Pump System Certification Exam
Formula Reference Sheet

Convert pressure to head

$$\mathbf{h} = \frac{\boldsymbol{p}}{\boldsymbol{\rho} \cdot \boldsymbol{g}}$$

Where:

- $\mathbf{h}$ = head, feet or meters
- $\boldsymbol{p}$ = pressure, psi (Pa)
- $\boldsymbol{\rho}$ = liquid density, lbm/ft^3 (kg/m^3)
- $\boldsymbol{g}$ = Acceleration due to gravity, ft/s^2 (m/s^2)

Convert pressure (psi) to head in feet

$$\mathbf{h} = \frac{\boldsymbol{p} \cdot \mathbf{2.31}}{\boldsymbol{s}}$$

Where:

- $\mathbf{h}$ = head, feet
- $\boldsymbol{p}$ = pressure, psi
- $\boldsymbol{s}$ = liquid specific gravity

Convert meters to feet

1 meter (m) = 3.281 feet (ft)

Calculation of velocity head

$$h_v = \frac{v^2}{2g}$$

Where:

- h_v = velocity head, ft (m)
- v = flow velocity, ft/s (m/s)
- g = acceleration constant due to gravity

Acceleration due to gravity

$$g = 32.2\frac{\text{ft}}{s^2} = 9.81\frac{m}{s^2}$$

Pump affinity rules with respect to impeller diameter

$$Q_2 = Q_1 \frac{D_2}{D_1} \; H_2 = H_1 \frac{D_2^2}{D_1^2} \; P_2 = P_1 \frac{D_2^3}{D_1^3}$$

Where:

Q = flow rate

H = total head

P = pump input power

D = impeller diameter

Pump affinity rules with respect to pump speed

$$Q_2 = Q_1 \frac{n_2}{n_1} \; H_2 = H_1 \frac{n_2^2}{n_1^2} \; P_2 = P_1 \frac{n_2^3}{n_1^3}$$

Where:

Q = flow rate

H = total head

P = pump input power

n = pump rotational speed

Calculation of NPSHA

NPSHA = $h_{atm} + h_{gs} + h_{vs} + z_s - h_{vp}$

Where:

h_{atm} = atmospheric pressure head, ft (m)

h_{gs} = suction gauge head, ft (m)

h_{vs} = suction velocity head, ft (m)

z_s = elevation from the suction gauge centerline to datum, ft (m)

h_{vp} = liquid vapor pressure head, ft (m)

Area of pipe

$A = \pi \cdot r^2$

Where:

A = cross-section area of the pipe inside diameter

r = radius of the pipe inside diameter

Velocity (v) in pipe

$$v = \frac{V}{A}$$

Where:

V = volume rate of flow

A = cross-section area of the pipe inside diameter

Velocity (v) in pipe in U.S. Customary Units

$$v = \frac{0.4085 \cdot Q}{d^2}$$

Where:

v = velocity, ft/s

Q = flow rate, gpm

d = average ID of piping, inches

Resistance to flow in pipes and fittings

$$h_f = f \cdot \frac{L}{d} \cdot \frac{v^2}{2 \cdot g}$$

Where:

h_f = frictional head loss, meters (feet)

f = piping friction factor

L = length of pipe, meters (feet)

d = average ID of piping, meters (feet)

v = average velocity, m/s (ft/s)

g = acceleration due to gravity

$$h_f = k \cdot \frac{v^2}{2 \cdot g}$$

Where:

h_f = frictional head loss, meters (feet)

k = resistance coefficient for valve or fitting

v = average velocity, m/s (ft/s)

g = acceleration due to gravity

Calculation of Synchronous Speed of a Motor

$$n = \frac{120 \cdot f}{P}$$

Where:

n = synchronous speed (rpm)

f = frequency (hertz)

P = number of poles

Calculation of Specific Speed

$$Ns(n_s) = \frac{n \cdot Q^{0.5}}{H^{0.75}}$$

For U.S. Customary Units (Ns)

Where:

n = revolutions per minute (rpm)

Q = total flow rate at best efficiency point (gpm)

H = pump total head per stage at best efficiency point (feet)

Metric Units (n_s)

