TOTAL HEAD, N.P.S.H. AND OTHER CALCULATION EXAMPLES

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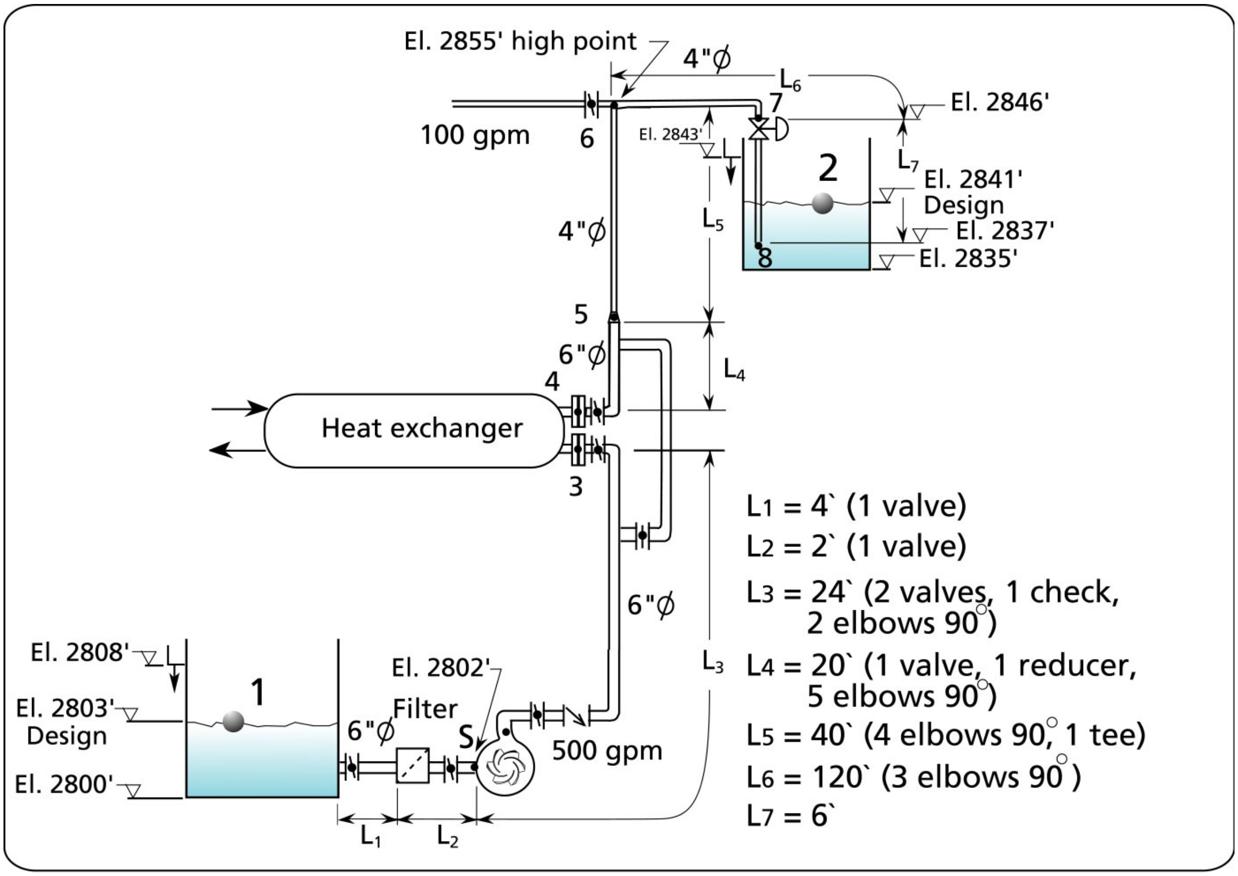


Figure 1 Calculation example flow schematic.

Situation

Water at 150 °F is to be pumped from a collecting tank located at the basement level (elevation 2800' above sea level). Both the suction and discharge tanks have a square section (6'L x 6'W x 10' H), the overflow level is at 8' from the bottom of the tanks. The flow through the pump is 500 USgpm and it is located on the basement floor. There is a filter on the suction line and a heat exchanger on the discharge side of the pump. The manufacturer of the filter specifies that there will be a pressure drop of 3 psi at 500 gpm. The manufacturer of the heat exchanger specifies that there will be a pressure drop of 5 psi at 500 gpm. There is a branch on the discharge side of the pump that requires 100 gpm. The control valve pressure head drop will be 10 feet of fluid. The piping material is stainless steel ID piping. All the manual valves are fully open butterfly valves.

***Notes and instructions**: disregard the reducer loss in the calculation. This calculation can be done however it is long it does not significantly enhance this exercise. For the pressure head loss due to the check valve use the CV coefficient given in Figure 5 and not the Hydraulic Institute fittings pressure head loss chart in Figure 9. The total head of the pump depends on the path of fluid particles that demands the most energy. It has been established that this path is between points 1 and 2 (see Figure 1). To calculate the friction loss in the pipe you may use schedule 40 new steel pipe friction table by Cameron included in this example or you can calculate the loss using the Darcy-Weisbach equation with the Moody diagram or the Colebrook or Swamee-Jain equation.*

Your task is to:

1. Calculate the total head and select the pump.
2. Calculate the NPSH available and check with respect to the NPSH required.
3. Calculate the specific speed and predict the pump efficiency. Calculate the suction specific speed and Thoma number and check the prediction of the Thoma number regarding cavitation.
4. Calculate the temperature rise of the fluid within the pump and compare with the maximum recommended.
5. Calculate the pressure ahead of the control valve using method 1 which uses the flow data between points 1 and the control valve inlet point 7 (see Figure 3) and method 2 which uses the flow data between points 2 and the control valve inlet point 7 (see Figure 3).

CALCULATIONS

1. Calculate the total head and select the pump

Total head is given by formula [1]. For the meaning of the variables see the nomenclature in table 20. If you would like to know more about how this equation was derived see J. Chaurette's book "Pump System Analysis and Centrifugal Pump Sizing" available at http://www.lightmypump.com/pump_book.htm (reference 1).

$$\Delta H_P(ft\ fluid)=(\Delta H_{F1-2}+\Delta H_{EQ1-2})+\frac{1}{2g}(v_2^2-v_1^2)+z_2+H_2-(z_1+H_1) \qquad [1]$$

Pressure head loss due to pipe friction

The velocity in the pipe is given by formula [2].

$$v(ft/s) = 0.4085 \times \frac{Q(USgal./\min)}{D^2\ (in)^2} \qquad [2]$$

The pressure head loss or piping friction is provided for in an extract of Cameron Hydraulic data book (see Figures 5 and 6). For the purpose of this exercise use schedule 40 steel pipe. The friction loss in pipes is typically given in terms of feet of fluid per 100 feet of pipe that the fluid moves through.

$$\frac{\Delta H_{FP}}{L}\left(\frac{ft\quad fluid}{100\ \ ft\quad pipe}\right) = see\quad Cameron\ \ tables$$

Or use the the Darcy-Weisbach equation with the Moody diagram (see Figure 15) or the Colebrook or Swamee-Jain equation.

Darcy-Weisbach equation

$$\frac{\Delta H_{FP}}{L}\left(\frac{ft\ fluid}{100ft\ \ of\,pipe}\right)=1200f\,\frac{(v(ft/s))^2}{D(in)\times 2g(ft/s^2)}$$

Colebrook equation

$$\frac{1}{\sqrt{f}} = -2\ \log_{10}\left(\frac{\varepsilon}{3.7\,D}+\frac{2.51}{R_e\sqrt{f}}\right)$$

Swamee-Jain equation

$$f = \frac{0.25}{\left(\log_{10}\left(\frac{\varepsilon}{3.7\ D}+\frac{5.74}{R_e^{\ 0.9}}\right)\right)^2}$$

SECTION	**FLOW (Usgal/min)**	**DIA (in)**	**VELOCITY (ft/s)**	**$\Delta H_{FP}/L$ (ft/100 ft pipe)**	**L (ft)**	**ΔH_{FP} (ft fluid)**
L_1	500	6	5.67	1.64	4	0.06
L_2	500	6	5.67	1.64	2	0.03
L_3	500	6	5.67	1.64	24	0.39
L_4	500	6	5.67	1.64	20	0.32
L_5	500	4	12.76	13.1	40	5.2
L_6	400	4	10.21	8.51	120	10.2
Sub-total ΔH_{FP1-7}	-	-	-	-	-	16.2
L_7	400	4	10.21	8.51	6	0.51
Total ΔH_{FP1-2}	-	-	-	-	-	16.71

Table 1 Friction loss for all pipe segments.

Sample calculation for line segment L_1

The friction loss in feet of fluid for 100 feet of pipe from the table in Figure 6 is 1.64. The friction loss is then:

$$\Delta H_{FP}\,(ft\;\;fluid) = 1.64 \times \frac{4}{100} = 0.06$$

Pressure head loss due to fittings friction

The friction loss for fittings is given by formula [3].

$$\Delta H_{FF}(ft\;\;fluid) = K\frac{v^2(ft/s)^2}{2g(ft/s^2)}\;\;for\;\;K\;\;see\;\;table \qquad [3]$$

The K factors for the different fittings type is given in the form of graphs (see Figures 8 and 9 which are extracts of the Hydraulic Engineering's Standards book, www.pumps.org). Use these figures for the K factors in equation [3] for fittings and manual valves.

SECTION	FLOW (Usgal/min)	TYPE	QTY	DIA (in)	VELOCITY (ft/s)	$v^2/2g$ (ft fluid)	K	ΔH_{FF} (ft fluid)
L_1	500	Entrance	1	6	5.67	0.5	1	0.5
L_1	500	Butterfly	1	6	5.67	0.5	1	0.5
L_2	500	Butterfly	1	6	5.67	0.5	1	0.5
L_3	500	Butterfly	2	6	5.67	0.5	1	1
L_3	500	Elbows	2	6	5.67	0.5	0.28	0.28
L_4	500	Elbows	5	6	5.67	0.5	0.28	0.7
L_4	500	Butterfly	1	6	5.67	0.5	1	0.5
L_5	500	Elbows	4	4	12.76	2.53	0.32	3.2
L_5	500	Tee	1	4	12.76	2.53	0.7	1.77
L_6	400	Elbows	3	4	10.21	1.62	0.32	1.55
Sub-total ΔH_{FF1-7}	-	-	-	-	-	-	-	10.5
L_7	400	Pipe exit	1	4	10.21	1.62	1	1.62
Total ΔH_{FF1-2}	-	-	-	-	-	-	-	12.12

Table 2. Friction loss for fittings.

Sample calculation for line segment L_1

The K value for the entrance loss is 1. The friction loss is then:

$$\Delta H_{FF}(ft\ \ fluid) = 1\times\frac{5.67^2\,(ft/s)^2}{2\times 32.17(ft/s^2)} = 0.5$$

Pressure head loss due to equipment

$$H(ft\ fluid) = 2.31\frac{p(psi)}{SG} \quad [4]$$

The pressure drop across the filter is given by the manufacturer, 3 psi at 500 gpm. We can calculate the pressure head loss by using equation [4]. The value of the specific gravity SG is very close to one, for water this value changes with the temperature (see Figure 12). A similar approach is taken for the heat exchanger whose pressure drop is given as 5 psi.

The control valve is a different matter, if this is a new system we will have to assume a reasonable value for a pressure drop that is consistent with good practice. Consultants have found that in general if one assumes a pressure head drop of 10 ft of fluid it will always be possible to select a valve of a reasonable size that will provide good control. If the system is existing then the manufacturer's data will have to be used to calculate the pressure drop for that specific valve at 500 gpm.

SECTION	**FLOW (Usgal/min)**	**TYPE**	**QTY**	**Δp (psi)**	**SG**	**Δp (ft fluid)**	**ΔH_{EQ} (ft fluid)**
L_2	500	Filter	1	3	0.98	7.07	7.07
L_3	500	Heat exchanger	1	5	0.98	11.78	11.78
L_7	400	Control valve	1	4.24	0.98	10	10
Total ΔH_{EQ1-2}	-	-	-	-	-	-	28.86

Table 3. Friction loss of the equipment.

