Centrifugal Pump and Mechanical Seal formula

Parameter	Metric unit	US unit	Application and Significance
• **Head ↔ Pressure**	$H = \frac{10.2 \times P}{SG}$	$H = \frac{2.31 \times P}{SG}$	• Centrifugal pump develops fixed head at given operating point irrespective of fluid type • Instruments are designed to measure pressure
• **Volumetric flow ↔ Mass flow**	$Q = \frac{M}{SG}$	$Q = \frac{M}{500 \times SG}$	• Process people follow mass flow rate to balance various chemical processes • Pump curves is based on volumetric flow rate
• **Hydraulic KW / HP**	$P_{hyd} = \frac{Q \times H \times SG}{367}$	$P_{hyd} = \frac{Q \times H \times SG}{3960}$	• Evaluate pump performance • Trouble shoot pump performance issues • Estimate actual operating point on Q-H curve • Estimate product specific gravity while the same pump being handled for different product • Define set points for interlock to protect plant, equipment or process • Implement automatic control system • Trouble shoot driver or power supply related issues
• **Pump KW or HP ↔ Efficiency**	$P_{bkw} = \frac{Q \times H \times SG}{367 \times \eta_p}$	$P_{bhp} = \frac{Q \times H \times SG}{3960 \times \eta_p}$	
• **Motor input current ↔ Power**	$P_{bkw} = \frac{\sqrt{3} \times VI \cos \emptyset \times \eta}{1000}$	$P_{bhp} = \frac{\sqrt{3} \times VI \cos \emptyset \times \eta}{1340}$	
• $NPSH_a$ **at Suction flange**	$NPSH_a = \frac{10.2\ (P_s - P_v)}{SG}$	$NPSH_a = \frac{2.31\ (P_s - P_v)}{SG}$	• Protect pump from cavitation • Protect mechanical seal or magnetic drive pump from dry running • Provide estimated set points for interlock
• **Seal box pressure (Please refer my exclusive post on this topic for more info)**	$P_{seal} = P_s + 0.25P_{diff}$ -- Impeller with back vanes $P_{seal} = P_s + 0.10P_{diff}$ – impeller with balance holes $P_{seal} = P_s$ - Double suction or Suction side of multistage $P_{seal} = P_d$ - Vertical pump VS1,2,3,6,7 $P_{seal} = P_{atm}$ – Vertical pump VS4 and VS5		• It is required to select suitable seal plan • Estimate seal flush or barrier fluid pressure • Ensure seal faces sees liquid phase at all the times • Trouble shoot and RCA of seal failure
Symbol	**Metric Unit**	**US Unit**	**Symbol stand for**
$P_s, P_d, P_{seal}, P_{atm}, P_v$ – Pressure	Bar	PSI	Suction, discharge, seal box, atmospheric and vapor pressure
$P_{hyd}, P_{bkw}, P_{bhp}$ – Power	KW	HP	Hydraulic power, Pump power KW, Pump power HP
SG – Specific gravity	NA	NA	
Q – Volumetric flow rate	M^3 / Hr	GPM	
M – Mass flow rate	$Tonn/Hr$	Lbm/Hr	
V – Supply voltage	Volts	Volts	
I – Current	Amps	Amps	
η, η_p – efficiency motor, pump	NA	NA	
$\cos \phi$ – Power factor	NA	NA	

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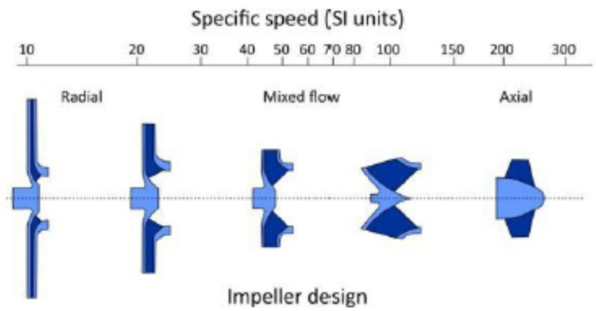
Parameter	Formula and other information	Application and Significance
Specific speed	$N_s = \frac{N\sqrt{Q}}{(H)^{3/4}}$ *Specific speed derived by SI units X 51.64 = specific speed in US units.*  	• For multistage pump, head to be considered per stage. Head per stage = Total head / No. of stage • For double suction impeller flow to be considered half of total flow • Specific speed is an index used to predict desired pump performance and the general shape of a pumps impeller.
Suction specific speed	$N_{ss} = \frac{N\sqrt{Q}}{(NPSH_r)^{3/4}}$ *Nss < 120 (SI units) or 6000 (US units) → Possibility of recirculation and cavitation.* *Nss > 210 (SI units) or 11,000 (US units) → Operation below 60-70% of BEP → possibility of casing,Impeller erosion, Shaft deflection, Bearing and Seal failure* *Higher Nss → Possibly narrower the safe operating range around BEP*	• Suction Specific Speed defines pump's suction characteristics. In particular, a value indicates the tendency of a pump to become unstable as a result of suction recirculation and cavitation. • It can also be used to assess the safe operating range around the BEP.
Affinity law	**Formulas for Refiguring Pump Performance with Impeller Diameter or Speed Change** Diameter Change Only: $Q_2 = Q_1\left(\frac{D_2}{D_1}\right)$, $H_2 = H_1\left(\frac{D_2}{D_1}\right)^2$, $bhp_2 = bhp_1\left(\frac{D_2}{D_1}\right)^3$ Speed Change Only: $Q_2 = Q_1\left(\frac{N_2}{N_1}\right)$, $H_2 = H_1\left(\frac{N_2}{N_1}\right)^2$, $bhp_2 = bhp_1\left(\frac{N_2}{N_1}\right)^3$ Diameter and Speed Change: $Q_2 = Q_1\left(\frac{D_2}{D_1} \times \frac{N_2}{N_1}\right)$, $H_2 = H_1\left(\frac{D_2}{D_1} \times \frac{N_2}{N_1}\right)^2$, $bhp_2 = bhp_1\left(\frac{D_2}{D_1} \times \frac{N_2}{N_1}\right)^3$ *Q_1, H_1, bhp_1, D_1, and N_1 = Initial capacity, head, brake horsepower, diameter, and speed.* *Q_2, H_2, bhp_2, D_2, and N_2 = New capacity, head, brake horsepower, diameter, and speed.*	• Predict pump flow, head and power with the new impeller diameter • Predict pump flow, head and power with the new operating speed • Applying smart pumping through variable frequency drive. • Troubleshoot performance related issue due to driver speed or impeller diameter • Applying Correction factor Actual required impeller diameter A can be derived as A = 16.2 + 0.838C C is required percentage of impeller diameter

