TechData Sheet

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Selecting a Pump that Saves Energy

Selecting the right pump will save energy and improve system performance. This TechData Sheet (TDS) provides instruction on how to select the most economical pump for the job while still meeting all required performance criteria.

Pumps are generally one of two types, kinetic (or dynamic) pumps or positive displacement pumps. Positive displacement pumps can be further classified as reciprocating, blow case, and rotary. Kinetic pumps can also be further classified as centrifugal, peripheral, and special effect. The focus of this TDS is on centrifugal pumps, which are the most common types of pumps found in Navy shore facility installations. The various types of centrifugal pumps are shown in Figure 1.

A centrifugal pump consists of an impeller, a casing that houses the impeller, the motor (usually electric), and the shaft to connect the motor to the impeller (see Figure 2). The fluid enters the casing driven by either atmospheric pressure or fluid pressure upstream from the pump, and is directed to the center of the spinning impeller by the casing. A series of guide vanes on the impeller force the fluid to the outside of the casing by centrifugal force where is then exits through the discharge side of the pump. The exiting fluid creates a vacuum on the inlet side causing more fluid to enter the pump. If the pump has non-condensable gases in the casing (such as air), the impeller will only compress the gas and will not draw more fluid into

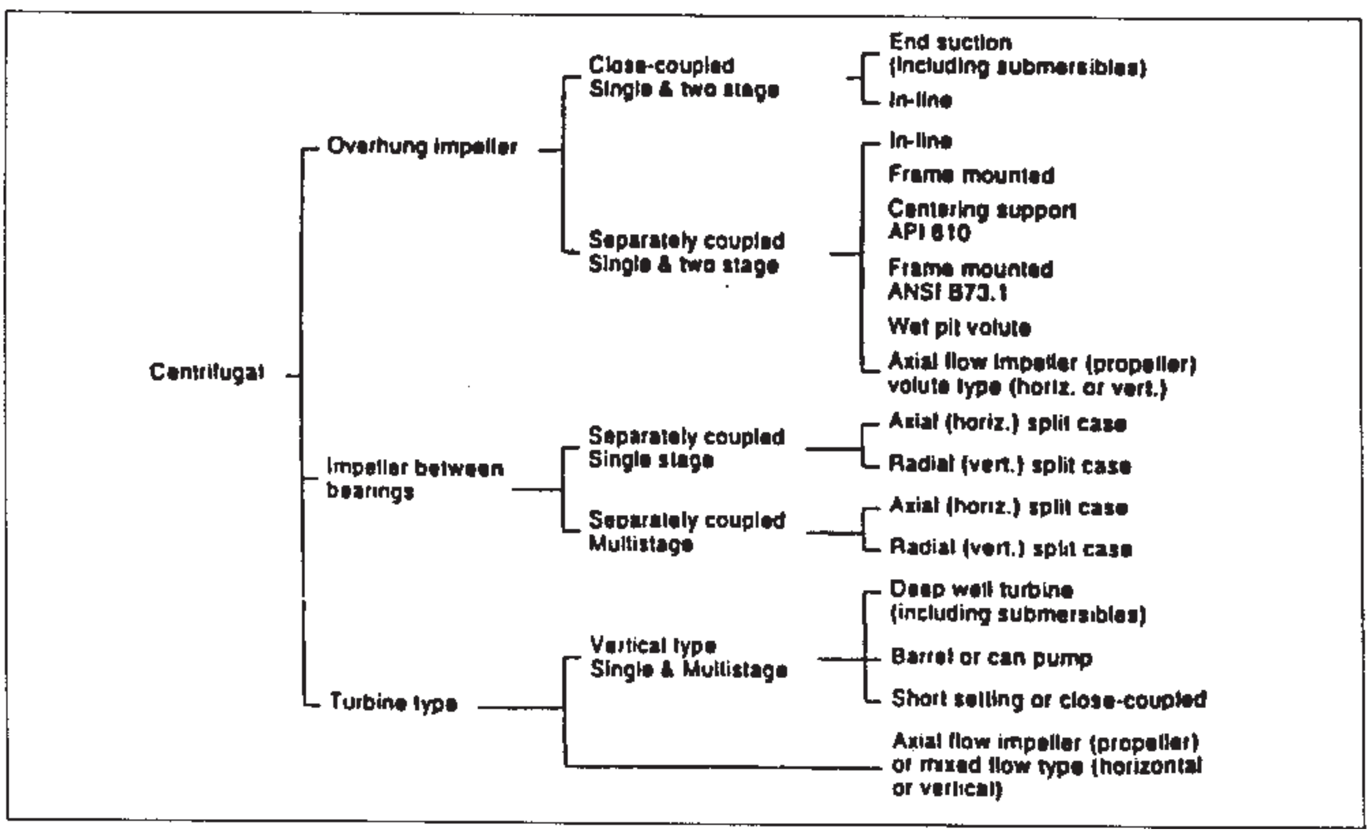

Figure 1. Classification of centrifugal type pumps. (Courtesy of the Hydraulic Institute, Parsippany, NJ)

the pump if the pump is higher than the source of the fluid. For this reason, a means to prime the centrifugal pump must be provided, unless it is a special type called a "self-priming pump."

The performance of a centrifugal pump is generally described by five terms:

- Capacity or rate of flow, usually expressed in gallons per minute.
- Head, which is the pressure increase of the fluid, expressed in feet.
- Input power, usually brake horsepower (bhp).
- Efficiency, which is the ratio of work performed to power input.
- Rotational speed in rpm.

All of these terms are interrelated; they are portrayed on a graph of pump curves which are determined experimentally and supplied by the pump manufacturer (see Figure 3).

Selecting a pump for a system that will minimize the initial cost and the energy to run it, yet maintain the required performance for the application, requires seven steps:

1. Determine the required pump capacity.
2. Determine the required total dynamic head of the pump from the system head.
3. Check pump manufacturers' selections to choose a standard pump and speed.
4. Determine the efficiency and the required horsepower of the pump.
5. Compare various standard pumps and speeds to determine the most efficient pump.
6. Compare Net Positive Suction Head Available ($NPSH_a$) with Net Positive Suction Head Required ($NPSH_r$) to ensure that cavitation will not occur.
7. Compare energy savings with first time cost and maintenance expense, as well as other factors, such as space, noise, and ease of control.