Note: Δp control valve = 10 ft fluid

Pressure head loss due to the check valve

To calculate the pressure head drop across the check valve we use the CV of the valve. The valve flow coefficient (CV) is used as an indicator of the pressure drop across a valve under specific flow conditions and is formally defined as the number of gallons per minute of room temperature water that will flow through the valve with a pressure drop of 1 psi across the valve (see equation [5]). The value for the check valve CV can be found in the table of Figure 4.

$$CV = \frac{q\,(USgpm)}{\sqrt{\dfrac{\Delta p\,(psi)}{SG}}} \qquad [5]$$

We can obtain the value of the pressure drop (Δp) across the check valve by using equation [6] which is equation [5] with the pressure drop term isolated on the left hand side of the equation.

$$\Delta p\,(psi) = \left(\frac{q\,(gpm)}{CV\left(\dfrac{gpm}{psi^{1/2}}\right)} \right)^2 \times SG \qquad [6]$$

TYPE	FLOW (Usgal/min)	QTY	DIA (in)	SG	CV (gpm/psi$^{1/2}$)	Δp (psi)	ΔH_{check}(ft fluid)
Tilting disc	500	1	6	.98	590	0.7	1.65
Table 4							

Total static head

Total static head is the difference between the elevations of the liquid surface of the discharge tank vs. the suction tank.

z_1	z_2	z_2-z_1 (ft fluid)
2803	2841	38

Velocity head difference between the outlet and inlet of the system

v_1 and v_2 are respectively the velocities of the fluid particles at the inlet of the system and the outlet. The inlet of the system is at the position of the surface of the liquid in the suction tank. The velocity (v_1) of the fluid particles at the surface is quite low and small enough to be considered nil. The outlet of the system is at the position of the surface of the liquid in the discharge tank. The velocity (v_2) of the fluid particles at the surface is quite low and small enough to be considered nil.
Notice that the discharge end of the pipe is submerged, the fluid particles will travel from the discharge pipe end to the liquid surface in the discharge tank. If the pipe were not submerged then the outlet of the system would be located at the discharge pipe end and the velocity v_2 would be the velocity at the end of the pipe.

v_1	v_2	$v_1^2/2g$	$v_2^2/2g$	$v_2^2/2g - v_1^2/2g$ (ft fluid)
0	0	0	0	0

Tank pressure head difference between the outlet and inlet of the system

If the suction tank were pressurized with pressure p_1, there would be a corresponding pressure head H_1. Since the tank is not pressurized and is open to atmosphere then the pressure p_1 is zero and therefore H_1 is zero. The same applies to the discharge tank.

H_1	H_2	$H_2 - H_1$ (ft fluid)
0	0	0

Calculation results (total head)

Table 5 brings together all the previous calculations and the result is the total head required of the pump.

Component	Sign	(ft fluid)	Results
Pipe friction head loss	+	ΔH_{FP1-2}	16.71
Fittings friction head loss	+	ΔH_{FF1-2}	12.12
Equipment friction head loss	+	ΔH_{EQ1-2}	28.86
Check valve head loss	+	ΔH_{CHECK}	1.65
Total static head	+	$z_2 - z_1$	38
Velocity head difference	+	$v_2^2/2g - v_1^2/2g$	0
Tank pressure head difference	+	$H_1 - H_2$	0
Total head (ft fluid)	=	ΔH_P	97.34

Table 5. Summary of the calculation results of the total head.

Brake horsepower
(determine the pump efficiency from the pump performance curve prior to doing this calculation)

The power absorbed by the pump is given by equation[7] (see reference 1):

$$P_{pump}(hp) \quad = \quad \frac{SG \times \Delta H_P(ft \quad fluid) \times \quad q(US\,gal/\min)}{3960 \times \quad \eta_{pump}} \qquad [7]$$

For example, we have selected an impeller size of 10.7 inches (see Figure 12). The pump efficiency at 500 gpm is given by the pump's characteristic curve and is 0.71. The total head is 97.3 feet as calculated.

$$P_{pump}(hp) \quad = \quad \frac{0.98 \times 97.3 \times 500}{3960 \ \times 0.71} = 16.9$$

SPECIFIC GRAVITY SG	**TOTAL HEAD ΔH_P (ft fluid)**	**FLOW q (Usgal/min)**	**PUMP EFFICIENCY η**	**BRAKE HORSEPOWER P(hp)**
0.98	97.3	500	.713	16.9

Table 6 Power to the pump shaft calculation results.

PUMP SELECTION DATA

This table lists the important information on the pump that was selected to meet the process requirements.

Pump Manufacturer	Goulds
Pump Model	3175 3X6-12
Type	End suction, direct drive
Suction dia. (in)	6
Discharge dia. (in)	3
Impeller speed (rpm)	1750
Operating head (ft)	97.3
Operating Flow (Usgpm)	500
Pump efficiency (%)	71.3
Predicted efficiency (%)	77
Specific speed	
Suction specific speed	
Temperature rise (°F)	
Fluid type	Water
Viscosity (cSt)	1.1
Temperature (°F)	150
Specific gravity	0.98
Specific heat (Btu/lb-°F)	1.0
Brake horsepower (hp)	16.9
Selected horsepower (hp)	20
Frame	256 T
Pump shut-off head (ft)	122
System high point (ft) $z_{high} - z_1$	52
NPSH required (ft abs.)	6
NPSH available (ft abs.)	15.3
Max. impeller size (in)	12
Min. impeller size (in)	9
Selected impeller size (in)	10.7

Table 7 Summary of the pump data.

2. Calculate the N.P.S.H. available and check against the N.P.S.H. required.

Most of the data required for the N.P.S.H. available has already been calculated.

H_S (see equation [8a]) is the pressure head at point S or the pump suction. The N.P.S.H. available is the value of the pressure head available at point S (H_S) plus the atmospheric pressure minus the vapor pressure of the liquid.

$$N.P.S.H._{avail}\ (ft\ \ fluid\ abs\ )\ = H_S + H_A - H_{va} \qquad [8a]$$

The value of the pressure head (H_S) at point S (see equation [8b]) will depend on the pipe and equipment loss between points 1 and S plus the velocity head at point 1 and plus the elevation difference the two same points. If you would like to know more about how this equation was derived see reference 1.

$$H_S = -(\Delta H_{F1-S} + \Delta H_{EQ-S}) + \frac{v_1^2}{2g} + (z_1 - z_s + H_1) \qquad [8b]$$

By replacing the value of H_S in equation [8b] into equation [8a] we obtain the N.P.S.H. available (see equation [8c]).

$$N.P.S.H._{avail}\ (ft\ \ fluid\ abs\ )\ = -(\Delta H_{F1-S} + \Delta H_{EQ-S}) + \frac{v_1^2}{2g} + (z_1 - z_s + H_1) + H_A - H_{va} \qquad [8c]$$

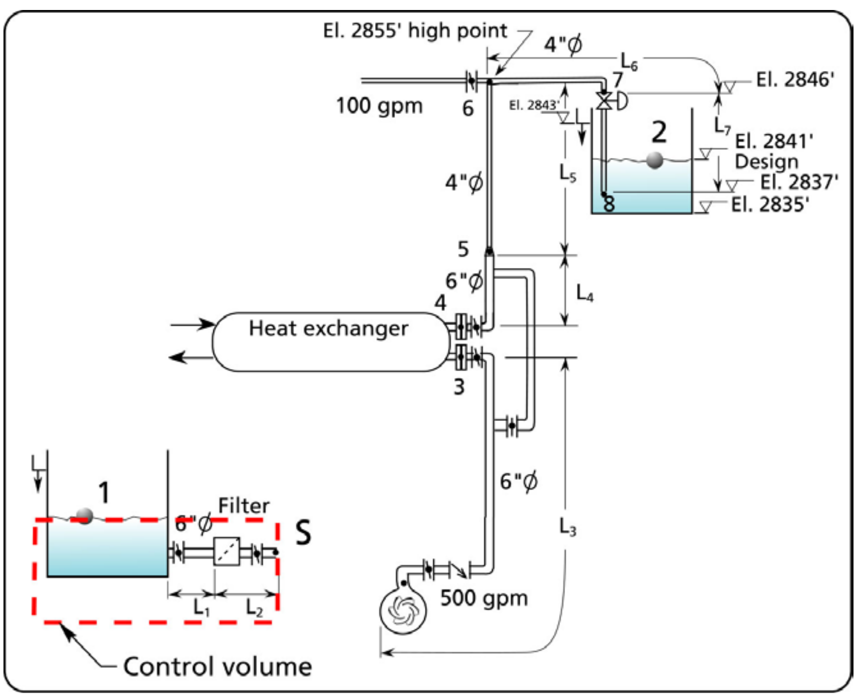


Figure 2 Position of the control volume which allows the calculation of the pressure head at point S.

Pressure head loss due to pipe friction

SECTION	FLOW (Usgal/min)	DIA (in)	VELOCITY (ft/s)	$\Delta H_{FP}/L$ (ft/100 ft pipe)	L (ft)	ΔH_{FP} (ft fluid)
L_1	500	6	5.67	1.64	4	0.06
L_2	500	6	5.67	1.64	2	0.03
Total $\Delta H_{FP1\text{-}S}$	-	-	-	-	-	0.09

Table 8

Pressure head loss due to fittings friction

SECTION	TYPE	QTY	FLOW (USgal/min)	DIA (in)	VELOCITY (ft/s)	$v^2/2g$ (ft fluid)	K	ΔH_{FF} (ft fluid)
L_1	Inward proj. entrance	1	500	6	5.67	0.5	1	0.5
L_1	Butterfly	1	500	6	5.67	0.5	1	0.5
L_2	Butterfly	1	500	6	5.67	0.5	1	0.5
Total $\Delta H_{FF1\text{-}S}$	-	-	-	-	-	-	-	1.5

Table 9

Pressure head loss due to equipment

SECTION	TYPE	QTY	FLOW (USgal/min)	Δp (psi)	SG	Δp (ft fluid)	$\Delta H_{EQ1\text{-}S}$ (ft fluid)
L_2	Filter	1	500	3	0.98	7.07	7.07

Table 10

Suction static head

z_1	z_S	z_1-z_S (ft fluid)
2803	2802	1

Tank pressure head at the inlet of the system

H_1 (ft fluid)
0

Velocity head at the inlet of the system

v_1	$v^2_1/2g$ (ft fluid)
0	0

Atmospheric pressure head

The atmospheric pressure in the environment of the pump depends on the elevation above sea level or the plant ground floor elevation which is considered precise enough. The chart in Figure 11 gives the pressure in psia corresponding to the pump's elevation. Using equation [4] we can calculate the corresponding pressure head.

p_A(psia)	SG	H_A(ft fluid abs.)
13.3	0.98	31.35

Vapor pressure head

The vapor pressure of the fluid depends on it's temperature. The table in Figure 11 gives the vapor pressure in psia corresponding to the temperature. Using equation [4] we can calculate the corresponding pressure head.

p_{va}(psia)	SG	H_{va}(ft fluid abs.)
3.6	0.98	8.47

Calculation results (N.P.S.H. available)

Component	Sign	(ft fluid)	Results
Pipe friction head loss	-	ΔH_{FP1-S}	0.09
Fittings friction head loss	-	ΔH_{FF1-S}	1.5
Equipment friction head loss	-	ΔH_{EQ1-S}	7.07
Suction static head	+	$z_1 - z_S$	1
Tank pressure head	+	H_1	0
Velocity head	+	$v_1^2/2g$	0
Atmospheric pressure head	+	H_B	31.35
Vapor pressure head	-	H_{va}	8.47
$NPSH_{avail.}$ (ft fluid abs.)	=	NPSH	15.4

Table 11. Summary of the calculation results of the N.P.S.H. available.

Compare the calculated value of the N.P.S.H. available with the N.P.S.H. required that the pump manufacturer provides on the characteristic curve which is approximately 6 feet of water absolute. We have a comfortable margin of safety compared to our calculated value for the system.

