of 10540 kcal/kg. engine speed is 260 rpm with brake mean effective pressure of 9.25 kg/cm². An estimated 22% energy loss is carried away by the jacket cooling water. Calculate:
- The brake horsepower
 - Mass flow rate of jacket cooling water assuming water available at 25°C and allowed to rise 15°F.

(ANS. a. 2011 bhp, b. 24.84 kg/sec)

3. A 3000 KW Diesel generating set which is using a 25° API fuel has the following data: fuel rate, 290 liters for 900 kw-hr; generator efficiency is 92% and mechanical efficiency is 82%. Calculate the following:
- Engine fuel rate
 - Engine-generator fuel rate
 - Indicated thermal efficiency
 - Brake thermal efficiency
 - Overall thermal efficiency

(ANS. a. 0.2683 kg/kw-hr, b. 0.2916 kg/kw-hr, c. 36.76%, d. 30.14%, e. 27.69%)

4. A 16-cylinder diesel engine is directly coupled to a 2400 volts, 3300 KW alternator. The engine consumes 1.252 drums of 25° API diesel fuel with energy output of 990 kw-hrs. The mechanical efficiency of the engine is 92%. Assume a drum of fuel contains 200 liters. Find:
- Engine fuel rate in kg/bhp-hr
 - Engine-alternator fuel rate in kg/kw-hr
 - Indicated thermal efficiency
 - Overall thermal efficiency
 - Brake thermal efficiency

(ANS. a. 0.157 kg/bhp-hr, b. 0.229 kg/kw-hr, c. 46.23%, d. 35.21%, e. 38.36%)

5. A 3500-bhp turbocharged diesel engine, 16-cylinder, 400 mm x 500 mm, 360 rpm has a fuel consumption of 0.173 kg/bhp-hr at full load using fuel with heating value of 10900 kcal/kg. For this engine heat carried by exhaust gases is 30% and heat carried by jacket water is 23%. A waste heat recovery boiler recovers 35% of the exhaust heat loss. Calculate the quantity of 136 KPa steam that can be produced in kg/hr if jacket water from engine at 70°C is used as boiler feed.

(ANS. 1210.7 kg/hr)

6. When the pressure is 101.3 KPa and 27°C, a diesel engine has the full throttle characteristics listed: Brake power: 200 KW; Brake specific fuel consumption: 0.218 kg/kw-hr; Air-fuel ratio: 22; Mechanical efficiency: 86%. What are the corresponding quantities of the engine if operated at 84.11 KPa and 15.5°C?

(Hint: Indicated power varies as the atmospheric air density.)

(ANS. BP = 168.2 KW; BSFC = 0.2592 kg/kw-hr; A/F = 18.99; η_m = 83.76%)

7. A six-cylinder four-stroke diesel engine, with 76 mm bore and 89 mm stroke was ran in the laboratory at 2000 RPM, when it was found that the brake torque was 15.6 kg-m with all cylinders firing but 12.5 kg-m when one cylinder was cut. The engine consumed 12.15 kg of fuel per hour with a heating value of 45,130 kJ/kg and 137.4 kg of air at 15.5°C per hour. Determine the following:

- Brake power in KW
- Indicated power in KW
- Mechanical efficiency
- Indicated thermal efficiency

- e. Indicated mean effective pressure in KPa
- f. Volumetric efficiency (air only)

(ANS. a. 32.052 KW, b. 38.190 KW, c. 83.92%, d. 25.07%, e. 945.89 KPa, f. 77.26%)

GAS TURBINE POWER PLANT

1. In a gas turbine operating on the air standard cycle, the air enters the compressor at 100 KPa and 30°C at the rate of 20 m³/sec and is compressed to 500 KPa. The maximum temperature is 780°C and the exit pressure of the turbine is 100 KPa.
 - a. Determine the net turbine power and the cycle efficiency.
 - b. What is the net turbine power and the cycle efficiency if the compressor efficiency is 80% and the turbine efficiency is 85%?

(ANS. 4853 KW, 36.82%; b. 2496 KW, 18.94%)

HYDRO-ELECTRIC POWER PLANT

1. At a proposed hydroelectric plant site, the headwater elevation is 700 meters and the tailwater elevation is 580 meters. Average annual water flow is determined to be equal to that volume flowing through a rectangular channel 4 meters wide and 0.5 meter deep and average velocity of 5.5 meters per second. Assuming that the plant will operate 360 days per year, find the annual energy in KWH that the power site can develop if the hydraulic turbine that will be used has an efficiency of 80% and generator efficiency of 92%. Consider a headwork loss of 4% of the available head.

(ANS. 79,050,704 KWH)

2. A Mindanao province where a mini-hydro plant is to be constructed has an average annual rainfall of 139 cm. The catchment area is 206 sq.km with an available head of 23 meters. Only 82% of the rainfall can be collected and 75% of the impounded water is available for power. Hydraulic friction loss is 6%, turbine efficiency is 78% and generator efficiency is 93%. Determine the average KW power that could be generated for continuous operation.

(ANS. 858.5 KW)

3. A hydro-electric plant discharging water at the rate of 0.75 m³/sec and entering the turbine at 0.35 m/sec with pressure of 275 KPa has a runner of 55 cm internal diameter. Speed is 514 RPM at 260 brake horsepower. The casing is 2 meters above the tailwater level. Calculate:
 - a. Effective head
 - b. Peripheral coefficient
 - c. Efficiency

(ANS. a. 30.039 m, b. 60.97%, c. 87.87%)

4. The flow of a river is 21.25 m³/sec and the head of the site is 30.47 m. It is proposed to develop the maximum capacity at the site with the installation of two turbines, one of which is twice the capacity of the other. The efficiency of both units is assumed to be 85%. Francis turbines will be used with specific speed of 65. Determine:
 - a. Rotative speed of each unit
 - b. KW output of each unit
 - c. Number of poles of each generator for 60 cycles current

(ANS a. 300 rpm, 450 rpm; b. 3600 KW, 1800 KW; c. 24 poles, 16 poles)

5. A hydro-electric pumped storage plant has a generator-motor efficiency of 95%, turbine efficiency of 81% and pump efficiency of 76%. Average elevation between upper and lower pools is 31m. Assume a 2% loss of head in pipe friction. This unit was installed to carry a daily peak load of 1500 kw-hrs. There is daily evaporation loss of 1000 metric tons. Calculate the overall efficiency of conversion.
(ANS. 51,2%)

MACHINE FOUNDATION

1. The following data refer to a 750-KW diesel generating set whose foundation is to be designed:
Overall weight of genset: 28,600 kg
Overall dimensions of bedplate: 7m x 2m
Efficiency of Generator: 85%

The soil has a safe load bearing capacity of 30 tons/m². A mass factor of 480 kg/bhp for the concrete foundation may be used. Density of concrete is 2.4 tons/m³. Top edges of foundation should not exceed 0.75 from the bedplate of the machines. Determine the dimensions of the foundation for this unit.

(ANS. Trapezoidal foundation: upper width = 3.5m; lower width = 4.676m, depth = 6.81m, length = 8.5m)

CHIMNEY

1. A boiler needs a smoke stack to produce 25mm water draft at sea level. Other data as follows:
Average air temperature: 25°C
Barometer reading: 760 mm Hg
Boiler flue gas temperature entering stack: 260°C
Flow gas flow rate: 45 kg/sec
Flue gas density: 0.72 kg/m³
Determine the required height and diameter of the stack
(ANS. Height = 53.76 m, Diameter = 1.75 m)

HEAT TRANSFER AND HEAT EXCHANGERS

1. Determine the thermal conductivity of a wood that is used in 1.5 meter square test panel, 25 mm thick, if during a 4-hour test period there are conducted 190000 Joules through the panel with a temperature differential of 6°C between the surfaces. Express answer in watts/m-°C.
(ANS. 0.0244 w/m-°C)
2. A heat exchanger is designed for the following specifications:
Hot gas temperature, 1145°C
Cold gas temperature, 45°C
Unit surface conductance on the hot side, 230 W/m²-K
Unit surface conductance on the cold side, 290 W/m²-K
Thermal conductivity of the metal wall, 115 W/m-K
Find the maximum wall surface temperature if the wall thickness is 25 mm.
(ANS. 548°C)
3. The walls of a cold storage plant are composed of an insulating material (k=0.2336 kJ per hr-mc-°C) 10.16 cm thick held between two layers of concrete (k=3.7382 kJ per hr-m-°C) each 10.16 cm thick. The film coefficients are 81.76 kJ/hr-m²-°C on the outside and 40.88 kJ/hr-m²-°C on the inside. Cold storage temperature is -6.67°C and the ambient temperature is 32.22°C. Determine the overall coefficient of heat transfer and the heat transmitted in KW through an area of 55.74m².
(ANS. U = 1.9012 kJ/hr-m²-°C; Q=1.1448 KW)
4. A counterflow heat exchanger is designed to heat fuel oil from 28°C to 90°C while the heating fluid enters at 138°C and leaves at 105°C. The fuel oil has a specific gravity of 21°C API, a specific heat of 0.5 kcal/kg-°K and enters the heat exchanger at the rate of 3,000 liters per hour.
a. Determine the true log mean temperature difference

- b. Determine the required heating surface area in m^2 if the overall coefficient of heat transfer for this heat exchanger is $400 \text{ kcal/hr-m}^2\text{-}^\circ\text{K}$.
(ANS. a. 61.36°C , b. 3.486m^2)

5. Brine enters a circulating brine cooler at the rate of $5.7 \text{ m}^3/\text{hr}$ at -10°C and leaves at -16°C . The specific heat of the brine is $1.072 \text{ kJ/kg-}^\circ\text{C}$ and the specific gravity is 1.10. The refrigerant evaporated at -25°C .
- What is the refrigerating load in KW and in tons refrigeration?
 - What is the log mean temperature difference?
 - What is the required heat transfer area if the overall coefficient of heat transfer is $0.454 \text{ KW/m}^2\text{-}^\circ\text{C}$?

(ANS. a. 11.2 KW , 3.185 TR ; b. 11.75°C ; 2.1m^2)

AIR (GAS) COMPRESSORS

- A single-acting air compressor operates at 450 rpm with an initial condition of air at 97.9 KPa and 27°C and discharges the air at 379 KPa to a cylindrical tank. The bore and stroke are 355 mm and 381 mm respectively with a 5% clearance. If the surrounding air is at 100 KPa and 20°C while the compression and re-expansion processes are $PV^{1.3} = C$, determine:
 - Free air capacity in m^3/sec
 - Power of the compressor

(ANS. a. $0.2455\text{m}^3/\text{sec}$ b. 39.9 KW)
- A single-stage, single-cylinder air compressor is rated at $4.25 \text{ m}^3/\text{min}$ of air. Suction conditions are 1 atm and 27°C and discharge pressure is 1034 KPa. The compression process follows the equation $PV^{1.35} = C$.

- Determine the power required to compress the air.
- What is the engine KW power needed to drive the unit if combined engine-compressor efficiency is 84%?
- If the compressor is to run two-stage at optimum intercooler pressure with perfect intercooling, what will be the percentage of power saved?

(ANS. 22.87 KW , 27.23 KW , c. 15%)

- A reciprocating two-stage air compressor takes in air at atmospheric pressure and 27°C . The flash point of the oil used in the air cylinder is 260°C . Safety precautions limits the temperature of the air in the high pressure cylinder to be 28°C below the flash point of the oil. Assuming perfect intercooling and no pressure drop through the intercooler, what would be the allowable working pressure of this compressor if the compression curve follows the equation $PV^{1.34} = C$?
(ANS. 6144 KPa)

- A two-cylinder single-acting air compressor is directly coupled to an electric motor running at 1000 rpm. Other data are as follows:

Size of each cylinder: 150 mm x 200 mm
Clearance volume: 10% of displacement
Polytropic exponent n: 1.36
Air molecular mass: 29

Calculate the following:

- The volume rate of air delivery in terms of standard air for a delivery pressure 8 times ambient pressure under ambient conditions of 300°K and 1 bar
- Shaft power required if mechanical efficiency is 81%.

(ANS. a. $4.374 \text{ m}^3/\text{min}$, b. 25.75 KW)

5. A two-stage reciprocating single-acting air compressor has a rated capacity of 80m^3 of free air 27°C and 1.033 kg/cm^2 abs when running at 600 rpm. The absolute discharge pressure is 30 kg/cm^2 and the air is discharged to an air receiver of 1,250 liters capacity. The compressor has two low-pressure cylinders each 127 mm diameter and one high-pressure cylinder of 69.85 mm diameter, piston stroke is 101.6 mm. The compressor is driven by a 1750 rpm, 3-phase, 60 hertz, 460 volt motor thru V-belts with transmission efficiency of 95%. Determine:
- Intercooler pressure in kg/cm^2
 - Volumetric efficiency
 - BHP at an efficiency of 85% and polytropic exponent n of 1.35
 - KW of driving motor

(ANS. a. 5.567 kg/cm^2 , b/ 86.33%, c. 15 hp, 11.78 KW)

6. A three-stage, single-acting, Diesel engine-driven reciprocating air compressor is guaranteed to deliver $170\text{ m}^3/\text{h}$ free air at suction conditions of 1.03 kg/cm^2 abs and 27°C and discharge pressure of 35 kg/cm^2 abs. Test results show that the polytropic exponent for both compression and re-expansion processes is 1.34 and the mechanical efficiency of the compressor is 80%. Assuming perfect intercooling with optimum interstage pressure, determine:
- The interstage pressures in kg/cm^2 abs
 - The brake horsepower of the engine drive
 - The fuel consumption in kg/h of the Diesel engine if the brake thermal efficiency is 30% and the fuel used has a heating value of 10,700 kcal/kg.

(ANS. a. 3.336 kg/cm^2 abs, 10.806 kg/cm^2 abs; b. 32.77 bhp, c. 6.55 kg/h)

PUMPS

1. A centrifugal pump delivers $227\text{ m}^3/\text{hr}$ of water from a source 4 meters below the pump to a pressure tank whose pressure is 2.8 kg/cm^2 . Friction loss estimates are 2 meters in the suction line and 1 meter in the discharge line. The diameter of the suction pipe is 250 mm and the discharge pipe is 200 mm. Find:
- The water horsepower
 - The KW rating of the driving motor if the pump efficiency is 70%.

(ANS. a. 29 hp, b. 31 KW)

2. A pump is to deliver 80 GPM of water at 60°C with a discharge pressure of 1000 KPag. Suction pressure indicates 50 mm of mercury vacuum. The diameter of the suction and discharge pipes are 5 inches and 4 inches, respectively. If the pump has an efficiency of 70%, determine the brake horsepower of the pump.

