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Papermaker's formulas

Scope

This is a set of equations that can be used by paper mill superintendents and engineers during their day-to-day operation of the paper machine. Also included are general guidelines for the acceptable ranges of some of the variables being calculated. This is expected to be a dynamic list and the Papermakers Committee would welcome any additions or corrections that will make the list more useful.

Safety precautions

Anyone working around paper machines needs to be well trained in the hazard associated with operating machinery. The use of these equations will not cause hazard conditions but collection of data to make some of these calculations will present situations where expertise in the safety requirements of operating paper machines is absolutely necessary.

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Formulas

1. Tank sizing and capacity

English Units	SI Units
$\text{Tons} = \frac{\frac{\text{lb}}{\text{ft}^3} \times \text{Volume}}{2000 \text{ lb/ton}}$ $= \frac{\%B.D. \times \text{Volume}}{1.6 \times 2000}$ $\text{Volume} = 3200 \times \text{tons} / \%B.D.$ $\text{US Gallons} = \text{Volume} / 7.4805$	$t = \text{Volume} \times \%B.D. / 100$ $\text{Volume} = t \times 100 / \%B.D.$
where: lb/ft^3 = Weight of dry stock per volume of slurry Volume = volume of tank (ft^3) %B.D. = percent consistency of stock 1 US gallon = 231 in^3	where: t = metric tons Volume = volume of tank (m^3) %B.D. = percent consistency of stock



2. Hydraulic pump power

English Units	SI Units
Hydraulic Pump Power = $H \times Q / 1714$	Hydraulic Pump Power = $H \times Q / 60000$
Power (hp) H = Differential pressure from pump (psi) Q = flow (gal/min)	Power (kW) H = Differential pressure from pump (kPa) Q = flow (l/min)

In centrifugal pumps or blowers -

- A. Capacity varies directly with speed
- B. Head varies as the square of speed
- C. Power varies as the cube of speed

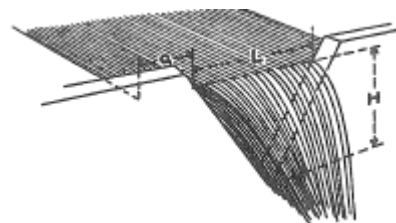
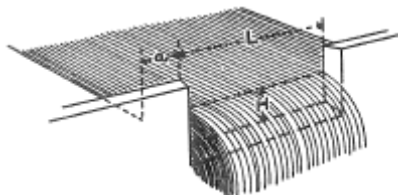
3. Pipeline and channel velocity

$$V = Q \times k_1 / r^2$$

$$V = Q \times k_2 / A$$

English Units	SI Units
Where, V = velocity (ft/s) Q = flow (gal/min) $k_1 = 0.0007092$ $k_2 = 0.321$ r = pipe inside radius (ft) A = pipe or channel cross sectional area (in. ²)	Where, V = velocity (m/s) Q = flow (L/s) $k_1 = 3142$ $k_2 = 0.001$ r = pipe inside radius (m) A = pipe or channel cross sectional area (m ²)
Screen to headbox acceptable range is 7 to 14 ft/s.	Screen to headbox acceptable range is 2.1 to 4.3 m/s.

Note: These formulas are for savealls and general pipe flow, since there is no orifice coefficient included.

4. Weir water flows

Rectangular weir with end contractions

English Units	SI Units
$Q = C_d \times \frac{2}{3} \times \sqrt{2g} \times L \times H^{3/2}$ Where $C_d = 0.622 \times \left(1 - 0.2 \times \frac{H}{L}\right)$	
$Q = 3.33 \times (L - 0.2 \times H) \times H^{1.5}$	$Q = 1.837 \times (L - 0.2 \times H) \times H^{1.5}$
Q = Flow (ft³/s) L = length of weir opening (ft) (should be 4-8 times H) H = head on weir (ft) (~6 ft back of weir opening) a = at least 3H (side of chamber to edge of weir opening)	Q = Flow (m³/s) L = length of weir opening (m) (should be 4-8 times H) H = head on weir (m) (~2 m back of weir opening) a = at least 3H (side of chamber to edge of weir opening)