3. Calculate the specific speed, suction specific speed and Thoma number and check the prediction of the Thoma number regarding cavitation

Specific speed (N_S)

Specific speed is a number that provides an indication of the speed of the impeller, the flow rate and the head produced. The number is low, below 2000 (see Figure 13) for pumps of radial design that provide high head and low flow. It is large, over 10000, for pumps that provide high flow and low head. Along with the suction specific speed, it can be used to predict cavitation.

$$N_S = \frac{N(rpm) \times \sqrt{Q(USgpm)}}{H(ft\ fluid)^{0.75}} \quad [9]$$

$$N_S = \frac{1780 \times \sqrt{500}}{97^{0.75}} = 1287 \quad [9a]$$

Predict the pump efficiency

The pump's efficiency is directly related to its specific speed. Efficiency increases as specific speed increases. Also, as shown in Figure 14, the efficiency increases as flow rate increase, this means that larger pumps at the same specific speed are more efficient. . For impeller sizes larger than 10" the effect of size or increased flow rate is small and generally insignificant. For impeller sizes 4" and less , the penalty for smaller sizes is severe.

The efficiency predicted by the chart in is Figure 14 is 0.77.

Suction specific speed (S)

Suction specific speed is a number that is dimensionally similar to the pump specific speed and is used as a guide to prevent cavitation.

$$S = \frac{N(rpm) \times \sqrt{Q(USgpm)}}{N.P.S.H._A(ft\ fluid)^{0.75}} \quad [10]$$

Instead of using the total head of the pump H, the $N.P.S.H._A$ (Net Positive Suction Head available) is used. Also if the pump is a double suction pump then the flow value to be used is one half the total pump output.

The Hydraulic Institute recommends that the suction specific speed be limited to 8500. Some pump manufactures limit this value to 10,000-12,000.

$$S = \frac{1780 \times \sqrt{500}}{15.4^{0.75}} = 5120 \quad [10a]$$

Thoma cavitation parameter σ

$$\sigma = \frac{N.P.S.H.}{H} \qquad [11]$$

The Thoma cavitation parameter is non dimensional and has been used to predict the onset of cavitation (see Figure 16). Use this number to verify that this pump will have sufficient N.P.S.H.A. to operate properly.

$$\sigma = \frac{N.P.S.H.A.}{H} = \frac{15.4}{97} = 0.16 \qquad [11a]$$

4. Calculate the temperature rise of the fluid within the pump and compare with the maximum recommended

Because the transmission of power between the impeller and the fluid is inefficient, heat is generated, when the process is very inefficient such as at low flows allot of heat is generated. The pump manufacturer's limit the amount of temperature rise to 15 °F. The temperature rise will depend on the total head, the specific heat of the fluid (water is 1 BTU/lb-°F) and the efficiency at the operating point.

To calculate the temperature rise:

$$\Delta T(F) = \frac{H(ft)}{778 \times Cp(BTU/lb-F) \times \eta} \qquad [12]$$

$$\Delta T(F) = \frac{97}{778 \times 1 \times .713} = 0.17 \qquad [12a]$$

5. Calculate the pressure ahead of the control valve using method 1

It is important to know the pressure just at the inlet of a control valve. This information is required to size the valve and ensure that it will control properly and avoid cavitation.

Method 1

Method 1 consists of calculating the pressure at the inlet of the control valve by making use of the total head of the pump and the friction loss and elevation difference between the inlet of the system and point 7, the inlet of the valve.

H_X (see equation [13]) is the pressure head of any point we choose on the discharge side of the pump (see reference 1).

$$H_X = \Delta H_P - (\Delta H_{F1-X} + \Delta H_{EQ1-X}) + \frac{1}{2g}(v_1^{\,2} - v_X^{\,2}) + (z_1 + H_1 - z_X) \qquad [13]$$

In our case point X will be point 7 or the point just at the inlet of the control valve.

$$H_7 = \Delta H_P - (\Delta H_{F1-7} + \Delta H_{EQ1-7}) + \frac{1}{2g}(v_1^{\,2} - v_7^{\,2}) + (z_1 + H_1 - z_7) \qquad [14]$$

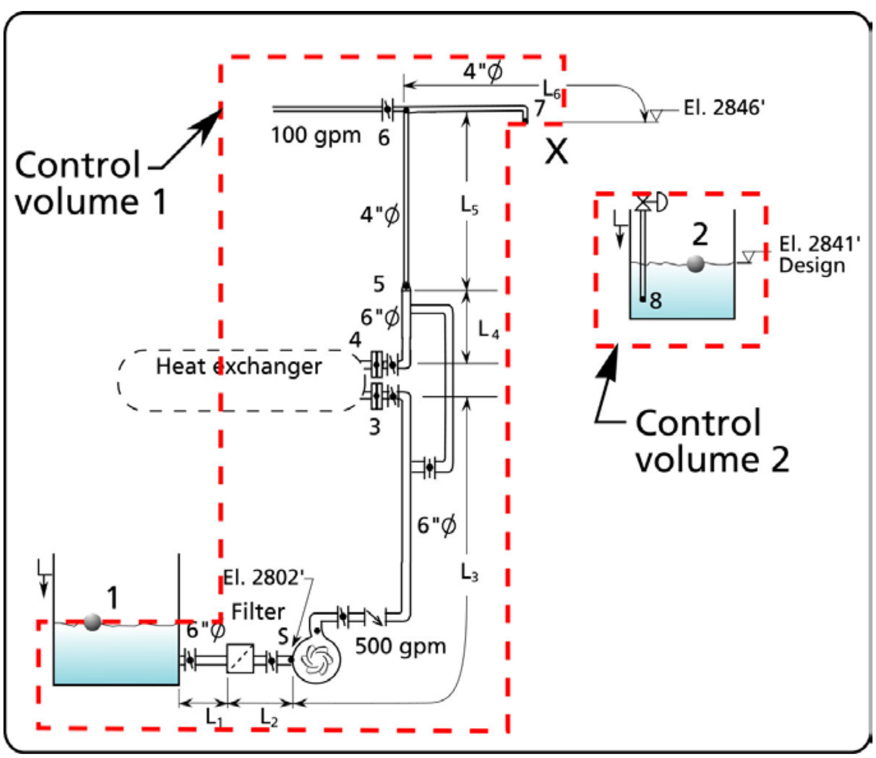


Figure 3 Position of point 7, the inlet of the control valve.

The value of the pressure head at point 7 depends on the total head of the pump minus the pipe and equipment head loss between points 1 and 7 minus the difference in velocity head between points 1 and 7 and minus the elevation difference between the two same points.

Once again most of the data required to calculate the pressure at point 7 has already been calculated.

Pressure head loss due to pipe friction

SECTION	FLOW (USgal/min)	DIA (in)	VELOCITY (ft/s)	$\Delta H_{FP}/L$ (ft/100 ft pipe)	L (ft)	ΔH_{FP} (ft fluid)
L_1	500	6	5.67	1.64	4	0.06
L_2	500	6	5.67	1.64	2	0.03
L_3	500	6	5.67	1.64	24	0.39
L_4	500	6	5.67	1.64	20	0.32
L_5	500	4	12.76	13.1	40	5.2
L_6	400	4	10.21	8.51	120	10.2
Total ΔH_{FP1-7}	-	-	-	-	-	16.2

Table 12

Pressure head loss due to fittings friction

SECTION	FLOW (USgal/min)	TYPE	QTY	DIA (in)	VELOCITY (ft/s)	$v^2/2g$ (ft fluid)	K	ΔH_{FF} (ft fluid)
L_1	500	Entrance	1	6	5.67	0.5	1	0.5
L_1	500	Butterfly	1	6	5.67	0.5	1	0.5
L_2	500	Butterfly	1	6	5.67	0.5	1	0.5
L_3	500	Butterfly	2	6	5.67	0.5	1	1
L_3	500	Elbows	2	6	5.67	0.5	0.28	0.28
L_4	500	Elbows	5	6	5.67	0.5	0.28	0.7
L_4	500	Butterfly	1	6	5.67	0.5	1	0.5
L_5	500	Elbows	4	4	12.76	2.53	0.32	3.2
L_5	500	Tee	1	4	12.76	2.53	0.7	1.77
L_6	400	Elbows	3	4	10.21	1.62	0.32	1.55
Total ΔH_{FF1-7}	-	-	-	-	-	-	-	10.5

Table 13

Pressure head loss due to equipment

$$H(ft\ fluid) = 2.31\frac{p(psi)}{SG}$$

SECTION	FLOW (USgal/min)	TYPE	QTY	Δp (psi)	SG	Δp (ft fluid)	ΔH_{EQ} (ft fluid)
L_2	500	Filter	1	3	0.98	7.07	7.07
L_3	500	Heat exchanger	1	5	0.98	11.78	11.78
Total $\Delta H_{EQ1\text{-}7}$	-	-	-	-	-	-	18.85

Table 14

Pressure head loss due to the check valve

$$\Delta p\ (psi) = \left(\frac{q\ (gpm)}{CV\ \left(\frac{gpm}{psi^{1/2}}\right)} \right)^2 \times SG$$

TYPE	FLOW (USgal/min)	QTY	DIA (in)	CV(gpm/psi$^{1/2}$)	SG	Δp (psi)	ΔH_{check} (ft fluid)
Tilting disc	500	1	6	590	0.98	0.7	1.65

Table 15

Static head

z_1	z_7	$z_1 - z_7$ (ft fluid)
2803	2846	- 43

Velocity head difference between points 1 and 7

v_1	v_7	$v_1^2/2g$	$v_7^2/2g$	$v_1^2/2g - v_7^2/2g$ (ft fluid)
0	10.21	0	1.62	- 1.62

Tank pressure head at the inlet of the system

H_1 (ft fluid)
0

Calculation results (method 1 – pressure at the control valve inlet)

The sign in the second column follows the signs of the terms in equation [16].

Component	Sign	(ft fluid)	Results
Total head	+	ΔH_P	97.34
Pipe friction head loss	-	ΔH_{FP1-7}	16.2
Fittings friction head loss	-	ΔH_{FF1-7}	10.5
Equipment friction head loss	-	ΔH_{EQ1-7}	18.85
Check valve head loss	-	ΔH_{CHECK}	1.65
Total static head	+	$z_1 - z_7$	- 43
Velocity head difference	+	$v^2_1/2g - v_7^2/2g$	- 1.62
Tank pressure head	+	H_1	0
Pressure head at the control valve (ft fluid)	=	H_7	5.52
Pressure at the control valve (psig)	=	p_7	2.34

Table 16 Summary of the results of the pressure calculation at point 7.

5. **Calculate the pressure ahead of the control valve using method 2**

Method 2

Method 2 consists of calculating the pressure at the inlet of the control valve by making use of the friction loss and elevation difference between the outlet of the system and point 7, the inlet of the valve.

H_X (equation [17] is the pressure of any point we choose on the discharge side of the pump.

$$H_X = \Delta H_{FX-2} + \Delta H_{EQX-2} + \frac{1}{2g}(v_2^{\ 2} - v_X^{\ 2}) + (z_2 + H_2 - z_X) \qquad [17]$$

In our case point X will be point 7 or the point just at the inlet of the control valve.

$$H_7 = \Delta H_{F7-2} + \Delta H_{EQ7-2} + \frac{1}{2g}(v_2^{\ 2} - v_7^{\ 2}) + (z_2 + H_2 - z_7) \qquad [18]$$

The value of the pressure head at point 7 will depend on the pipe and equipment loss between points 7 and 2 (the outlet) plus the difference in velocity heads between points 2 and 7 and plus the elevation difference between the two same points. Notice that with this method we do not consider the total head of the pump.

The pressure at point 7 is dictated by the flow rate. The fluid particles that are ahead of point 7 do not know that they have gotten to that point thanks to the energy supplied by the pump, all that they see is that they have arrived at point 7 with a certain amount of pressure and velocity. We can therefore do an energy balance between points 7 and 2 and find out what the pressure at point 7 has to be to maintain the pressure and velocity energy at this point.