Where:

n = revolutions per minute (rpm)

Q = total flow rate at best efficiency point (m^3/s)

H = pump total head per stage at best efficiency point (m)

Pump total head

$$H = \left(\frac{p_2}{\rho \cdot g} + \frac{{v_2}^2}{2 \cdot g} + Z_2\right) - \left(\frac{p_1}{\rho \cdot g} + \frac{{v_1}^2}{2 \cdot g} + Z_1\right) + (h_{f_2} + h_{f_1})$$

Where:

H = pump total head, meters (feet)

p = gauge pressure at measurement location, Pa (psi)

v = velocity at measurement location, m/s (ft/s)

Z = gauge or liquid level elevation head to datum, meters (feet)

g = acceleration due to gravity

ρ = liquid density, kg/m^3 (lbm/ft^3)

h_f = friction head loss between measurement and pump flange

Subscript 1 = Measurement point 1 at pump suction (inlet)

Subscript 2 = Measurement point 2 at pump discharge (outlet)

Calculation of electrical input power

$$Input\ power(kW) = \frac{I \cdot V \cdot PF \cdot C}{1000}$$

Where:

I = current in amperes (A) (meter reading)

V = volts (meter reading)

PF = power factor (motor curve or measured)

C = 1 for single-phase current

= 2 for two-phase four-wire control

= 1.73 for three-phase current

Pump Output Power

$$P_W = \frac{Q \cdot H \cdot s}{C}$$

Where:

P_W = Pump output power, kW (hp)

H = Pump total head, meters (feet)

Q = Flow rate, m^3/s (gpm)

s = Specific gravity, dimensionless

C = 0.1022 for metric units or 3960 for U.S. Customary units

Pump Output Power using metric units and density

$$P_W = \frac{Q \cdot H \cdot \rho \cdot g}{1000}$$

Where:

P_W = Hydraulic power (kW)

Q = Flow rate (m^3/s)

H = Head (m)

ρ = Density of fluid (kg/m^3)

g = Acceleration due to gravity

Pump Input Power

$$P = \frac{P_W}{\eta}$$

Where:

P = Pump input power, kW (hp)

P_W = Pump output power, kW (hp)

η = Pump efficiency

Power unit conversion factor

Power (kW) = 0.746 × Horsepower

Pump efficiency (%)

$$\eta = \frac{P_W}{P} \times 100$$

Where:

η = pump efficiency, percent

P_W = pump output power, kW (hp)

P = pump input power, kW (hp)

Overall efficiency

$$\eta_{OA} = \frac{P_W}{P_{Elc}} \times 100$$

Where:

η_{OA} = overall efficiency, percent

P_W = pump output power, kW (hp)

