Publication 5002

AGRICULTURAL MATERIALS HANDLING MANUAL

PART 2 CONVEYING EQUIPMENT

SECTION 2.5

LIQUID CONVEYORS

Agriculture
Canada

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LIQUID CONVEYORS

The Agricultural Materials Handling Manual is produced in several parts as a guide to designers of materials handling systems for farms and associated industries. Sections deal with selection and design of specific types of equipment for materials handling and processing. Items may be required to function independently or as components of a system. The design of a complete system may require information from several sections of the manual.

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PREPARED FOR THE CANADA COMMITTEE
ON AGRICULTURAL ENGINEERING SERVICES
OF
CANADIAN AGRICULTURAL SERVICES
COORDINATING COMMITTEE

PUBLICATION 5002, available from
Information Services, Agriculture Canada, Ottawa K1A 0C7

Cat. No. A-21–12/5-/5-1979 ISBN: 0-662-10744-6
Printed 1979 1.5M–12:79

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SECTION 2.5 LIQUID CONVEYORS

2.5.1 LIQUID CONVEYORS

Fluid conveying implies handling both liquids and vapors. While liquids comprise the bulk of materials handled on farms some materials such as LP gas and ammonia are handled in the vapor phase. Because of convenience and economy liquids are usually handled in bulk which implies continuous flow either by gravity or some form of pump.

2.5.1.1 **Properties of Liquids**

The design and prediction of the behavior of a liquid handling system requires an understanding of the properties of the material.

Specific weight (α) is an expression commonly used in the British system to express the weight per unit volume, for example pounds per cubic foot. Since specific weight varies with temperature, temperature should be specified, for example, the specific weight of water at 60 °F is 62.4 lb/ft^3. In the S.I. system the term specific weight is not used.

Density or mass density (ρ) is the term used in the S.I. system to express mass per unit volume. The common unit is kilograms per cubic meter. The density of water at 3.98°C (temperature for maximum density) is 1000 kg/m^3, or 1 t/m^3.

Specific gravity (G), (or *relative density*, in the S.I. system) of a liquid is a relative term defined as the ratio of its density to that of water at some standard temperature. Physicists commonly use 4°C; in engineering practice 60°F has been used.

The specific gravity (relative density) of liquids is usually measured by means of a hydrometer. Hydrometers to suit various needs are commercially available. The scale is graduated to read either specific gravity referred to water or in some other arbitrary units. Arbitrary scales used by various industries are: API (American Petroleum Institute), used to specify the gravity of petroleum products; Baumé, used in the food industry; and Brix, used to specify the gravity of molasses, honey and syrups.

The API gravity, a function of the specific gravity, may be expressed as:

$$\text{Degrees API} = \frac{141.5}{G\ 60/60°F} - 131.5 \qquad (1)$$

No statement of reference temperature is required since 60°F is included in the definition.

In the dairy industry density is frequently expressed in degrees Baumé rather than specific gravity. The relationship between Baumé and specific gravity is given by the following expressions:

For liquids heavier than water

$$\text{Degrees Baumé} = 145 - \frac{145}{G\ 60/60°F} \qquad (2)$$

For liquids lighter than water

$$\text{Degrees Baumé} = \frac{140}{G\ 60/60°F} - 130 \qquad (3)$$

Viscosity (μ) is that property of a liquid which resists any force tending to produce motion or shear between adjacent particles. In the metric system the unit of absolute viscosity was the poise, g/(cm·s). In the SI system of units dynamic viscosity is expressed as (Pa·s), which is equivalent to kg/(m·s).

Kinematic viscosity (Υ) is the ratio of the absolute viscosity to the density. In the metric system the unit of absolute viscosity was the stoke (cm^2/s). In the SI system the preferred unit is m^2/s.

In practice the absolute viscosity is somewhat difficult to measure directly; however, instruments using indirect methods have been developed. The absolute viscosity of a liquid may be determined by measuring the torque required to rotate a spindle in the liquid. Kinematic viscosity is measured by determining the time for a specific volume of liquid to flow through an orifice or tube under its own head. Numerous viscosimeters have been developed and procedures for viscosity determination standardized.

Rotating spindle viscosimeters suitable for viscosity determination of both Newtonian and non-Newtonian liquids are available. Examples of these instruments are the Brookfield, Haake, Stormer and MacMichael.

A procedural outline for the determination of kinematic viscosity using calibrated glass capillary instruments with "gravity flow" is given in ASTM Designation: D445-74 (1). Determinations may be made at any temperature in the range - 55 to 100°C at which the liquid is Newtonian.

The Saybolt viscosimeter ASTM Designation: D 88 - 56 (1) measures the time flow rate through a short tube of small bore under prescribed conditions of head and temperature. The viscosity is reported in seconds for 60 mL of fluid to flow through the orifice. The Saybolt Universal viscosimeter is used for light to medium liquids while the Saybolt Fural, having a larger bore, is used for heavier liquids.

Tables to convert kinematic viscosity to Saybolt Universal or Saybolt Fural viscosity are given in ASTM D 2146 - 74 (1). Table 2.5.1 lists approximate conversions for several commonly used viscosity measurements including the SI system. The viscosity of a number of common liquids is given in Table 2.5.2.

Vapor pressure above an enclosed liquid is caused by the evaporation of the liquid. Both the liquid and its temperature influence the value of the vapor pressure, for example, the saturated vapor pressure of water varies from 0.61048 kPa at 0°C to 101.32 kPa at 100°C.

The specific heat (Cp) of a substance is the quantity of heat required to raise unit mass of a substance one degree of temperature. In the SI system the unit of specific heat is joules per kilogram-degree kelvin, J/(kg·K).

Bulk modulus is a measure of the elasticity of a fluid. It may be expressed as:

$$BM = \frac{(p_2 - p_1)\, v_1}{v_1 - v_2} \qquad (4)$$

where p_1, p_2 and v_1, v_2, are the initial and final pressures and volumes respectively. For most agricultural applications pressures are relatively low and liquids may be considered incompressible.

Corrosion and toxic tendencies of liquids should be considered in the design and selection of equipment for a liquid handling system. Abrasion may also be a factor particularly when solids are suspended in a liquid.

Liquid handling systems are also used to convey emulsions, such as are used for herbicide and insecticide sprays, and slurries such as liquid manure.

TABLE 2.5.1 Approximate Viscosity Comparisons

Kinematic	Viscosity	Absolute Viscosity Pa.s (For specific gravities listed)						
		Specific Gravity						
m^2/s	SUS	0.8	0.9	1.0	1.1	1.2	1.3	1.4
2.10×10^{-2}	10×10^4	16.8	18.9	21.0	23.1	25.2	27.3	29.4
1.89×10^{-2}	9×10^4	15.1	17.0	18.9	20.8	22.7	24.6	26.4
1.68×10^{-2}	8×10^4	13.4	15.1	16.8	18.5	20.2	21.8	23.5
1.47×10^{-2}	7×10^4	11.7	13.2	14.7	16.2	17.6	19.1	20.6
1.26×10^{-2}	6×10^4	10.1	11.3	12.6	13.9	15.1	16.5	17.6
1.05×10^{-2}	4.0×10^4	8.40	9.45	10.5	11.6	12.6	13.7	14.7
9.45×10^{-3}	4.5×10^4	7.56	8.50	9.45	10.4	11.4	12.3	13.2
8.50×10^{-3}	4.0×10^4	6.80	7.65	8.50	9.35	10.2	11.1	11.9
7.35×10^{-3}	3.5×10^4	5.88	6.62	7.35	8.09	8.83	9.56	10.3
6.30×10^{-3}	3.0×10^4	5.04	5.67	6.30	6.94	7.56	8.20	8.83
5.25×10^{-3}	2.5×10^4	4.20	4.72	5.25	5.78	6.30	6.83	7.35
4.25×10^{-3}	2.0×10^4	3.40	3.82	4.25	4.68	5.10	5.53	5.95
3.15×10^{-3}	1.5×10^4	2.52	2.84	3.15	3.46	3.78	4.09	4.41
2.20×10^{-3}	1.0×10^4	1.76	1.98	2.20	2.42	2.64	2.86	3.08
1.95×10^{-3}	9×10^3	1.56	1.75	1.95	2.15	2.34	2.53	2.73
1.70×10^{-3}	8×10^3	1.36	1.53	1.70	1.87	2.04	2.21	2.38
1.50×10^{-3}	7×10^3	1.20	1.35	1.50	1.65	1.80	1.95	2.10
1.30×10^{-3}	6×10^3	1.04	1.17	1.30	1.43	1.56	1.69	1.82
1.05×10^{-3}	5×10^3	0.840	0.945	1.05	1.15	1.26	1.37	1.47
8.50×10^{-4}	4×10^3	0.680	0.765	0.850	0.935	1.02	1.10	1.19
6.30×10^{-4}	3×10^3	0.505	0.567	0.630	0.694	0.756	0.820	0.883
4.20×10^{-4}	2×10^3	0.336	0.378	0.420	0.462	0.504	0.546	0.588
2.20×10^{-4}	1×10^3	0.176	0.198	0.220	0.242	0.264	0.286	0.308
1.95×10^{-4}	9×10^2	0.156	0.175	0.195	0.214	0.234	0.253	0.273
1.70×10^{-4}	8×10^2	0.136	0.153	0.170	0.187	0.204	0.221	0.238
1.50×10^{-4}	7×10^2	0.120	0.135	0.150	0.165	0.180	0.195	0.210
1.30×10^{-4}	6×10^2	0.104	0.117	0.130	0.143	0.156	0.169	0.182
1.05×10^{-4}	5×10^2	0.084	0.094	0.105	0.109	0.126	0.136	0.147
8.50×10^{-5}	4×10^2	0.086	0.077	0.085	0.094	0.102	0.111	0.119
6.30×10^{-5}	3×10^2	0.050	0.057	0.063	0.069	0.076	0.083	0.088
4.20×10^{-5}	2×10^2	0.034	0.038	0.042	0.046	0.050	0.055	0.059
2.20×10^{-5}	1×10^2	0.018	0.020	0.022	0.024	0.026	0.029	0.031
1.90×10^{-5}	90	0.015	0.017	0.019	0.021	0.023	0.025	0.027
1.70×10^{-5}	80	0.014	0.015	0.017	0.019	0.020	0.022	0.024
1.50×10^{-5}	70	0.012	0.014	0.015	0.017	0.018	0.020	0.021
1.0×10^{-5}	60	0.008	0.009	0.010	0.011	0.012	0.013	0.014
7.4×10^{-6}	50	0.006	0.006	0.007	0.008	0.008	0.009	0.010
4.2×10^{-6}	40	0.003	0.004	0.004	0.004	0.005	0.005	0.006
1.2×10^{-6}	30	0.001	0.001	0.001	0.001	0.002	0.002	0.002