(ANS. 9.732 hp)

3. An acceptance test was conducted on a centrifugal pump having a suction pipe 25.4 cm in diameter and a discharge pipe 12.7 cm in diameter. Flow was $186\text{ m}^3/\text{hr}$ of clear cold water. Pressure at suction was 114.3 mm Hg vac and discharge pressure was 107 KPag at a point 91 cm above the point where the suction pressure was measured. Input to the pump was 15 hp.
- Determine the pump efficiency
 - If the pump runs at 1750 rpm, what new flow, head and brake hp would be developed and required if the pump speed were increased to 3500 rpm? Assume constant efficiency.

(ANS a. 64.4%, b. $372\text{m}^3/\text{hr}$, 120 bhp)

4. A motor driven pump draws water from an open reservoir A and lifts to an open reservoir B. Suction and discharge pipes are 150 mm and 100 mm in inside diameter, respectively. The loss of head in the suction line is 3 times the velocity head in the 150 mm pipe and the loss of head in the discharge line is 20 times the velocity head in the 100 mm pipeline. Water level at reservoir A is at elevation 6m and that of reservoir B at elevation 75m. Pump centerline is at elevation 2m. Overall efficiency of the system is 73%. Determine the following:
 - a. Power input of the motor
 - b. Reading in KPa of the pressure gauges installed just at the outlet and inlet of the pump

Discharge is 10 li/sec.

(ANS. a. 9.51 KW, b. $P_o = 732.34$ KPag, $P_i = 38.76$ KPag)

5. A boiler feed pump receives 40 liters per second at 180°C. It operates against a total head of 900 meters with an efficiency of 60%. Determine:
 - a. The enthalpy leaving the pump in kJ/kg
 - b. Power output of the driving motor in kilowatts
 - c. Discharge pressure in KPa at suction pressure of 4 MPa

(ANS. a. 773.57 kJ/kg, b. 523.3 KW, c. 11850.3 KPa)

6. A plant has installed a single suction centrifugal pump with a discharge of 68 m³/hr under 60 m head and running at 1200 rpm. It is proposed to install another pump with double suction but of the same type to operate at 30 m head and deliver 90 m³/hr.
 - a. Determine the speed of the proposed pump
 - b. What must be the impeller diameter of the proposed pump if the diameter of the existing pump is 150 mm?

(ANS. a. 877 rpm, b. 145 mm)

7. A 4 m³/hr pump delivers water to a pressure tank. At the start, the gage reads 138 KPa until it reads 276 KPa and then the pump was shut off. The volume of the tank is 160 liters. At 276 KPa the water occupied 2/3 of the tank is 160 liters. At 276 KPa the water occupied 2.3 of the tank volume.
 - a. Determine the volume of water that can be taken out until the gage reads 138 KPa
 - b. If 1 m³/hr of water is constantly used, in how many minutes from 138 will the pump run until the gage reads 276 KPa?

(ANS. a. 30.75 li, b. 0.615 min)

FANS AND BLOWERS

1. Find the air horsepower of an industrial fan that delivers 25.98 m³/sec of air through a 0.915 m x 1.22 m outlet. Static pressure is 127 mm of water. Air temperature is 21°C and the barometric pressure is 700 mm of mercury.

(ANS. 53.82 HP)
2. A forced draft fan is used to provide the combustion air requirements for a boiler that burns coal at the rate of 10 metric tons per hour. The air requirements are 100,000 m³/hr, air is being provided under 150 mm water gauge by a fan to deliver at a total pressure of 150 mm water gauge. Find the size of the driving motor in KW.

(ANS. 68.1 KW)
3. At 101.325 KPa and 21°C, an industrial fan develops a brake power of 100 KW and head of 120mm water gage. What will be power and head if this fan is operated at 98 KPa and 32°C at the same speed?

(ANS. 93.17 KW, 111.8 mm water gage)

REFRIGERATION

1. An ammonia refrigeration system operating on the simple vapor compression cycle is designed to have a capacity of 100 tons of refrigeration. The condensing temperature is 24°C and the evaporating temperature is -18°C . Find the following:
 - a. Draw the P-h diagram
 - b. Refrigerating effect in kJ/kg
 - c. Circulation rate of refrigerant in kg/sec
 - d. Power requirement of the compressor in KW
 - e. Volume flow per ton in $\text{m}^3/\text{min-ton}$
 - f. Coefficient of performance
 - g. Power per ton in kw/ton

(ANS. b. 1127 kJ/kg, c. 0.312 kg/sec, d. 65.54 KW, e. $0.1072 \text{ m}^3/\text{min-ton}$, f. 5.12, g. 0.6554 kw/ton)

2. An ammonia compressor operates between the standard temperature limits of 30°C and -15°C . Determine the COP for the following conditions:
 - a. Ideal saturation cycle
 - b. Vapor at suction to compressor superheated by 3°C
3. An ammonia compressor operates at a condensing temperature of 30°C and evaporator temperature of -14°C . The suction vapor enters the compressor at -7°C . The liquid at the expansion valve is after cooled to 24°C . For a refrigerating load of 100 KW of refrigeration, determine:
 - a. Mass of ammonia circulated in kg/min
 - b. Compressor work in KW

(ANS. 5.204 kg/min, b. 19.25 KW)

4. A vapor compression system using Freon-12 as refrigerant includes a liquid-to-suction heat exchanger. Saturated liquid at 38°C coming from the condenser is cooled to 27°C with vapor from the evaporator at -10°C . Compression is isentropic. Calculate the coefficient of performance of the system.

(ANS. 4.22)

5. An ammonia compressor operates at a condensing temperature of 30°C and evaporator temperature of -14°C . The suction vapor enters the compressor at -7°C . The liquid at the expansion valve is after cooled to 24°C and the compression is isentropic. Determine the following:
 - a. Weight in kg ammonia circulated per ton of refrigeration
 - b. The work per ton
 - c. The piston displacement per ton of refrigeration if the volumetric efficiency is 90%
 - d. The percentage flash gas after expansion

(ANS. a. 0.183 kg/min-TR, b. 0.677 kw/TR, c. $0.1057 \text{ m}^3/\text{min-TR}$ d. 13.52%)

6. A 140 mm x 140 mm twin cylinder, single-acting Freon-12 compressor running at 500 rpm, carries an air conditioning load of 142,433 kJ/hr while operating at 344 KPa suction and 1241 KPa discharge pressure. If the discharge pressure were raised to 1343 KPa, at what speed should the compressor be run to have the same load, assuming the volumetric efficiency remains the same.

(ANS. 518 rpm)

7. A vapor compression refrigeration system is designed to cool 9,500 liters of milk received each day from an initial temperature of 27°C to a final temperature of 3.33°C in 3 hours. The density of milk is 1.03 kg/liter, and the specific heat is $0.94 \text{ kcal/kg-}^{\circ}\text{C}$.

- a. Determine the refrigerating capacity in tons of refrigeration
 - b. Determine the size of the drive motor in KW if the actual coefficient of performance is 5.

(ANS. 14.4 TR, b. 10.126 KW)
8. It is desired to design a Freon-12 ice making unit to produce 5 metric tons of ice at -9.5°C from raw water at 26.7°C in 20-hour operation. The condenser temperature is -16°C . Find
 - a. The tons of refrigeration capacity
 - b. The KW capacity of the driving motor assuming a compressor efficiency of 75%.

(ANS. a. 9.2 tons ref, b. 9.85 KW)

AIR CONDITIONING

1. In an air-conditioning unit $3.5 \text{ m}^3/\text{s}$ of air at 27°C dry-bulb temperature, 50 percent relative humidity, and standard atmospheric pressure enters the unit. The leaving condition of the air is 13°C dry-bulb temperature and 90 percent relative humidity. Using properties from the psychometric chart,
 - a. Calculate the refrigerating capacity in kilowatts, and
 - b. Determine the rate of water removal from the air

(ANS. a. 88 KW, b. 0.0113 kg/s)
2. In a cooling tower, $28.34 \text{ m}^3/\text{min}$ of air at $32^{\circ}\text{C}_{\text{db}}$ and $24^{\circ}\text{C}_{\text{wb}}$ enter the tower and leave saturated at 29°C .
 - a. To what temperature can the air stream cool a spray of water which enters at 38°C with a flow of $34 \text{ kg}/\text{min}$ of water?
 - b. How many kg per hour of make up water is needed to compensate for the water that is evaporated
 - c. What is the efficiency of the cooling tower?

(ANS. a. 33°C , b. 19.21 kg/hr, c. 35.7%)

3. A rotary dryer is to deliver 1.4 MTons per hour of copra with moisture content not to exceed 3%. The wet feed contains 40% moisture. The air enters the dryer with a humidity ratio of $0.016 \text{ kg}/\text{kg}$ dry air and leaves at 60°C and 100% relative humidity. If the dryer operates at atmospheric pressure, determine:
 - a. The amount of wet feed in MTons per hour
 - b. The amount of air entering the dryer in kg per hour

(ANS. a. 2.425 MTons/hr, b. 6801.5 kg/hr)
4. The cooling load calculations on a theater show that at design conditions the sensible heat load is 200 KW and the latent heat load is 70KW. The indoor design conditions are 26°C dry bulb and 50% relative humidity. Air is to be supplied to the theater at 16°C while the outside air is at 30°C dry bulb and 60% relative humidity. Take ventilating air as 25% of the supply air. Calculate the tons of refrigeration required by the conditioner.

(ANS. 102.4 TR)

INDUSTRIAL EQUIPMENT (DRYER)

1. A rotary dryer produces 12 metric tons per hour of dried sand containing 0.5% moisture from a wet feed containing 10% sand is 115°C . Fuel used per hour of bunker oil is 165 liters, with a HHV of 41,145 kJ/liter. Specific heat of sand is $0.21 \text{ Btu}/\text{lb}^{\circ}\text{F}$. Neglecting radiation loss, calculate the efficiency of the sand dryer.

(ANS. 61%)

SECTION

3

POWER AND
INDUSTRIAL
PLANT
ENGINEERING

SIMPLE, COMBINED AND VARIABLE STRESSES

$$\text{Stress (S)} = \frac{\text{Force or Load}}{\text{Area}}, \frac{\text{lb}}{\text{in}^2}, \frac{\text{kg}}{\text{m}^2}, \frac{\text{KN}}{\text{m}^2}$$

Ultimate Stress (S_u) = stress that would cause failure

Yield Stress (S_y) = maximum stress without causing deformation
(within elastic limit)

Allowable Stress (S_d) = stress used in determining the size of a member (allowable stress or less)
 $= \frac{S_u}{FS} \text{ or } \frac{S_y}{FS}$

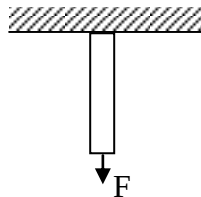
Working Stress (S_w) = stress actually occurring under operating conditions

Endurance Limit or Fatigue Limit (S_e, S_n) = maximum stress that will not cause failure when the force is reversed indefinitely

Residual Stress = internal, inherent, trapped, locked-up body stress that exists within a material as a result of things other than the external loading such as cold working, heating or cooling, etching, repeated stressing and electroplating

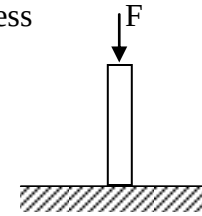
Simple or Direct Stresses:

1. Tensile Stress



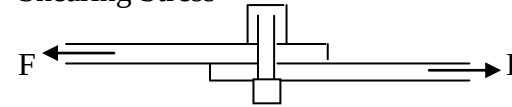
$$s_t = F/A$$

2. Compressive Stress



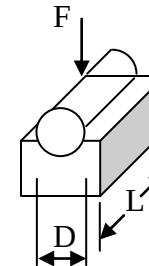
$$s_c = F/A$$

3. Shearing Stress



$$s_s = F/A$$

4. Bearing Stress



$$s_b = F/DL$$

5. Torsional Stress

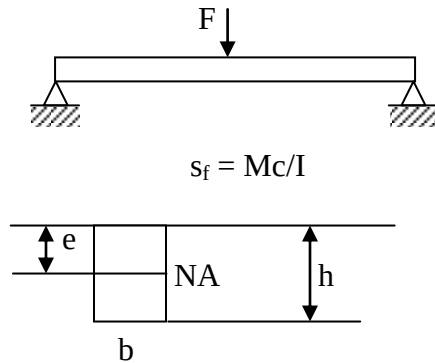
$$s_s = Tc/J$$

$$s_s = 16T/\pi D^3$$

T = torque

J = polar moment of inertia

6. Bending (Flexural) Stress



where: M = moment
 c = distance of farthest fiber neutral axis (NA)
 I = moment of inertia about the neutral axis
 $= bh^3/12$ for rectangular section

7. Strain; Elongation

$$\text{Strain} = Y/L$$

$$\text{Stress} = F/A$$

E = Modulus of Elasticity
 (Young's Modulus)

$$= \frac{F/A}{Y/L}$$

$$Y = FL/AE = s(L/E)$$

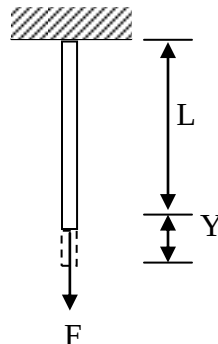
Y = elongation (or shortening)

L = length

F = force

A = area

s = stress



8. Thermal Elongation; Stress

$$Y = k L (t_2 - t_1)$$

Y = elongation due to temperature change, m

k = coefficient of thermal expansion, $m/m-^{\circ}C$

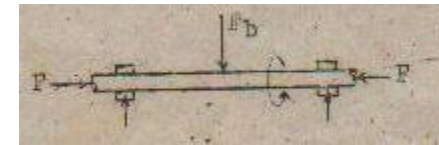
t_1 = initial temperature, $^{\circ}C$

t_2 = final temperature, $^{\circ}C$

Combined and Induced Stresses

1. Combined Axial and Flexural Stress

$$S = F/A + Mc/I$$



2. Maximum shear induced by external tension and shearing loads (Vallance p. 66)

$$S_s \text{ max} = \frac{1}{2} \sqrt{S_t^2 + 4S_s^2}$$

* Induced stresses are those tensile, compressive, and shear stresses induced within a body by application of external forces and/or torques onto the body.