Pressure head loss due to pipe friction

SECTION	**FLOW (USgal/min)**	**DIA (in)**	**VELOCITY (ft/s)**	**$\Delta H_{FP}/L$ (ft/100 ft pipe)**	**L (ft)**	**ΔH_{FP7-2} (ft fluid)**
L_7	400	4	10.21	8.51	6	0.51
Total ΔH_{FP7-2}						

Table 17

Pressure head loss due to fittings friction

SECTION	FLOW (USgal/min)	TYPE	QTY	DIA (in)	VELOCITY (ft/s)	$v^2/2g$ (ft fluid)	K	ΔH_{FF7-2} (ft fluid)
L_7	400	Pipe exit	1	4	10.21	1.62	1	1.62
Total ΔH_{FF7-2}								

Table 18

Pressure head loss due to equipment

$$H(ft\ fluid) = 2.31 \frac{p(psi)}{SG}$$

SECTION	FLOW (USgal/min)	TYPE	QTY	Δp (psi)	SG	Δp (ft fluid)	ΔH_{EQ7-2} (ft fluid)
L_7	400	Control valve	1	4.24	0.98	10	10
Total ΔH_{EQ7-2}							

Table 19

Total static head

z_7	z_2	z_2-z_7 (ft fluid)
2846	2841	- 5

Velocity head difference between points 7 and 2

v_7	v_2	$v_7^2/2g$	$v_2^2/2g$	$v_2^2/2g - v_7^2/2g$ (ft fluid)
10.21	0	1.62	0	- 1.62

Tank pressure head at the outlet of the system

H_2 (ft fluid)
0

Calculation results (method 2 – pressure at the control valve inlet)

The sign in the second column follows the signs of the terms in equation [18].

Component	Sign	(ft fluid)	Results
Pipe friction head loss	+	ΔH_{FP7-2}	0.51
Fittings friction head loss	+	ΔH_{FF7-2}	1.62
Equipment friction head loss	+	ΔH_{EQ7-2}	10
Static head	+	$z_2 - z_7$	- 5
Velocity head difference	+	$v^2_2/2g - v_7^2/2g$	- 1.62
Tank pressure head	+	H_2	0
Pressure head at the control valve (ft fluid)	=	H_7	5.51
Pressure at the control valve (psig)	=	p_7	2.34

Table 20 Results of the pressure calculation at point 7.

Symbols

Variable nomenclature		Imperial system (FPS units)	Metric system (SI units)
H	head	ft (feet)	m (meter)
ΔH_P	total tead	ft (feet)	m (meter)
ΔH_{EQ1-2}	equipment friction head loss between points 1 and 2	ft (feet)	m (meter)
ΔH_{F1-2}	friction head loss in pipes between points 1 and 2	ft (feet)	m (meter)
H_A	atmospheric pressure head	ft (feet)	m (meter)
H_{va}	vapor pressure head	ft (feet)	m (meter)
p	pressure	psi (pound per square inch)	kPa (kiloPascal)
SG	specific gravity; ratio of the fluid density to the density of water at standard conditions	non-dimensional	
N_S	Specific speed		
S	Suction specific speed		
c_p	Specific heat	BTU/lb-°F	KJ/kg-°C
σ	Thoma cavitation parameter	non-dimensional	
q	flow rate	gpm (gals./min)	L/min (liters/mi)
v	velocity	ft/s (feet/second)	m/s (meter/second)
g	acceleration due to gravity, 32.17 ft/s^2	ft/s^2 (feet/second squared)	m/s^2 (meter/second squared)
z	*vertical position*	ft (feet)	m (meter)

Table 21 Variable nomenclature.

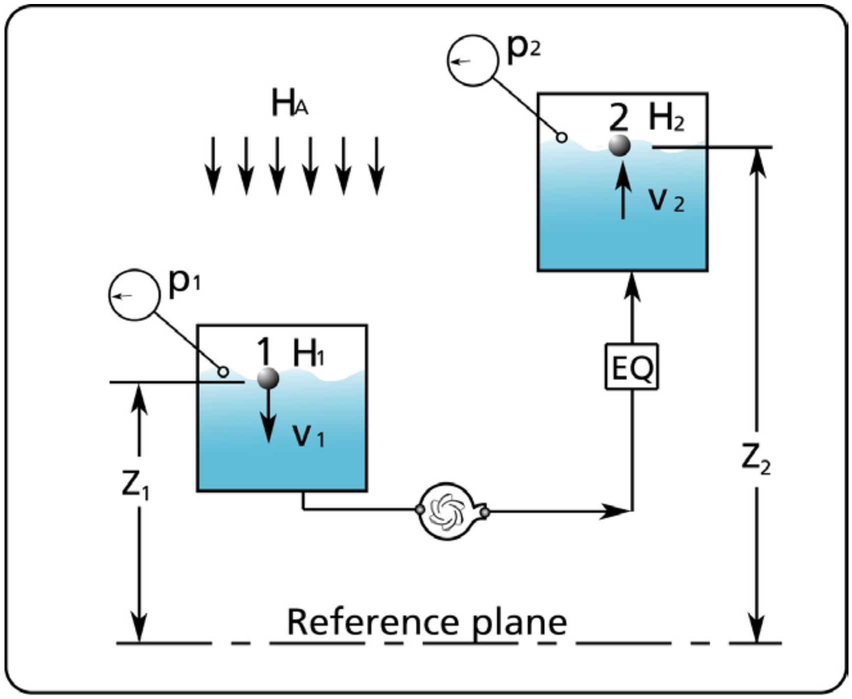


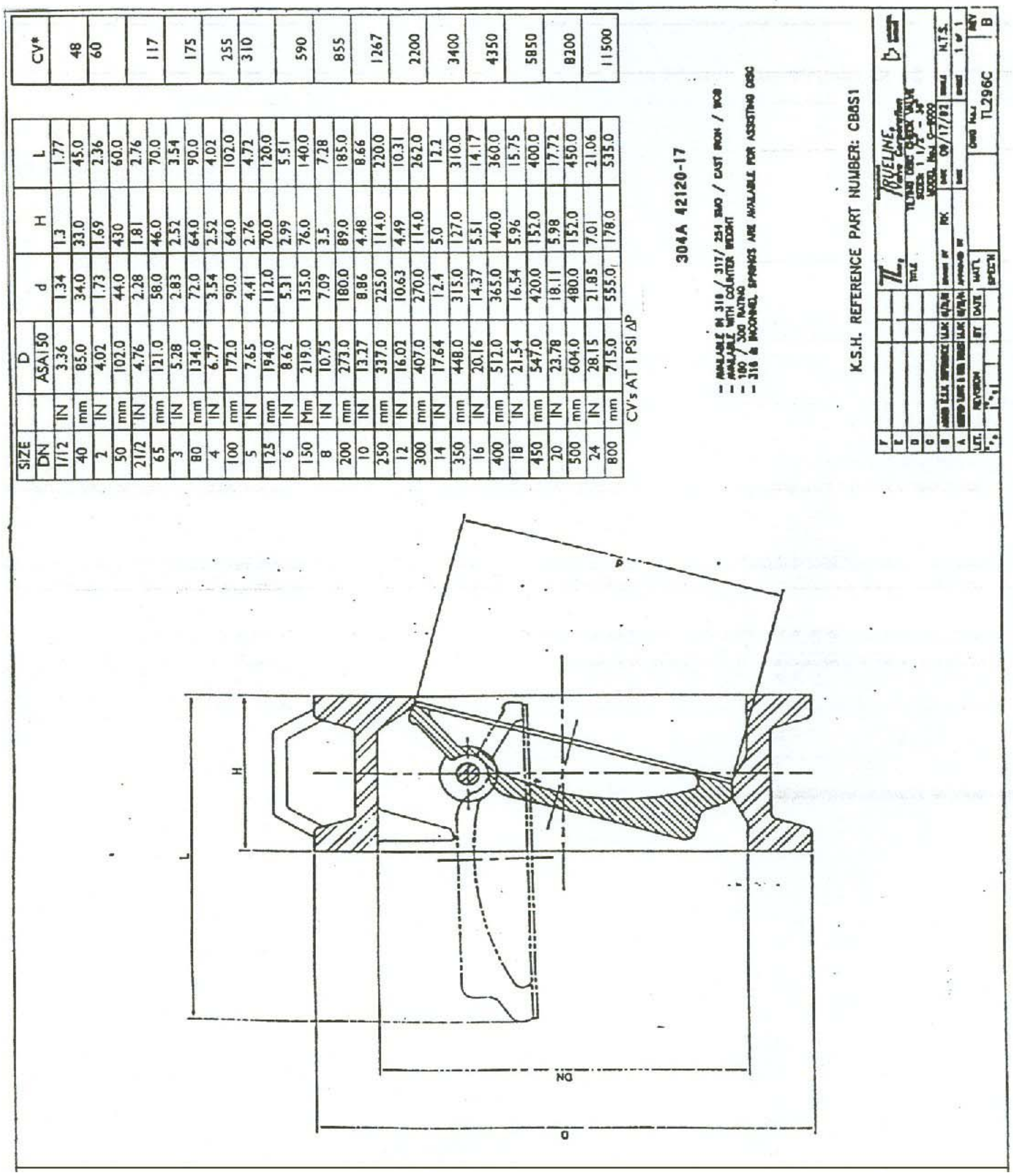
Figure 4 Nomenclature

References

1. Pump System Analysis and Centrifugal Pump Sizing by J. Chaurette published by http://www.lightmypump.com/pump_book.htm, January2003

2. Standards by the Hydraulic Institute, New Jersey www.pumps.org

3. The Cameron Hydraulic data book by Ingersoll Rand



SIZE DN		D ASA150	d	H	L	CV*
1/12	IN	3.36	1.34	1.3	1.77	48
40	mm	85.0	34.0	33.0	45.0	
2	IN	4.02	1.73	1.69	2.36	60
50	mm	102.0	44.0	430	60.0	
21/2	IN	4.76	2.28	1.81	2.76	117
65	mm	121.0	58.0	46.0	70.0	
3	IN	5.28	2.83	2.52	3.54	175
80	mm	134.0	72.0	64.0	90.0	
4	IN	6.77	3.54	2.52	4.02	255
100	mm	172.0	90.0	64.0	102.0	
5	IN	7.65	4.41	2.76	4.72	310
125	mm	194.0	112.0	70.0	120.0	
6	IN	8.62	5.31	2.99	5.51	590
150	Mm	219.0	135.0	76.0	140.0	
8	IN	10.75	7.09	3.5	7.28	855
200	mm	273.0	180.0	89.0	185.0	
10	IN	13.27	8.86	4.48	8.66	1267
250	mm	337.0	225.0	114.0	220.0	
12	IN	16.02	10.63	4.49	10.31	2200
300	mm	407.0	270.0	114.0	262.0	
14	IN	17.64	12.4	5.0	12.2	3400
350	mm	448.0	315.0	127.0	310.0	
16	IN	20.16	14.37	5.51	14.17	4350
400	mm	512.0	365.0	140.0	360.0	
18	IN	21.54	16.54	5.96	15.75	5850
450	mm	547.0	420.0	152.0	400.0	
20	IN	23.78	18.11	5.98	17.72	8200
500	mm	604.0	480.0	152.0	450.0	
24	IN	28.15	21.85	7.01	21.06	11500
800	mm	715.0	555.0	178.0	535.0	

Figure 5 CV coefficients for check valves (source Trueline Valve Corp).