TABLE 2.5.2 Specific Gravity and Viscosity of Liquid Materials

Material	Temp. °C	Specific Gravity G	Viscosity Pa.s
Water	0	1.000	1.79×10^{-3}
	20	0.998	1.00×10^{-3}
	50	0.987	5.49×10^{-4}
Sucrose 20%	0	1.086	3.82×10^{-3}
	20	1.082	1.92×10^{-3}
	80	1.055	5.92×10^{-4}
60%	20	1.289	6.02×10^{-2}
	80	1.252	5.42×10^{-3}
Lub oil SAE 10	15	0.90	1.0×10^{-1}
	65	0.87	1.0×10^{-2}
30	15	0.90	4.0×10^{-1}
	65	0.87	2.7×10^{-2}
CaC/2 23%	0	1.22	3.6×10^{-3}
23%	-20	1.22	5.9×10^{-3}
29%	-30	1.28	1.08×10^{-2}
Molasses, heavy dark	20	1.40	6.60
	40	1.37	1.87
	50	1.13	9.2×10^{-1}
	65	1.16	3.7×10^{-1}
Soybean oil	30	0.92	4.06×10^{-2}
Olive oil	20	0.92	8.4×10^{-2}
Rapeseed	15	0.91	1.18×10^{-1}
Milk, whole	0	1.04	4.28×10^{-3}
	20	1.03	2.12×10^{-3}
Milk, skim	25	1.04	1.37×10^{-3}
Cream 20%	3	1.01	6.2×10^{-3}
30%	3	1.00	1.38×10^{-3}

2.5.1.2 Behavior of Liquids

Pressure In the SI system of units pressure is expressed as Newtons per square meter or Pascals (N/m^2).

Static pressure A body of fluid at rest is acted on only by compressive forces. The intensity of this force is known as the static pressure.

Gauge pressure is the difference between a given fluid pressure and that of the atmosphere. Most pressure gauges are calibrated to indicate gauge pressure.

Absolute pressure The gauge (taken with the proper sign) plus the atmospheric pressure is the true total or absolute pressure. For a homogeneous fluid exposed to atmospheric pressure the absolute pressure may be expressed as:

$$p(abs) = p_a + phg \qquad (5)$$

where

p(abs) = absolute pressure
p_a = atmospheric pressure
p = fluid density
h = head of liquid above the point where the pressure is measured
g = dimensional constant (For SI system = 9.80665 m/s^2)

Static head In the above expression for absolute pressure the term h, measured in units of height of the given liquid, is frequently referred to as the static head.

Energy The energy of a liquid at rest, excluding thermal and chemical energy, consists of the sum of the potential energy due to its elevation above a datum, the potential energy due to the pressure to which it has been raised and the elastic energy. In the agricultural industry pressures are relatively low and most liquids are considered incompressible, thus the elastic energy is assumed equal to zero.

For a liquid in motion the kinetic energy must also be included. Assuming no change in internal energy and that no energy is transferred into or out of the system the total energy must remain constant, thus:

$$\frac{mv^2}{2g} + mh + \frac{mp}{pg} = C \qquad (6)$$

and in terms of specific energy

$$\frac{v^2}{2g} + h + \frac{p}{pg} = C' \qquad (7)$$

As stated the above equation assumes that no transfer of energy occurs between the liquid and its surroundings. In a practical system the total energy contained by the liquid may change because,

heat may be transferred between the liquid and its surroundings;
work may be done by the flowing material on the surroundings, which is frequently called shaft work (W_s); and
friction losses (F) occur between the flowing material and the surroundings.

Equation (8), frequently referred to as Bernoulli's equation, may be used to express the change in energy between two points in a system. Assuming no change in density and no heat transfer:

$$\frac{v_1^2}{2g} + h_1 + \frac{p_1}{pg} = \frac{v_2^2}{2g} + h_2 + \frac{p_2}{pg} + F + W_s \qquad (8)$$

2.5.2 PROPERTIES OF PIPE AND TUBING

2.5.2.1 General

Pipe materials are selected on the basis of the requirements set up in various codes and standards which refer in most cases to specifications established by the Canadian Standards Association, the American Society of Testing Materials or other recognized institutes or government purchasing boards.

2.5.2.2 Steel Pipe and Tubing

CSA 63 - 1966 or ASTM A 120 pipe is available in both the black and galvanized type. It is a common variety of pipe used for low pressure domestic service. Physical dimensions are listed in Table 2.5.3.

Cold drawn round seamless steel mechanical tubing is available in sizes ranging from ⅛ to 12 in. in increments ranging from 1/16 to ¼ in. depending on pipe size. This type of tubing should not be used for pressure purposes.

Steel boiler, condenser, heat exchanger or hydraulic tubing is recommended where tubing will be subjected to an internal pressure. This material is available in a wide variety of outside diameters and wall thickness ranging from ¼ to 8 in. OD and 0.035 to 0.320 in. in wall thickness. Table 2.5.4 illustrates the size ranges available from 3/16 to 2 in.