3. Maximum normal stress induced by external tension and shearing loads (Vallance p.66)

$$S_n \text{ max} = S_t/2 + \frac{1}{2} \sqrt{S_t^2 + 4S_s^2}$$

Relation between shearing and tensile stress based on theories of failure: (Vallance p.73)

$$S_t \text{ max} = S_{ty}$$

$$S_s \text{ max} = S_{ty}/2$$

where: S_{ty} = yield stress in tension

Variable Stress (Faires p. 107)

$$\frac{1}{N} = \frac{S_m}{S_y} + \frac{S_a}{S_n}$$

where: N = factor of safety

S_y = yield point

S_n = endurance limit

S_m = mean stress

$$= S_{\max} + S_{\min} / 2$$

S_a = variable component stress

$$= \frac{S_{\max} - S_{\min}}{2}$$

$S_{\max}$ = maximum stress

$S_{\min}$ = minimum stress

ENGINEERING MATERIALS

Some Important Properties (Faires, pp 42-44)

Brittleness – tendency to fracture without appreciable deformation

Ductility – that property that permits permanent deformation before fracture in tension

Elasticity – ability of a material to be deformed and to return to the original shape

Hardness – resistance to indentation

Machinability – relative ease with which a material can be cut

Malleability – susceptibility to extreme deformation in rolling and hammering

Plasticity – ability of a metal to be deformed considerably without rupture

Stiffness – ability to resist deformation

Toughness – ability to withstand shock load without breaking

Heat Treatment Practices (Faires, pp 45-46, p 53)

Annealing – heating above the transformation range, usually 1300 to 1350°F, and cooling slowly to soften the metal and increase ease in machining

Hardening – heating above the transformation temperature and quenching usually in oil, for the purpose of increasing the hardness

Normalizing – heating to some 100°F above the transformation range with subsequent cooling to below that range in still air at room temperature to produce uniform structure of the metal

Stress Relieving – heating to a subcritical temperature, about 110 to 1300°F and holding at that temperature for a suitable time for the purpose of reducing internal residual stresses

Tempering – reheating to a temperature below the transformation range, followed by any desired rate of cooling to attain the desired properties of the metal

Case hardening – process of hardening the surface or case of a metal to provide a hard, wear-resistant surface while retaining toughness in the core

Metal Forming Processes

Rolling – process of forming metal parts by the use of dies after the metal is heated to its plastic range

Forging – process of forming metal parts by the use of powerful pressure from a hammer or press to obtain the desired shape, after the metal has been heated to its plastic range

AISI and SAE Designation of Steel (Fairies p. 47)

AISI Y XXXX SAE XXXX

Y is a letter, used in AISI only, to indicate the method of manufacturing; first number (or first two numbers) represents class of steel; second number indicates the approximate percentage of the principal alloying element; last two numbers indicate 100 times the approximate percentage of carbon present in the metal.

(From Faires p 48)

Steel	SAE	Steel	SAE
Plain carbon	10XX	Molybdenum-chromium-	47XX
Free Cutting	11XX	nickel	48XX
Manganese	13XX	Chromium	5XXX
Boron	14XX	heat and corrosion	514XX
Nickel	2XXX	resistant	515XX
Nickel-chromium	3XXX	Chromium-vanadium	6XXX
heat and corrosion		Nickel-chromium-	
resistant	303XX	molybdenum	8XXX
Molybdenum	4XXX	Silicon-manganese	92XX
Molybdenum-chromium	41XX	Nickel-chromium-	
Molybdenum-chromium-		molybdenum	
Nickel	43XX	(except 92XX)	9XXX
Molybdenum-nickel	46XX		

Commonly Used Metals (Faires pp 57-62)

Metal	Description	Uses
Wrought Iron	Iron by hammering and rolling operations	Rivets, welded steam and water pipes
Cast Iron	Iron formed by casting	Cylinder block, brake drum, gears, machine tool ways
Malleable Iron	Heat treated cast iron which is strong, ductile and easily machined	Gears
Nodular Cast Iron	Cast Iron added with magnesium, and cerium to become stronger and more ductile	Casing, crankshafts, hubs, rolls, forming dies
Cast Steel	Steel formed by casting	Gears, crankshafts, cylinder barrels
Wrought Steel	Steel formed by hammering, rolling or drawing	Bars, tubes
Stainless Steel	Steel obtained by addition of chromium	Steam turbine blades, valves
Brass	Alloy of copper and zinc	Propeller shaft, piston Rods, screws, etc.
Bronze	Alloy of copper, tin and Phosphorous	Clutch disks, pump rods, shafts, valve stems, etc

Tabulated Properties of Materials

Tables of different materials shows the following important properties: ultimate strength, yield stress, endurance limit, BHN modulus of elasticity, elongation, density

Tables in Faires:

Tables AT 4 – AT 11, pp 568 – 582 (Appendix)

Tables in Vallance:

Table 2 – 4, p 25, Table 2 – 5, p 27, Table 2 – 6, p 30

THIN-WALL PRESSURE VESSELS (Faires: pp 34-35; Vallance: pp 443-445)

Definition: A thin-wall pressure vessel is one in which the ration of the wall thickness to the diameter is less than 0.07.

Thin-Wall Cylinder:

$$S_t = PD_i / 2t \quad \text{where: } P = \text{internal pressure}$$
$$D_i = \text{inside diameter}$$
$$t = \text{wall thickness}$$
$$S_t = \text{tangential (tensile) stress}$$

When there is a seam or joint, the oint efficiency E must be considered, thus

$$S_t = PD_i / 2Et$$

Thin-Wall Sphere:

$$S_t = PD_i / 4t$$

SHAFTS

(Faires: pp 263-280; Vallance: pp 177-194)

Definitions:

Shaft – a rotating member transmitting power

Axle – a stationary member carrying rotating wheels, pulleys, etc.

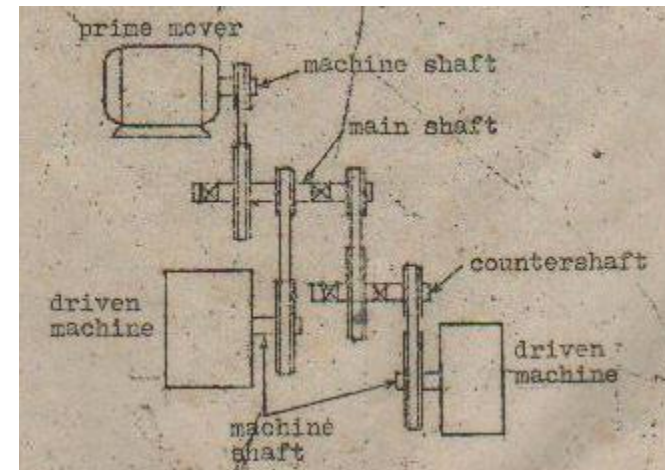
Spindle – a short shaft or axle on machines

Machine shaft – a shaft which is an integral part of the machine

Transmission Shaft – shaft which is used to transmit power between the source and the machine absorbing the power

Line Shaft or main shaft – transmission shaft driven by the prime mover

Countershaft, jackshaft, headshaft, short shaft – transmission shaft intermediate between the line shaft and the driven machine



Commercial Sizes of Shafts, Inches (Faires: p 269; Vallance p 181):

(1/2, 9/16, 5/8, 11/16, 3/4, 13/16, 7/8)

15/16, 1 3/16, 1 7/16, 1 11/16, 1 15/16, 2 3/16, 2 7/16, 2 15/16,

3 7/16, 3 15/16, 4 7/16, 4 15/16, 5 7/16, 5 15/16, 6 1/2, 7, 7 1/2, 8

Materials for Transmission Shafts: cold-rolled, hot-rolled, forged carbon steel

Relation of Power, Torque and Speed

$$P = 2 TN$$

$$T = Fr$$

Where: P = power transmitted (KW)
 T = torque or torsional moment (Kn-m)
 N = speed (rev/sec)
 F = transmitted load or tangential force (KN)
 r = radius (m)

Stresses in Shafts, Subject to Torsion Only

$$S_s = Tc / J \quad \text{and} \quad \theta = TL/JG$$

$$S_s = 16T / D^3 \quad (\text{for solid circular shaft})$$

where: S_s = torsional shear and stress

T = torque or torsional moment

c = distance from neutral axis to outermost fiber
 = radius (for solid circular shaft)

J = polar moment of inertia
 = $\pi/32 D^4$ (for solid circular shaft)

D = diameter of shaft

L = length of shaft

θ = angular deformation in length L, radians

G = modulus of rigidity in shear

For hollow circular shaft:

$$S_s = \frac{16TD_o}{\pi(D_o^4 - D_i^4)}$$

D_o = outside diameter
 D_i = inside diameter

Stresses in Solid Circular Shaft Subject to Torsion and Bending

$$S_s \text{ max} = (16/\pi D^3) \sqrt{M^2 + T^2}$$

$$S_t \text{ max} = (16/\pi D^3) M + \sqrt{M^2 + T^2}$$

M = bending moment

T = torsional moment

$S_s \text{ max}$ = maximum shear stress

$S_t \text{ max}$ = maximum tensile or compressive stress

Strength of Shaft with Assumed Allowable Stresses (PSME Code p 18)

For main power-transmitting shafts:

$$P = D^3 N / 80 \quad \text{or} \quad D = \sqrt[3]{80P/N}$$

For lineshafts carrying pulleys:

$$P = D^3 N / 53.5 \quad \text{or} \quad D = \sqrt[3]{53.5P/N}$$

For small, short shafts:

$$P = D^3 N / 38 \quad \text{or} \quad D = \sqrt[3]{38P/N}$$

where:

P = power transmitted in HP

D = diameter of shaft in inches

N = speed in rpm

KEYS

(Faires: pp 281-286; Vallance: pp 97-102)

Definitions:

Key – a machine member employed at the interface of a pair of mating male and female circular cross-sectional members to prevent relative angular motion between these mating members.

Keyway – a groove in the shaft and mating member to which the key fits.

Splines – permanent keys made integral with the shaft and fitting into keyways broached into the mating hub

Types of Keys:

Square key has a square cross-section with half of its depth sunk in the shaft and half in the hub.

Flat key has a rectangular cross-section with the smaller dimension placed in the radial direction with half sunk in the shaft and half in the hub and is used where the weakening of the shaft by the keyway is serious.

Round key has a circular cross-section.

Barth key is a square key with bottom two corners beveled.

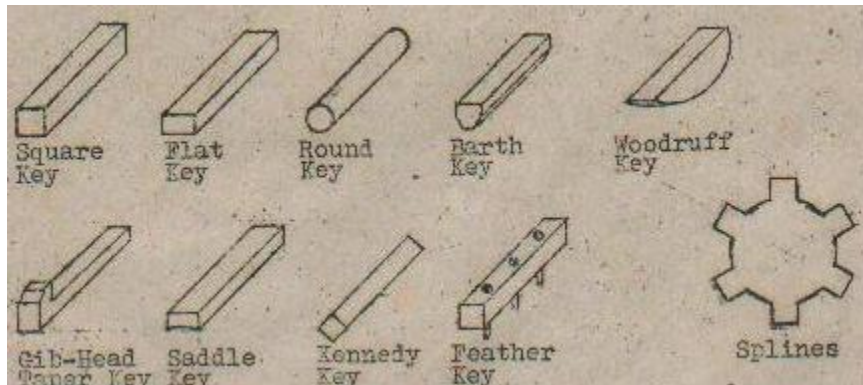
Woodruff key consists of one-half of a circular disk fitting into a rectangular keyway in the female member and a semicircular keyway in male member.

Gib-head taper key is a flat key with a special gib-head to facilitate easy driving and removal of the key.

Saddle key is a flat key used without a keyway in the shaft.

Kennedy keys are tapered square keys with the diagonal dimension in a circumferential direction.

Feather key is one which has tight fit into one member and a loose sliding fit in the other mating member thus allowing the hub to move along the shaft but prevents rotation on the shaft.



Stresses in Keys

$$F = T/r = T/(D/2)$$

F = transmitted load

T = torque

r = radius

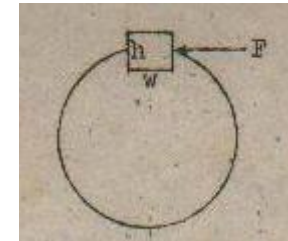
D = diameter

Crushing (Compressive) Stress:

$$S_c = F / [h/2 (L)]$$

Shearing Stress:

$$S_s = F / wL$$



When key and shaft are of same material: (Vallance p 102)

$$W = D/4 \text{ and } L = 1.2D$$

w = width of key

h = thickness of key

L = length of key

Tabulated dimensions of standard keys:

Square, Flat, Gib-head: Vallance p 100; faires p 594

Woodruff: Faies p 286

Splines: Faies p 287

COUPLINGS

(Faies: pp 290-297 Vallance: pp 331-339)

Definition:

Coupling – a mechanical device which is used to connect lengths of shafting permanently

Types of Couplings:

Rigid Couplings – couplings that do not allow angular, axial or rotational flexibility and used with collinear shafts

Flange Coupling – type of rigid coupling which consists of two halves of flanges connected to each other by bolts

Sleeve or Collar Coupling – rigid coupling which is a cylindrical collar pressed over the ends of two collinear shafts

Flexible Couplings – couplings which allow angularity to take care of misalignment of the shafts

Oldham coupling, chain coupling, flexible disk coupling, flexible gear type coupling, hydraulic coupling, universal joints, are examples of flexible couplings.

Stresses in Flange Coupling

F = total transmitted load on bolts
= Torque / $(D/2)$

F_b = force per bolt = $\frac{F}{\text{No. of bolts}}$

S_s = shear stress in bolts = $F_b / [\pi/4(d_2)]$

S_c = compressive stress on flange = F_b / td

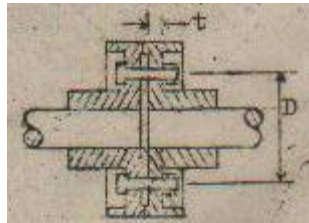
D = diameter of bolt circle

t = thickness of flange

d = diameter of bolt

Tabulated dimensions of flange couplings:

Kent (Design): p 15-19



FLYWHEELS (Faires: pp 533-537)

Definition:

Flywheel – a rotating energy reservoir which absorbs energy from a power source during a portion of the operating cycle and delivers that stored energy as useful work during the other portion of the cycle.