Triangular Notch Weir with End Contractions

English Units	SI Units
$Q = C \times (4/15) \times L \times H \times \sqrt{2 \times g \times H}$	
Q = Flow (ft³/s) L = width of notch at H distance above apex (ft) H = head of water above apex of notch (ft) C = 0.57 a = should be not less than ¾L (side of chamber to edge of weir opening) g = 32.174 ft/s²	Q = Flow (m³/s) L = width of notch at H distance above apex (m) H = head of water above apex of notch (m) C = 0.57 a = should be not less than ¾L (side of chamber to edge of weir opening) g = 9.81 m/s²
For 90° notch, the formula becomes:	
$Q = 2.4381 \times H^{5/2}$	$Q = 1.3466 \times H^{5/2}$
For 60° notch, the formula becomes:	
$Q = 1.4076 \times H^{5/2}$	$Q = 0.7776 \times H^{5/2}$

5. Theoretical head (approximate headbox pressure required to achieve target jet speed)

English Units		SI Units
Theoretical Head = $(V/100)^2 / K$		Theoretical Head = $(V)^2 / 70610$
V = spouting velocity (ft/min) K = constant (see table)		Head (m of H ₂ O) V = spouting velocity (m/min)
Units for Head	K	
in. of H ₂ O	1.9304	
ft. of H ₂ O	23.165	
in. of Hg	26.196	
PSIG	53.336	

6. Approximate spouting velocity

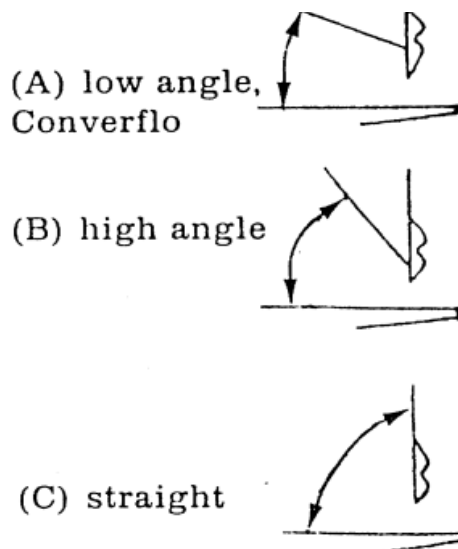
English Units	SI Units
$V = K\sqrt{h}$	$V = 265.7\sqrt{h}$
V = spouting velocity (ft/min) h = head (units consistent with table for K) K = constant (see table below)	V = spouting velocity (m/min) h = head (m H ₂ O)

Head	in. of H ₂ O	ft. of H ₂ O	in. of Hg	PSIG
K	139.2	481.5	513.3	732.3

7. Headbox flow rate per unit width (slice method)

English Units	SI Units
$\text{gal/min/in.} = \text{S.O.} \times V \times 0.052 \times C_c$	$\text{L/min/m} = \text{S.O.} \times V \times C_c$
V = spouting velocity (ft/min) S.O. = slice opening (in.) C_c = orifice (contraction) coefficient (See table for approximate values)	V = spouting velocity (m/min) S.O. = slice opening (mm) C_c = orifice (contraction) coefficient (See table for approximate values)

Type	C_c
Nozzle	0.95
A	0.75
B	0.70
C	0.60

8. Approximate headbox slice flow rate per unit width (consistency method)

English Units	SI Units
$\text{gal/min/in.} = \frac{(\text{B.D.Ton} / 24\text{hr/in.})(16.76)(1.5 - \text{Tray Consistency})}{1.5 \times \text{Net Consistency}}$	$\text{L/min/m} = \frac{(\text{B.D.MT} / \text{d/m})(70)(1.5 - \text{Tray Consistency})}{1.5 \times \text{Net Consistency}}$
Net Consistency = Headbox Consistency - Tray Consistency	

9. Tissue headbox flow rate per unit width

English Units	SI Units
$\text{gal/min/in.} = \text{T.O.} \times V / 19.25 = \text{T.O.} \times V \times 0.052$	$\text{L/min/m} = \text{T.O.} \times V$
T.O. = throat opening (in.) V = spouting velocity (ft/min)	T.O. = throat opening (mm) V = spouting velocity (m/min)

Note: assumes contraction (orifice) coefficient = 1.0

10. Headbox free jet length