TABLE 2.5.3 Dimensions of Welded and Seamless Steel Pipe

Nominal Diameter	Schedule	Outside Diameter		Wall Thickness		Interal Area		$\epsilon/D \times 10^{-4}$
in.		mm	in.	mm	in.	cm^2	$in.^2$	ϵ=0.00015 ft
⅛	40 (s)	10.3	0.405	1.7	0.068	0.366	0.0568	66.9
	80 (x)			2.4	0.095	0.235	0.0363	83.7
¼	40 (s)	13.7	0.504	2.2	0.088	0.672	0.1041	49.5
	80 (x)			3.0	0.119	0.462	0.0716	59.6
⅜	40 (s)	17.1	0.675	2.3	0.091	1.23	0.1909	36.5
	80 (x)			3.2	0.126	0.906	0.1405	42.6
½	40 (s)	21.3	0.840	2.8	0.109	1.96	0.3039	28.9
	80 (x)			3.7	0.147	1.51	0.2341	33.0
	160			4.7	0.187	1.10	0.1706	38.6
	(xx)			7.5	0.294	0.322	0.0499	71.4
¾	40 (s)	26.7	1.050	2.9	0.113	3.44	0.5333	21.8
	80 (x)			3.9	0.154	2.79	0.4324	24.3
	160			5.6	0.219	1.90	0.2942	29.3
	(xx)			7.8	0.308	0.954	0.1479	41.5
1	40 (s)	33.4	1.315	3.4	0.133	5.58	0.8643	17.2
	80 (x)			4.6	0.179	4.64	0.7193	18.8
	160			6.35	0.250	3.37	0.5217	22.1
	(xx)			9.1	0.358	1.82	0.2818	30.1
1¼	40 (s)	42.1	1.660	3.6	0.140	9.65	1.496	13.0
	80 (x)			4.8	0.191	8.28	1.283	14.1
	160			6.35	0.250	6.82	1.057	15.5
	(xx)			9.7	0.382	4.07	0.6305	20.1
1½	40 (s)	48.3	1.900	3.7	0.145	13.1	2.036	11.2
	80 (x)			5.1	0.200	11.4	1.767	12.0
	160			7.1	0.231	9.07	1.406	13.5
	(xx)			10.2	0.400	6.13	0.9503	16.4
2	40 (s)	60.2	2.375	3.9	0.154	21.6	3.356	8.7
	80 (x)			5.5	0.218	19.0	2.953	9.3
	160			8.7	0.344	14.4	2.235	10.7
	(xx)			11.1	0.436	11.4	1.774	12.0
2½	40 (s)	73.0	2.875	5.2	0.203	30.9	4.788	7.29
	80 (x)			7.0	0.276	27.3	4.238	7.75
	160			9.5	0.375	13.7	2.125	8.47
	(xx)			14.0	0.552	11.4	1.771	10.2
3	40 (s)	88.4	3.500	5.5	0.216	47.7	7.393	5.87
	80 (x)			7.6	0.300	42.6	6.605	6.21
	160			11.1	0.438	34.9	5.408	6.85
	(xx)			15.2	0.600	26.8	4.155	7.83
4	40 (s)	114.3	4.500	6.0	0.237	82.1	12.73	4.47
	80 (x)			8.6	0.337	74.2	11.50	4.70
	120			11.1	0.438	66.7	10.32	4.96
	160			13.5	0.531	59.9	9.283	5.24
	(xx)			17.1	0.674	50.3	7.803	5.71
5	40 (s)		5.563	6.6	0.258	129	20.01	3.57
	80 (x)			9.5	0.375	117	18.19	3.74
	120			12.7	0.500	105	16.35	3.94
	160			15.9	0.625	94.3	14.61	4.17
	(xx)			19.0	0.750	83.7	12.97	4.43
6	40 (s)		6.625	7.1	0.280	186	28.89	2.93
	80 (x)			11.0	0.432	168	26.07	3.12
	120			14.3	0.562	153	23.77	3.27
	160			18.3	0.719	136	21.13	3.47
	(xx)			22.0	0.864	121	18.83	3.68

S = Wall thickness formerly designated standard weight
x = Wall thickness formerly designated extra strong
xx = Wall thickness formerly designated double extra strong

TABLE 2.5.4 Cold Drawn Seamless Steal Hydraulic Line Tube (SAE 1008)

Outside Diameter in.	Wall Gauge B.W.G.	Inside Diameter in.	Theoretical Working Pres. psi
3/16	20	0.117	5610
1/4	20	0.180	4200
	18	0.152	5890
	16	0.120	7850
	13	0.060	10820
5/16	20	0.305	3370
	18	0.277	4710
	16	0.245	6290
3/8	20	0.305	2800
	18	0.277	3920
	16	0.245	5240
1/2	20	0.430	6930
	18	0.402	9702
	16	0.370	12953
	14	0.334	16500
	13	0.310	18876
9/16	20	0.493	6171
	16	0.432	11517
5/8	20	0.555	1680
	18	0.527	2350
	16	0.495	3140
	14	0.459	4000
	13	0.435	4580
3/4	20	0.680	4620
	18	0.652	6468
	16	0.620	8580
	14	0.584	10956
	13	0.560	12540
	12	0.532	14388
	11	0.510	15840
7/8	20	0.805	3960
	18	0.777	5544
	16	0.745	7342
	14	0.709	2845
	13	0.685	3255
	12	0.657	3750
1	20	0.930	1050
	18	0.902	1470
	16	0.870	1950
	14	0.834	2490
	13	0.810	2850
	12	0.782	3270
	11	0.760	3600
	10	0.732	4020
1 1/8	16	0.995	1735
	11	0.885	3200
1 1/4	16	1.120	5148
	14	1.084	6574
	13	1.060	7524
	11	1.010	9504
	10	0.982	10613
1 3/8	16	1.245	4676
1 1/2	16	1.370	4290
	14	1.334	5478
	13	1.310	6270
	11	1.260	7920
	10	1.232	8844
1 5/8	10	1.357	2474
	0.156	1.312	2880
1 3/4	13	1.560	1629
1 7/8	16	1.745	1040
2	16	1.870	975
	13	1.810	1425
	11	1.760	1800
	0.156	1.688	2340

2.5.2.3 Copper Tubing

Copper water tubing suitable for plumbing and similar applications for conveying fluids is available in three series of wall thickness, designated K, L and M. The dimensions for the various series are given in Table 2.5.5. Type K and L are available in both the annealed (soft) and hard drawn (hard) forms. Type M is only available in the hard drawn form. Type K tubing, in coils, is used for underground work where a minimum number of joints and greater wall thickness is an advantage. Type L and M tubing are recommended for interior applications.

The maximum working pressure for copper pipe can be calculated from the following expression:

$$P_w = \frac{2\,St}{dF} \tag{9}$$

where,

S = tensile strength, psi (30,000 psi for copper)
t = pipe wall thickness, in.
d = inside diameter, in.
F = safety factor. A factor of 6 based on the tensile strength is common.

2.5.2.4 Aluminum Tubing

Minimum standards for aluminum irrigation tubing are contained in ASAE S263.2 published in the American Society of Agricultural Engineers Year Book (2).

The standard prescribes the minimum requirements for 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 14 in. (51, 76, 102, 127, 152, 178, 203, 229, 254, 279, 305 and 356 mm) outside diameter tubing.

The wall thickness of the tubing is not specified, however, due to the relationship of wall thickness, diameter and mechanical properties of the material, the minimum wall thickness for each size of tubing must satisfy all of the following conditions:

1. To prevent denting in field handling the tubing must have a denting factor equal or superior to that given in Table 2.5.6. The denting factor is given by:

Denting factor $= Y_s(t)^2$

Y_s = specified yield strength of the material, (psi Table 2.5.7)

t = wall thickness, in.

2. The tubing must be capable of spanning 30 ft (9.1 m) as a simple beam without permanent deflection or local buckling when filled with water at zero pressure. The bending stress (f) of aluminum alloy tubing that results

TABLE 2.5.5 Dimensions, Weights, and Diameter for Standard Copper Water Tube Sizes*

Standard Size, in.	Nominal Outside Diameter in.	Nominal Wall Thickness in.			Theoretical Weight lb per ft		
		Type K Wall Thickness	Type L Wall Thickness	Type M Wall Thickness	Type K	Type L	Type M
1/4	0.375	0.035	0.030	a	0.145	0.126	a
3/8	0.500	0.049	0.035	0.025	0.269	0.198	0.145
1/2	0.625	0.049	0.040	0.028	0.344	0.285	0.204
5/8	0.750	0.049	0.042	a	0.418	0.362	a
3/4	0.875	0.065	0.045	0.032	0.641	0.455	0.328
1	1.125	0.065	0.050	0.035	0.839	0.655	0.465
1 1/4	1.375	0.065	0.055	0.042	1.04	0.884	0.682
1 1/2	1.625	0.072	0.060	0.049	1.36	1.14	0.940
2	2.125	0.083	0.070	0.058	2.06	1.75	1.46
2 1/2	2.625	0.095	0.080	0.065	2.93	2.48	2.03
3	3.125	0.109	0.090	0.072	4.00	3.33	2.68
3 1/2	3.625	0.120	0.100	0.083	5.12	4.29	3.58
4	4.125	0.134	0.110	0.095	6.51	5.38	4.66
5	5.125	0.160	0.125	0.109	9.67	7.61	6.66
6	6.125	0.192	0.140	0.122	13.8	10.2	8.92

a Indicates that the material is not generally available.
* Extracted from ASTM Designation B88-76.

TABLE 2.5.6 Denting Factors

Outside Diameter in.	Outside Diameter mm	Denting Factor
2	51	62
3	76	62
4	102	62
5	127	67
6	152	84
7	178	105
8	203	133
9	229	168
10	254	206

shall not exceed the smaller of the two values found as follows:

f = 90% of the specified yield strength

or

$$f = 1.57Y_s - (1.7(Y_s)^2/10{,}000{,}000)(d/t)$$

where,

Y_s = specified yield strength, psi (Table 2.5.7)
d = outside diameter, in.
t = wall thickness, in.