Machines in which flywheels are used: punch presses and shears, internal combustion engines, compressors, reciprocating, pumps and steam engines

Design Calculations:

Kinetic Energy = $\frac{1}{2} mv^2$

$KE = W/2g (V_1^2 - V_2^2)$

KE = kinetic energy released by flywheel

W = weight of flywheel

V_1 = maximum (operating) speed

= πDN_1

V_2 = minimum speed = πDN_2

D = mean diameter of flywheel

b = width of flywheel rim

t = thickness of flywheel rim

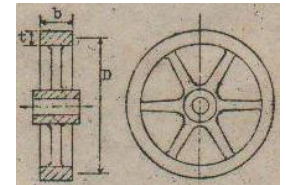
$W = W_r + W_{ah}$

W_r = weight of flywheel rim

W_{ah} = weight of arms and hub

$W_r = \pi Dbtw$

W = density of flywheel material



Coefficient of Fluctuation of Flywheel

$$C_f = \frac{V_1 - V_2}{V}$$

$$V = \frac{V_1 + V_2}{2}$$

C_f = coefficient of fluctuation

V_1 = maximum speed

V_2 = minimum speed

Tabulated values of coefficient of fluctuation:

Faires p 534

Energy requires to punch a metal:

$$E = \frac{1}{2} Ft = \frac{1}{2} S_{su} At$$

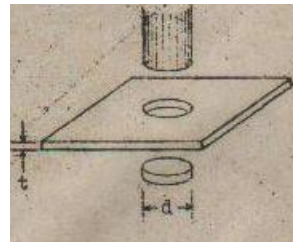
S_{su} = ultimate shearing stress

A = shear area

t = thickness of metal plate

For circular hole:

$$A = \pi dt$$



BOLTS AND SCREWS (Faires: pp 155-180; Vallance: pp 127-152)

Definitions:

Bolts and Screws are threaded fasteners which are used to hold together machine members which requires easy dismantling.

Bolts are provided with nuts; screws are without nuts.

Commonly used types of bolts and screws:

Machine bolt, stud bolt, eye bolt, U-bolt, stove bolt, cap screw, set screw

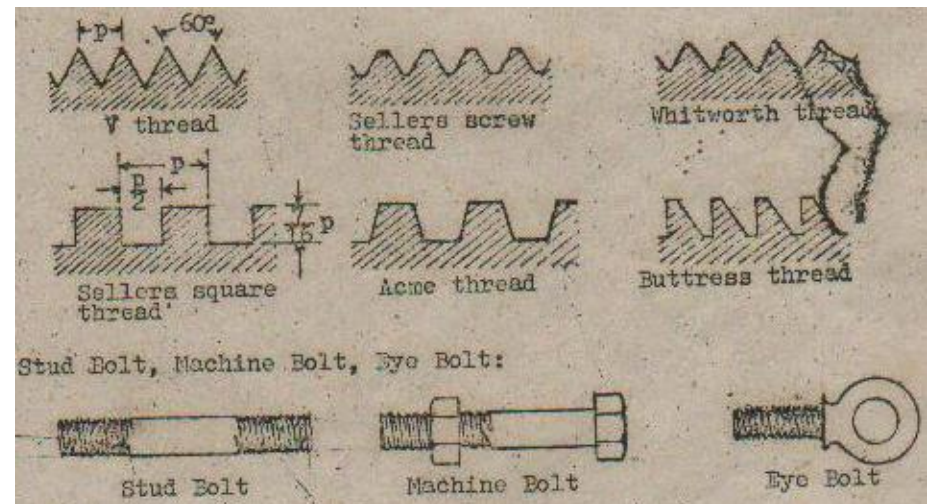
Types of Threads

UNC (Unified National Course) – for general use, except where other types are recommended

UNF (Unified National Fine) – frequently used in automotive and aircraft work and where a fine adjustment is required

UNEF (Unified National Extra Fine) – used in aeronautical equipment and where very fine adjustment is required

Forms of Threads



Definitions of Terms:

Pitch, p , is the axial distance between adjacent threads.

$$P = \frac{1}{\text{Number of threads per inch}}, \text{ in}$$

Load is the axial distance a thread advances in one revolution.
Major diameter is the outside diameter of the threads and is the nominal diameter.

Minor diameter or root diameter is the smallest diameter of the threads

Pitch diameter is the mean of the major and minor diameters.
Stress area is the area of an imaginary circle whose diameter is the mean of the pitch and minor diameters.

Tabulated data on threads:

Tables of data on threads show the nominal size, threads per inch, minor diameter and stress area.

Table in Vallance: Table 6-1, p 130

Table in faires: Table AT 14, p 588

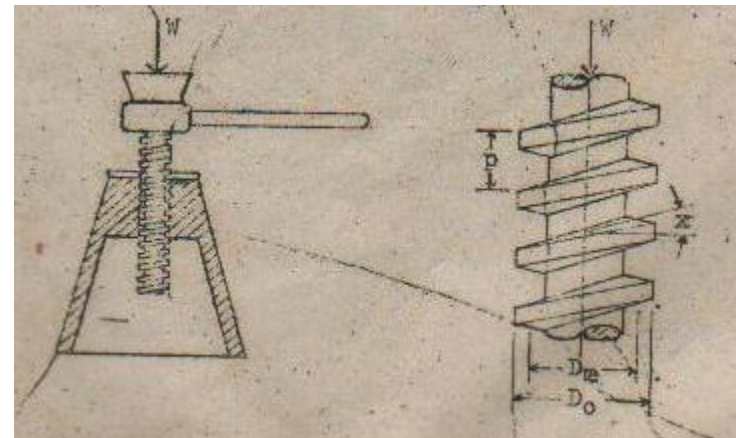
Formulas from Vallance and Faïres:

	Vallance	Faïres
Tensile Stress in Bolts	$S_w = C(A_r)^{0.418}$ (p 138) $F_a = C(A_r)^{1.418}$ where: S_w = permissible working stress F_a = applied load A_r = stress area $C = 5,000$ for carbon steel $= 15,000$ for alloy steel	$S_d = S_y/6 (A_s)^{1/2}$ (p 159) $F_e = \frac{S_y A_s}{6}$ ^{3/2} where: S_d = design tensile stress F_e = tensile load A_s = stress area S_y = yield stress
Depth of Tap	(p 134) $1.5 D$ in cast iron $1.25 D$ in steel where: D = nominal diameter	(p 178) $1.5 D$ in cast iron D in steel or wrought iron D = nominal diameter
Initial Tension and Torque	(p 134) $T = 0.2 F_a D$ where: T = torque	(p 159) $T = C D F_i$ where: $C = 0.20$ for as received

	F_a = initial tension D = nominal diameter	$= 0.15$ for lubricated D = nominal diameter F_i = initial tension
--	---	--

Power Screws (Faïres pp 246-249)

Power screws are used to move weights and machine parts and use square, acme or buttress threads.



P = pitch = the distance between adjacent threads, in.
 $= \frac{1}{\text{Number of threads per inch}}$, in

Lead = the distance the screw advances in one turn
 $= p$ (for single threaded screw)
 $= 2p$ (for double threaded screw)

Linear velocity = (rotational speed) (lead)

X = lead angle

D_m = mean diameter of threads

$$\tan x = \frac{\text{Lead}}{\pi D_m}$$

f = coefficient of friction of threads

T = torque applied to turn screw

$$T = \frac{WD_m(\tan x + f)}{2(1 - f \tan x)} \quad (\text{for square thread})$$

$$T = \frac{WD_m}{2} [(\cos \theta \tan x + f)/(\cos \theta - f \tan x)] \quad (\text{for Acme thread})$$

where: $\theta = 14.5^\circ$

For the Collar: (Faires, Eq. 18.2, p 496)

T_c = torque required to overcome collar friction

$$= \frac{f_c W(r_o + r_i)}{2}$$

Where: r_o = outside radius of collar

r_i = inside radius of collar

f_c = coefficient of friction of collar

Total torque required to operate screw = $T + T_c$

Efficiency of power screw (Vallance p 147)

Efficiency = $\frac{\text{Useful work}}{\text{Work input}}$

$$= \frac{\tan x (1 - f \tan x)}{\tan x + f + \frac{f_c d_c}{D_m} (1 - f \tan x)}$$

(for square thread)

$$= \frac{\tan x (\cos \theta - f \sin x)}{\tan x \cos \theta + f \sin x + \frac{f_c D_c}{D_m} (\cos \theta - f \sin x)}$$

(for Acme thread, where: $\theta = 14.5^\circ$)

D_e = mean diameter of the collar

$$= \frac{D_o + D_i}{2}$$

SPRINGS

(Faires: pp 183-210; Vallance: pp 309-329)

Uses of springs:

1. to absorb energy or shock loads, as in automobile shock absorbers
2. to maintain contact between machine members, as in valves and clutches
3. to act as source of energy, as in clocks
4. to serve as measuring device, as in spring scales

Types of springs:

Helical, compression, tension, and torsion; conical; spiral; disk (Belleville); leaf spring

Materials for springs:

Oil-tempered spring wire, music wire, hard-drawn spring wire, carbon steel, chrome-vanadium steel, chrome-silicon steel, stainless steel

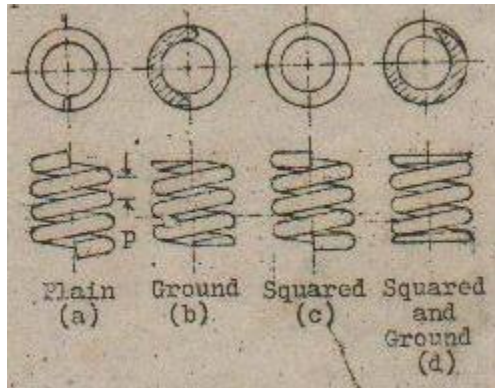
Tabulated data on springs:

Tables of springs give the following data: wire size, ultimate stress, yield stress, modulus of elasticity and rigidity

Tables in Vallance: Table 13-1, p 316; Table 13-2, p 317

Table in Faires: Table AT 17, p 590

Types of ends of coil springs:



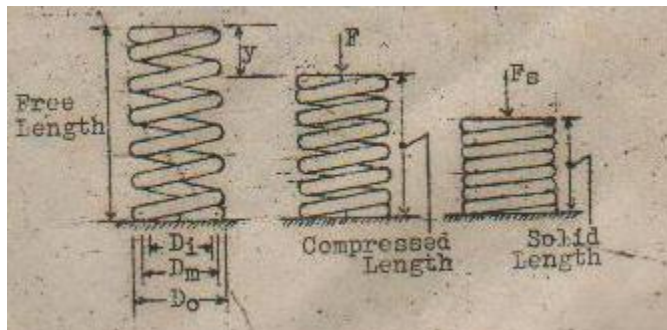
	Actual no. of coils	Solid Length	Free Length
(a)	n	$(n+1)d$	$np+d$
(b)	n	nd	np
(c)	$n+2$	$(n+3)d$	$np+3d$
(d)	$n+2$	$(n+2)d$	$np+2d$

n = effective number of coils

p = pitch

d = diameter of the wire

Stress and Deflection of Coil Springs (Vallance pp 310-312)



$$S_s = K (SFD_m / \pi d^3)$$

$$K = \frac{4C_1}{40-4} + \frac{0.615}{0} \quad (\text{Free length})$$

$$C = D_m/d \quad (\text{Spring index})$$

$$y = 8FG^3n / Gd$$

where:

S_s = torsional stress in the wire

F = axial load

D_m = mean diameter

d = wire diameter

y = deflection

n = effective number of coils

G = modulus of rigidity

Spring Rate or spring scale (Faires p 186)

Spring rate = F/y (Usually lb/in)

$$= \frac{F_2 - F_1}{y_2 - y_1}$$

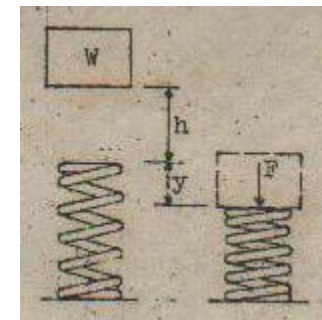
$$y_2 - y_1$$

Impact load on springs:

$$W(h+y) = F(y/2)$$

where: F = maximum force on the spring

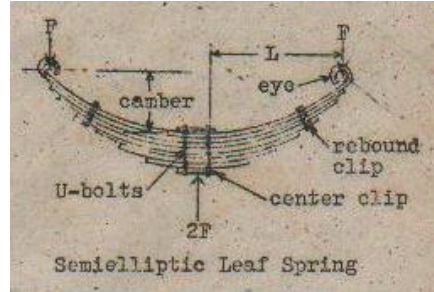
y = deflection of the spring



Leaf Springs (Vallance pp 322-323)

$$S_f = \frac{18FL}{bt^2(2n_g + 3n_f)}$$

$$y = \frac{12FL^3}{bt^3E(2n_g + 3n_f)}$$



where:

S_f = flexural stress

F = load at the supports

L = distance of force F to produce maximum moment

b = width of plates

t = thickness of plates

n_g = number of graduated leaves

n_f = number of full length leaves

y = deflection of the spring

BELTS

(Faires: pp 441-463; Vallance: pp 377-397)

Types of transmission belts:

Flat belt: used with flat pulleys and allows long distance between shafts

V-belt: used with sheaves or grooved pulleys and provides stronger grip at short distance between shafts

Toothed belt: paired with toothed pulleys and used as timing belt where speed ratio must be maintained

Materials for transmission belts:

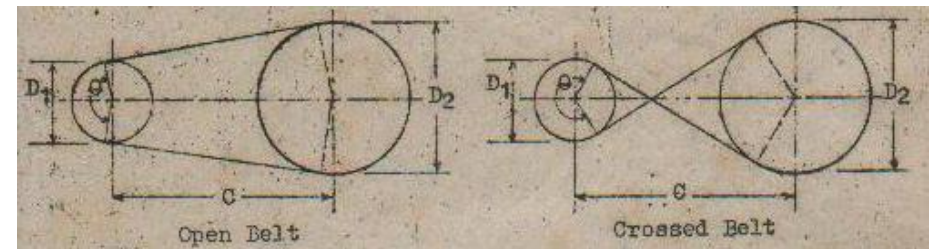
Oak-tanned leather is the standard material for the flat belts.

Chrome leather is used where very pliable material is desired.

Rubber belt is used when exposed to moisture, acids and alkalies.

Fabric and canvas belts are used for light power transmission.