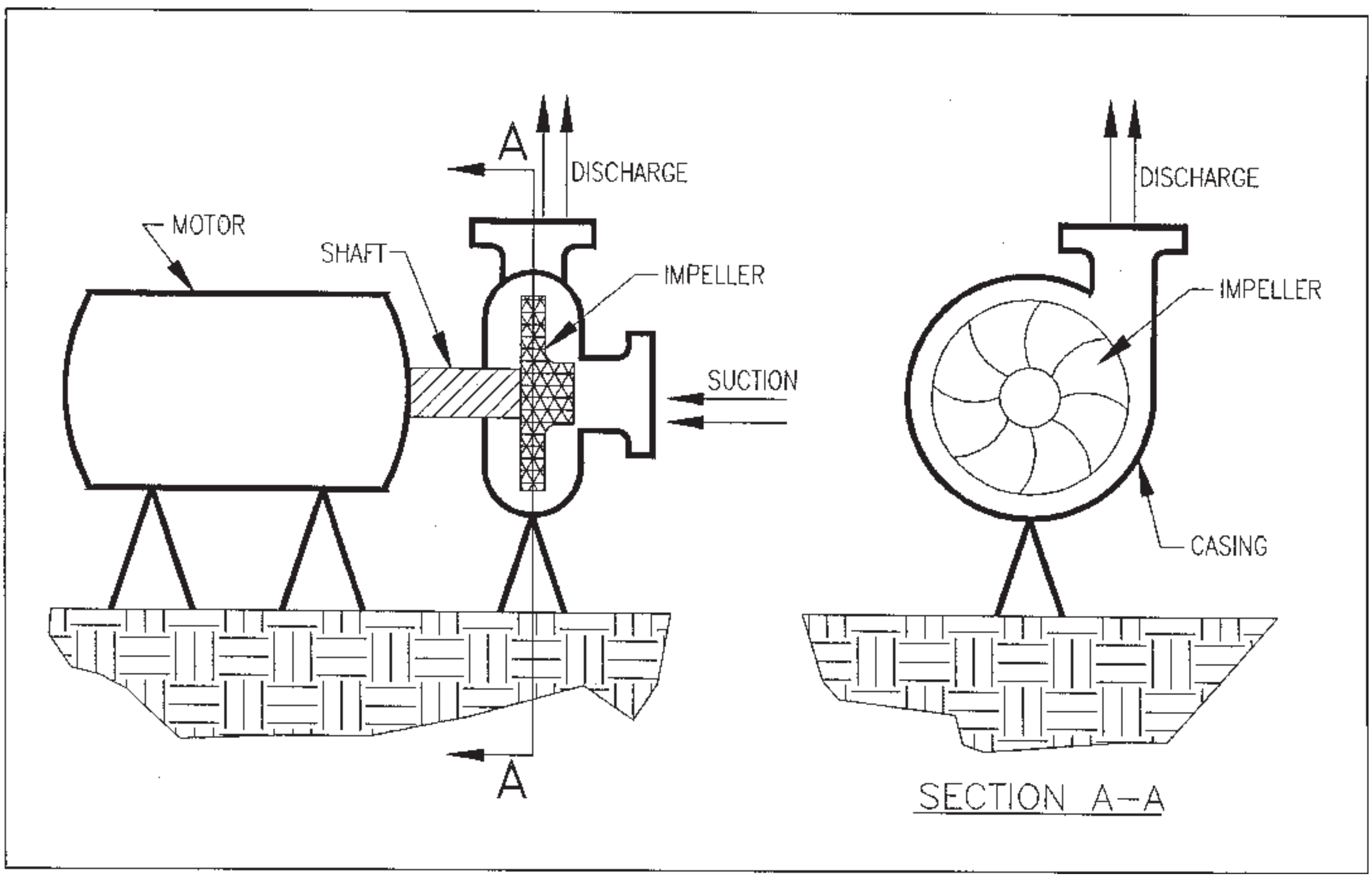

Figure 2. Centrifugal pump.

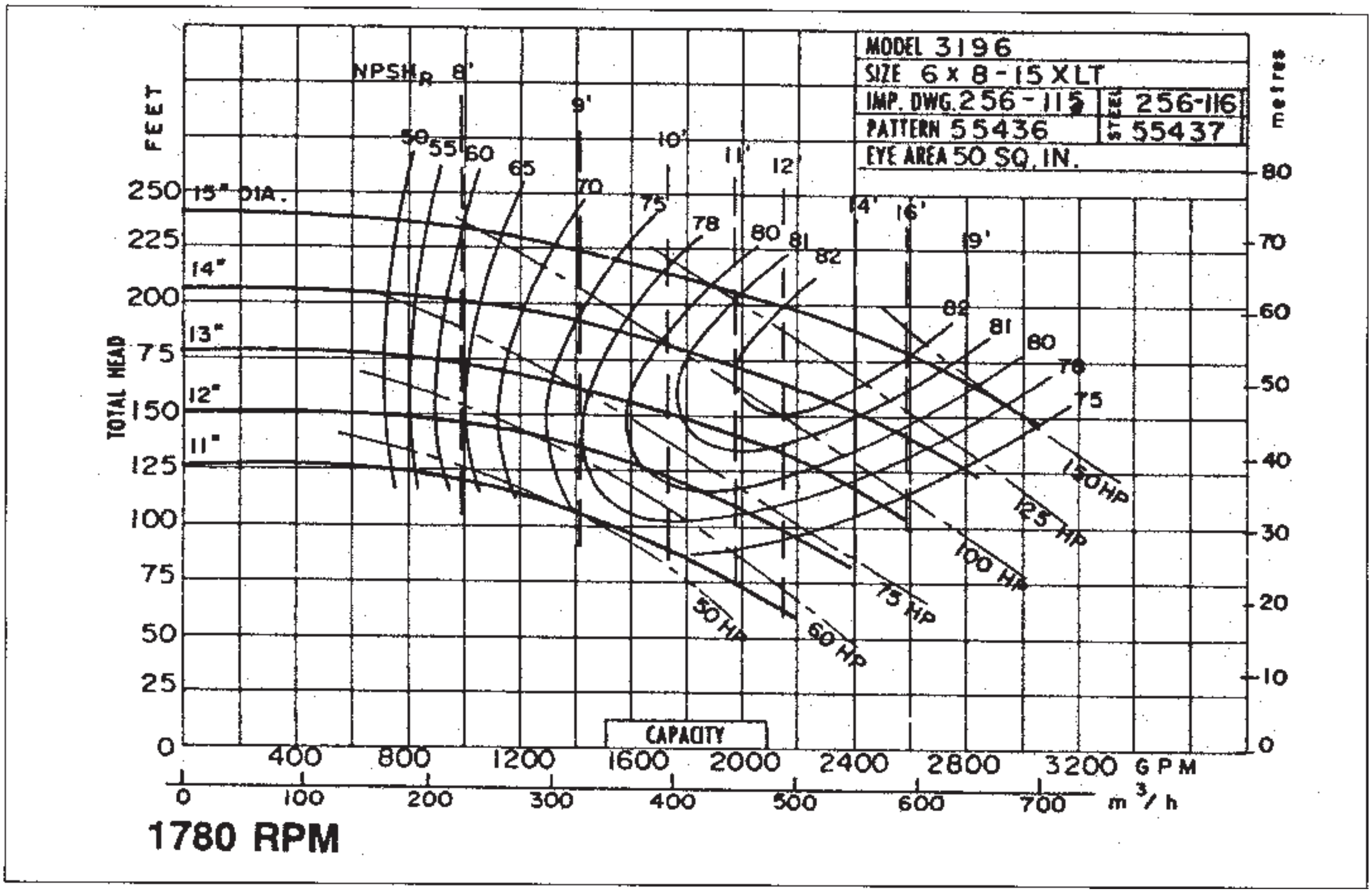

Figure 3. Typical manufacturer's published performance curve family for a centrifugal pump operating at a fixed speed and with a range of impeller diameters. (Courtesy of Goulds Pumps, Inc., Seneca Falls, NY)

Step 1. The first step in selecting a pump is to determine the required capacity of the pump. This will be determined by what the application of the pump will be.