The bending stress, $f = \frac{M}{S}$

where,

$$M = \frac{wl^2}{8} \text{ (maximum moment)}$$

w = total weight per foot of length, lb
l = length of tubing, ft

$$S = \frac{\pi (d^4 - d_1^4)}{32d}$$

d = outside diameter, in.
d_1 = inside diameter, in.

3. For mechanical move systems it is recommended that a safety factor of two be used in establishing safety devices to protect the tubing from excessive torque loads.

Torque resistance of aluminum tubing may be calculated from the following:

$$\text{Torque resistance} = 11{,}500{,}000\ K\ d^{0.5}\ (t)^{2.5}$$

where,

K = stiffening factor (For extruded tubing K = 1; For welded tubing K has not been determined. A value of 1 is recommended)

d = outside diameter, in.

t = wall thickness, in.

4. The theoretical bursting pressure of tubing can be determined from the formula:

$$P = 2S\,(t/d)$$

where,

P = bursting pressure, psi

t = wall thickness, in.

d = outside diameter, in.

S = allowable working stress given in Table 2.5.7

The operating pressure of irrigation tubing should not exceed 150 psi (1034 kPa). On the basis of this maximum operating pressure, tubing which meets the ASAE Standard must be capable of withstanding an internal hydrostatic pressure of 450 psi (3102 kPa) for 2 minutes without leaking.

TABLE 2.5.7 Minimum Yield and Maximum Working Stress for Aluminum Alloy Tubing

Aluminum Alloys and Tempers ASTM No.	Minimum Yield (Y_s)		Maximum Allowable Working Stress (S Value)			
			Welded tubing‡ tensile		Seamless tubing tensile	
	psi	kg/cm²	psi	kg/cm²	psi	kg/cm²
3003-H14	17,000**	120	14,000	100	20,000**	140
3003-H16	21,000**	150	14,000	100	24,000**	170
3003-H18	24,000**	170	14,000	100	27,000**	190
3004-H32	21,000**	150	23,000	160	28,000**	200
3004-H34	25,000*	180	23,000	160	32,000**	220
5050-H34	20,000**	140	18,000	130	25,000**	180
5050-H36	22,000**	150	18,000	130	27,000**	190
5050-H38	24,000**	170	18,000	130	29,000**	200
5052-H32	23,000**	160	25,000	180	31,000**	220
5052-H34	26,000**	180	25,000	180	34,000**	240
5052-H36	29,000**	200	25,000	180	37,000*	260
5052-H38	31,000**	220	25,000	180	39,000**	270
5086-H32	28,000**	200	35,000	250	40,000**	280
5086-H34	34,000**	240	35,000	250	44,000**	310
5086-H36	38,000**	270	35,000	250	47,000**	330
5154-H32	26,000*	180	30,000	210	36,000*	250
5154-H34	29,000**	200	30,000	210	39,000**	270
5154-H36	32,000*	220	30,000	210	42,000*	300
5154-H38	34,000**	240	30,000	210	45,000**	320
6061-T6	35,000*†	250	24,000†(a)	170	38,000†(c)	270
6063-T6	25,000†(b)	180	17,000†(a)	120	30,000†(d)	210
6063-T31	28,000**	200			30,000	210

*ASTM B313, Spec. for Aluminum-Alloy Round Welded Tubes
**ASTM B210, Spec. for Aluminum-Alloy Drawn Seamless Tubes
†ASTM B241, Spec. for Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube
‡ASME Boiler and Pressure Vessel Code, Section IX, Par. QN-6(c)
(a)ASME Boiler and Pressure Vessel Code, Section VIII, Div. 1, Table UNF 23.1
(b)ASTM B210 allows 28,000 psi (200 kg per sq cm) for drawn tubing
(c)ASTM B210 allows 42,000 psi (300 kg per sq cm) for drawn tubing
(d)ASTM B210 allows 33,000 psi (230 kg per sq cm) for drawn tubing

2.5.2.5. Plastic Pipe and Tubing

Most plastic pipe for domestic or agricultural use is manufactured from one of the following materials:

ABS acrylonitrile - butadiene - styrene

PB polybutylene

PE polyethylene

PVC polyvinyl chloride

In classifying material for use in the manufacture of plastic pipe the following ASTM Standards are relevant:

ASTM Standard D 1248 polyethylene plastics molding and extrusion material.

ASTM Standard D 1784 rigid polyvinyl chloride compounds and chlorinated polyvinyl chloride compounds.

ASTM Standard D 1788 rigid acrylonitrile - butadiene - styrene. (ABS) plastic.

ASTM Standard D 2581 polybutylene.

Pipe is manufactured for both pressurized and nonpressurized applications.

For pressure applications pipe should have the following code marked on the pipe:

1. Material abbreviation

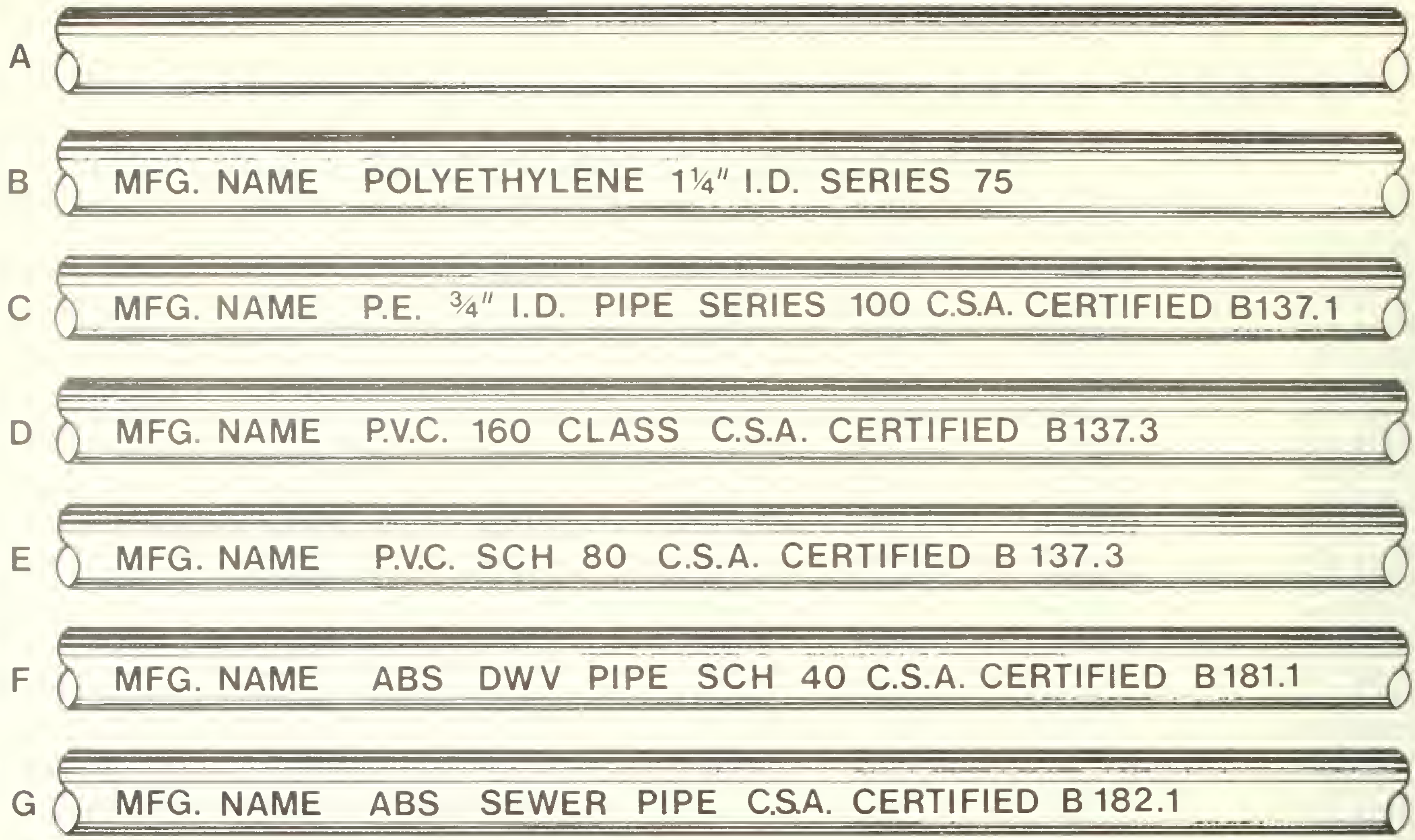
2. Type and grade as defined in the appropriate ASTM Standard

3. Recommended hydrostatic design stress (RHDS) for water at 23°C in hundreds of psi. For example PVC 1220 means PVC Type 1, Grade 2, as defined in ASTM Standard D 1784 with an RHDS of 2000 psi. Other types of coding such as PVC Type 1 Grade 11 Class 160 are also used. Figure 2.5.1 illustrates pipe identification.