Ingersoll-Dresser Pumps Cameron Hydraulic Data

Friction of Water — Asphalt-dipped Cast Iron and New Steel Pipe

(Based on Darcy's Formula)

4 Inch *(Continued)*

Flow US gal per min	Asphalt-dipped cast iron, 4.0" inside dia			Std wt steel sch 40, 4.026" inside dia			Extra strong steel sch 80, 3.826" inside dia			Schedule 160—steel, 3.438" inside dia		
	Velocity ft per sec	Velocity head ft	**Head loss ft per 100 ft**	Velocity ft per sec	Velocity head ft	**Head loss ft per 100 ft**	Velocity ft per sec	Velocity head ft	**Head loss ft per 100 ft**	Velocity ft per sec	Velocity head ft	**Head loss ft per 100 ft**
20	.511	.004	**.038**	.504	.004	**.035**	.56	.00	**.045**	.691	.007	**.074**
30	.766	.009	**.076**	.756	.009	**.072**	.84	.01	**.092**	1.04	.017	**.154**
40	1.02	.016	**.128**	1.01	.016	**.120**	1.12	.02	**.153**	1.38	.030	**.258**
50	1.28	.025	**.194**	1.26	.025	**.179**	1.40	.03	**.230**	1.73	.046	**.387**
60	1.53	.037	**.273**	1.51	.036	**.250**	1.67	.04	**.320**	2.07	.067	**.540**
70	1.79	.050	**.365**	1.76	.048	**.330**	1.95	.06	**.424**	2.42	.091	**.691**
80	2.04	.065	**.470**	2.02	.063	**.422**	2.23	.08	**.541**	2.77	.119	**.885**
90	2.30	.082	**.588**	2.27	.080	**.523**	2.51	.10	**.649**	3.11	.150	**1.10**
100	2.55	.101	**.719**	2.52	.099	**.613**	2.79	.12	**.789**	3.46	.185	**1.34**
110	2.81	.123	**.862**	2.77	.119	**.732**	3.07	.15	**.943**	3.80	.224	**1.61**
120	3.06	.146	**1.02**	3.02	.142	**.861**	3.35	.17	**1.11**	4.15	.267	**1.89**
130	3.32	.171	**1.19**	3.28	.167	**1.00**	3.63	.20	**1.29**	4.49	.313	**2.20**
140	3.57	.199	**1.37**	3.53	.193	**1.15**	3.91	.24	**1.48**	4.84	.363	**2.53**
150	3.83	.228	**1.57**	3.78	.222	**1.31**	4.19	.27	**1.69**	5.18	.417	**2.89**
160	4.08	.259	**1.77**	4.03	.253	**1.48**	4.47	.31	**1.91**	5.53	.475	**3.26**
170	4.34	.293	**1.99**	4.28	.285	**1.66**	4.75	.35	**2.14**	5.88	.536	**3.66**
180	4.60	.328	**2.23**	4.54	.320	**1.85**	5.02	.39	**2.38**	6.22	.601	**4.09**
190	4.85	.368	**2.47**	4.79	.356	**2.05**	5.30	.44	**2.64**	6.57	.669	**4.53**
200	5.11	.406	**2.73**	5.04	.395	**2.25**	5.58	.48	**2.91**	6.91	.742	**5.00**
220	5.62	.490	**3.29**	5.54	.478	**2.70**	6.14	.59	**3.49**	7.60	.897	**6.00**
240	6.13	.583	**3.90**	6.05	.569	**3.19**	6.70	.70	**4.13**	8.30	1.07	**7.09**
260	6.64	.685	**4.55**	6.55	.667	**3.72**	7.26	.82	**4.81**	8.99	1.25	**8.27**
280	7.15	.794	**5.26**	7.06	.774	**4.28**	7.82	.95	**5.54**	9.68	1.45	**9.55**
300	7.66	.912	**6.02**	7.56	.888	**4.89**	8.38	1.09	**6.33**	10.37	1.67	**10.9**
320	8.17	1.04	**6.84**	8.06	1.01	**5.53**	8.94	1.24	**7.17**	11.06	1.90	**12.4**
340	8.68	1.17	**7.70**	8.57	1.14	**6.22**	9.50	1.40	**8.06**	11.75	2.14	**13.9**
360	9.19	1.31	**8.61**	9.07	1.28	**6.94**	10.0	1.6	**9.00**	12.44	2.40	**15.5**
380	9.70	1.46	**9.58**	9.58	1.43	**7.71**	10.6	1.7	**9.99**	13.13	2.68	**17.3**
400	10.2	1.62	**10.6**	10.1	1.58	**8.51**	11.2	1.9	**11.0**	13.82	2.97	**19.1**
420	10.7	1.79	**11.6**	10.6	1.74	**9.35**	11.7	2.1	**12.1**	14.52	3.27	**21.0**
440	11.2	1.96	**12.8**	11.1	1.91	**10.2**	12.3	2.3	**13.3**	15.21	3.59	**22.9**
460	11.7	2.14	**13.9**	11.6	2.09	**11.2**	12.8	2.5	**14.5**	15.90	3.92	**25.0**
480	12.3	2.33	**15.2**	12.1	2.27	**12.1**	13.4	2.8	**15.7**	16.59	4.27	**27.2**
500	12.8	2.53	**16.4**	12.6	2.47	**13.1**	14.0	3.0	**17.0**	17.28	4.64	**29.5**
550	14.0	3.06	**19.8**	13.9	2.99	**15.8**	15.3	3.6	**20.5**	19.00	5.61	**35.5**
600	15.3	3.65	**23.6**	15.1	3.55	**18.7**	16.7	4.3	**24.3**	20.74	6.67	**42.1**
650	16.6	4.28	**27.6**	16.4	4.17	**21.7**	18.1	5.1	**28.4**	22.46	7.83	**49.2**
700	17.9	4.96	**32.0**	17.6	4.84	**25.3**	19.5	5.9	**32.8**	24.19	9.08	**57.0**
750	19.1	5.70	**36.6**	18.9	5.55	**28.9**	20.9	6.8	**37.6**	25.92	10.4	**65.2**
800	20.4	6.48	**41.6**	20.2	6.32	**32.8**	22.3	7.7	**42.7**	27.65	11.7	**74.1**
850	21.7	7.32	**46.9**	21.4	7.13	**37.0**	23.7	8.7	**48.1**	29.38	13.4	**83.4**
900	23.0	8.20	**52.6**	22.7	8.00	**41.4**	25.1	9.8	**53.8**	31.10	15.0	**93.4**
950	24.3	9.14	**58.5**	23.9	8.91	**46.0**	26.5	10.9	**59.8**	32.83	16.7	**104**
1000	25.5	10.1	**64.8**	25.2	9.87	**50.9**	27.9	12.1	**66.2**	34.56	18.5	**115**
1100	28.1	12.3	**78.3**	27.7	11.9	**61.4**	30.7	14.6	**79.8**	38.02	22.4	**139**

Note: No allowance has been made for age, difference in diameter, or any abnormal condition of interior surface. Any factor of safety must be estimated from the local conditions and the requirements of each particular installation. It is recommended that for most commercial design purposes a safety factor of 15 to 20% be added to the values in the tables—see page 3-5.

Figure 6 Piping pressure head losses (source Cameron Hydraulic data book).

Ingersoll-Dresser Pumps Cameron Hydraulic Data

Friction of Water — Asphalt-dipped Cast Iron and New Steel Pipe

(Based on Darcy's Formula) *(Continued)*

6 Inch

Flow US gal per min	Asphalt-dipped cast iron, 6.0" inside dia			Std wt steel sch 40, 6.065" inside dia			Extra strong steel sch 80, 5.761" inside dia			Schedule 160—steel, 5.187" inside dia		
	Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft	Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft	Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft	Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft
50	.57	.005	**.027**	.56	.005	**.025**	.62	.01	**.032**	.759	.009	**.053**
60	.68	.007	**.038**	.67	.007	**.034**	.74	.01	**.044**	.911	.013	**.073**
70	.79	.010	**.048**	.78	.009	**.045**	.86	.01	**.058**	1.06	.018	**.096**
80	.91	.013	**.062**	.89	.012	**.057**	.98	.01	**.074**	1.22	.023	**.123**
90	1.02	.016	**.077**	1.00	.016	**.071**	1.11	.02	**.091**	1.37	.029	**.152**
100	1.13	.020	**.094**	1.11	.019	**.086**	1.23	.02	**.110**	1.52	.036	**.184**
120	1.36	.029	**.132**	1.33	.028	**.120**	1.48	.03	**.154**	1.82	.052	**.256**
140	1.59	.039	**.176**	1.55	.038	**.158**	1.72	.05	**.203**	2.13	.070	**.340**
160	1.82	.051	**.226**	1.78	.049	**.202**	1.97	.06	**.260**	2.43	.092	**.435**
180	2.04	.065	**.283**	2.00	.062	**.251**	2.22	.08	**.323**	2.73	.116	**.522**
200	2.27	.080	**.346**	2.22	.077	**.304**	2.46	.09	**.392**	3.04	.143	**.635**
220	2.50	.097	**.415**	2.44	.093	**.363**	2.71	.11	**.451**	3.34	.173	**.760**
240	2.72	.115	**.490**	2.66	.110	**.411**	2.96	.14	**.530**	3.64	.206	**.895**
260	2.95	.135	**.571**	2.89	.130	**.477**	3.20	.16	**.616**	3.95	.242	**1.04**
280	3.18	.157	**.658**	3.11	.150	**.548**	3.45	.19	**.708**	4.25	.281	**1.20**
300	3.40	.180	**.752**	3.33	.172	**.624**	3.69	.21	**.807**	4.56	.322	**1.36**
320	3.63	.205	**.851**	3.55	.196	**.705**	3.94	.24	**.911**	4.86	.366	**1.54**
340	3.86	.231	**.957**	3.78	.222	**.790**	4.19	.27	**1.02**	5.16	.414	**1.73**
360	4.08	.259	**1.07**	4.00	.240	**.880**	4.43	.31	**1.14**	5.47	.464	**1.93**
380	4.31	.289	**1.19**	4.22	.277	**.975**	4.68	.34	**1.26**	5.77	.517	**2.14**
400	4.54	.320	**1.31**	4.44	.307	**1.07**	4.93	.38	**1.39**	6.07	.572	**2.36**
450	5.10	.403	**1.65**	5.00	.388	**1.34**	5.54	.48	**1.74**	6.82	.725	**2.95**
500	5.67	.500	**2.02**	5.55	.479	**1.64**	6.16	.59	**2.13**	7.59	.894	**3.61**
550	6.24	.605	**2.44**	6.11	.580	**1.97**	6.77	.71	**2.55**	8.35	1.08	**4.34**
600	6.81	.720	**2.89**	6.66	.690	**2.33**	7.39	.85	**3.02**	9.11	1.29	**5.13**
650	7.37	.845	**3.38**	7.22	.810	**2.71**	8.00	.99	**3.52**	9.87	1.51	**5.99**
700	7.94	.980	**3.90**	7.77	.939	**3.13**	8.63	1.16	**4.06**	10.63	1.75	**6.92**
750	8.51	1.12	**4.47**	8.33	1.08	**3.57**	9.24	1.33	**4.64**	11.39	2.01	**7.91**
800	9.08	1.28	**5.07**	8.88	1.23	**4.04**	9.85	1.51	**5.25**	12.15	2.29	**8.96**
850	9.64	1.44	**5.72**	9.44	1.38	**4.55**	10.5	1.7	**5.90**	12.91	2.59	**10.1**
900	10.2	1.62	**6.40**	9.99	1.55	**5.08**	11.1	1.9	**6.60**	13.67	2.90	**11.3**
950	10.8	1.80	**7.11**	10.5	1.73	**5.64**	11.7	2.1	**7.33**	14.42	3.23	**12.5**
1000	11.3	2.00	**7.87**	11.1	1.92	**6.23**	12.3	2.4	**8.09**	15.18	3.58	**13.8**
1100	12.5	2.42	**9.50**	12.2	2.32	**7.49**	13.5	2.8	**9.74**	16.71	4.33	**16.7**
1200	13.6	2.88	**11.3**	13.3	2.76	**8.87**	14.8	3.4	**11.5**	18.22	5.15	**19.8**
1300	14.7	3.38	**13.2**	14.4	3.24	**10.4**	16.0	4.0	**13.5**	19.74	6.05	**23.1**
1400	15.9	3.92	**15.3**	15.5	3.76	**12.0**	17.2	4.6	**15.6**	21.26	7.01	**26.7**
1500	17.0	4.50	**17.5**	16.7	4.31	**13.7**	18.5	5.3	**17.8**	22.78	8.05	**30.6**
1600	18.2	5.12	**19.9**	17.8	4.91	**15.6**	19.7	6.0	**20.3**	24.29	9.16	**34.7**
1700	19.3	5.78	**22.4**	18.9	5.54	**17.5**	20.9	6.8	**22.8**	25.81	10.34	**39.1**
1800	20.4	6.48	**25.1**	20.0	6.21	**19.6**	22.2	7.7	**25.5**	27.33	11.59	**43.8**
1900	21.6	7.22	**28.0**	21.1	6.91	**21.8**	23.4	8.4	**28.4**	28.85	12.92	**48.7**
2000	22.7	8.00	**31.0**	22.2	7.67	**24.1**	24.6	9.4	**31.4**	30.37	14.31	**53.9**
2200	25.0	9.68	**37.4**	24.4	9.27	**29.1**	27.1	11.4	**37.9**	33.40	17.32	**65.0**
2400	27.2	11.5	**44.5**	26.6	11.0	**34.5**	29.6	13.6	**44.9**	36.44	20.61	**77.2**

Note: No allowance has been made for age, difference in diameter, or any abnormal condition of interipr surface. Any factor of safety must be estimated from the local conditions and the requirements of each particular installation. It is recommended that for most commercial design purposes a safety factor of 15 to 20% be added to the values in the tables—see page 3-5.