Step 2. The second step is to determine what the required total dynamic head of the pump will be. This is determined by the system in which the pump will be installed and is equal to the total system head. The total system head is the sum of:

1. Static Head (H_s)
2. Friction Head (H_f)
3. Pressure Head (H_p)
4. Velocity Head (H_v)

Static head is the change in elevation (in feet) that the fluid undergoes in the system without regard to the location of the pump.

Friction head is the force required to overcome the internal friction of the piping system. Note that this force changes with the velocity of the fluid. In order to determine this value, tables have been compiled that give the friction loss (in feet of head loss per 100 feet of pipe) for various diameters of pipe at different flow rates (see Table 1). To compute the total friction head for the system, divide the total length of pipe in the system by 100 and multiply by the value given in the table. The total head loss due to the piping is then added to the head loss due to various fittings in the piping system. Each fitting has a head loss which can be provided by the formula $H_f = K \times (V^2/2g)$. $V^2/2g$ is shown in the pipe friction table for different flow rates and valve/fitting diameters. K is the resistance coefficient for valves and fittings found in Figures 4(a) and 4(b). Each graph is unique for each valve or fitting and gives K versus the diameter of the fitting. For valves, note that K applies to a fully open valve. If a valve will be used to throttle flow, the manufacturer must be consulted to determine the value of K for a partially open valve. All the fitting/valve head loss values are summed and added to the head loss for the piping to determine the total friction head loss for the system.

Pressure head is the difference in pressure between the fluid supply reservoir and the fluid delivery reservoir. This value is zero if the supply and delivery reservoir pressures are the same as would occur in two reservoirs open to the atmosphere. In order to convert from psi or inches of vacuum, the following equations are used:

Pressure: H_p(feet) = psi x 2.31/s.g.
Where s.g. is the specific gravity of the fluid, s.g. = 1.0 for water.
Vacuum: H_p(feet) = Vacuum (inches Hg) x 1.133/s.g.

Velocity head is the change in head of the fluid due to the change in velocity through the pump. This value is usually small and is sometimes ignored but may be significant in special cases where the total dynamic head of the pump is smaller than normal. Velocity head (H_v) is given by the value $V^2/2g$ found in the pipe friction tables. Since the diameter of the pipe on the suction side of the pipe is normally larger than the discharge side, this value will be different on either side of the pump and the difference between the two values is the velocity head loss.

All four system head loss terms are added together to determine the total system head loss which will equal the total dynamic head of the pump.

In order to obtain a variety of flow rates and total dynamic head values, the impellers are machined down from a maximum size (limited by the size of the casing) to a minimum size determined by the manufacturer. These various flow rates and heads are then graphed by the manufacturer, resulting in a curve similar to Figure 5. An entire family of pumps can then be graphed for a specific rpm resulting in a family of curves similar to Figures 6(a) and 6(b). The sizes of the pumps are given by three numbers on the graph, e.g., 3 x 6 x 9. The first number is the suction size, the second is the discharge size, and the third is the maximum impeller diameter. All three are expressed in inches. Various pump sizes and speeds that will meet the required performance can be determined from the manufacturer-provided family of pump curves.

Steps 3, 4, and 5. The performance curve for each pump that meets the performance requirements should be evaluated (see Figure 3). The required impeller diameter, pump efficiency, required horsepower, and $NPSH_r$ can be determined from the specific curve. The horsepower requirements for the various pumps and speeds can be compared to determine which pump or speed will be the most efficient (lowest horsepower requirement).

Step 6. Following selection of the most efficient pump, the $NPSH_a$ should be calculated to verify that it is greater than the $NPSH_r$. $NPSH_r$ is a characteristic of the pump inlet opening and is determined during testing of the pump by the manufacturer for various operating conditions. The $NPSH_a$ is a characteristic of the piping upstream of the pump and is the sum of four variables (all expressed in feet):

- The pressure on the surface of the fluid in the supply reservoir.
- The distance from the surface of the fluid to the centerline of the pump's impeller. If the fluid is higher than the impeller's centerline, this value is positive; if it is below the centerline, this value is negative.
- The friction loss in the suction line is calculated from Table 1. This value is negative. Since friction increases with flow, the $NPSH_a$ can only be calculated at a specified flow rate.
- The vapor pressure of the liquid, which is also negative.

To prevent cavitation, $NPSH_a$ should always exceed $NPSH_r$. Cavitation occurs when bubbles form in the fluid where the pressure of the fluid drops below the vapor pressure of the fluid. When the fluid reaches an area of higher pressure, the bubbles collapse and the resulting shock waves create excessive noise, reduce the efficiency of the pump, and can actually damage the pump's impeller, seal, and/or bearings.

Selecting the proper pump is the easiest and best way to prevent cavitation. However, if an incorrect choice is made and the pump cavitates, there are ways to eliminate it. The most obvious is to increase the $NPSH_a$ by moving the pump to a lower elevation. Friction losses on the suction side can also be reduced by moving the pump closer to the supply reservoir. Pressurizing the supply reservoir (e.g., with a blanket of nitrogen) will also raise the $NPSH_a$. Finally, by decreasing the flow rate, the $NPSH_a$ will be raised and the $NPSH_r$ will be decreased. Reducing the flow rate can be accomplished by adding restriction (e.g., partially closing a throttle valve) downstream from the pump. However, this could increase power required and lower efficiency.

Step 7. Since more efficient pumps have a higher first-time cost, performing a life cycle cost analysis for different types of pumps is beneficial. For instance, multistage pumps are usually more efficient than single-stage pumps but their first-time cost is higher. If electricity costs are excessive, the extra first-time cost could be recovered in a short length of time, concluding that the multistage pump has the lowest life cycle cost. Another point to consider is that running a pump at a higher speed (at the same flow rate) is generally more efficient, but the higher speed pump may have to be aligned more precisely and require a higher annual maintenance. In order to determine how much it will cost to run the pump, first convert the required pump horsepower to kilowatts (1 HP = 0.746 kW); then multiply by the number of hours the pump is expected to run per year and the cost of electricity in $/kW-hr. Now the various costs of different pumps can be compared directly.

In order to choose the correct pump for the job, factors other than cost may have to be considered. These factors include such things as size, noise, and vibration. Multistage pumps, although more efficient, are also physically large and may not fit in the available space. While high speed pumps are more efficient, a high speed pump motor will be louder than a lower speed motor with the same horsepower rating, which may be a concern if the pump is to be installed where the noise level will be a nuisance. Sound attenuation also involves added space and cost.