Plastic pipe to be used for pressure applications should be pressure rated. The pressure rating is the estimated maximum internal pressure the pipe will withstand with a high degree of certainty that it will not fail. The pipe must be strong enough to withstand not only the highest static pressure but also any reasonable pressure surge.

There are two systems used to classify pipe based on the pressure rating.

Schedule System - Under this system plastic pipe is grouped under the headings of Schedule 40, 80 and 120. This designation is similar to that used for iron pipe where the outside diameter and wall thickness are fixed by specification. Each pipe size within each Schedule has a recommended working pressure which is dependent on the dimensions of the pipe and the design stress of the material. **The safe working pressure must be obtained from the pipe manufacturer.** Pipe classified under the Schedule system is used primarily for industrial purposes.



A No coding. This is a utility pipe for use in residential and farm use. It may not be manufactured to CSA standard and should not be used for high pressure applications and it is recommended that it not be buried or installed in non-accessible locations.

B This is a polyethyline pipe manufactured to meet Series 75 CSA pipe dimensions but is not CSA certified.

C A polyethyline pipe which meets CSA Series 100 dimensional and pressure requirements.

D A polyvinyl chloride pipe which meets the pressure and dimensional requirements for CSA class 160 pipe.

E A PVC (rigid) pipe which meets the pressure and dimensional requirements of CSA schedule 40 pipe.

F Schedule 40 ABS pipe for use as a drain, waste or ventilation pipe. This pipe is not pressure rated.

G This pipe is manufactured from ABS material and is suitable for sewer applications. A perforated version may be used for sewage disposal fields.

Figure 2.5.1 Plastic pipe identification coding.

An example of Schedule rated PVC pipe is given in Tables 2.5.8 and 2.5.9.

Class, Series or SDR System - In this system of classifying plastic pipe based on working pressure each pipe in the same class or series has the same pressure rating. The pipe is grouped according to its **standard dimensional ratio** (SDR) which is a relationship between pipe diameter and wall thickness expressed by:

SDR = outside diameter/wall thickness.

Pipe which is pressure rated under the SDR system is classified as Series or Class XXX, where XXX is a two- or three-digit number which represents the pressure rating in psi for water at 23°C, for example:

2 in PVC Type 1 Series 160 pipe

Outside diameter = 2.375 in.

Wall thickness = 0.091 in.

SDR = 2.375/0.091 = 26

Maximum working pressure 160 psi (Table 2.5.10)

Common series or class numbers are 50, 75, 100, 125, 160 and 200. The class or series to which a particular pipe is assigned depends on the pipe material and wall thickness, thus pipes made from different materials but having the same SDR do not necessarily fall in the same series or class.

Pipe and tubing that is not pressure rated is manufactured for use as electrical conduit, sewer, drain and vent pipe. A corrugated and perforated plastic tubing which meets the Canadian Government Purchasing Board (7) specifications is available for underground drainage lines.

A number of pipe manufacturers produce a utility pipe which is not CSA approved; this material is suitable for minor aboveground or drainage applications. For underground or other major installations only CSA approved pipe with the proper pressure rating should be used.

Plastic pipe is available in both flexible and rigid form. Flexible pipe can be obtained in coil lengths of 100 to 500 feet. Rigid pipe is sold in lengths of 10 to 20 feet.

TABLE 2.5.8 Schedule 40 PVC Type 1 pipe

Nominal Size in.	Outside Diameter in.	Inside Diameter in.	Wall Thickness in.	Working Pressure psi @ 73°F
½	0.840	0.622	0.109	600
¾	1.050	0.824	0.113	480
1	1.315	1.049	0.133	450
1¼	1.660	1.380	0.140	370
1½	1.900	1.610	0.145	330
2	2.375	2.067	0.154	280
2½	2.875	2.469	0.203	300
3	3.500	3.068	0.216	260
4	4.500	4.026	0.237	220
5	5.563	5.305	0.258	200
6	6.625	6.065	0.280	180

TABLE 2.5.9 Schedule 80 PVC Type 1 pipe

Nominal Side in.	Outside Diameter in.	Inside Diameter in.	Wall Thickness in.	Working Pressure psi @ 73°F
½	0.840	0.546	0.147	850
¾	1.050	0.742	0.154	690
1	1.315	0.957	0.179	630
1¼	1.660	1.278	0.191	520
1½	1.900	1.500	0.200	470
2	2.375	1.939	0.218	400
2½	2.875	2.323	0.276	420
3	3.500	2.900	0.300	370
4	4.500	3.826	0.337	320
5	5.563	5.188	0.375	300
6	6.625	5.761	0.432	280

TABLE 2.5.10 Series or Class 160 PVC pipe (SDR=26)

Nominal Size in.	Outside Diameter in.	Inside Diameter in.	Wall Thickness in.	Working Pressure psi
½	0.840	0.720	0.062*	160
¾	1.050	0.926	0.062*	160
1	1.315	1.189	0.063*	160
1¼	1.665	1.537	0.064	160
1½	1.900	1.754	0.073	160
2	2.375	2.193	0.091	160
2½	2.875	2.655	0.110	160
3	3.500	3.230	0.135	160
4	4.500	4.150	0.173	160
5	5.563	5.135	0.214	160
6	6.625	6.115	0.255	160
8	8.625	7.961	0.332	160
10	10.750	9.924	0.413	160
12	12.750	11.770	0.490	160

*These pipe sizes are not included in the SDR 26 classification.

TABLE 2.5.11 Plastic Pipe Applications

Application	Pipe Type	Remarks
1. Cold water service	PE Type 1 (Flexible) PVC Type 1 (Rigid)	Pipe should be pressure rated
2. Hot water	PB 21 PVC Pipe IV Grade 1	Pipe should be pressure rated
3. Pump lines	PE Type 1 (Flexible) PVC Type 1 (Rigid)	 Class 160 or 200 or schedule 40. When used with a submersible pump a torque arrestor is recommended.
4. Sewer lines	PE Type 1 (Flexible) PVC Type 1 Grade 1 (Rigid)	 Solid or perforated pipe available
5. Drain or vent pipe	ABS DWV pipe	
6. Underground drainage lines	PE Type 1 (Flexible and corrugated) PVC Type 1 Grade 1 (Rigid) ABS (Rigid)	Solid or perforated Solid or perforated Solid or perforated
7. Conduit	PVC Type 11 Grade 1 (Rigid) Schedule 40 (Rigid)	UL approved Not pressure rated
8. Chemical, petroleum products, etc.	Consult pipe manufacturer for recommendation	

A list of common applications and suggested pipe types is given in Table 2.5.11.

Pipe manufacturers and distributors usually supply a line of standard fittings. There are several systems in use.

1. Standard threaded fittings using the same size and thread system as is used with Schedule pipe. Where threads are to be cut on plastic pipe only Scheduled sizes should be used.

2. Insert fittings with clamps.

3. Socket fittings. With this system the pipe is slid into a socket and cemented in place.

4. Field welding. A technique is available whereby thermoplastic pipe may be welded using a hot inert gas to minimize surface oxidation.

5. Patent joints. With this system a bell end with a seal is formed on one end of the pipe, the connecting pipe end is usually beveled for easy entry into the bell end. The system allows for some flexibility at the joints and for rapid assembly at any temperature.

When plastic pipe is used at temperatures above 23°C a loss in fiber stress results. The percentages shown in Table 2.5.12 may be used as a guide for the reduction in working pressure with temperature. Some pipe manufacturers allow higher percentages than those shown in Table 2.5.12.

TABLE 2.5.12 Percent Reduction in Working Pressure for Temperatures above 23°C

Temperature °C	Percent of Stated Working Pressure at 23°C
23	100
25	95
30	83
35	72
40	60
45	47
50	36
55	24
60	13

2.5.3 FRICTION LOSS

2.5.3.1 Fluid Friction in Hydraulic Piping

When liquids flow in a conduit frictional resistance occurs. The energy loss due to friction can be estimated by the Darcy-Weisbach equation:

$$F = f \frac{L}{d} \frac{V^2}{2g} \qquad (10)$$

The friction factor (f) in equation (10) has been found to be a function of Reymolds number and pipe roughness. Moody (6) related these factors in a resistance diagram shown in Figure 2.5.2. Values for the roughness factor (ϵ), for various types of pipe material are listed in Table 2.5.13. To determine the relative roughness for use in Figure 2.5.2 the pipe diameter must be expressed in feet.