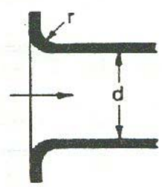
Figure 7 Piping pressure head losses (source Cameron Hydraulic data book).

Ingersoll-Dresser Pumps Cameron Hydraulic Data

Friction of Water *(Continued)*

Friction Loss in Pipe Fittings

Resistance coefficient $\left(\text{use in formula } h_f = K\frac{V^2}{2g}\right)$

Fitting	Description	All pipe sizes K value
Pipe exit	projecting sharp edged rounded	1.0
Pipe entrance	inward projecting	0.78
Pipe entrance flush 	sharp edged	0.5
	r/d = 0.02	0.28
	r/d = 0.04	0.24
	r/d = 0.06	0.15
	r/d = 0.10	0.09
	r/d = 0.15 & up	0.04

From Crane Co. Technical Paper 410.

Figure 8 Entrance pressure head loss K coefficients (source Cameron Hydraulic data book).

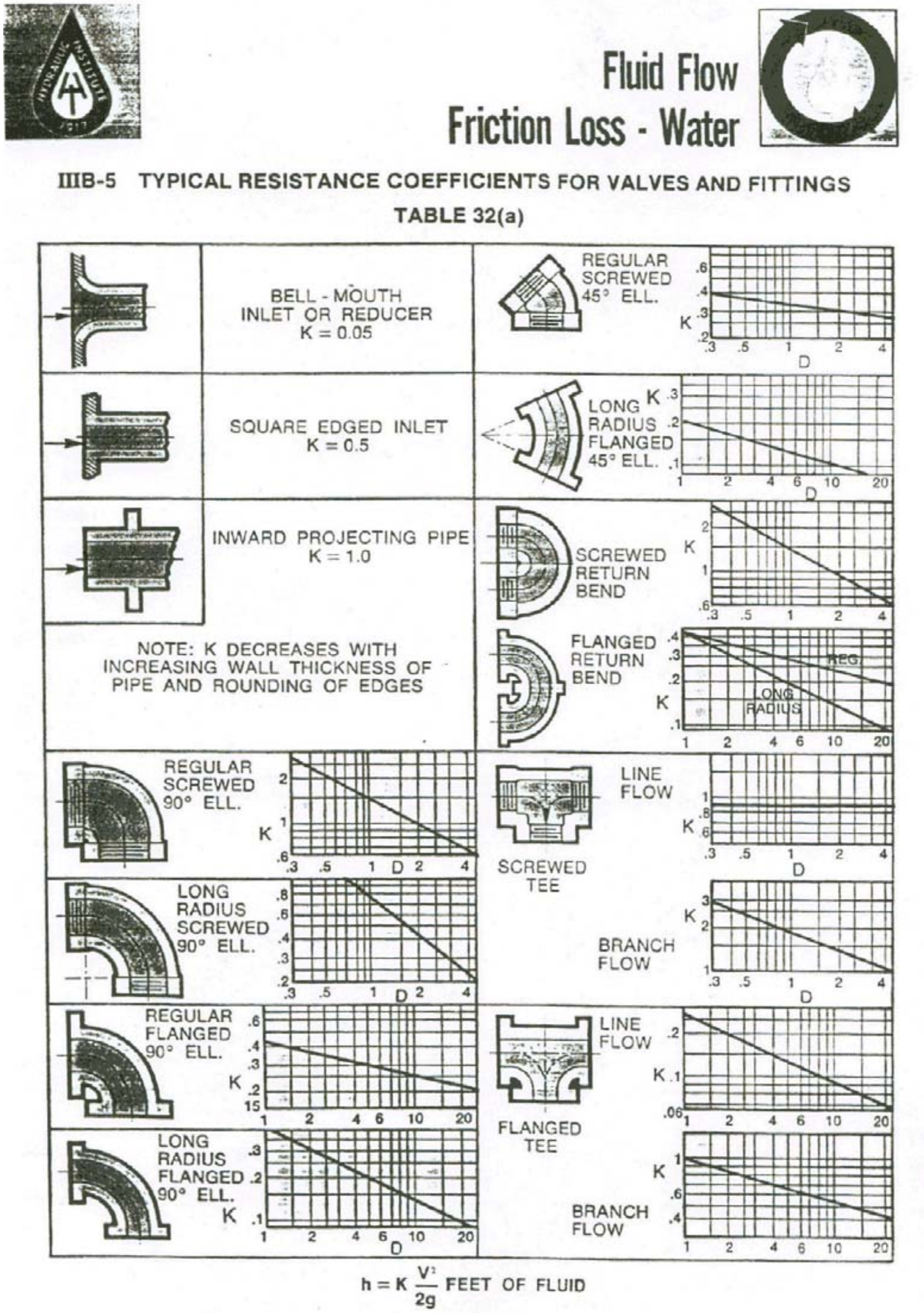


Figure 9 Pressure head loss K coefficients for fittings (source the Hydraulic Institute Standards book www.pumps.org).

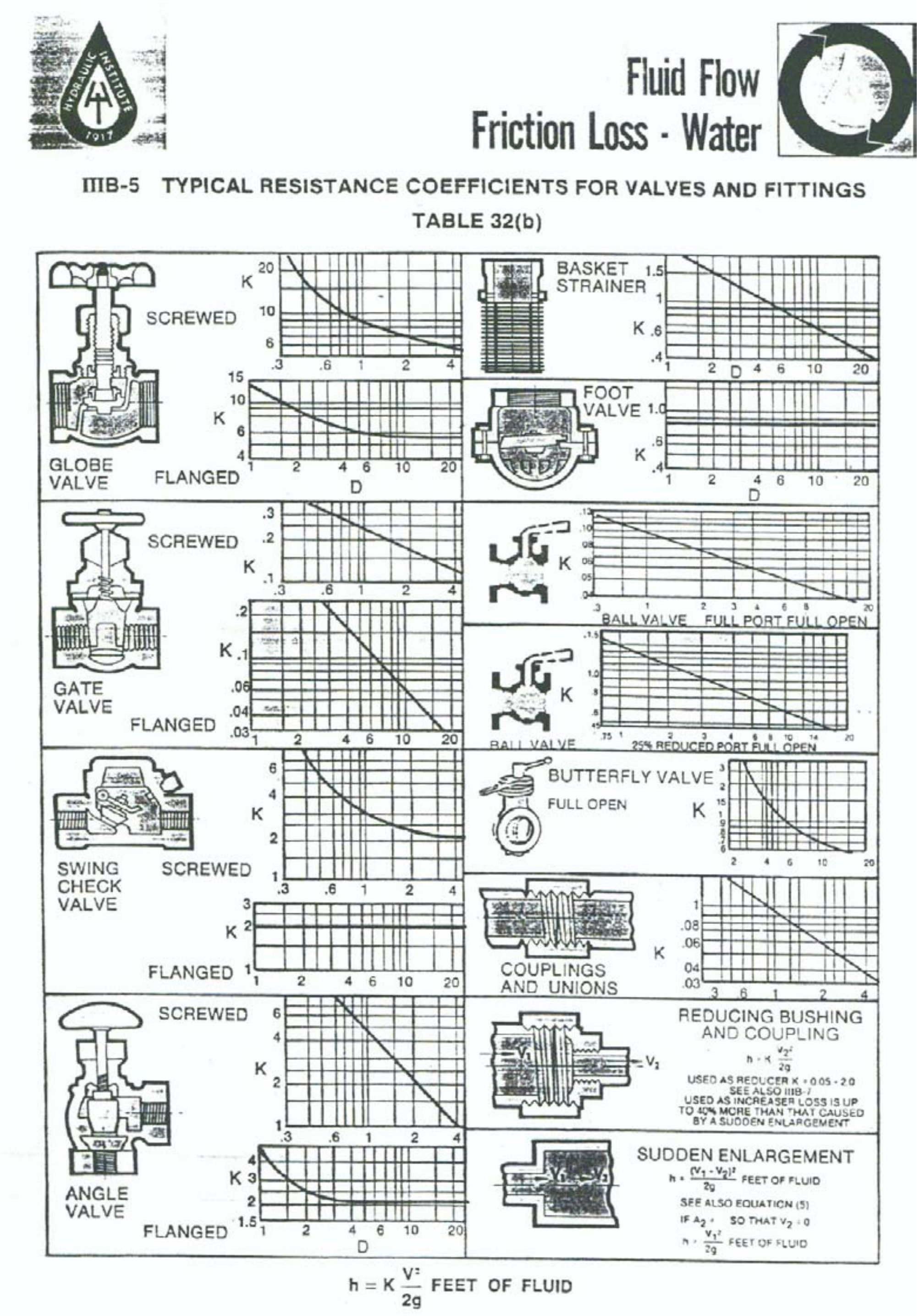


Figure 10 Pressure head loss K coefficients for manual valves and other devices (source the Hydraulic Institute Standards book www.pumps.org).

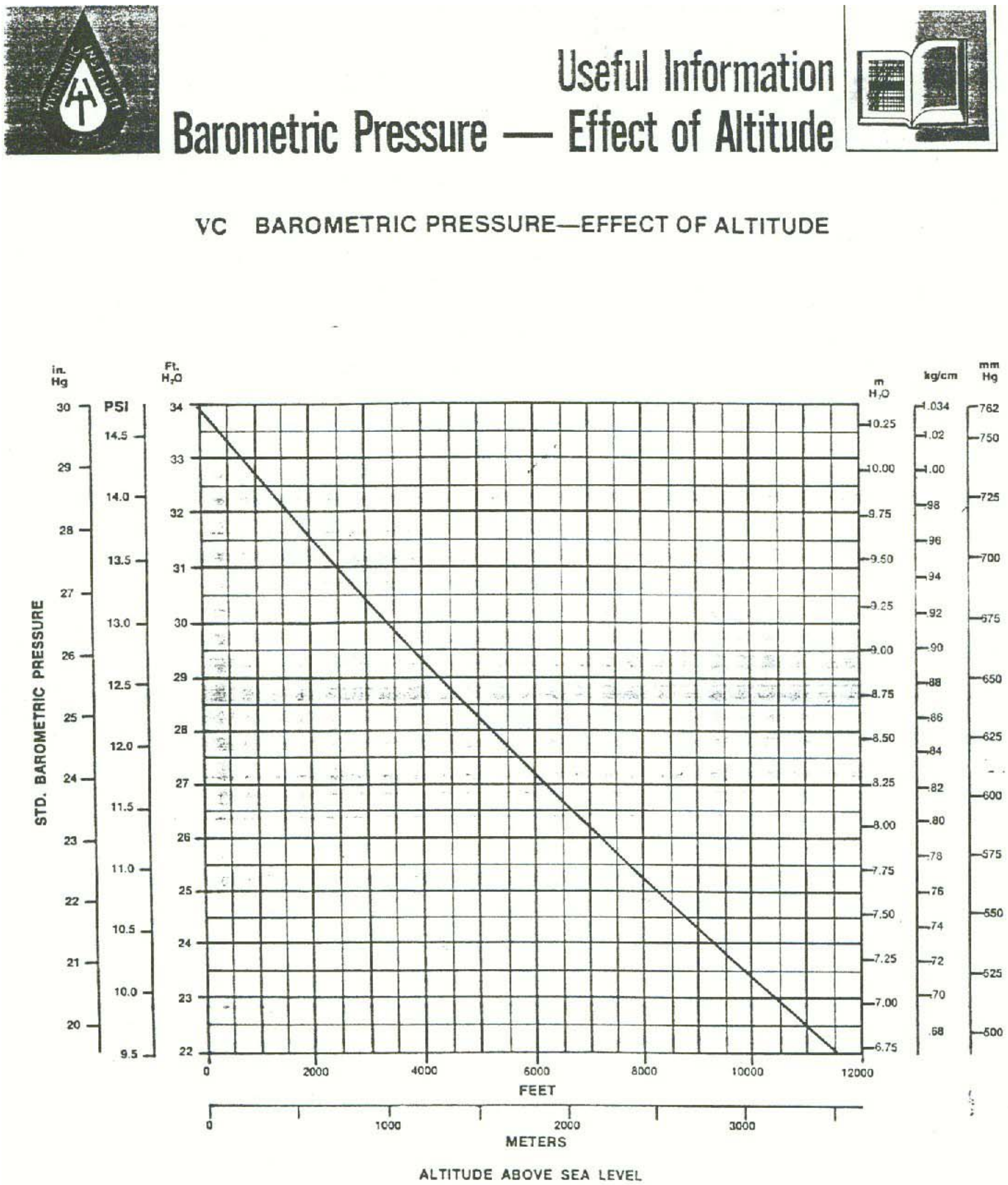


Figure 11 Atmospheric pressure vs. elevation (source the Hydraulic Institute Standards book www.pumps.org).