Length and Arc of Contact of Flat Belts:



$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C}$$

$$\theta = \pi \pm 2\sin^{-1} \frac{R-r}{C} = \pi \pm \frac{D_2 - D_1}{C}$$

+ sign for larger pulley

- sign for smaller pulley

where: L = length of belt

D_1 = diameter of smaller pulley

D_2 = diameter of larger pulley

R = radius of larger pulley

r = radius of smaller pulley

θ = arc of contact, radians

C = center distance

Speed ratio; relation of speed and diameter

$$\text{Speed ratio} = N_1 / N_2$$

$$D_1 N_1 = D_2 N_2$$

where: N_1 = speed of smaller pulley
(usually the driver)

N_2 = speed of the larger pulley
(usually the driven)

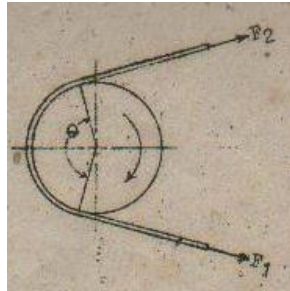
D_1 = diameter of smaller pulley

D_2 = diameter of larger pulley

Tensions in Belts

Neglecting centrifugal tension
(slow velocity)

$$F_1 / F_2 = e^{f \theta}$$



Where: F_c = centrifugal tension = $12wbv^2 / g$

w = belt weight, lb/in³

b = belt width, in

t = belt thickness, in

v = belt velocity, feet per second

Net belt pull (tangential force on pulley)

$$= F_1 - F_2$$

Power transmitted by belt:

$$T = \text{torque} = (F_1 - F_2)r$$

where: r = radius of pulley

$$P = \text{power} = 2 \pi TN$$

Stress in belt:

$$S_w = F_1 / bt$$

where: S_w = working stress = 300 psi in leather belts

F_1 = tension in tight side

Formulas relating power, stress, etc: (Vallance p 383):

$$hp = \frac{(F_1 - F_2)v}{550}$$

$$Bt = \frac{550hp}{V(S_w - 12wbv^2/g)} \frac{e^{f \theta}}{e^{f \theta} - 1}$$

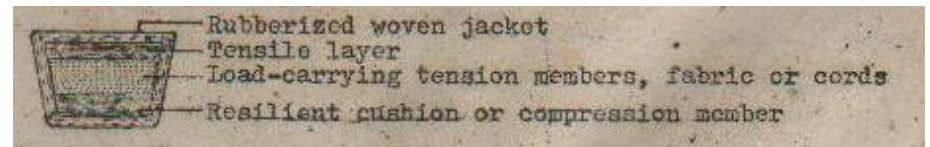
Tabulated data on horsepower rating of belts:

Vallance: Table 16-6, p 387

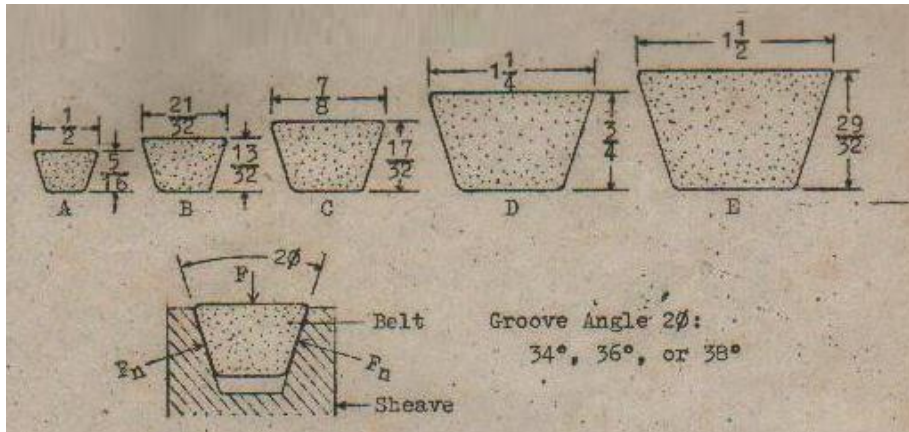
Faires: Table 17.1, p 450

V-Belts (PSME code pp 19-23)

Construction of V-Belt:



Standard V-belt and sheave dimensions:



Belt Length and Center Distance; Arc of Contact:

$$L = 2C + 1.57(D+d) + \frac{(D-d)^2}{4C}$$

$$C = \frac{b}{16} + \frac{\sqrt{b^2 - 32(D-d)^2}}{16}$$

$$\begin{aligned} \text{Arc of Contact on Small Sheave} \\ = 180^\circ - \frac{(D-d)60^\circ}{C} \end{aligned}$$

where:

L = pitch length of belt

C = center distance

D = pitch diameter of large sheave

d = pitch diameter of small sheave

$$b = 4L - 6.28 (D+d)$$

Standard Pitch Length and Designation of V-belts:

Table 3.3, p21 – PSME Code

Example: B75 is Section B V-belt with length of 76.8 inches

Horsepower rating for V-belts:

$$HP = XS^{0.91} - YS/d_e - ZS^3$$

where: HP = recommended horsepower

X, Y, Z are constants (Table 3.6)

S = belt speed in thousands of feet per minute

D_e = equivalent diameter of small sheave which is equal to pitch diameter multiplied by small diameter factor (Table 3.9)

Design procedure in determining the number of V-belts required:

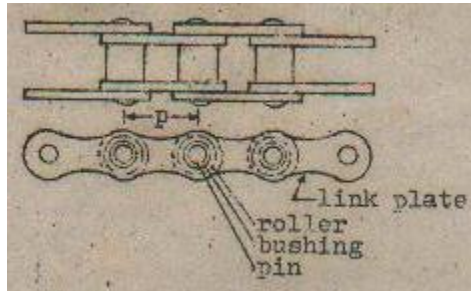
Given: Size of belt, sheave diameters, speed, power transmitted

1. Find the length of the belt from Table 3.3.
2. Solve for the center distance and the arc of contact.
3. Find the values of X, Y and Z from Table 3.6.
4. Solve for the speed ratio and find the small diameter factor from Table 3.9, then solve for d_e .
5. Compute the HP rating per belt.
6. Find the length correction factor from table 3.7 and arc of contact correction factor from Table 3.8, then solve for the corrected HP rating per belt.
7. Find the service factor from Table 3.5, then divide the corrected power transmitted by the HP rating per belt.

ROLLER CHAINS

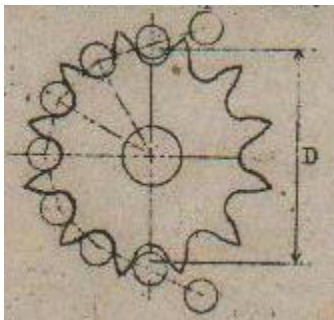
(PSME Code: pp 23-83; Vallance: pp 399-416)

Construction of Roller Chain:



p = pitch of chain
= distance between centers of adjacent rollers

Construction of Sprocket:



$$D = \frac{p}{\sin(180/T)}$$

where: D = pitch diameter
 p = pitch chain
 T = number of teeth

Designation of Chain Sizes:

Chain No.	25	35	40	50	60	80	100	120	140	160	200
Pitch, in.	1/4	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	1 3/4	2	2 1/2

Tabulated Data on Roller Chains:

Tables of roller chains gave the following data: Chain No., no. of teeth of small sprocket, speed, horsepower rating per strand, type of lubrication.

Tables in PSME Code: Table 3.11 pp 25-28

Tables in Vallance: Table 17-2 pp 406-408

Center Distance Between Sprockets:

$$C = p/8[2L - T - t + \sqrt{(2L - T - t)^2 - 0.810(T - t)^2}]$$

(PSME Code, p 25, corrected and using T and t for number of teeth)

Where: C = center distance (mm)
 p = pitch of chain (mm)
 L = length of chain in pitches
 T = number of teeth of large sprocket
 t = number of teeth of small sprocket

The center distance between sprockets, as general rule, should not be less than $1 \frac{1}{2}$ times the diameter of the larger sprocket and not less than 30 times the pitch nor more than about 50 times the pitch.

Length of Chain (Faires p 466):

$$L = 2C + \frac{T + t}{2} + \frac{(T - t)^2}{40C}$$

Where: L = length in pitches
 C = center distance in pitches (may contain a fraction)
 T = number of teeth of large sprocket
 t = number of teeth of small sprocket

Lubrication of Chains:

Types of Lubrication:

- Type I – manual lubrication applied at least once every 8 hours of operation
- II – drip lubrication
- III – bath or disc lubrication
- IV – oil stream lubrication

Recommended SAE viscosities for various operating temperatures:

Temperature	Viscosity
20-40 °F	SAE 20
40-100 °F	SAE 30
100-200 °F	SAE 40
120-140 °F	SAE 50

Design Procedure in determining the number of strands:

Given: Size of Chain, speed, number of teeth of small sprocket, power transmitted

1. Find the service factor from Table 3.5, (or Table 17.7, Faires, p 460), then compute the design power.
2. Find the horsepower rating per strand from Table 3.11.
3. Divide the design horsepower by the horsepower rating per strand to get the number of strands.

WIRE ROPES

(Faires: pp 469-477; Vallance pp 417-430)

Uses of Wire Ropes:

Elevators, hoists, cranes, drilling, conveyors, tramways, haulage devices, suspension cables, guy wires

Materials for Wire Ropes:

Plow steel (PS), mild plow steel (MPS), improved plow steel (IPS), wrought iron, cast steel, alloy steel, stainless steel, copper, bronze

Construction of Wire Rope:

The individual wires are first twisted into strands, and then the strands are twisted around a hemp or steel center to form the rope. Often the central element is an independent wire rope core (IWRC). In a Regular Lay rope, the wires and strands are twisted in opposite directions while in a Lang Lay rope, the wires and strands are twisted in the same direction.

Designation of Wire Rope:

First number is the number of strands, second number is the number of wires per strand.



Nominal diameter of rope (D_r) is the diameter of the circle that just encloses the rope.

Example: 6x7 IPS, 1" Diameter is the wire rope with 6 strands, 7 wires per strand, made of improved plow steel material, having nominal diameter of 1 inch.

Various rope sizes and their applications:

- 6x7 – haulage, tramways, guy wires
- 6x19 – general purpose rope, hoist, cranes, drilling, elevators
- 6x37 – high speed elevators, cranes, hoists
- 8x19 – extra flexible hoisting rope applications

Tabulated Data on Wire Ropes:

Faires: Table AT 28, p 605

Vallance: Table 18-1, p 421 and table 18-2, p 422

Design Calculations (Faires, pp 471-472; 605)

F_t = tensile force due to the load (including acceleration forces)

F_b = equivalent bending load due to the curvature of the sheave or drum

$$= S_b A_m$$

$$S_b = \frac{E D_w}{D_s} = \text{equivalent bending stress}$$

where: A_m = cross-section area of metal

D_w = wire diameter

D_s = sheave or drum diameter

E = modulus of elasticity = 30×10^6 psi for steel

F_u = breaking strength of rope

$$N = \text{factor of safety} = \frac{F_u - F_b}{F_t}$$

Recommended factors of safety for wire ropes, based on ultimate strength: (Vallance, Table 18-4, p 426)

Service	Factor of Safety
Elevators	8-12
Mine Hoists	2.5-5
Cranes, motor driven	4-6
hand powered	3-5
Derricks	3-5

GEARS

(Faires: p 355-440; Vallance: pp 255-308)

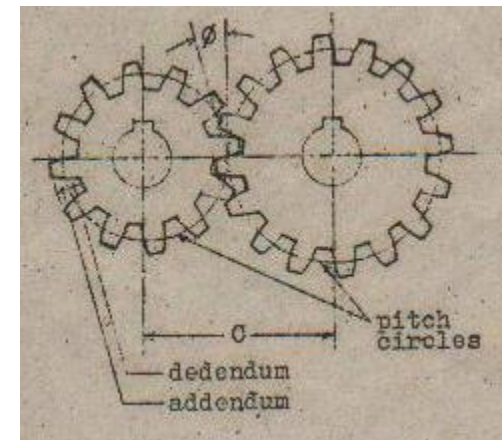
Definition:

Gears are machine elements that transmit motion by means of successively engaging teeth.

SPUR GEARS

Spur gears have tooth elements that are straight and parallel to the shaft axis and they are used to transmit motion and power without slippage between parallel shafts.

Spur Gear Nomenclature



Pitch Surface – the surface of the rolling cylinder that the gear may be considered to replace

Pitch Circle – the circle which is the right section of the pitch surface

Pitch point – the point of tangency of the pitch circles

Pitch diameter – the diameter of the pitch circle

Outside circle or addendum circle – the circle that bounds the outer ends of the teeth

Outside diameter – the diameter of the outside circle

Root circle or dedendum circle – the circle that bounds the bottoms of the teeth

Root diameter – the diameter of the root circle

Addendum – the radial distance between the pitch circle and the addendum circle

Dedendum – the radial distance from the pitch circle to the root circle

Whole depth – addendum plus dedendum

Working depth – sum of the addendums of the mating gears

Clearance – the dedendum minus the mating addendum

Tooth thickness – the width of tooth measured along the pitch circle

Tooth space or space width – the space between teeth measured along the pitch circle

Backlash – tooth space minus the tooth thickness

Face width – the length of teeth in an axial direction

Involute – the curve with which the tooth profile of gears are based

Pressure angle, ϕ – the angle between the line of action of the force on the gear tooth and the line tangent to the pitch circles

$$\text{Diametrical Pitch} = \frac{\text{Number of Teeth}}{\text{Pitch diameter (in Inches)}}$$

$$\text{Circular Pitch} = \frac{\text{Circumference of Pitch Circle (in Inches)}}{\text{Number of Teeth}}$$

$$\text{Module} = \frac{\text{Pitch Diameter in mm}}{\text{Number of Teeth}}$$

Table of gear-tooth Proportions

Vallance: Table 11-1, p 262

Faires: p 362

Basic Equations Involving Mating Gears:

Pinion is the smaller of the two mating gears.

$$T_1 N_1 = T_2 N_2$$

$$D_1 N_1 = D_2 N_2$$

$$C = \frac{D_1 + D_2}{2}$$

where: T_1, D_1, N_1 = number of teeth, pitch diameter, speed of pinion

T_2, D_2, N_2 = number of teeth, pitch diameter, speed of gear

C = center distance

$$\text{Velocity Ratio} = \frac{\text{Angular Velocity of Driver}}{\text{Angular Velocity of Driven}}$$

$$\text{Gear Ratio} = \frac{\text{Number of Teeth in Gear}}{\text{Number of Teeth in Pinion}}$$

Strength of Spur Gears (Vallance pp 266-270)

Power = $2 \pi \times \text{Torque} \times \text{Speed}$

F_t = transmitted load or tangential force

$$= \frac{\text{Torque}}{D/2} = \frac{\text{Power}}{\text{Pitch Line Velocity}}$$

Pitch Line Velocity = πDN

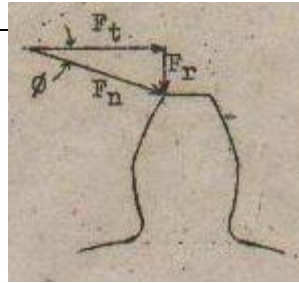
F_n = Normal Load = $F_t / \cos \phi$

F_r = Separating Load = $F_t \tan \phi$

where: D = pitch diameter

N = speed

ϕ = pressure angle



Modified Lewis Equations:

$$F_t = \frac{S_w f Y}{P} \frac{600}{600 + V}$$

for ordinary industrial gears
operating at velocities up to
2000 feet per minute

$$F_t = \frac{S_w f Y}{P} \frac{1200}{1200 + V}$$

for accurately cut gears operating
at velocities up to 4000 ft/min

$$F_t = \frac{S_w f Y}{P} \frac{78}{678 + \sqrt{V}}$$

for precision gears cut with a high
degree of accuracy and operating
At velocities of 4000ft/min and
over

where: F_t transmitted load or tangential force

$$= \frac{\text{Power}}{\text{Pitch Line Velocity}}$$

S_w = safe stress, Table 11-3

F = face width

Y = form factor, Table 11-2

P = diametral pitch

V = pitch line velocity = πDN

D = pitch diameter

N = speed

Dynamic Load on Gear Teeth (Vallance pp 271-273)

$$F_d = F_t + F_i = F_t + \frac{0.5V(Cf + F_t)}{0.5V + \sqrt{Cf + F_t}}$$

where: F_d = total equivalent load applied at pitch lin, lb

F_t = tangential load required for power transmission, lb

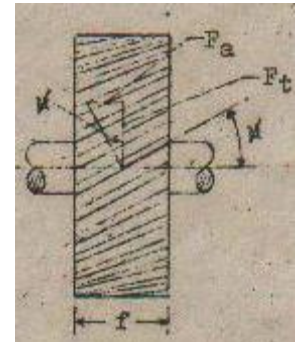
F_i = increment load (variable load), lb

C = a factor depending upon machining errors

(Table 11-5 and Table 11-6)

HELICAL GEARS (Vallance, pp 281-285)

Helical gears have teeth which are cut in the form of helix about an axis of rotation. They are used to connect parallel and non-parallel shafts, can be ran at faster speeds, are quieter and can sustain greater tangential loads than spur gears.