For water flowing in various kinds of pipe and fittings the friction head loss expressed in m/100m or ft/100 ft of pipe and the equivalent length of pipe for pipe fittings is given in Tables 2.5.14 to 2.5.22 inclusive.

2.5.4 PUMPS

Pumps are usually designated by class with a further designation of types within classes. Three classes of pumps in common use are centrifugal, rotary and reciprocating. These terms apply to the mechanics by which the fluid is moved and not to the service for which the pump is designed. There is a wide variety of pump types, many designed for a specific application.

Table 2.5.23 lists the classes together with a number of types used in the agricultural industry. A fourth miscellaneous class has been added to include systems of moving fluids, usually water, which do not fit into other classes.

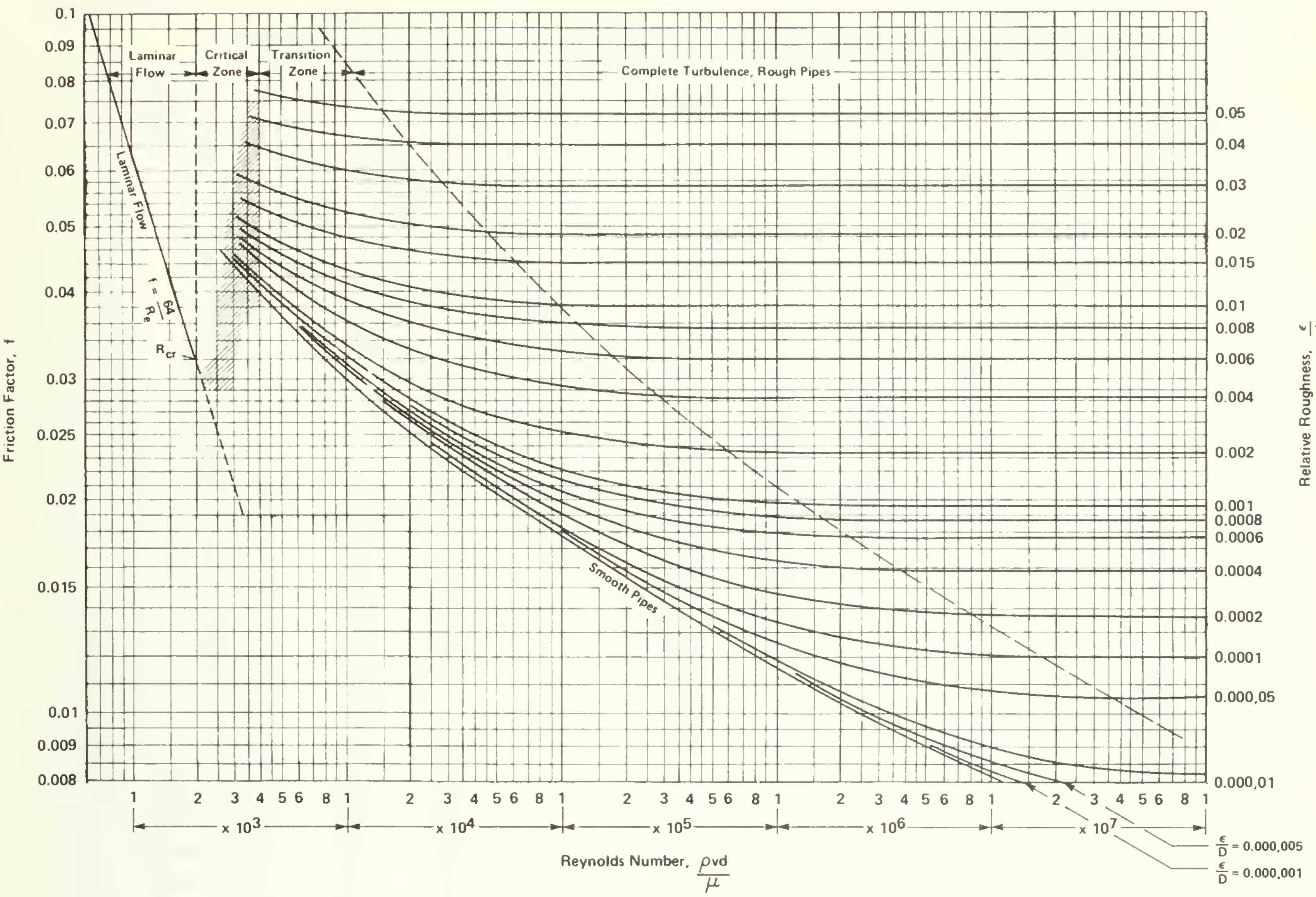


Figure 2.5.2 Friction factors for fluid flow in pipes.

2.5.4.1 **General Characteristics**

The general characteristics of the various classes of pumps can be divided into several groups, by:

flow characteristics;

construction materials; and

type of drive.

The flow characteristics are summarized in Table 2.5.24.

The Hydraulic Institute (5) uses the following designations for pump materials of construction:

Bronze Fitted - These pumps have a cast iron casing with bronze impeller, bronze casing ring and shaft sleeves (if used).

All Bronze - All parts of the pump are manufactured from bronze.

Specific Application Bronze - Same as designation 2 except that the type of bronze is specified for particular applications.

All Iron - Ferrous metal is used for all parts of the pump which come in contact with the liquid.

Stainless Steel Fitted - Casing may be made from ferrous metal or bronze while the impeller, casing ring and shaft sleeves, if used, are stainless steel.

Stainless Steel - All pump parts contacting the liquid must be made from stainless steel.

Two types of pump drives are common in the agricultural industry.

Direct Drive - Where the power unit is coupled directly to the pump.

Belt Drive - These are usually used where a speed change is required. Both flat and V-belt drives are used, however, the V-belt drive is most common.

TABLE 2.5.13 Roughness Indices for Various Types of Pipe

Pipe material	Roughness factor ϵ1
Riveted pipe	3×10^{-3} - 3×10^{-2}
Concrete	1×10^{-3} - 1×10^{-2}
Wood stave	6×10^{-4} - 3×10^{-3}
Cast iron	8.5×10^{-4}
Galvanized iron	5×10^{-4}
Asphalted cast iron	4×10^{-4}
Commercial steel	1.5×10^{-4}
Drawn and plastic tubing	5×10^{-6}

TABLE 2.5.14 Friction Head Loss of Water in Meters* of Water/100 Meters *or* Feet of Water/100 ft of Scheduled 40 Steel Pipe (Based on C = 100 in Hazen & Williams Formula)

Flow Rate		Nominal Pipe Size, (in.)										
L/s	gal/min (US)	½	¾	1	1¼	1½	2	2½	3	4	5	6
0.1	1.58	4.9	1.2									
0.2	3.17	17.7	4.5	1.4								
0.3	4.76	37.5	9.5	2.9	0.8							
0.4	6.34	63.9	16.2	5.0	1.3	0.6						
0.5	7.93	96.5	24.5	7.6	2.0	0.9						
0.6	9.51	135.3	34.4	10.6	2.8	1.3						
0.7	11.1		45.8	14.1	3.7	1.7	0.5					
0.8	12.7		58.6	18.1	4.7	2.2	0.7					
0.9	14.3		72.9	22.5	5.9	2.8	0.8					
1.0	15.8		88.6	27.3	7.2	3.4	1.0					
1.5	23.8			57.9	15.2	7.2	2.1	0.9				
2.0	31.7			98.7	25.9	12.2	3.6	1.5	0.5			
2.5	39.6			149	39.2	18.5	5.5	2.3	0.8			
3.0	47.6				55.0	25.9	7.7	3.2	1.1			
3.5	55.5				73.1	34.5	10.2	4.3	1.5			
4.0	63.4				93.7	44.2	13.1	5.5	1.9	0.5		
4.5	71.3				116	55.0	16.3	6.8	2.4	0.6		
5.0	79.3				142	66.8	19.8	8.3	2.9	0.8		
5.5	87.2				169	79.7	23.6	9.9	3.4	0.9		
6.0	95.1					93.7	27.7	11.7	4.0	1.1		
6.5	103					109	32.2	13.5	4.7	1.2		
7.0	111					125	36.9	15.5	5.4	1.4		
7.5	119					142	41.9	17.6	6.1	1.6	0.5	
8.0	127					160	47.2	19.9	6.9	1.8	0.6	
8.5	135					178	52.9	22.2	7.7	2.1	0.7	
9.0	143						58.8	24.7	8.6	2.3	0.8	
9.5	151						64.9	27.3	9.5	2.5	0.9	
10	158						71.2	30.1	10.4	2.8	1.0	
12	190						100	42.1	14.6	3.9	1.3	0.5
14	222						133	56.0	19.5	5.2	1.7	0.7
16	254						170	71.8	24.9	6.6	2.2	0.9
18	285							89.3	31.0	8.2	2.7	1.1
20	317							108	37.7	10.0	3.3	1.4
25	396							164	56.9	15.2	5.0	2.1
30	476								79.8	21.2	7.1	2.9
35	555								106	28.3	9.4	3.8
40	634								136	36.2	12.0	4.9
45	713								169	45.0	15.0	6.1
50	793									54.7	18.2	7.4
55	872									65.3	21.7	8.9
60	951									76.7	25.5	10.4
65	1030									88.9	29.6	12.1
70	1110									102	33.9	13.9
75	1189									116	38.6	15.8
80	1268									131	43.4	17.8
85	1347									146	48.6	19.9
90	1427									162	54.0	22.1
95	1506									180	59.7	24.4
100	1585										65.7	26.8