Characteristics of Fluids Water

IIA-1 PROPERTIES OF WATER AT VARIOUS TEMPERATURES FROM 32° TO 705.4° F

Temp. F	Temp. C	Specific Volume Cu Ft/Lb	SPECIFIC GRAVITY			Wt in Lb/Cu Ft	Vapor Pressure Psi Abs
			39.2 F Reference	60 F Reference	68 F Reference		
32	0	.01602	1.000	1.001	1.002	62.42	0.088
35	1.7	.01602	1.000	1.001	1.002	62.42	0.100
40	4.4	.01602	1.000	1.001	1.002	62.42	0.1217
50	10.0	.01603	.999	1.001	1.002	62.38	0.1781
60	15.6	.01604	.999	1.000	1.001	62.34	0.2563
70	21.1	.01606	.998	.999	1.000	62.27	0.3631
80	26.7	.01608	.996	.998	.999	62.19	0.5069
90	32.2	.01610	.995	.996	.997	62.11	0.6982
100	37.8	.01613	.993	.994	.995	62.00	0.9492
120	48.9	.01620	.989	.990	.991	61.73	1.692
140	60.0	.01629	.983	.985	.986	61.39	2.889
160	71.1	.01639	.977	.979	.979	61.01	4.741
180	82.2	.01651	.970	.972	.973	60.57	7.510
200	93.3	.01663	.963	.964	.966	60.13	11.526
212	100.0	.01672	.958	.959	.960	59.81	14.696
220	104.4	.01677	.955	.956	.957	59.63	17.186
240	115.6	.01692	.947	.948	.949	59.10	24.97
260	126.7	.01709	.938	.939	.940	58.51	35.43
280	137.8	.01726	.928	.929	.930	58.00	49.20
300	148.9	.01745	.918	.919	.920	57.31	67.01
320	160.0	.01765	.908	.909	.910	56.66	89.66
340	171.1	.01787	.896	.898	.899	55.96	118.01
360	182.2	.01811	.885	.886	.887	55.22	153.04
380	193.3	.01836	.873	.874	.875	54.47	195.77
400	204.4	.01864	.859	.860	.862	53.65	247.31
420	215.6	.01894	.846	.847	.848	52.80	308.83
440	226.7	.01926	.832	.833	.834	51.92	381.59
460	237.8	.0196	.817	.818	.819	51.02	466.9
480	248.9	.0200	.801	.802	.803	50.00	566.1
500	260.0	.0204	.785	.786	.787	49.02	680.8
520	271.1	.0209	.765	.766	.767	47.85	812.4
540	282.2	.0215	.746	.747	.748	46.51	962.5
560	293.3	.0221	.726	.727	.728	45.3	1133.1
580	304.4	.0228	.703	.704	.704	43.9	1325.8
600	315.6	.0236	.678	.679	.680	42.3	1542.9
620	326.7	.0247	.649	.650	.650	40.5	1786.6
640	337.8	.0260	.617	.618	.618	38.5	2059.7
660	348.9	.0278	.577	.577	.578	36.0	2365.4
680	360.0	.0305	.525	.526	.527	32.8	2708.1
700	371.1	.0369	.434	.435	.435	27.1	3093.7
705.4	374.1	.0503	.319	.319	.320	19.9	3206.2

Computed from Keenan & Keyes' Steam Table.

Figure 12 Properties of water (source the Hydraulic Institute Standards book www.pumps.org).

TABLE 14

FRAME DESIGNATIONS FOR SINGLE-PHASE, DESIGN L, HORIZONTAL AND VERTICAL MOTORS, 60 HERTZ, CLASS B INSULATION SYSTEM, OPEN TYPE, 1.15 SERVICE FACTOR, 230 VOLTS AND LESS [MG1-13.1]

	Speed, Rpm		
HP	3600	1800	1200
3/4	—	—	145T
1	—	143T	182T
1-1/2	143T	145T	184T
2	145T	182T	—
3	182T	184T	—
5	184T	213T	—
7-1/2	213T	215T	—

TABLE 15

FRAME DESIGNATIONS FOR POLYPHASE, SQUIRREL-CAGE, DESIGNS A AND B HORIZONTAL AND VERTICAL MOTORS, 60 HERTZ, CLASS B INSULATION SYSTEM, OPEN TYPE, 1.15 SERVICE FACTOR, 575 VOLTS AND LESS* [MG1-13.2]

	Speed, Rpm			
HP	3600	1800	1200	900
1/2	—	—	—	143T
3/4	—	—	143T	145T
1	—	143T	145T	182T
1-1/2	143T	145T	182T	184T
2	145T	145T	184T	213T
3	145T	182T	213T	215T
5	182T	184T	215T	254T
7-1/2	184T	213T	254T	256T
10	213T	215T	256T	284TS
15	215T	254T	284TS	286TS
20	254T	256T	286TS	324TS
25	256T	284TS	324TS	326TS
30	284TS	286TS	326TS	364TS
40	286TS	324TS	364TS	365TS
50	324TS	326TS	365TS	404TS
60	326TS	364TS†	404TS	405TS
75	364TS	365TS†	405TS	444TS
100	365TS	404TS†	444TS	445TS
125	404TS	405TS†	445TS	447TS
150	405TS	444TS†	447TS	449TS
200	444TS	445TS†	449TS	—
250	445TS‡	447TS†	—	—
300	447TS‡	449TS‡	—	—
350	449TS‡	—	—	—

*The voltage rating of 115 volts applies only to motors rated 15 horsepower and smaller.

†When motors are to be used with V-belt or chain drives, the correct frame size is the size shown but with the suffix letter S omitted. For the corresponding shaft extension dimensions, Table 20.

‡The 250, 300, and 350 horsepower ratings at the 3600 rpm speed have a 1.0 service factor.

Figure 13 Electric motor frame NEMA standard designations with respect to horsepower.

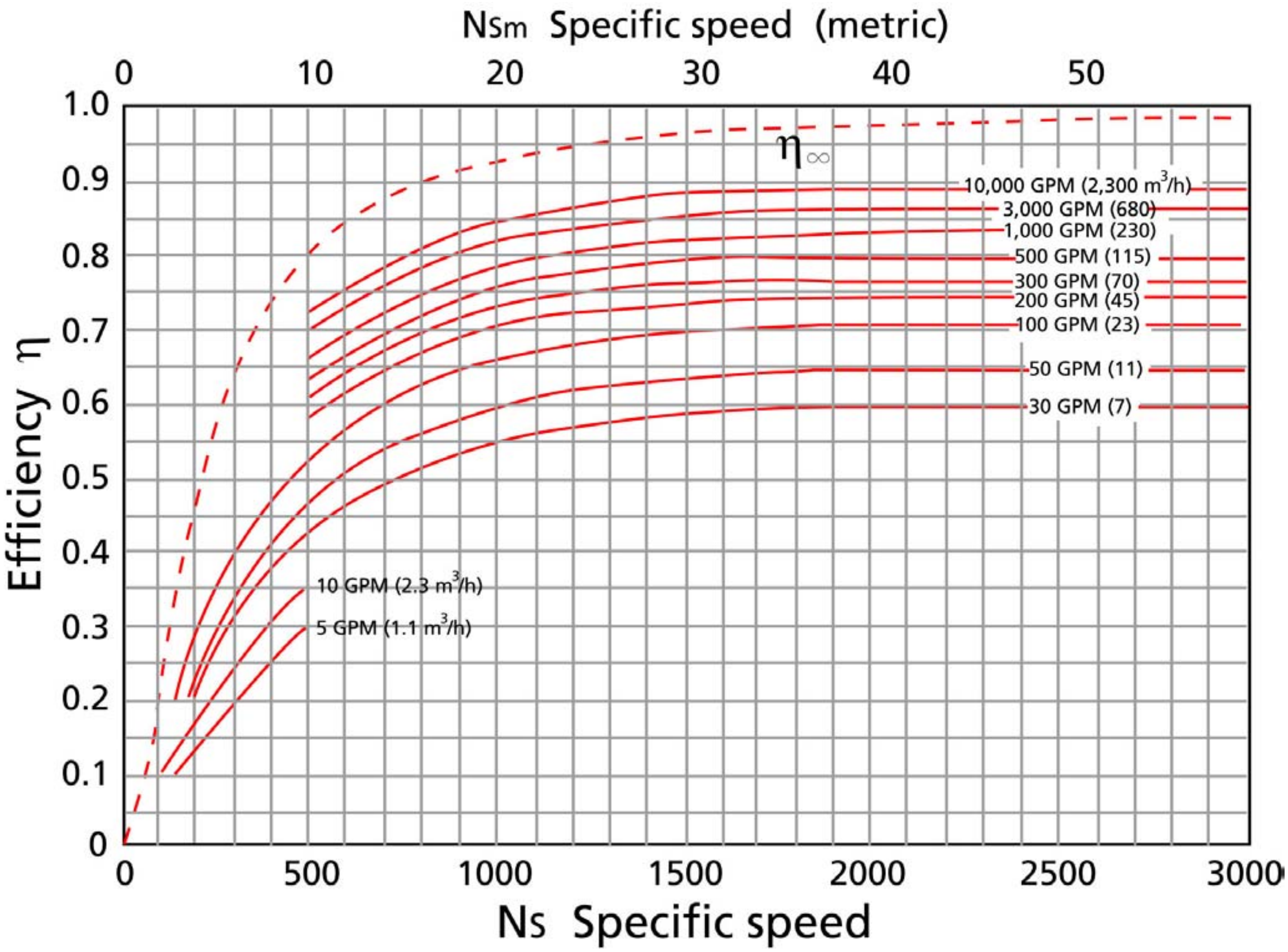


Figure 14 Efficiency values for pumps of similar construction at different specific speeds.