Symbol	Metric Unit	US Unit	Symbol stand for
Q – Volumetric flow	*M^3 / s*	*GPM*	***BEP flow rate per Impeller eye***
H – Head	*m*	*Feet*	***Total differential head at BEP per stage***
N – Operating speed	*rpm*	*rpm*	
$NPSH_r$	*m*	*Feet*	

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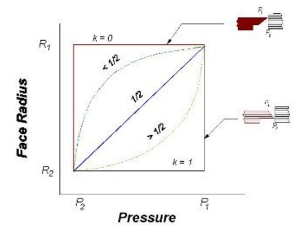
Subject	Formula	Application and significance
Balance Ratio	$B = \frac{D_o^2 - D_b^2}{D_o^2 - D_i^2}$ *for OD pressurize,* $B = \frac{D_b^2 - D_i^2}{D_o^2 - D_i^2}$ *for ID pressurize,*  a) Seal with higher pressure at outer diameter b) Seal with higher pressure at inner diameter	• The balance ratio is a ratio of closing area to opening area. Ac/Ao. • Seal with a balance ratio less than 1 is called a balanced seal. Most balance seals have balance ratio between 0.6 to 0.9. • Seal with a balance ratio greater than 100 percent is called an unbalanced seal. Most unbalanced seals have a balance ratio between 1.1 to 1.6.
Seal box pressure (Please refer my earlier post exclusive on this topic for more info)	$P_{seal} = P_s + 0.25P_{diff}$ → *Impeller with back vanes* $P_{seal} = P_s + 0.10P_{diff}$ → *impeller with balance holes* $P_{seal} = P_s$ → *Double suction or Suction side of multistage* $P_{seal} = P_d$ → *Vertical pump VS1,2,3,6,7* $P_{seal} = P_{atm}$ → *Vertical pump VS4 and VS5*	• It is required to calculate face load, heat generation and select suitable seal as well as seal plan • Estimate seal flush or barrier fluid pressure • Ensure seal faces sees liquid phase at all the times • Trouble shoot and RCA of seal failure
Total seal face pressure	$P_f = \Delta p(B - K) + P_{sp}$ *in MPa* Δp → *Seal box pressure in MPa* K → *Pressure drop co-efficient (Please refer the chart for its value), assume 0.5* $Spring\ pressure\ P_{sp} = Spring\ force\ in\ N/seal\ face\ area\ A$	 • Input parameter for seal torque and seal design
Running Torque	$T = P_f\, A\, f\, \frac{D_m}{2000}$ *in Nm* f → *Co-efficient of friction, assume 0.07* D_m → *Mean face diameter in mm*	• Estimation of power consumption by mechanical seal. • Startup torque is approximate 3 to 5 times of running torque • Input parameter to calculate seal face heat generation
Seal face generated heat	$Q = \frac{T\,N}{9548}$ *in KW* N → *Rotational speed in rpm*	• Estimation of temperature increase, selection of seal • Selection of suitable API plan
Heat soak of seal	$Q_{hs} = 0.00025\ X\ D_b\ \Delta T$ *in KW* D_b → *Seal balance diameter* $\Delta T = (T_p - T_s)$ T_p → *Process temperature in Kelvin* T_s → *Seal area desired temperature in Kelvin*	• Important while handling hot fluid • Sizing and selection of plan 21, plan 23
Seal flush temperature rise or Seal flush flow rate	$\Delta T = \frac{60{,}000\,(Q + Q_{hs})}{q_f c_p s}$ in Kelvin q_f → *Flush flow rate in LPM* c_p → *Specific heat of flush fluid* s → *Specific gravity of flush fluid*	• Important parameter to select suitable API plan • Sizing and selection of API Plan • Selection of proper flush fluid and its flow rate