*Head loss in m x 9.806 = Head loss in kPa

TABLE 2.5.15 Friction Head Loss of Water in Meters* of Water/100 Meters *or* Feet of Water/100 Feet of Type L Copper Tubing (Based on C = 130 in Hazen & Williams Formula)

Flow Rate		Nominal Pipe Size, (in.)											
L/s	gal/min (US)	½	⅝	¾	1	1¼	1½	2	2½	3	4	5	6
0.1	1.58	5.7	2.2	1.0									
0.2	3.17	20.7	7.8	3.5	0.9								
0.3	4.76	43.9	16.5	7.4	2.0	0.7							
0.4	6.34	74.8	28.2	12.6	3.4	1.2	0.5						
0.5	7.93	113	42.6	19.1	5.2	1.9	0.8						
0.6	9.51	158	59.7	26.8	7.3	2.6	1.1						
0.7	11.1		79.4	35.6	9.7	3.5	1.5						
0.8	12.7		102	45.6	12.4	4.5	1.9						
0.9	14.3		126	56.8	15.5	5.6	2.4	0.6					
1.0	15.8		154	69.0	18.8	6.7	2.9	0.7					
1.5	23.8			146	39.9	14.3	6.1	1.6	0.5				
2.0	31.7				67.9	24.4	10.5	2.7	0.9				
2.5	39.6				103	36.9	15.8	4.1	1.4	0.6			
3.0	47.6				144	51.7	22.2	5.8	2.0	0.8			
3.5	55.5					68.7	29.5	7.7	2.7	1.1			
4.0	63.4					88.0	37.8	9.8	3.4	1.4			
4.5	71.3					109	47.0	12.2	4.2	1.8			
5.0	79.3					133	57.1	14.8	5.2	2.2	0.5		
5.5	87.2					159	68.1	17.7	6.2	2.6	0.6		
6.0	95.1						80.0	20.8	7.2	3.0	0.8		
6.5	103						92.8	24.1	8.4	3.5	0.9		
7.0	111						106	27.6	9.6	4.0	1.0		
7.5	119						121	31.4	10.9	4.6	1.2		
8.0	127						136	35.4	12.3	5.2	1.3		
8.5	135						152	39.6	13.8	5.8	1.5		
9.0	143						169	44.0	15.3	6.4	1.6	0.5	
9.5	151							48.7	16.9	7.1	1.8	0.6	
10	158							53.5	18.6	7.8	2.0	0.8	
12	190							75.0	26.1	11.0	2.8	0.9	
14	222							100	34.7	14.6	3.7	1.2	0.5
16	254							128	44.5	18.7	4.7	1.6	0.7
18	285							159	55.3	23.3	5.9	2.0	0.8
20	317								67.3	28.3	7.1	2.4	1.0
25	396								102	42.7	10.8	3.7	1.5
30	476								142	59.9	15.2	5.1	2.1
35	555									79.7	20.2	6.8	2.8
40	634									102	25.8	8.8	3.6
45	713									127	32.1	10.9	4.5
50	793									154	39.0	13.2	5.5
55	872										46.6	15.8	6.5
60	951										54.6	18.6	7.7
65	1030										63.5	21.5	8.9
70	1110										72.8	24.7	10.2
75	1189										82.7	28.1	11.6
80	1268										93.2	31.6	13.1
85	1347										104	35.4	14.6
90	1427										116	39.4	16.2
95	1507										128	43.5	18.0
100	1585										141	47.8	19.8

*Head loss in m x 9.806 = Head loss in kPa

TABLE 2.5.16 Friction Head Loss of Water in Meters* of Water/100 Meters *or* Feet of Water/100 Feet of Series 75 Polyethylene Pipe (Based on C = 140 in Hazen & Williams Formula)

Flow Rate		Nominal Pipe Size, (in.)								
L/s	gal/min (US)	½	¾	1	1¼	1½	2	2½	3	4
0.1	1.58	2.6	0.7							
0.2	3.17	9.5	2.4	0.7						
0.3	4.76	20.1	5.1	1.6						
0.4	5.34	34.2	8.7	2.7	0.7					
0.5	7.93	51.8	13.2	4.1	1.1	0.5				
0.6	9.15	72.6	18.4	5.7	1.5	0.7				
0.7	11.1	96.5	24.5	7.6	2.0	0.9				
0.8	12.7	124	31.4	9.7	2.5	1.2				
0.9	14.3	154	39.1	12.1	3.2	1.5				
1.0	15.8		47.5	14.7	3.8	1.8	0.5			
1.5	23.8		101	31.0	8.2	3.8	1.1			
2.0	31.7		171	52.9	13.9	6.6	1.9	0.8		
2.5	39.6			80.0	21.0	9.9	2.9	1.3		
3.0	47.6			112	13.9	29.5	4.1	1.8	0.6	
3.5	55.5			149	39.2	18.5	5.5	2.4	0.8	
4.0	63.4				50.2	23.7	7.0	3.1	1.0	
4.5	71.3				62.5	29.5	8.7	3.8	1.3	
5.0	79.3				75.9	35.8	10.6	4.6	1.6	
5.5	87.2				90.6	42.7	12.7	5.5	1.9	
6.0	95.1				106	50.2	14.9	6.5	2.2	0.6
6.5	103				123	58.2	17.2	7.5	2.6	0.7
7.0	111				142	66.8	19.8	8.6	2.9	0.8
7.5	119				161	75.9	22.5	9.8	3.3	0.9
8.0	127					85.6	25.3	11.0	3.7	1.0
8.5	135					95.7	28.3	12.4	4.2	1.1
9.0	143					106	31.5	13.8	4.6	1.2
9.5	151					118	34.8	15.2	5.2	1.4
10	158					129	38.3	16.7	5.7	1.5
12	190						53.7	23.5	8.0	2.1
14	222						71.4	31.2	10.6	2.8
16	254						91.6	40.0	13.5	3.6
18	285						114	49.7	16.9	4.5
20	317						138	60.4	20.5	5.4
25	396							91.3	31.0	8.2
30	476						128	43.4	11.5	
35	555						170	57.8	15.3	
40	634								74.0	19.6
45	713								92.0	24.4
50	793								112	30.0
55	872								133	35.3
60	951									41.6
65	1030									48.2
70	1110									55.3
75	1189									62.9
80	1268									70.8
85	1347									74.2
90	1427									88.1
95	1506									97.4
100	1585									107

*Head loss in m x 9.806 = Head loss in kPa

TABLE 2.5.17 Friction Head Loss of Water in Meters of Water/100 Meters *or* Feet of Water/100 Feet of Portable Aluminum Irrigation Pipe Couplers Every 20 Feet (Based on C = 116 in Hazen & Williams Formula)