One final consideration from an economics standpoint is over-sizing the pump. Frequently, purchasers of a pump will increase the required flow rate by a margin to ensure that the existing pump will be able to handle future increases to the system's output requirements. Others also increase the head requirements by a margin to ensure that the pump will be able to handle future corrosion product buildup and precipitates. (Note: only the friction head component of the system head should be increased since this is the only one that will change over time.) Prior to increasing the pump size, the cost of running the larger pump versus the smaller pump should be calculated using the method outlined above. The difference in energy cost may prove it cheaper in the long run to buy the smaller pump first, and then replace the small pump with a larger one when needed.

Once a pump is purchased and installed, the purchaser should properly operate and maintain the pump to ensure that the pump continues to perform its job as efficiently as possible. Make certain that the impeller settings for open impellers and the wear ring clearances are at their recommended minimums. Clearances should be checked and adjusted as often as feasible to minimize leakage (recirculation loss) from the discharge side of the impeller to the suction side.

Do not operate the pump at a higher flow rate than necessary, since the higher the flow rate, the more energy is consumed. At the same time, ensure that no unnecessary throttling is taking place in the system (i.e., throttling not necessary to control cavitation and flow rate). If possible, ensure that throttle valves are fully open and any restrictions such as reducers are removed. If flow needs to be reduced, look into reducing the impeller diameter or installing a variable speed motor as discussed below. If the pump is a multistage pump, consider destaging the pump during periods of low flow requirements. Also consider installing multiple pumps in parallel or series to provide greater flexibility in flow rates.

When a system has a variable flow requirement, rather than operating a throttle valve which increases the system's friction head and thus decreases the efficiency of the pump, it is more efficient to vary the speed of the pump by using a variable frequency drive (VFD) on the motor. This operates by changing the speed of the drive motor and thus the pump. By decreasing the flow rate by slowing down the pump, the friction head decreases since it is dependent on flow rate. The efficiency of the pump will stay the same as at the higher flow rate.

For additional information contact:

NFESC Code 20 at (805) 982-1465, DSN 551-1465

Table 1. Pipe friction: Water/Schedule 40 Steel Pipe

U.S. Gallons per Minute	⅛ In. (0.269" I.D.)			¼ In. (0.364" I.D.)			⅜ In. (0.493" I.D.)			½ In. (0.622" I.D.)			U.S. Gallons per Minute
	V (Ft./Sec.)	$\frac{V^2}{2g}$	h_f (Ft./100 ft.)	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	
0.2	1.13	0.020	2.72										0.2
0.4	2.26	0.079	16.2	1.23	0.024	3.7							0.4
0.6	3.39	0.178	33.8	1.85	0.053	7.6	1.01	0.016	1.74				0.6
0.8	4.52	0.317	57.4	2.47	0.095	12.7	1.34	0.028	2.89				0.8
1.0	5.65	0.495	87.0	3.08	0.148	19.1	1.68	0.044	4.30	1.06	0.017	1.86	1.0
1.5	8.48	1.12	188	4.62	0.332	40.1	2.52	0.099	8.93	1.58	0.039	2.85	1.5
2.0	11.3	1.98	324	6.17	0.591	69.0	3.36	0.176	15.0	2.11	0.069	4.78	2.0
2.5				7.71	0.923	105	4.20	0.274	22.6	2.64	0.106	7.16	2.5
3.0				9.25	1.33	148	5.04	0.395	31.8	3.17	0.156	10.0	3.0
3.5				10.79	1.81	200	5.88	0.538	42.6	3.70	0.212	13.3	3.5
4.0				12.33	2.36	259	6.72	0.702	54.9	4.22	0.277	17.1	4.0
4.5				13.87	2.99	326	7.56	0.889	68.4	4.75	0.351	21.3	4.5
5				15.42	3.69	398	8.40	1.10	83.5	5.28	0.433	25.8	5
6							10.1	1.58	118	6.34	0.624	36.5	6
7							11.8	2.15	158	7.39	0.849	48.7	7
8							13.4	2.81	205	8.45	1.11	62.7	8
9							15.1	3.56	258	9.50	1.40	78.3	9
10							16.8	4.39	316	10.6	1.73	95.9	10
12										12.7	2.49	136	12
14										14.8	3.40	183	14

Table 1. Pipe friction: Water/Schedule 40 Steel Pipe (*Continued*)

U.S. Gallons per Minute	¾ In. (0.824" I.D.)			1 In. (1.049" I.D.)			1¼ In. (1.3880 I.D.)			1½ In. (1.610" I.D.)			U.S. Gallons per Minute
	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	
4	2.41	0.090	4.21	1.48	0.034	1.29							4
5	3.01	0.141	6.32	1.86	0.053	1.93							5
6	3.61	0.203	8.87	2.23	0.077	2.68	1.29	0.026	0.70				6
7	4.21	0.276	11.8	2.60	0.105	3.56	1.50	0.035	0.93				7
8	4.81	0.360	15.0	2.97	0.137	4.54	1.72	0.046	1.18	1.26	0.025	0.56	8
9	5.42	0.456	18.8	3.34	0.173	5.65	1.93	0.058	1.46	1.42	0.031	0.69	9
10	6.02	0.563	23.0	3.71	0.214	6.86	2.15	0.071	1.77	1.58	0.039	0.83	10
12	7.22	0.810	32.6	4.45	0.308	9.62	2.57	0.103	2.48	1.89	0.056	1.16	12
14	8.42	1.10	43.5	5.20	0.420	12.8	3.00	0.140	3.28	2.21	0.076	1.53	14
16	9.63	1.44	56.3	5.94	0.548	16.5	3.43	0.183	4.20	2.52	0.099	1.96	16
18	10.8	1.82	70.3	6.68	0.694	20.6	3.86	0.232	5.22	2.84	0.125	2.42	18
20	12.0	2.25	86.1	7.42	0.857	25.1	4.29	0.286	6.34	3.15	0.154	2.94	20
25	15.1	3.54	134	9.29	1.34	37.4	5.37	0.448	9.66	3.94	0.241	4.50	25
30	18.1	5.06	187	11.1	1.93	54.6	6.44	0.644	13.6	4.73	0.347	6.26	30
35				13.0	2.62	73.3	7.52	0.879	18.5	5.52	0.473	8.38	35
40				14.8	3.43	95.0	8.58	1.14	23.5	6.30	0.618	10.8	40
45				16.7	4.33	119	9.66	1.45	29.5	7.10	0.783	13.5	45
50				18.6	5.35	146	10.7	1.79	36.0	7.88	0.965	16.4	50
60				22.3	7.71	209	12.9	2.57	51.0	9.46	1.39	23.2	60
70				26.0	10.5	283	15.0	3.50	68.8	11.0	1.89	31.3	70
80							17.2	4.58	89.2	12.6	2.47	40.5	80
90							19.3	5.79	112	14.2	3.13	51.0	90
100							21.5	7.15	138	15.8	3.86	62.2	100
120							25.7	10.3	197	18.9	5.56	88.3	120
140										22.1	7.56	119	140

Table 1. Pipe friction: Water/Schedule 40 Steel Pipe (*Continued*)