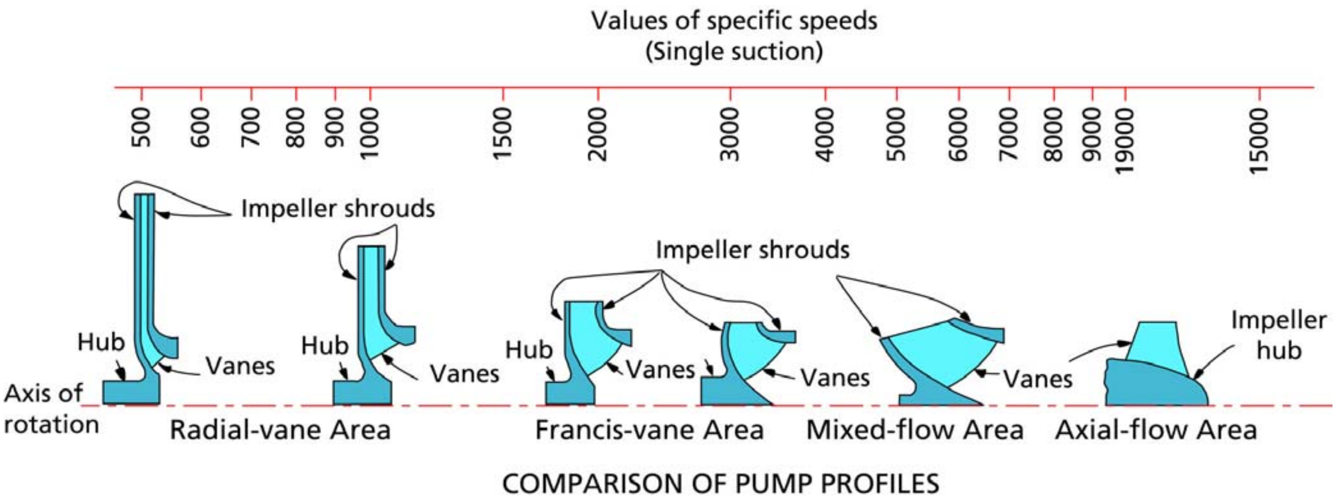


Figure 15 Specific speed values for the different pump designs.
(source: the Hydraulic Institute Standards book, see www.pumps.org)

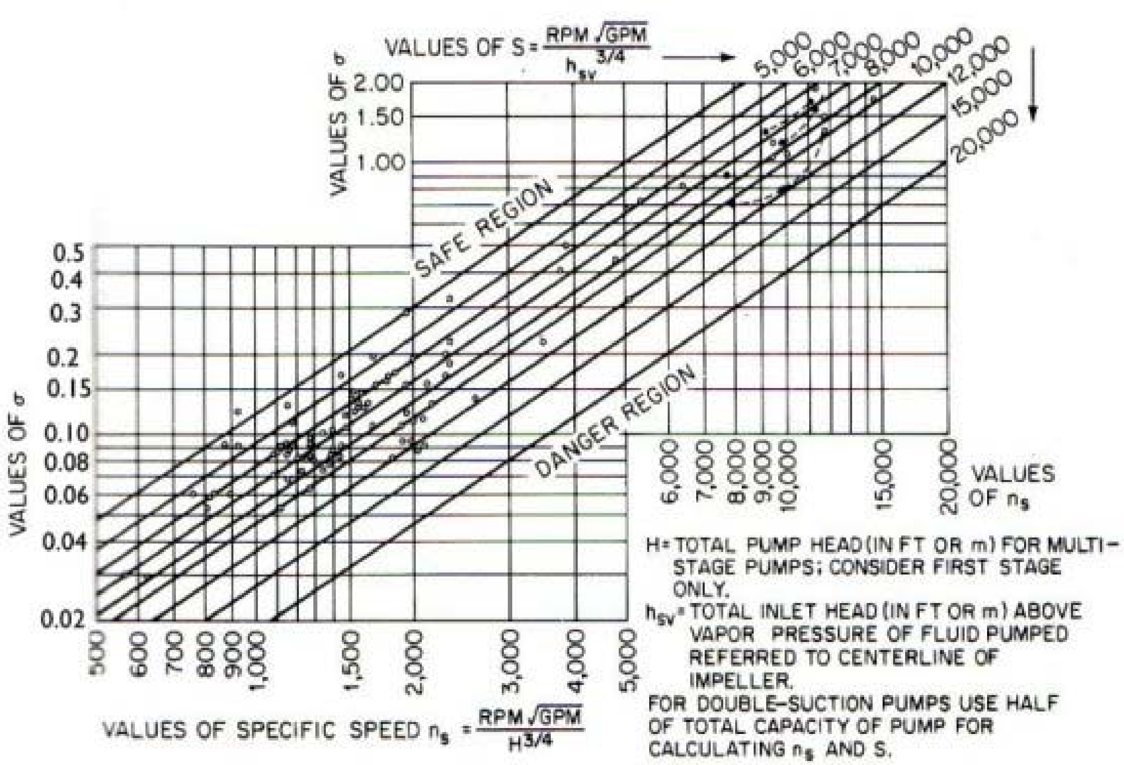


Figure 16 The Thoma number vs. specific speed and suction specific speed to predict cavitation (source: the Pump Handbook, McGraw-Hill).

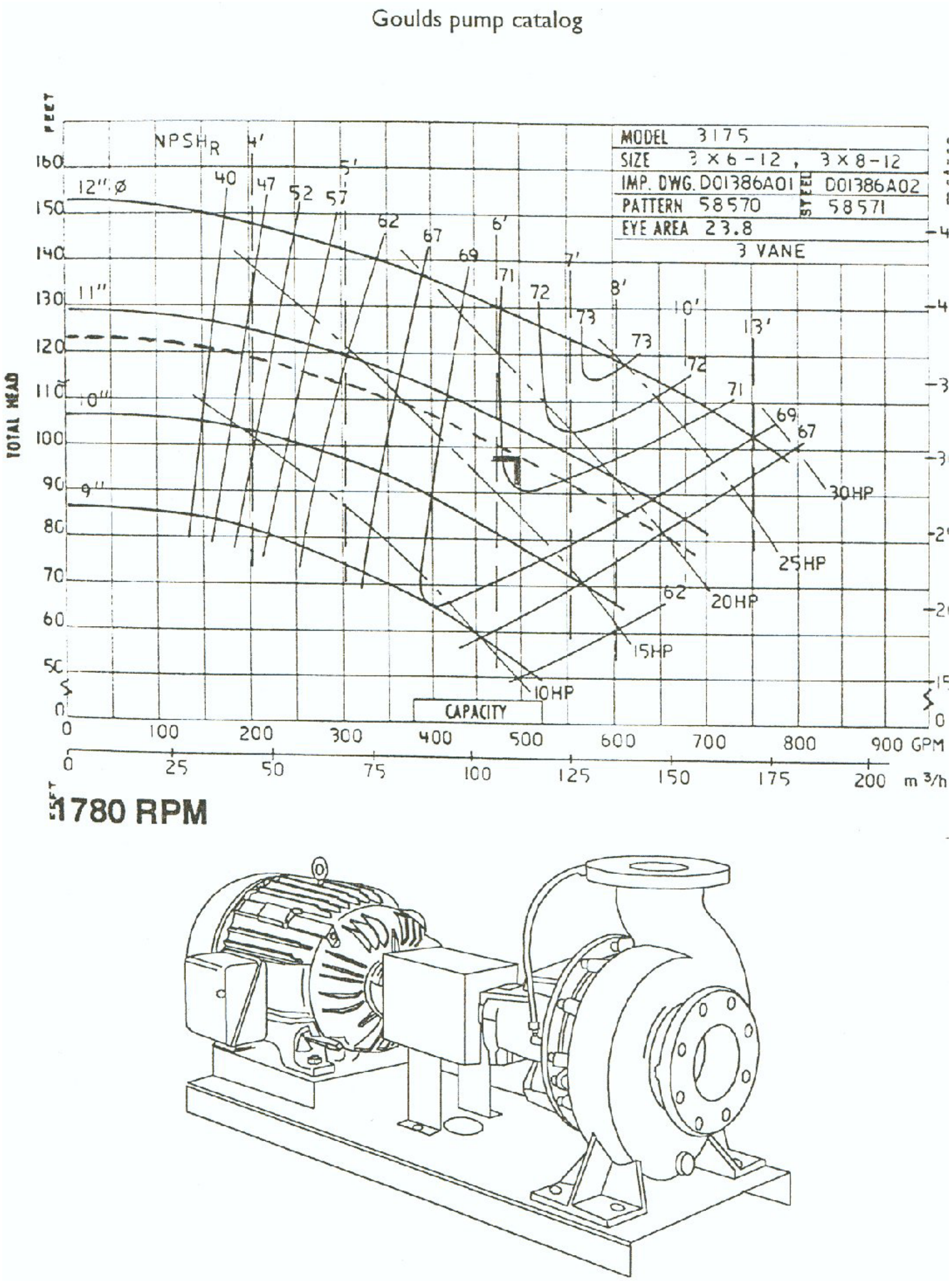
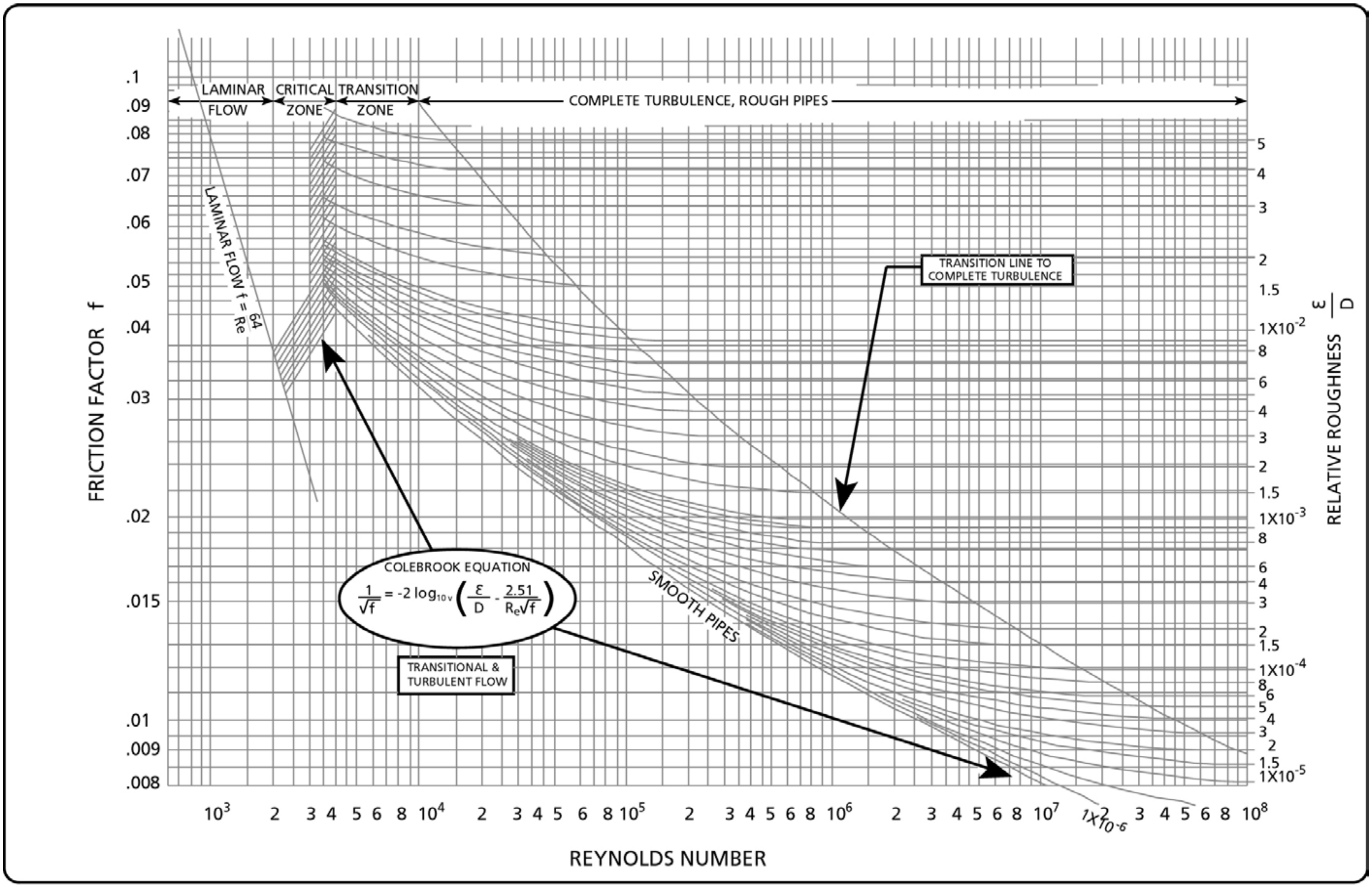


Figure 17 Selected pump characteristic curve (source the Gould pump catalogue www.goulds.com).



18 The Moody diagram, friction factor vs. Reynolds number for laminar and turbulent flow at various pipe roughness-values.