Herringbone gears consist of two helical gears in opposite hands, to balance the axial thrust and are used to connect the parallel shafts.

Helical Gear Nomenclature:

μ = helix angle

P = diametral pitch

P_n = normal diametral pitch

ϕ = pressure angle

ϕ_n = normal pressure angle

F_t = transmitted or tangential load

$P_n = P / \cos \mu$
 $\tan \phi_n = \tan \phi \tan \phi$
 $F_a = F_t \tan \mu$
 $N_v = N / \cos^3 \mu$
 F_a = axial load or end thrust
 N = actual number of teeth
 N_v = virtual number of teeth
 = number of teeth measured in the normal direction
 f = face width

Strength of Helical Gears:

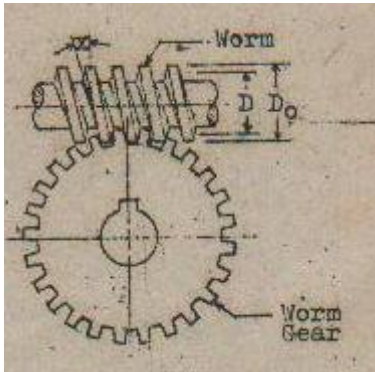
$$F_t = \frac{S_w f Y}{P} \frac{78}{78 + \sqrt{V}}$$

where: Y should be based upon the virtual number of teeth.

Dynamic Loads on Helical Gears:

$$F_d = F_t + \frac{0.05V (C_f \cos^2 \mu + F_t) \cos \mu}{0.05V + (C_f \cos^2 \mu + F_t)^{1/2}}$$

WORM GEARS (Vallance pp 287-297)



Worm gears are used where high speed ratios (10:1 and above) are desired. The mating members are called worm and worm gear or wheel.

p = lineal pitch = distance between adjacent threads

Lead = the distance from any point on one thread to the corresponding point

on the next turn of the same thread.

= pitch (in single threaded worm)

= 2 x pitch (in double threaded worm)

Lead angle, x = the angle between the tangent to the pitch helix and the plane of rotation

ϕ = pressure angle

ϕ_n = normal pressure angle

Velocity ratio = $\frac{\text{number of teeth on the gear}}{\text{number of threads on the worm}}$

$$\tan x = \text{Lead} / \pi D$$

$$\tan \phi_n = \tan \phi (\cos x)$$

Strength of Worm Gears:

The worm gear is weaker than the worm, therefore the design for strength is based on the worm gear.

$$F_t = S_w p f y \sqrt{1200}$$

where: F_t = tangential pitch line load on the gear

S_w = safe stress, table 12-2

p = circular pitch

f = face width

y = form factor, table 11-2

V = pitch line velocity of the gear

Efficiency of Worm and Gear

$$= \frac{\tan x (\cos \phi_n - f \tan x)}{\cos \phi_n \tan x + f}$$

where: f = coefficient of friction

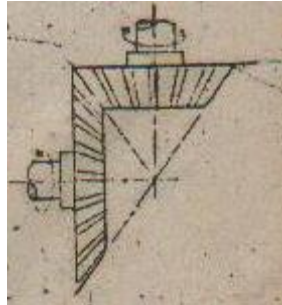
BEVEL GEARS (Faires pp 407-425)

Bevel gears are used to connect intersecting shafts, usually but not necessarily, at right angle.

Miter gears are bevel gears of the same size connecting shafts at right angle.

$$T_1 N_1 = T_2 N_2$$

where: T_1, N_1 = number of teeth and speed of smaller gear
 T_2, N_2 = number of teeth and speed of larger gear



CLUTCHES

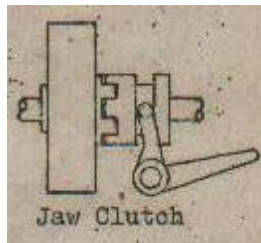
(Faires: pp 497-502; Vallance pp 341-360)

Definition:

Clutch is a machine member which is used to connect shafts so that the driven shaft will rotate with the driving shaft, and to disconnect them at will.

Types of Clutches:

1. Jaw clutches: jaws or teeth in the two elements interlock
2. Friction clutches: the driving force is transmitted by friction; the major types are: plate or disk clutch, cone clutch, band clutch, block clutch and expanding-ring clutch
3. Hydraulic clutches: the torque is transmitted by a moving fluid
4. electromagnetic clutches: the torque is transmitted by means of a magnetic field



Disk or Plate Clutches



$$T = n f F_a r_f$$

where: T = torque transmitted

n = number of pairs of mating friction surfaces

f = coefficient of friction

F_a = axial force

r_f = mean friction radius

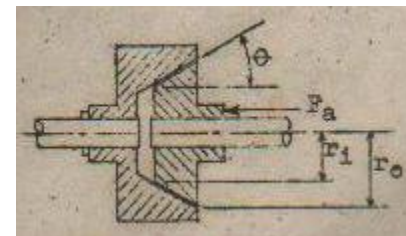
$$= \frac{2}{3} [(r_o^3 - r_i^3) / (r_o^2 - r_i^2)]$$

for uniform pressure disk clutch
(new unworn clutch)

$$= (r_o + r_i) / 2$$

For uniform wear clutch
(Worn clutch)

Cone Clutches



$$T = F_a f r_f / \sin \theta$$

BRAKES

(Faires: pp 481-497; Vallance: pp 361-376)

Definition:

Brake is a device which is used to regulate or stop the motion of a body.

Types of brakes:

Mechanical brakes: bans, block, shoe, disk and spot brake

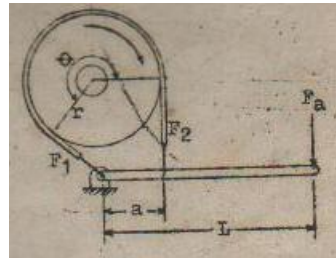
Hydrodynamic brakes: utilize fluid friction

Electrical brakes: utilize the strength of electromagnetic fields

Simple Band Brake

Tensions in Brake

$$F_1/F_2 = e^{f \theta}$$



where: F_1 = force on high tension side

F_2 = force on low tension side

f = coefficient of friction

θ = angle of contact

Brake torque developed:

$$T = (F_1 - F_2)r$$

where: T = brake torque

r = radius of friction surface on the drum

Actuating force requires: (by taking moment about the pivot point)

$$F_a = a F_2 / L$$

Maximum unit pressure:

$$P_{\max} = F_1 / wr$$

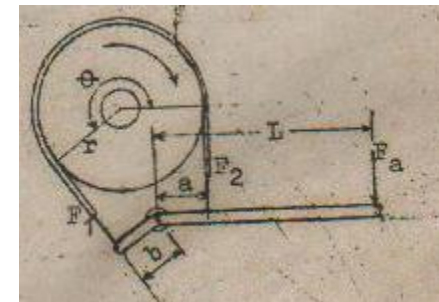
where: w = width of the band

Stress in band:

$$S = F_1 / wt$$

where: t = thickness of the band

Differential Band Brake



By taking moment about the pivot point:

$$F_a = \frac{F_2(a) - F_1(b)}{L}$$

Self-Locking Differential band Brake:

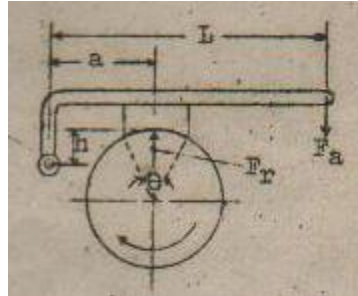
A differential band brake is self-locking when F_a is zero or negative.

Block brake (Vallance p 364)

$$T = fF_r h$$

$$T = \frac{4fF_r r \sin(\theta/2)}{\theta + \sin \theta}$$

$$= \frac{p_{\max} W r}{2} (\theta + \sin \theta)$$



where: T = banking torque

F_r = radial force between the drum and each shoe

f = coefficient of friction

h = effective moment arm of the friction force

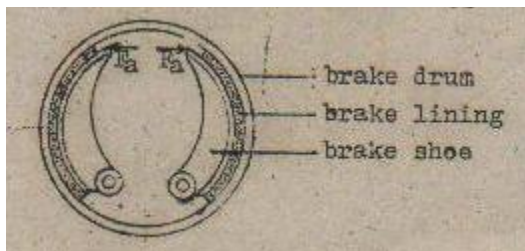
r = radius of the friction surface of the drum

θ = angle of contact

$p_{\max}$ = maximum normal pressure between block and drum

W = axial width of block

Automotive Shoe Brake (Vallance pp 366-370)



Heat Dissipated in Brakes (Vallance p 374)

$$H = fE_r V$$

where: H = heat dissipated

f = coefficient of friction

F_r = radial force

V = surface velocity

For brake used in lowering of a weight:

$$H = Wh$$

where: W = weight lowered

h = total distance traveled

BEARINGS

(Faires: pp 299-354; Vallance: pp 195-254)

Definitions:

Bearing – a machine member which supports, guide or control the motion of another

Lubricant – any substance that will form a film between the two surfaces of a bearing

Babbitt – a tin or lead base alloy which is used as bearing material

Sliding (or sliding element) bearing – type of bearing where essentially sliding friction exists

Ball bearing – type of rolling-element bearing which uses spherical balls as rolling elements

Roller bearing – type of rolling element bearing which uses cylindrical rollers as rolling elements

Classification of bearings according to load application:

Radial bearing (journal bearing): supports radial load

Thrust bearing: carries a load collinear to the axis

Guide bearing: primarily guides the motion of a machine member without specific regard to the direction of load application

Viscosity – a resistance to flow or the property which resists shearing of the lubricant

Absolute viscosity – viscosity which is determined by direct measurement of shear resistance

Kinematic viscosity – absolute viscosity divided by the specific gravity

Units of viscosity:

$$1 \text{ reyn} = 1 [(\text{lb-sec})/\text{in}^2]$$

$$1 \text{ poise} = 1[(\text{dyne-sec})/\text{cm}^2]$$

SLIDING BEARINGS

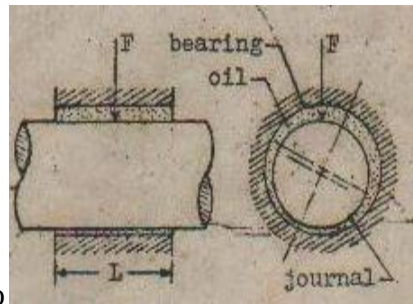
$$C_d = \text{diametral clearance} \\ = D - d$$

$$C_r = \text{radial clearance} \\ = \frac{D-d}{2}$$

$$\text{Diametral clearance ratio} \\ = C_d/D = D-d/D$$

$$P = \text{unit loading or bearing pressure} \\ = F/LD$$

$$e = \text{eccentricity} \\ = \text{radial distance between center of bearing and the displaced center of the journal}$$



D = diameter (bore) of the bearing

d = diameter of the journal

L = axial length of the journal inside the bearing

F = radial load

$$\text{Bearing modulus} = un / p$$

where: u = viscosity in reyns

n = speed in rps

p = unit loading, psi

Frictional torque in bearings (Vallance p 231)

$$T_b = \frac{F f_b D}{2}$$

where: T_b = frictional torque

F = radial load

f_b = coefficient of friction

D = bearing diameter

Petroff's equation for frictional torque (fares p 302)

$$T_f = \frac{4 u \pi^2 r^3 L n_s}{C_r}$$

where: T_f = frictional torque, in-lb

u = viscosity, reyns (Fig. AF, p 595)

r = journal radius, in

L = axial length of bearing, in.

N_s = journal speed, rps

C_r = radial clearance, in.

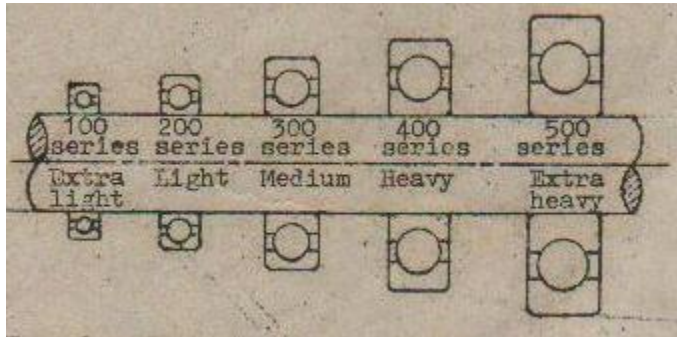
Heat dissipation in journal bearings (Vallance p 240)

$$H = \frac{C_h L D}{778}$$

where: H = heat dissipated in Btu/min
 C_h = heat dissipation coefficient,
 $\frac{\text{ft-lbs}}{\text{min-in}^2}$ of projected area
 L = length of bearing, in.
 D = diameter of bearing, in.