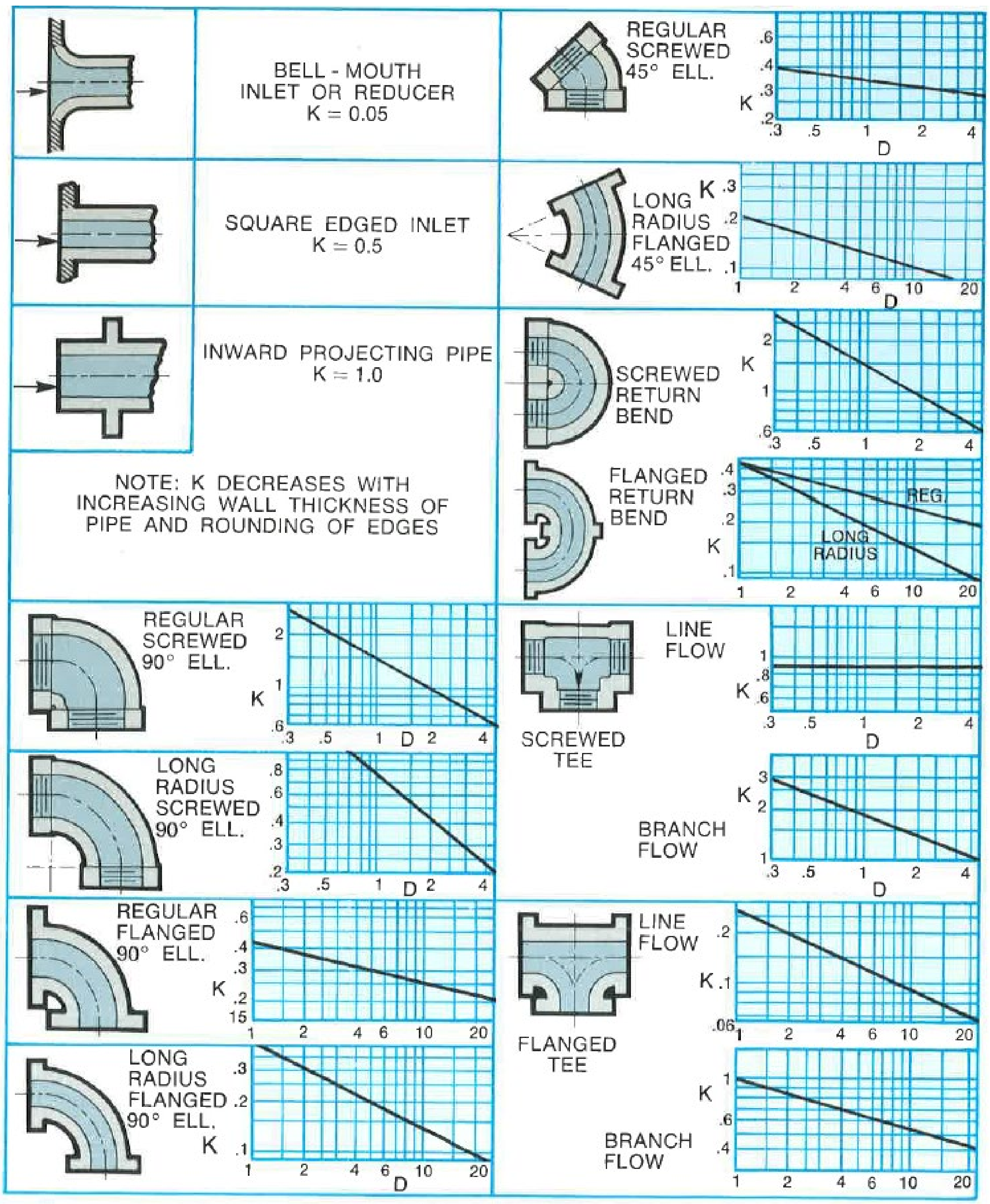
P_{Elc} = electrical input power to motor or drive, kW (hp)