U.S. Gallons per Minute	2 in. (2.067" I.D.)			2½ in. (2.469" I.D.)			3 in. (3.068" I.D.)			3½ in. (3.548" I.D.)			U.S. Gallons per Minute
	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	
30	2.87	0.128	1.82	2.01	0.063	0.75							30
35	3.35	0.174	2.42	2.35	0.085	1.00							35
40	3.82	0.227	3.10	2.68	0.112	1.28							40
50	4.78	0.355	4.67	3.35	0.174	1.94	2.17	0.073	0.66				50
60	5.74	0.511	6.59	4.02	0.251	2.72	2.60	0.105	0.92	1.95	0.059	0.45	60
80	7.65	0.909	11.4	5.36	0.447	4.66	3.47	0.187	1.57	2.60	0.105	0.77	80
100	9.56	1.42	17.4	6.70	0.698	7.11	4.34	0.293	2.39	3.25	0.164	1.17	100
120	11.5	2.05	24.7	8.04	1.00	10.0	5.21	0.421	3.37	3.89	0.236	1.64	120
140	13.4	2.78	33.2	9.38	1.37	13.5	6.08	0.574	4.51	4.54	0.321	2.18	140
160	15.3	3.64	43.0	10.7	1.79	17.4	6.94	0.749	5.81	5.19	0.419	2.80	160
180	17.2	4.60	54.1	12.1	2.26	21.9	7.81	0.948	7.28	5.84	0.530	3.50	180
200	19.1	5.68	66.3	13.4	2.79	26.7	8.68	1.17	8.90	6.49	0.655	4.27	200
220	21.0	6.88	80.0	14.7	3.38	32.2	9.55	1.42	10.7	7.14	0.792	5.12	220
240	22.9	8.18	95.0	16.1	4.02	38.1	10.4	1.69	12.6	7.79	0.943	6.04	240
260	24.9	9.60	111	17.4	4.72	44.5	11.3	1.98	14.7	8.44	1.11	7.04	260
280	26.8	11.1	128	18.8	5.47	51.3	12.2	2.29	16.9	9.09	1.28	8.11	280
300	28.7	12.8	146	20.1	6.28	58.5	13.0	2.63	19.2	9.74	1.47	9.26	300
350				23.5	8.55	79.2	15.2	3.57	26.3	11.3	2.00	12.4	350
400				26.8	11.2	103	17.4	4.68	33.9	13.0	2.62	16.2	400
500				33.5	17.4	160	21.7	7.32	52.5	16.2	4.09	25.0	500
600							26.0	10.5	74.8	19.5	5.89	35.6	600
700							30.4	14.3	101	22.7	8.02	48.0	700
800							34.7	18.7	131	26.0	10.5	62.3	800
1000										32.5	16.4	96.4	1000

Table 1. Pipe friction: Water/Schedule 40 Steel Pipe (*Continued*)

U.S. Gallons per Minute	4 in. (4.026" I.D.)			5 in. (5.047" I.D.)			6 in. (6.065" I.D.)			8 in. (7.981" I.D.)			U.S Gallons per Minute
	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	
140	3.53	0.193	1.16	2.25	0.078	0.38							140
160	4.03	0.253	1.49	2.57	0.102	0.49							160
180	4.54	0.320	1.86	2.89	0.129	0.61							180
200	5.04	0.395	2.27	3.21	0.160	0.74	2.22	0.077	0.30				200
240	6.05	0.569	3.21	3.85	0.230	1.03	2.66	0.110	0.42				240
280	7.06	0.774	4.30	4.49	0.313	1.38	3.11	0.150	0.56				280
320	8.06	1.01	5.51	5.13	0.409	1.78	3.55	0.196	0.72				320
360	9.07	1.28	6.92	5.77	0.518	2.22	4.00	0.240	0.90				360
400	10.1	1.58	8.47	6.41	0.639	2.72	4.44	0.307	1.09	2.57	0.102	0.28	400
450	11.3	2.00	10.5	7.23	0.811	3.42	5.00	0.388	1.37	2.89	0.129	0.35	450
500	12.6	2.47	13.0	8.02	0.999	4.16	5.55	0.479	1.66	3.21	0.160	0.42	500
600	15.1	3.55	18.6	9.62	1.44	5.88	6.66	0.690	2.34	3.85	0.230	0.60	600
700	17.6	4.84	25.0	11.2	1.96	7.93	7.77	0.939	3.13	4.49	0.313	0.80	700
800	20.2	6.32	32.4	12.8	2.56	10.2	8.88	1.23	4.03	5.13	0.409	1.02	800
900	22.7	8.00	40.8	14.4	3.24	12.9	9.99	1.55	5.05	5.77	0.518	1.27	900
1000	25.2	9.87	50.2	16.0	4.00	15.8	11.1	1.92	6.17	6.41	0.639	1.56	1000
1200	30.2	14.2	72.0	19.2	5.76	22.5	13.3	2.76	8.76	7.70	0.920	2.20	1200
1400	35.3	19.3	97.6	22.5	7.83	30.4	15.5	3.76	11.8	8.98	1.25	2.95	1400
1600				25.7	10.2	39.5	17.8	4.91	15.4	10.3	1.64	3.82	1600
1800				28.8	12.9	49.7	20.0	6.21	19.4	11.5	2.07	4.79	1800
2000				32.1	16.0	61.0	22.2	7.67	23.8	12.8	2.56	5.86	2000
2400							26.6	11.0	34.2	15.4	3.68	8.31	2400
2800							31.1	15.0	46.1	18.0	5.01	11.2	2800
3200							35.5	19.6	59.9	20.5	6.55	14.5	3200
3600										23.1	8.28	18.4	3600
4000										25.7	10.2	22.6	4000

Table 1. Pipe friction: Water/Schedule 40 Steel Pipe (*Continued*)