BALL AND ROLLER BEARINGS

Bearing Sizes and Designation



Example of bearing designation:
 SAE (or IS) 314 is 300 series, No.14

Tabulated data on ball and roller bearings:
 Faies: Table AT 12.4 p 342
 Vallance: Table 9-2 p 206

Bearing capacity based on stresses (Vallance p 205):

$$F_r = K_1 n D^2 / 5 \quad (\text{for ball bearings})$$

$$F_r = K_2 n L D / 5 \quad (\text{for roller bearings})$$

where: F_r = total radial load, lbs
 n = number of balls or rollers
 D = ball diameter or roller diameter, in.
 L = length of rollers, in.

K_1 = 550 for unhardened steel
 700 for hardened carbon steel
 1000 for hardened alloy steel on flat races
 1500 for hardened carbon steel
 2000 for hardened alloy steel on grooved races
 K_2 = 7000 for hardened carbon steel
 = 10000 for hardened alloy steel

Radial Load Catalog Capacities of Ball and Roller Bearings

(Vallance: pp 207-213)

Tabulated catalog capacities of ball and roller bearings:
 Table 9-7, p 212 and Table 9-8, p 213

$$F_c = (K_a K_1) K_o K_p K_s K_t F_r$$

Where: F_c = catalog rating of bearing, lb (Tables 9-7 and 9-8)
 F_r = actual radial load on the bearing, lb
 H_a = desired life of bearing, hr of use
 H_c = catalog rated life of bearing, hr
 K_a = application factor taking into account the amount of shock (Table 9-4)
 $K_1 = \sqrt[3]{H_a/H_c K_{rel}}$, the life factor
 K_o = oscillation factor
 = 1.0 for constant rotational speed of the races
 = 0.67 for sinusoidal oscillation of the races
 K_p = preloading factor
 = 1.0 for nonpreloaded ball bearings and straight roller bearings
 K_r = rotational factor
 = 1.0 for bearings with fixed outer races and rotating inner races
 K_{rel} = reliability factor, Table 9-3
 $K_s = \sqrt[3]{K_r N_a/N_c}$, the speed factor
 K_t = thrust factor
 = 1.0 if there is no thrust-load component

THICK-WALL CYLINDERS (Faires: pp 254-257; Vallance: pp 443-461)

Review of Thin-Wall Cylinders and Spheres

A thin wall cylinder or sphere is one in which the ratio of the wall thickness to the inside diameter is less than 0.07.

For thin-wall cylinder:

$$S_t = PD_i / 2t$$

where: S_t = tangential (tensile) stress
 P = internal pressure
 D_i = inside diameter
 t = wall thickness

When there is a seam or joint, the joint efficiency E must be considered, thus

$$S_t = PD_i / 2Et$$

For thin-wall sphere:

$$S_t = PD_i / 4t$$

Thick-Wall Cylinders:

Lame's equation (Vallance p 451), for internal pressure:

$$t = D/2 \left(\sqrt{\frac{S_t + P_i}{S_t - P_i}} - 1 \right)$$

where: t = wall thickness
 D = inside diameter
 S_t = tangential stress
 P_i = internal pressure

When subject to internal and external pressures (Faires p 255):
 Maximum tangential stress at the inside

$$S_{ti} = \frac{p_i (r_o^2 + r_i^2)}{r_o^2 - r_i^2} = \frac{2p_o r_o^2}{r_o^2 - r_i^2}$$

Maximum tangential stress at the outside

$$S_{to} = \frac{2p_i r_i^2 - p_o (r_o^2 + r_i^2)}{r_o^2 - r_i^2}$$

where: p_i = internal pressure
 p_o = external pressure
 r_i = inside radius
 r_o = outside radius

Specific equations for cylinders (Vallance pp 452-453)

Clavarino's equations: for closed cylinders
 (Poisson's ratio given)

Birnie's equations: for open cylinders (Poisson's ratio given)

Barlow equation: for thin cylinders, high internal pressures

RIVETED JOINTS

(Faires: pp 179-182; Vallance: pp 162-175)

Uses of Riveted Joints

To produce permanent joints in tanks, pressure vessels, bridges and building structures

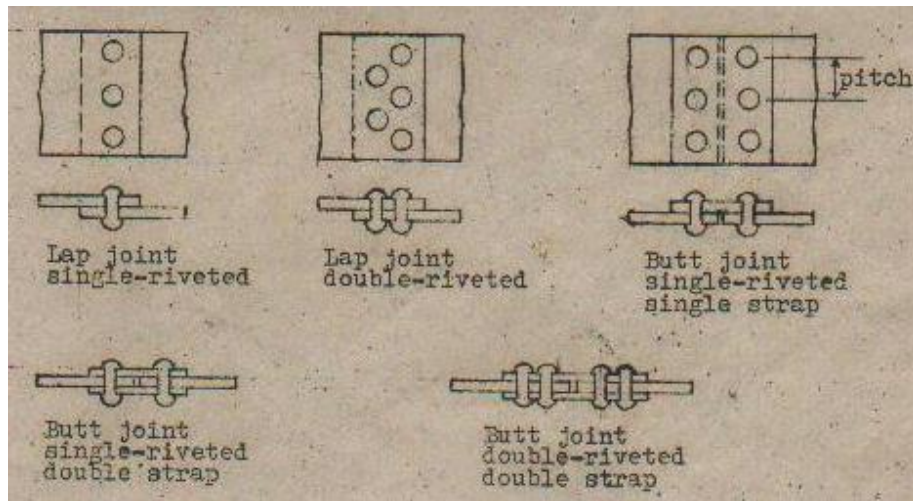
Materials for Rivets:

Wrought iron, soft steel, copper, aluminum

Size of Rivets:

Before driving, the rivets have diameter approximately 1/16 in. smaller than the rivet holes. After driving, the rivet diameter is the same as that of the rivet holes.

Types of Riveted Joints:



Strength of Riveted Joint

In analyzing a riveted joint, usually the free body diagram of a repeating group is drawn and investigated for the following forces:

1. Force that will cause shearing of rivets
2. Force that will cause tearing (tension) of plate between rivets
3. Force that will cause crushing (compression, bearing) of plate
4. Force that will cause shearing of plate in front of rivets

The smallest force is the force that will produce the allowable stress in the joint.

Efficiency of Riveted Joint = $\frac{\text{Load that will produce the allowable stress in the joint}}{\text{Load that will produce the allowable tension stress in the unpunched plate}}$

Pitch = center distance of rivet holes

Tabulated data on riveted joints:

Valance: Table 7-5, 7-6, 7-7, 7-8, pp 166-168

WELDED JOINTS

(Faires: pp 505-521; Vallnace: pp 153-162)

Definitions:

Welding – process of joining metal by heating the metal to a state of fusion permitting it flow together into a solid joint.

Gas Welding – type of welding which utilizes the heat of the flame which is produced by the combustion of a gas. The most commonly used are acetylene, hydrogen and natural gas in combination with oxygen. Acetylene welding is widely used in welding thin plates and in welding gas, steam and hydraulic pipelines.

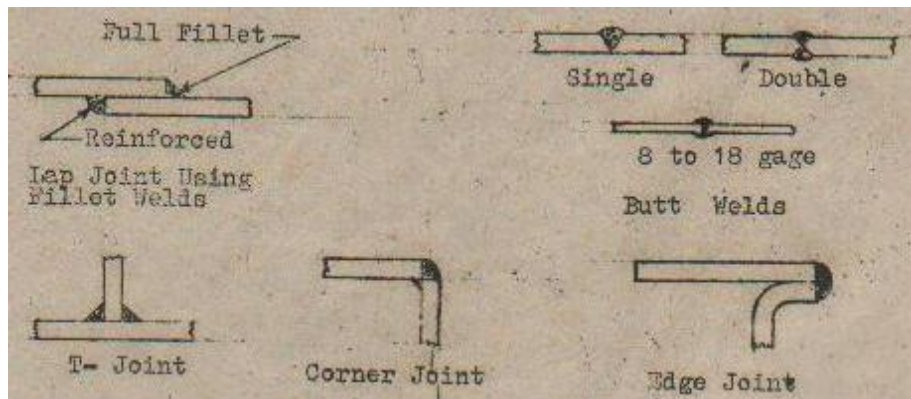
Electric Arc Welding – type of welding in which heat is supplied by a continuous arc drawn between two electrodes, the work forms one electrode and the welding rods forms the other. Shielded arc welding uses coated welding rods to prevent oxidation of the metal.

Thermit Welding – type of fusion welding in which the weld metal is essentially cast steel fused into the parts welded. This process is principally used in repairing heavy machine parts and in building up defective castings.

Atomic-Hydrogen and Helium Arc Welding – type of welding in which a jet of hydrogen or helium is forced through the arc drawn between two tungsten electrodes to prevent oxidation of the metal.

Electric Resistance Welding – type of welding, requiring both heat and pressure, in which the parts to be welded are brought into contact and a heavy current at low voltage is passed through the junction which causes the metal to fuse. Examples of electric resistance welding are spot welding, butt and flash welding, seam, projection and upset welding.

Types of Welds and Welded Joints



Strength of Butt Weld (Faires: p 506)

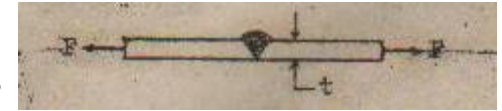
$$F = S_t L$$

where: F = load

S_t = tensile stress

t = plate thickness

L = length of weld



Strength of Fillet Weld (Faires: p 507)

$$F = 2 S_s L (\cos 45^\circ)$$

where: F = load

S_s = shear stress

L = length of weld

b = leg dimension of weld which is the size of the fillet weld

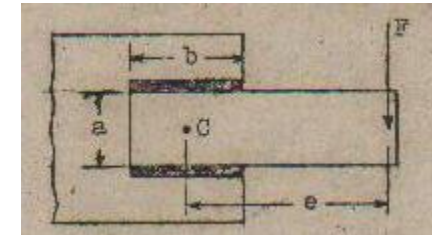
$b \cos 45^\circ$ - throat thickness



Tabulated data on strength of welds:

Vallance: Tables 7-1, 7-2, 7-3, pp 155-157

Eccentric Loading on Fillet Welds (Vallance: pp 158-160)



L = total length of weld

t = size of weld

S_1 = primary stress F/tL

S_2 = secondary stress = stress due to eccentric loading

$$= \frac{F_e \sqrt{a^2 + b^2}}{2J}$$

Where: J = polar moment of inertia (Table 7-4)

$$S_s \text{ max} = \text{maximum total shear} \\ = \sqrt{S_1^2 + S_2^2} + s S_1 S_2 \cos \theta \\ \text{where: } \cos \theta = \frac{b}{\sqrt{a^2 + b^2}}$$

Other methods of joining metals:

Soldering – method of joining metal by using an alloy of lead and tin (called the solder) applied between the two pieces in a molten state.

Brazing – method of joining metal using a non-ferrous filler (copper alloy) which is melted and applied to the pieces being joined.

MACHINE SHOP PRACTICE (PSME Code, pp 225-237)

Machine Tools and machining Operations

Lathe – a machine tool in which the work revolves on a horizontal axis and acted upon by cutting tool.
Machining operations that are performed in a lathe:

Straight turning: the cutting tool is made to move along the horizontal axis to produce cylindrical shape metal parts.

Facing or Squaring: the cut is at right angle with the axis of rotation to produce flat surfaces.

Tapering: cutting tool is made to move at an angle with the axis of rotation.

Drilling and boring: using a drill bit to produce or enlarge hole.

Threading: the horizontal feed is made automatic and set to produce the size of thread desired.

Shaper – a machine tool in which the cutter moves in a reciprocating motion to produce flat or partly curved surfaces on metal pieces which are held securely in a vise.

Planer – a machine tool which is used to produce flat surfaces on pieces which are too large or too heavy to be worked in a shaper. The work is securely fastened to the table which moves in reciprocating motion while the tool head moves in either direction including down feed. Other operations performed in a planer are slotting and broaching.

Drill or Drill Press – a machine tool which is used mainly to produce holes in metal parts by the use of rotating drill bit which acts on a securely held piece.

Grinding Machine or Grinder – a machine tool which uses rotating abrasive wheels to smoothen metal parts and to sharpen or shape tools. Other operations performed in a grinder are polishing, buffing and honing.

Boring Machine – a machine tool purposely designed for finishing holes. Vertical boring machine is used to finish vertical holes using a tool that moves up and down. In a horizontal boring machine, the tool revolves in a horizontal axis and used for finishing holes in the horizontal direction. Other machining operations performed in a boring machine are reaming and honing.

Milling Machine – a machine tool which is used to produce a variety of surfaces by using a circular type cutter with multiple teeth

Universal milling machine has a table which can be swiveled at an angle.

Plain milling machine does not have the swivel table construction.

Vertical spindle milling machine, in which the axis of rotation of the spindle is vertical, is used for end milling and face milling operations.

The machining operations which are performed in a milling machine, with the use of suitable milling cutters, are gear cutting, sprocket cutting, slotting, grooving and facing.

Band Saw (for Metal) – a machine tool which is used to cut metal parts by the use of an endless band with saw teeth moving around two pulleys

Power Hacksaw – a machine tool which is used to cut metal parts of light, medium and large sections using a reciprocating hacksaw blade

Hydraulic Press – a machine tool which consists of a ram which is being actuated by the pressure of a hydraulic fluid, which is used in various operations such as bending, drawing, forced fitting, or disassembling of parts

Mechanical Press – a machine tool which is driven by an electric motor or mechanical power source and is used in sheet metal work like punching, shearing, bending, drawing, and other sheet metal forming operations

Turret Lathe – a type of lathe which consists of multiple-station tool holders or turrets allowing the production of multiple cuts

PRACTICE PROBLEMS

THIN-WALL PRESSURE VESSELS

1. A cylindrical air receiver is used to store air at maximum pressure of 1.5 MPa. If the diameter of the receiver is 0.50 meter and the allowable tangential stress is 50 MPa, find the required wall thickness.
(ANS. 7.5 mm)
2. A vertical steel cylindrical water tank is 20 meters diameter and 30 meters high is to be designed for an allowable stress of 100 MPa. Determine the plate thickness required at the bottom of the tank and the mid-height.
(ANS. 29.43 mm; 14.7 mm)
3. Determine the required wall thickness of a spherical tank whose diameter is 800 mm. The working pressure is 2.75 MPa with an allowable stress of 50 MPa.
(ANS. 11 mm)
4. a thin walled cylindrical pressure vessel is subjected to an internal pressure which varies from 690 KPa to 3450 Kpa continuously. The diameter of the shell is 1.5 meters. Find the required thickness of the wall based on yield point of 480 MPa, net endurance strength of 205 MPa and factor of safety of 2.
(ANS. 16.56 mm)

SHAFTS, KEYS AND COUPLINGS

1. A solid shaft is to be used to transmit 50 KW at 1800 RPM. If the shaft design stress is not to exceed 30 N/mm^2 , determine the diameter of the solid shaft.
(ANS. 35.58 mm)
2. A motor delivers 50 HP at 120 RPM to a shafting $1 \frac{1}{2}$ inches diameter and 3 feet long. Compute the maximum shearing

stress produced by torsion and the total angle of twist in the shaft. $G = 12 \times 10^6$ psi.