Friction Loss for Water in Feet Per 100 Feet of Pipe

10 INCH NOMINAL		STEEL SCHEDULE 40 ID = 10.020 INCHES ϵ/D = 0.000180			ASPHALT-DIPPED CAST IRON ID = 10.00 INCHES ϵ/D = 0.000480		
DISCHARGE CFS	DISCHARGE GPM	V ft/sec	$V^2/2g$ feet	h_f feet per 100 feet of pipe	V ft/sec	$V^2/2g$ feet	h_f feet per 100 feet of pipe
0.0223	10	0.0407	0.0000257	0.000138	0.0409	0.0000259	0.000140
0.0446	20	0.0814	0.000103	0.000451	0.0817	0.000104	0.000460
0.0891	40	0.163	0.000412	0.00149	0.163	0.000415	0.00154
0.134	60	0.244	0.000926	0.00304	0.245	0.000934	0.00315
0.178	80	0.325	0.00165	0.00505	0.327	0.00166	0.00525
0.223	100	0.407	0.00257	0.00747	0.409	0.00259	0.00783
0.267	120	0.488	0.00370	0.0103	0.490	0.00373	0.01085
0.312	140	0.570	0.00504	0.0136	0.572	0.00508	0.0144
0.356	160	0.651	0.00659	0.0174	0.654	0.00664	0.0183
0.401	180	0.732	0.00834	0.0215	0.735	0.00840	0.0227
0.446	200	0.814	0.0103	0.0260	0.817	0.0104	0.0276
0.490	220	0.895	0.0125	0.0309	0.899	0.0126	0.0329
0.535	240	0.976	0.0148	0.0362	0.980	0.0149	0.0387
0.579	260	1.06	0.0174	0.0417	1.06	0.0175	0.0449
0.624	280	1.14	0.0202	0.0478	1.14	0.0203	0.0514
0.668	300	1.22	0.0232	0.0542	1.23	0.0233	0.0583
0.780	350	1.42	0.0315	0.0719	1.43	0.0318	0.0778
0.891	400	1.63	0.0412	0.0917	1.63	0.0415	0.0990
1.003	450	1.83	0.0521	0.114	1.84	0.0525	0.1235
1.11	500	2.03	0.0643	0.138	2.04	0.0648	0.151
1.23	550	2.24	0.0778	0.164	2.25	0.0785	0.181
1.34	600	2.44	0.0926	0.192	2.45	0.0934	0.214
1.45	650	2.64	0.109	0.224	2.66	0.110	0.250
1.56	700	2.85	0.126	0.256	2.86	0.127	0.288
1.67	750	3.05	0.145	0.291	3.06	0.146	0.328
1.78	800	3.25	0.165	0.328	3.27	0.166	0.370
1.89	850	3.46	0.186	0.368	3.47	0.187	0.415
2.01	900	3.66	0.208	0.410	3.68	0.210	0.462
2.12	950	3.87	0.232	0.455	3.88	0.234	0.512
2.23	1 000	4.07	0.257	0.500	4.09	0.259	0.565
2.45	1 100	4.48	0.311	0.600	4.49	0.314	0.680
2.67	1 200	4.88	0.370	0.703	4.90	0.373	0.805
2.90	1 300	5.29	0.435	0.818	5.31	0.438	0.945
3.12	1 400	5.70	0.504	0.940	5.72	0.508	1.09
3.34	1 500	6.10	0.579	1.07	6.13	0.584	1.25
3.56	1 600	6.51	0.659	1.21	6.54	0.664	1.42
3.79	1 700	6.92	0.743	1.36	6.94	0.749	1.60
4.01	1 800	7.32	0.834	1.52	7.35	0.840	1.78
4.23	1 900	7.73	0.929	1.68	7.76	0.936	1.97
4.46	2 000	8.14	1.03	1.86	8.17	1.04	2.17
4.90	2 200	8.95	1.25	2.23	8.99	1.26	2.64
5.35	2 400	9.76	1.48	2.64	9.80	1.49	3.12
5.79	2 600	10.6	1.74	3.08	10.6	1.75	3.63
6.24	2 800	11.4	2.02	3.56	11.4	2.03	4.18
6.68	3 000	12.2	2.32	4.06	12.3	2.33	4.79
7.13	3 200	13.0	2.63	4.59	13.1	2.66	5.47
7.58	3 400	13.8	2.97	5.16	13.9	3.00	6.18
8.02	3 600	14.6	3.33	5.76	14.7	3.36	6.91
8.47	3 800	15.5	3.71	6.40	15.5	3.74	7.68
8.91	4 000	16.3	4.12	7.07	16.3	4.15	8.50
10.03	4 500	18.3	5.21	8.88	18.4	5.25	10.7
11.1	5 000	20.3	6.43	10.9	20.4	6.48	13.2
12.3	5 500	22.4	7.78	13.2	22.5	7.85	15.9
13.4	6 000	24.4	9.26	15.6	24.5	9.34	18.9
14.5	6 500	26.4	10.9	18.3	26.6	11.0	22.2
15.6	7 000	28.5	12.6	21.1	28.6	12.7	25.8
16.7	7 500	30.5	14.5	24.3	30.0	14.6	29.6
17.8	8 000	32.5	16.5	27.5	32.7	16.6	33.6
18.9	8 500	34.6	18.6	30.9	34.7	18.7	37.8
20.1	9 000	36.6	20.8	34.6	36.8	21.0	42.2
21.2	9 500	38.7	23.2	38.5	38.8	23.4	46.9
22.3	10 000	40.7	25.7	42.6	40.9	25.9	51.8

Reference: Hydraulic Institute Engineering Data Book

Typical Resistance Coefficients for Valves and Fittings



$$h = K \frac{V^2}{2g} \text{ FEET OF FLUID}$$

Reference: Hydraulic Institute Engineering Data Book