U.S. Gallons per Minute	10 in. (10.020" I.D.)			12 in. (11.938" I.D.)			14 in. (13.124" I.D.)			16 in. (15.000" I.D.)			U.S. Gallons per Minute
	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	
800	3.25	0.165	0.328										800
900	3.66	0.208	0.410	2.58	0.103	0.173							900
1000	4.07	0.257	0.500	2.87	0.128	0.210	2.37	0.087	0.131				1000
1200	4.88	0.370	0.703	3.44	0.184	0.296	2.85	0.126	0.185				1200
1400	5.70	0.504	0.940	4.01	0.250	0.395	3.32	0.171	0.247				1400
1600	6.51	0.659	1.21	4.59	0.327	0.509	3.79	0.224	0.317	2.90	0.131	0.163	1600
1800	7.32	0.834	1.52	5.16	0.414	0.636	4.27	0.283	0.395	3.27	0.166	0.203	1800
2000	8.14	1.03	1.86	5.73	0.511	0.776	4.74	0.349	0.483	3.63	0.205	0.248	2000
2500	10.2	1.62	2.88	7.17	0.799	1.19	5.93	0.546	0.738	4.54	0.320	0.377	2500
3000	12.2	2.32	4.06	8.60	1.15	1.68	7.11	0.786	1.04	5.45	0.461	0.535	3000
3500	14.2	3.13	5.46	10.0	1.55	2.25	8.30	1.07	1.40	6.35	0.627	0.718	3500
4000	16.3	4.12	7.07	11.5	2.04	2.92	9.48	1.40	1.81	7.26	0.820	0.921	4000
4500	18.3	5.21	8.88	12.9	2.59	3.65	10.7	1.77	2.27	8.17	1.04	1.15	4500
5000	20.3	6.43	10.9	14.3	3.19	4.47	11.9	2.18	2.78	9.08	1.28	1.41	5000
6000	24.4	9.26	15.6	17.2	4.60	6.39	14.2	3.14	3.95	10.9	1.84	2.01	6000
7000	28.5	12.6	21.1	20.1	6.26	8.63	16.6	4.28	5.32	12.7	2.51	2.69	7000
8000	32.5	16.5	27.5	22.9	8.17	11.2	19.0	5.59	6.90	14.5	3.28	3.49	8000
9000	36.6	20.8	34.6	25.8	10.3	14.1	21.3	7.08	8.7	16.3	4.15	4.38	9000
10,000				28.7	12.8	17.4	23.7	8.74	10.7	18.2	5.12	5.38	10,000
12,000				34.4	18.3	24.8	28.5	12.6	15.2	21.8	7.38	7.69	12,000
14,000				40.1	25.0	33.5	33.2	17.1	20.7	25.4	10.0	10.4	14,000
16,000							37.9	22.4	26.8	29.0	13.1	13.5	16,000
18,000							42.7	28.3	33.9	32.7	16.6	17.2	18,000
20,000										36.3	20.5	21.2	20,000

Table 1. Pipe friction: Water/Schedule 40 Steel Pipe (*Continued*)

U.S. Gallons per Minute	18 in. (16.876" I.D.)			20 in. (18.812" I.D.)			24 in. (22.624" I.D.)			U.S. Gallons per Minute
	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	V	$\frac{V^2}{2g}$	h_f	
2000	2.87	0.128	0.139							2000
3000	4.30	0.288	0.297	3.46	0.186	0.174				3000
4000	5.74	0.512	0.511	4.62	0.331	0.298	3.19	0.158	0.120	4000
5000	7.17	0.799	0.781	5.77	0.517	0.455	3.99	0.247	0.181	5000
6000	8.61	1.15	1.11	6.92	0.745	0.645	4.79	0.356	0.257	6000
8000	11.5	2.05	1.93	9.23	1.32	1.11	6.38	0.633	0.441	8000
10,000	14.3	3.20	2.97	11.5	2.07	.70	7.98	0.989	0.671	10,000
12,000	17.2	4.60	4.21	13.8	2.98	2.44	9.58	1.42	0.959	12,000
14,000	20.1	6.27	5.69	16.2	4.06	3.29	11.2	1.94	1.29	14,000
16,000	22.9	8.19	7.41	18.5	5.30	4.26	12.8	2.53	1.67	16,000
18,000	25.8	10.4	9.33	20.8	6.71	5.35	14.4	3.21	2.10	18,000
20,000	28.7	12.8	11.5	23.1	8.28	6.56	16.0	3.96	2.58	20,000
22,000	31.6	15.5	13.9	25.4	10.0	7.91	17.6	4.79	3.10	22,000
24,000	34.4	18.4	16.5	27.7	11.9	9.39	19.2	5.70	3.67	24,000
26,000	37.3	21.6	19.2	30.0	14.0	11.0	20.7	6.69	4.29	26,000
28,000	40.2	25.1	22.2	32.3	16.2	12.7	22.3	7.76	4.96	28,000
30,000	43.0	28.8	25.5	34.6	18.6	14.6	23.9	8.91	5.68	30,000
34,000				39.2	23.9	18.7	27.1	11.4	7.22	34,000
38,000				43.9	29.9	23.2	30.3	14.3	9.00	38,000
42,000							33.5	17.5	11.0	42,000
46,000							36.7	20.9	13.2	46,000
50,000							39.9	24.7	15.5	50,000

(Courtesy of Hydraulic Institute, Parsippany, NJ)

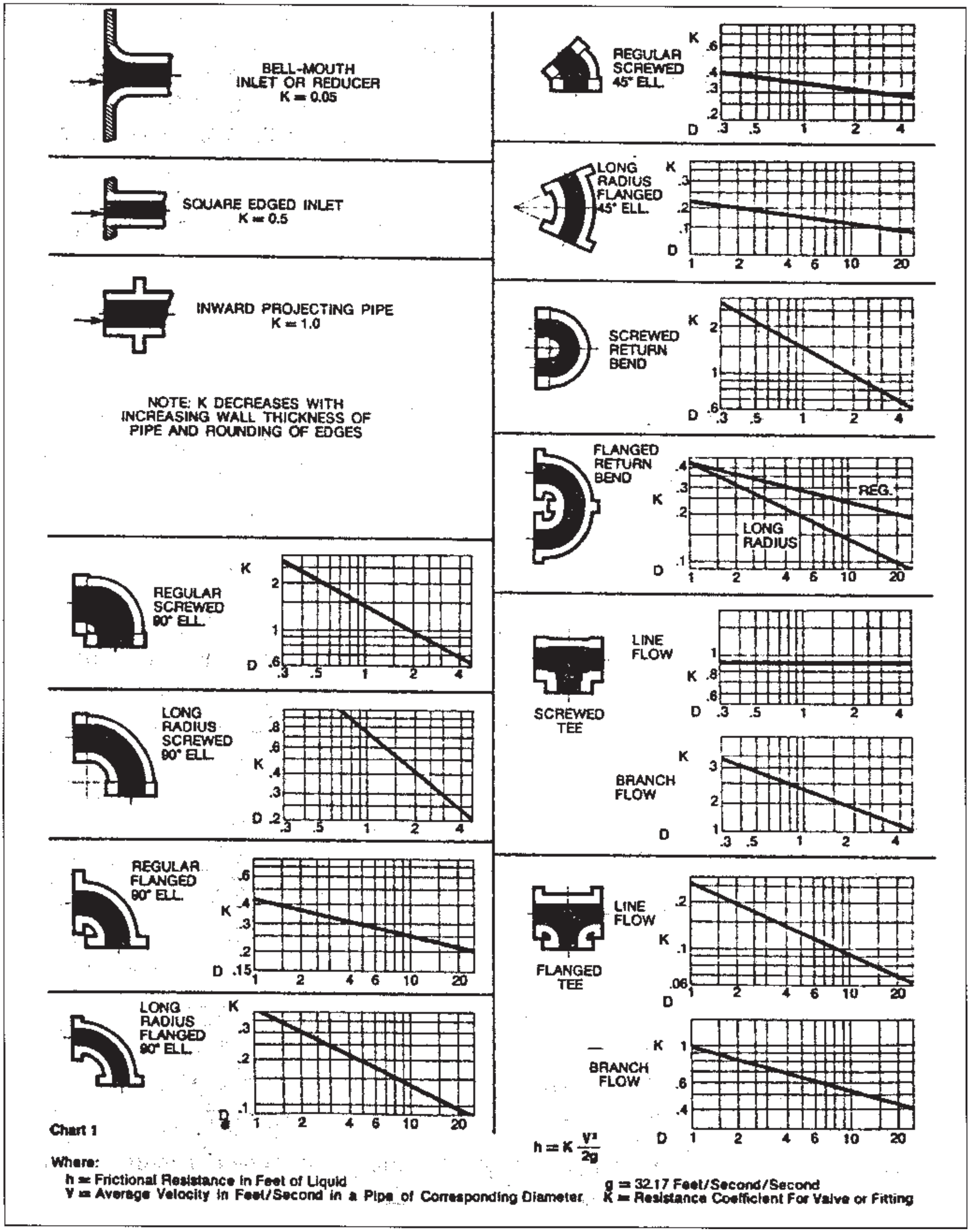

Figure 4(a). Resistance coefficients (K) for valves and fittings. (Courtesy of Hydraulic Institute, Parsippany, NJ)