(ANS. 39,628 psi; 9.08°)

3. A line shaft is to transmit 150 HP at 1800 RPM. Using commercial size of shafting, determine:
- The diameter of the shaft
 - If the line shaft is connected to a countershaft with speed of 900 RPM, find the diameter of the countershaft assuming no power loss in transmission.

(ANS. a. 1 11/16 b. 1 15/16)

4. A pulley fastened by a rectangular key to a line shaft transmits 10 KW at a speed of 1000 rev/min. if the shearing stress in the shaft is 30 MPa and in the key is 24 MPa, find (a) the shaft diameter and (b) the length of the rectangular key if the width is one-fourth that of the shaft diameter.

(ANS. (a) 25 mm (b) 50.9 mm)

5. Two short shafts of identical diameters transmitting 50 HP at 600 RPM are connected by a flange coupling having 4 bolts with a 90 mm diameter bolt circle. The design shearing stress of the bolts is $12 \text{ N}_2/\text{mm}^2$ and the design compressive stress of the flange is $15 \text{ N}/\text{mm}^2$.
- What is the required diameter of the shafts in mm?
 - What diameter of bolt should be used?
 - How thick should the flange be in mm?

(ANS. a. 37.3 mm; b. $\frac{3}{4}$ in. = 19.05 mm; c. 11.54 mm)

6. A coupling fastened two shafts by means of eight (8) equally spaced bolts on a pitch circle of 16 cm in diameter. The diameter of each bolt is 12mm. Find the average shear stress developed in each bolt when the power being transmitted is 100 KW at rev/min.

(ANS. 94.233 MPa)

7. A vehicle weighing 1325 kg is decelerated by means of engine brake from 70km/hr to 20km/hr in a distance of 30 meters. The wheel diameter is 712 mm. The universal hollow shaft has an outside diameter and wall thickness of 76 mm and 10 mm respectively. Speed ratio on differential; is 40:11. Calculate the torsional stress developed in the hollow shaft.

(ANS. 12.34 MPa)

8. The shaft of a heavy duty tractor transmits 120 KW at 600 RPM, and at the same time supports a load just like a cantilever carrying 5.5 KN load located 610 mm from the support. If the allowable shear stress is 138 MPa, calculate the minimum diameter required. Neglect axial load.

(ANS. 52.23 mm)

FLYWHEELS

1. The mean diameter of the flywheel of a shearing machine is 76 cm. It's normal operating speed is 3.3 rev/sec. It requires 2500 N-m of energy to shear a steel plate and it slows down to 3 rev/sec during the shearing process. The width of the rim is 30 cm and the weight of the cast iron flywheel is $7210 \text{ kg}/\text{m}^3$. Assuming that the hub and the arms account for 10% of the rim weight concentrated at the mean diameter, find the thickness of the rim.

(ANS. 8.16 cm)

2. A mechanical press is used to punch 6 holes per minute on a 25mm thick plate. The hole is 25mm in diameter and the plate has an ultimate strength in shear of 420 MPa. The normal operating speed of the flywheel is 200 rev/min and it slows down to 180 rev/min during the punching process. The flywheel has a mean diameter of one meter and the rim width is 3 times the rim thickness. Assume that the hub and arms account for 5% of the rim weight concentrated at the mean diameter and density of cast iron is $7200 \text{ kg}/\text{m}^3$. Find

- a. Energy required to punch a hole on the plate
- b. How much power must the motor supply to the flywheel
- c. The width and thickness of the rim

(ANS. a. 10.31 kN-m b. 1 KW c. 353 mm, 118 mm)

BOLTS AND SCREWS

1. The cylinder head of a 10cm x 12cm air compressor is held by four stud bolts with a yield stress of 4500 kg/cm^2 . If the maximum pressure in the compressor is 12 kg/cm^2 , determine the size in inches of UNF bolts required.

(ANS. 3/8 in.)

2. The root diameter of a triple threaded square power screw is 550mm. It has a pitch of 10mm. It is used to lift a load of 15 KN. The collar of the screw has an outside diameter of 100mm and an inner diameter of 60mm. Find the force applied at a radius of 950mm if the coefficient of friction for both threads and collar is 0.20.

(ANS. 1083 N)

3. A square thread power screw has an efficiency of 65% when raising a load. The coefficient of thread friction is 0.15 with collar friction negligible. The pitch diameter of the screw is 70 mm. When lowering the load, a uniform velocity is maintained by a brake mounted on the screw. If the load is 10 metric tons, what torque must the brake exert?

(ANS. 567.8 N-m)

4. A 60 mm double square thread screw with a pitch of 12mm is to be used to lift a load of 20KN. The friction radius of the collar is 50 mm and the coefficient of thread and collar friction are 0.10 and 0.15, respectively. The velocity of the nut carrying the load is 3 meters per minute. Find:

- a. The power required to drive the screw
- b. The efficiency of the screw and collar

(ANS. a. 3.69 KW b. 27%)

SPRINGS

1. A pump valve spring having a rate of 65 lb/in exerts an initial load of 100 lbs. on the closed suction valve. During pumping, the valve opens to its full limit of 1 in. Physical dimensions of the helical spring are: 3.55 in. outside coil diameter, 0.283 in. wire diameter, free length of 4.22 in. and 6 total coils with ends squared and ground. When the valve is fully opened, determine the total deflection, total load, and maximum stress in the spring.

(ANS. 2.5835 in., 165 lbs, 68,098 psi)

2. A tension spring is to stretch 100 mm when subjected to a maximum load of 250 N. The mean diameter of the spring is 7 times the diameter of the wire. The maximum permissible stress is to be 415 MPa. Modulus of elasticity in shear for the wire material is 80 GN/m^2 . Determine:

- a. Proper wire diameter
- b. Outside diameter of the coil
- c. Number of active coils

(ANS. a. 0.418 in. = 3.76mm; b. 30.06 mm; 43.8 coils)

3. A helical compression steel spring with squared and ground ends is subjected to a continuously varying load. No.7 oil tempered wire is used with a mean radius of 13 mm. The yield point of the spring material is 620MPa and the endurance strength in shear is 303 MPa. In the most compresses condition, the force is 400 N. After 8mm of release, the minimum force is 260 N. $G = 80 \text{ GPa}$. Find the following:

- a. Spring rate
- b. Factor of safety
- c. Number of active coils

(ANS. a. 17.5 N/mm b. 1.428; c. 13.3 coils)

4. A spring is designed to fire a 2-kg projectile. The outside diameter of the coil is 160mm with 18 wire and a total of 22 coils. When set or loaded, the spring is compressed to a length of 450 mm. the shear elastic limit of the spring material is 580 MPa with a shear modulus of elasticity of 82 GN/m². Free length of the spring is 650 mm. Determine:
 - a. The spring rate
 - b. Vertical height to which the projectile can be fired
 - c. Stress and factor of safety when spring is set or loaded

(ANS. a. 18.85 N/mm b. 19 m c. 277 MPa, 2)

BELTS

1. A pulley 610 mm in diameter transmits 37 KW at 600rpm. The arc of contact between the belt and pulley is 144 degrees, the coefficient of friction between the belt and pulley is 0.35, and the safe working stress of the belt is 2.1 MPa. Find:
 - a. The tangential force at the rim of the pulley
 - b. The effective belt pull
 - c. The width of the belt used if its thickness is 6mm.

(ANS. a. 1.93 KN, b. 1.93 KN, c. 261 mm)

2. A nylon-core flat belt has an elastomer envelope; is 200 mm wide, and transmits 60 KW at a belt speed of 25m/s. The belt has a mass of 2 kg/m of belt length. The belt is used in a crossed configuration to connect a 300mm diameter driving pulley to a 900 mm diameter driven pulley at a shaft spacing of 6m.

- a. Calculate the belt length and the angles of wrap
- b. Compute the belt tensions based on a coefficient of friction of 0.33

(ANS. a. 13.95m, 3.34 rad = 191.4°; b. 1.76 KN, 1.96 KN)

3. A 420 rpm blower is belt driven by 10 Hp synchronous motor at 1800 rev/min. Determine the suitable size and number of V-belts and suitable pitch diameters of the sheaves based on a belt speed of 3500 ft/min. Center distance between sheaves is approximately 32 inches.

(ANS. B 128, 2 belts, 7.4 in and 30 in.)

ROLLER CHAINS

1. A 10 HP engine speed of 1200 RPM is used to drive a blower with a velocity ratio of 3. The pitch diameter of the driving sprocket is 85 mm and the center distance between the sprockets is 260mm. The service factor is 1.2 while a No.40 roller chain is used with an equivalent pitch of 13mm. Find:
 - a. Number of teeth of driver sprocket
 - b. Number of teeth of driven sprocket
 - c. Length of power chain in pitches
 - d. Number of strands

(ANS. a. 21 teeth, b. 63 teeth, c. 84 pitches, d. 2 strands)

2. A No.80 roller chain is used in a conveyor drive that requires 60 HP. The driver sprocket has 23 teeth and runs at 1200 rpm. Assuming a service factor of 1.2, determine the number of strands required for the chain drive.

(ANS. 2 strands)

WIRE ROPES

1. Find the factor of safety when a $\frac{1}{2}$ in., 6x19 medium plow steel wire rope carrying a load of 2 metric tons is bent around a 610 mm sheave.
(ANS. 2.738)

GEARS

1. A machinist made two 8 diametral pitch spur gears to be mounted at a center distance of 16 inches with a speed ratio of 7 to 9. Find the following
 - a. Number of teeth of each gear
 - b. Pitch diameter of each gear
 - c. Outside diameter of each gear
 - d. Circular pitch
(ANS. a. 144 and 112; b. 18" and 14"; c. 18.25" and 14.25"; d. 0.393")
2. There are three parallel shafts A, B and C. Shaft A carries a 24-tooth gear of 4 DP meshing with a large gear of shaft B having 70 teeth. A small gear with 20 teeth and 3 DP of shaft B meshes with a 50-tooth gear of shaft C.
 - a. If the shafts are on level plane, find the distance between shaft A and C
 - b. Find the rpm of shaft C if shaft A turns at 1200 rpm
 - c. Find the torque of shaft C if the input hp at shaft A is 50 hp and the efficiency of each pair of gears is 98%
(ANS. a. 23.417", b. 164.57 rpm; c. 18,383 in-lbs)
3. A pair of meshing spur gears has a module of 2. The pinion has 18 teeth and the gear has 27 teeth. Find
 - a. Pitch diameter of each gear
 - b. Center distance between gears
(ANS. a. 36mm, 54mm; b. 45 mm)

CLUTCHES AND BRAKES

1. The force applied by the clutch pedal to disengage the clutch from the engine while it is running at 8 rev/sec is 1810 kg. If the clutch disk has an outside diameter of 36 cm and inside diameter of 12 cm, determine
 - a. The spring pressure in kg/cm^2 when the coefficient of friction is 0.60
 - b. The power transmitted by the clutch disk in KW
(ANS. A. 2 kg/cm^2 b. 69.6 KW)
2. An automobile engine develops maximum torque at 1000 rpm, at which speed the horsepower is 35. The engine is to be equipped with a single plate clutch having two pairs of friction surfaces. Using the equation for torque derived on the basis of "uniform wear" distribution and assuming $f = 0.40$ and that the mean diameter of the clutch disks is 7-5/8 inches, determine the axial force required to be applied to the clutch.
(ANS. 722.95 lbs)
3. A band brake is to operate on a 600 mm diameter drum rotating at 200 rpm. The coefficient of friction between band and drum is 0.25. The band brake has an angle of contact of 1.5 pi radians and the band width is 60mm. One end of the lever is fastened to the fixed end pin at the end of the lever while the other end on the brake arm 120 mm from the fixed pin. The straight brake arm is 760mm long and is placed perpendicular to the diameter bisecting the angle of contact.
 - a. Calculate the torque capacity of the brake if the maximum band pressure is not to exceed 300 KPa
 - b. What is the minimum pull necessary at the end of the lever arm in order to absorb the torque
 - c. How much power can be handled at the given speed?
 - d. Calculate the tensile stress in the band if the band thickness is 10 mm.

(ANS. a. 1.12 KN-m; b. 0.185 KN; c. 23.478 KW; d. 9000 KPa)

BEARINGS

1. A journal bearing 50 mm in diameter and 25 mm long supports a radial load of 1500 kg. If the coefficient of bearing friction is 0.01 and the journal rotates at 900 rpm, find the horsepower loss in the bearing.
(ANS. 0.465 hp)
2. Select a roller bearing to support a 60-mm diameter shaft rotating at 900 rpm. The bearing is to carry a radial load of 2000 kg and no thrust load. Determine the probable life of this bearing assuming the load is applied with moderate shock.
(ANS. SAE 312; 6, 368 hours)

THICK-WALL CYLINDERS

1. Pressurized water at 1.37 MPa is stored in a steel cylindrical tank 1.4 meters in diameter. If the allowable tangential stress is 8.5 MPa, find the required wall thickness of the tank.
(ANS. 124 mm)
2. A cylinder with an internal diameter of 500 mm and external diameter of 900 mm is subjected to an internal pressure of 70 MPa and external pressure of 14 MPa. Determine the hoop stress on the inner and outer surface of the shell.
(ANS. 92 MPa; 36 MPa)

RIVETED AND WELDED JOINTS

1. A steel boiler 1270 mm diameter is made of 13 mm plate and has single-riveted circumferential joints. The rivets are of 25 mm diameter and rivet pitch is 64 mm. Find the maximum allowable boiler pressure as limited by the circumferential joints if the allowable stresses are: tension 79.3 MPa, bearing 135 MPa, shear 60.7 MPa.
(ANS. 733.17 KPa)
2. A single-riveted butt joint with double straps is used to join 6-mm thick plates. The pitch of the rivets is 50 mm and rivet holes are 15 mm in diameter. Design stresses are: 550 kg/cm² for shear, 1400 kg/cm² for bearing and 700 kg/cm² for tension. Solve for the safe tensile load and the joint efficiency.
(ANS. 1260 kg, bearing; 60%)
3. A 5/8 in. plate is lapped over and secured by transverse weld on the inside and outside to form a penstock 60 inches in diameter. Determine the safe internal pressure assuming stress $S_t = 20,000$ psi for the plate and $S_s = 13,000$ psi on the throat of the 9/16 in. fillet weld.
(ANS. 344.7 psi)