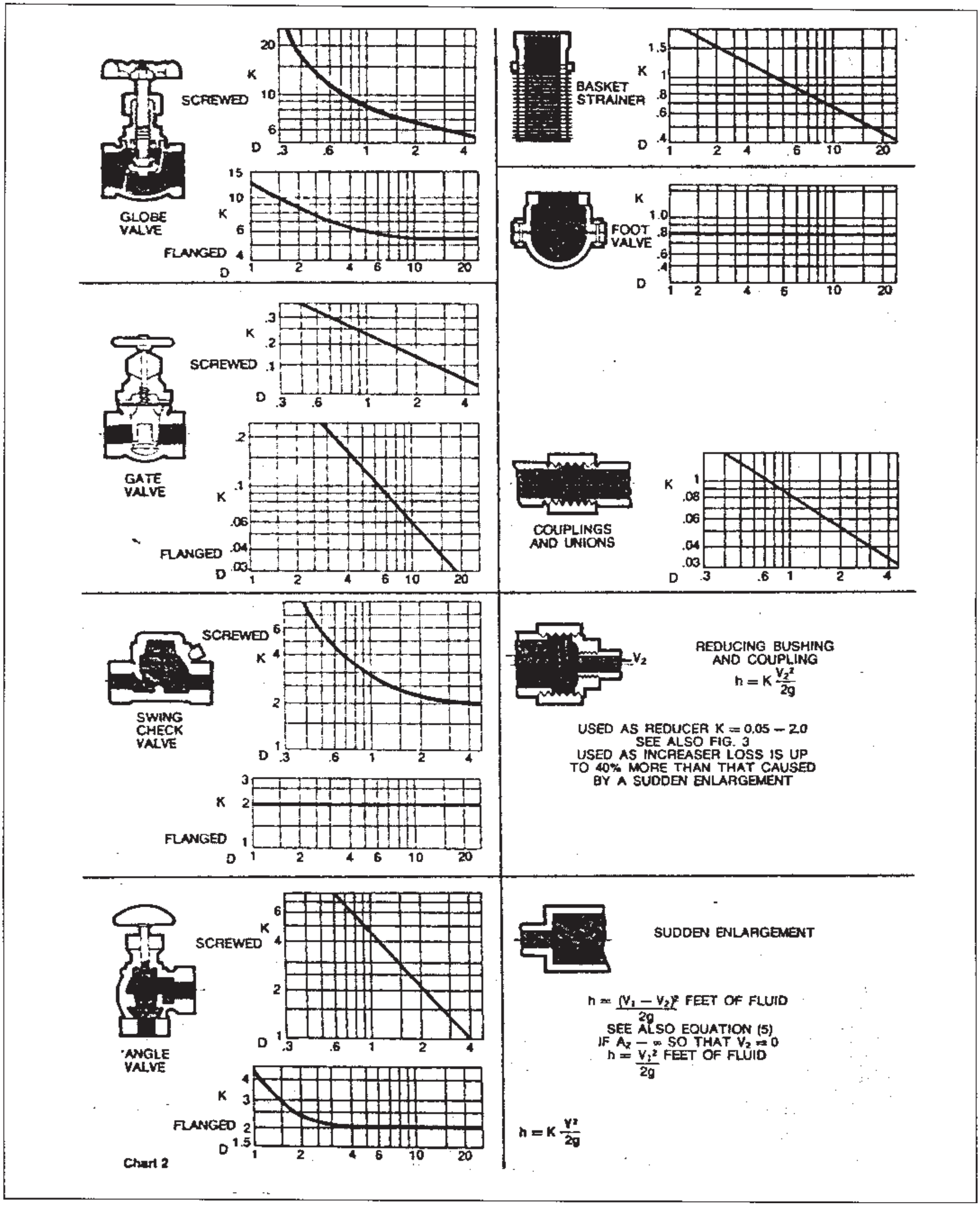

Figure 4(b). Resistance coefficients (K) for valves and fittings. (Courtesy of Hydraulic Institute, Parsippany, NJ)

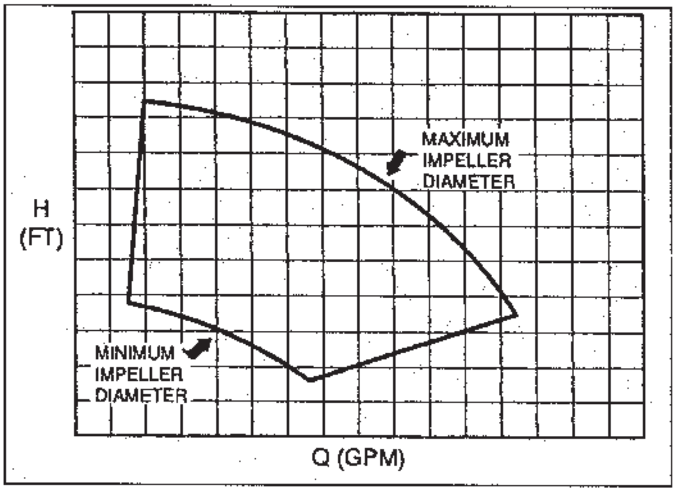

Figure 5. Head-capacity envelope for a constant speed centrifugal pump. (Courtesy of Marcel Dekker, Inc., New York, NY)

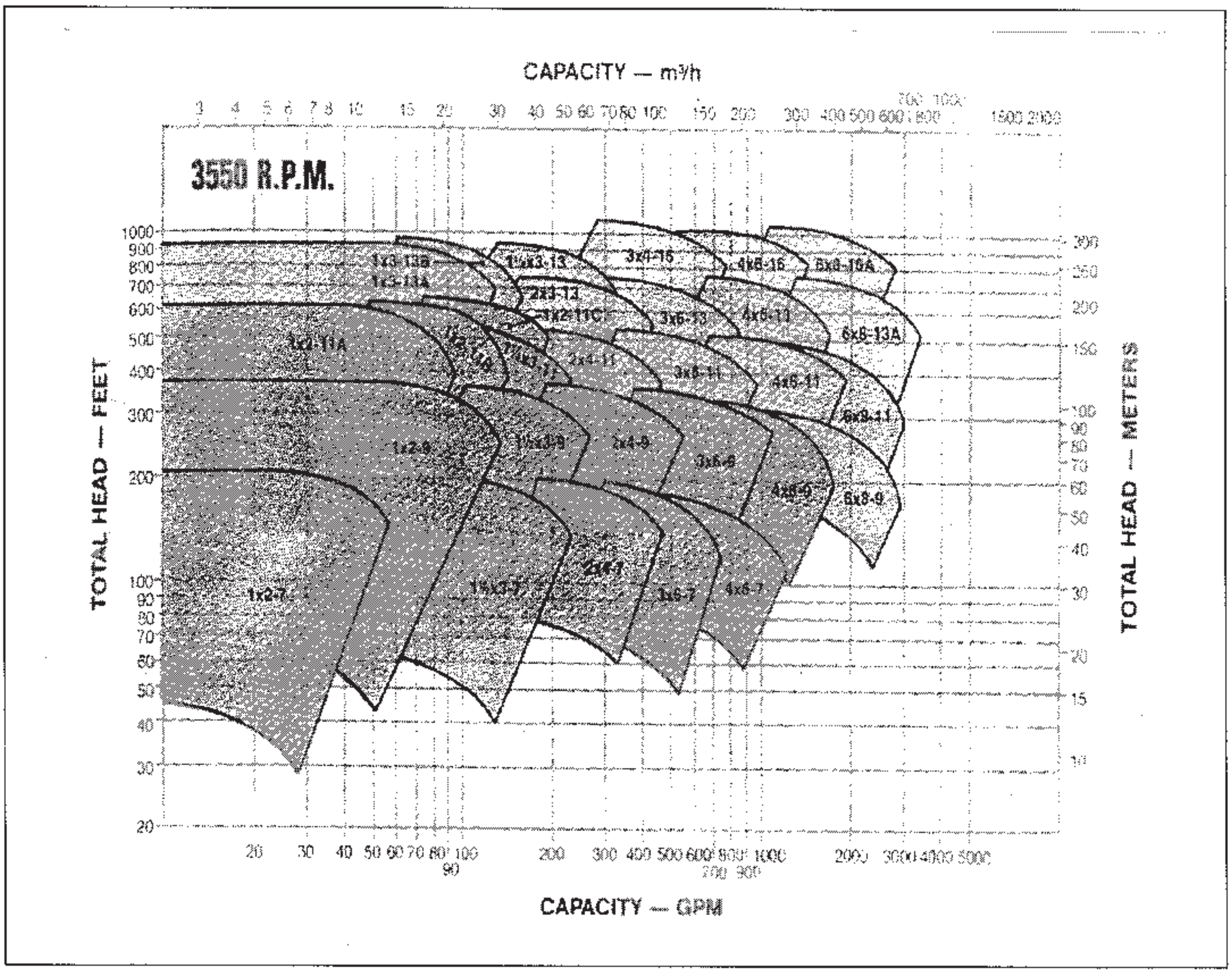

Figure 6(a). Typical family of envelope performance curves for a line of end section centrifugal pumps, shown at 3,600 rpm. (Courtesy of Goulds Pumps, Inc., Seneca Falls, NY)

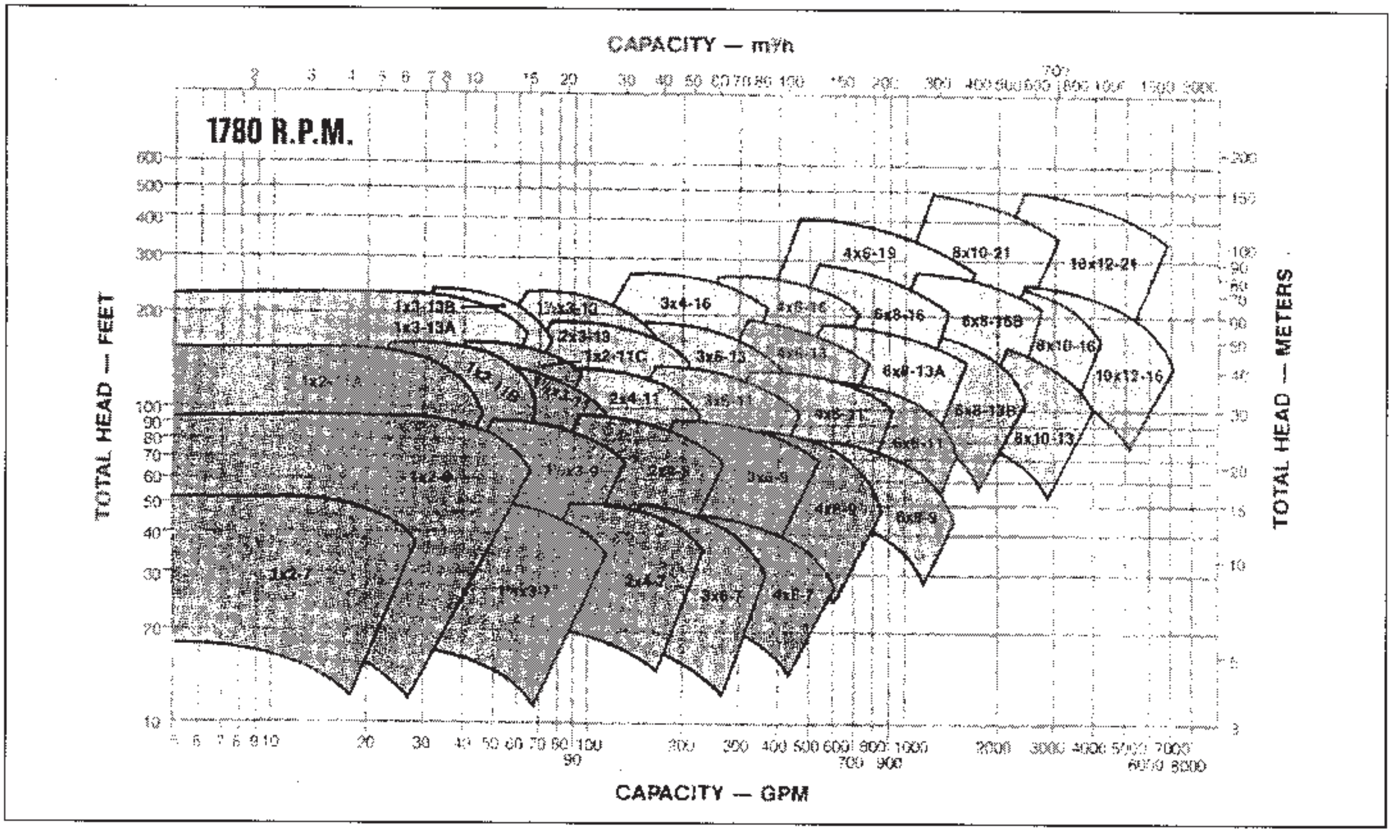

Figure 6(b). Typical family of envelope performance curves for a line of end section centrifugal pumps, shown at 1,800 rpm. (Courtesy of Goulds Pumps, Inc., Seneca Falls, NY)