Flow Rate		Nominal Pipe Size, (in.)							
L/s	gal/min (US)	2	3	4	5	6	7	8	10
0.7	11.1	0.6							
0.8	12.7	0.7							
0.9	14.3	0.9							
1.0	15.8	1.1							
1.5	23.8	2.4							
2.0	31.7	4.0	0.5						
2.5	39.6	6.1	0.8						
3.0	47.6	8.6	1.1						
3.5	55.5	11.4	1.5						
4.0	63.4	14.6	1.9						
4.5	71.3	18.2	2.3	0.5					
5.0	79.3	22.1	2.8	0.7					
5.5	87.2	26.3	3.4	0.8					
6.0	95.1	31.0	4.0	0.9					
6.5	103	35.9	4.6	1.1					
7.0	111	41.2	5.3	1.3					
7.5	119	46.8	6.0	1.4					
8.0	127	52.8	6.8	1.6	0.5				
8.5	135	59.0	7.6	1.8	0.6				
9.0	143	65.6	8.4	2.0	0.7				
9.5	151	72.5	9.3	2.2	0.7				
10	158	79.7	10.3	2.4	0.8				
12	190	112	14.4	3.4	1.1				
14	222	149	19.1	4.5	1.5	0.6			
16	254		24.5	5.8	1.9	0.8			
18	285		30.5	7.2	2.4	1.0			
20	317		37.0	8.8	2.9	1.2	0.6		
25	396		56.0	13.3	4.4	1.8	0.8		
30	476		78.4	18.6	6.2	2.5	1.2	0.6	
35	555		104	24.8	8.2	3.4	1.6	0.8	
40	634		134	31.7	10.6	4.3	2.0	1.1	
45	713		166	39.4	13.1	5.4	2.5	1.3	
50	793			48.0	16.0	6.6	3.1	1.6	0.5
55	872			57.1	19.0	7.8	3.7	1.9	0.6
60	951			67.2	22.4	9.2	4.3	2.2	0.8
65	1030			77.9	26.0	10.7	5.0	2.6	0.9
70	1110			89.4	29.8	12.2	5.7	3.0	1.0
75	1189			101	33.8	13.9	6.5	3.4	1.1
80	1268			114	38.1	15.7	7.3	3.8	1.3
85	1347			128	42.6	17.5	8.2	4.3	1.4
90	1427			142	47.4	19.5	9.1	4.7	1.6
95	1506			157	52.4	21.6	10.1	5.2	1.8
100	1585			173	57.6	23.7	11.1	5.8	2.0
110	1744				68.8	28.3	13.2	6.9	2.3
120	1902				80.8	33.2	15.6	8.1	2.7
130	2061				93.7	38.5	18.1	9.4	3.2
140	2219				107	44.2	20.7	10.8	3.6
150	2378				122	50.2	23.5	12.2	4.1

TABLE 2.5.18 Friction Head Loss of Water in Meters of Water/100 Meters *or* Feet of Water/100 Feet of Smooth Bore Hose (Based on C = 140 in Hazen & Williams Formula)

Flow Rate		Nominal Size, (inside diameter, in.)										
L/s	gal/min (US)	⅝	¾	1	1¼	1½	2	2½	3	4	5	6
0.1	1.58	2.6	1.1									
0.2	3.17	9.3	3.8	0.9								
0.3	4.76	19.6	8.1	2.0	0.7							
0.4	6.34	33.4	13.8	3.4	1.1							
0.5	7.93	50.6	20.8	5.1	1.7	0.7						
0.6	9.15	70.9	29.2	7.2	2.4	1.0						
0.7	11.1	94.3	38.8	9.6	3.2	1.3						
0.8	12.7	121	49.7	12.2	4.1	1.7						
0.9	14.3	150	61.8	15.2	5.1	2.1	0.5					
1.0	15.8		75.1	18.5	6.2	2.6	0.6					
1.5	23.8		159	39.2	13.2	5.4	1.3					
2.0	31.7			66.8	22.5	9.3	2.3	0.8				
2.5	39.6			101	34.0	14.0	3.4	1.2				
3.0	47.6			142	47.7	19.6	4.8	1.6	0.7			
3.5	55.5				63.5	26.1	6.4	2.2	0.9			
4.0	63.4				81.3	33.5	8.2	2.8	1.1			
4.5	71.3				101	41.6	10.2	3.5	1.4			
5.0	79.3				123	50.6	12.5	4.2	1.7			
5.5	87.2				147	60.3	14.9	5.0	2.1	0.5		
6.0	95.1				172	70.9	17.5	5.9	2.4	0.6		
6.5	103					82.2	20.2	6.8	2.8	0.7		
7.0	111					94.3	23.2	7.8	3.2	0.8		
7.5	119					107	26.4	8.9	3.7	0.9		
8.0	127					121	29.7	10.0	4.1	1.0		
8.5	135					135	33.3	11.2	4.6	1.1		
9.0	143					150	37.0	12.5	5.1	1.3		
9.5	151					166	40.9	13.8	5.7	1.4		
10	158						45.0	15.2	6.2	1.5	0.5	
12	190						63.0	21.3	8.7	2.1	0.7	
14	222						83.9	28.3	11.6	2.9	1.0	
16	254						107	36.2	14.9	3.7	1.2	0.5
18	285						134	45.0	18.5	4.6	1.5	0.6
20	317						162	54.8	22.5	5.5	1.9	0.8
25	396							82.8	34.1	8.3	2.8	1.2
30	476							116	47.7	11.8	4.0	1.6
35	555							154	63.5	15.6	5.3	2.2
40	634								81.3	20.0	6.8	2.8
45	713								101	24.9	8.4	3.5
50	793								123	30.3	10.2	4.2
55	872								147	36.1	12.2	5.0
60	951								172	42.4	14.3	5.9
65	1030									49.2	16.6	6.8
70	1110									56.5	19.0	7.8
75	1189									64.2	21.7	8.9
80	1268									72.3	24.4	10.0
85	1347									80.9	27.3	11.2
90	1427									89.9	30.3	12.5
95	1506									99.4	33.5	13.8
100	1585									109	36.9	15.2
110	1744									130	44.0	18.1
120	1902									153	51.7	21.3
130	2061									178	59.9	24.7
140	2219										68.7	28.3
150	2378										78.1	32.1

TABLE 2.5.19 Friction Head Loss Due to Pipe Fittings. Equivalent Length of Pipe - Meter

Nominal Size in.	Type of Fitting									
	90° El	45° El	T Line Flow	T Branch Flow	Gate Valve*	Globe Valve*	Check Valve*	Faucet*	Foot Valve*	Strainer
¼	0.70	0.23	0.24	0.73	0.10	6.40	2.19			
⅜	0.94	0.16	0.37	1.07	0.14	6.71	2.22			
½	1.10	0.22	0.52	1.28	0.17	6.71	2.44	4.88	1.22	3.05
¾	1.34	0.28	0.73	1.61	0.20	7.31	2.68	6.40	1.52	3.66
1	1.58	0.40	0.97	2.01	0.26	8.84	3.35		1.83	4.27
1¼	2.01	0.52	1.40	2.65	0.33	11.3	3.96		2.13	4.88
1½	2.25	0.64	1.71	3.02	0.37	12.8	4.57		2.44	5.49
2	2.59	0.83	2.34	3.66	0.46	16.5	5.79		2.74	6.10
2½	2.83	0.97	2.83	3.96	0.52	18.9	6.70		3.05	6.71
3	3.35	1.22	3.66	5.18	0.58	24.1	8.23		3.66	7.62
4	3.96	1.68	5.8	6.40	0.76	33.5	11.6			

*Fully open condition

TABLE 2.5.20 Friction Head Loss Due to Pipe Fittings. Equivalent Length of Pipe - *Feet*

Nominal Size in.	Type of Fitting									
	90° El	45° El	T Line Flow	T Branch Flow	Gate Valve*	Globe Valve*	Check Valve*	Faucet*	Foot Valve*	Strainer
¼	2.3	0.34	0.79	2.4	0.32	21	7.2			
⅜	3.1	0.52	1.2	3.5	0.45	22	7.3			
½	3.6	0.71	1.6	4.2	0.56	22	8.0	16	4	10
¾	4.4	0.92	2.4	5.3	0.67	24	8.8	21	5	12
1	5.2	1.3	3.2	6.6	0.84	29	11		6	14
1¼	6.6	1.7	4.6	8.7	1.1	37	13		7	16
1½	7.4	2.1	5.6	9.9	1.2	42	15		8	18
2	8.5	2.7	7.7	12	1.5	54	19		9	20
2½	9.3	3.2	9.3	13	1.2	62	22		10	22
3	11	4.0	12	17	1.9	79	27		12	25
4	13	5.5	17	21	2.5	110	38			

*Fully open condition

TABLE 2.5.21 Friction Head Loss due to Insert Fittings in Plastic Pipe. Equivalent Length of Pipe - Meters

Nominal Size in.	Type of Fittings	
	Insert Coupling Pipe Length, m	Insert Adapter Pipe Length, m
½	0.15	0.30
¾	0.23	0.46
1	0.30	0.61
1¼	0.38	0.84
1½	0.46	1.07
2	0.61	1.37
3	0.91	1.98
4	1.22	2.74
6	1.90	4.27

TABLE 2.5.22 Friction Head Loss Due to Insert Fittings in Plastic Pipe. Equivalent Length of Pipe - Feet

Nominal Size in.	Type of Fitting	
	Insert Coupling Pipe Length, ft	Insert Adapter Pipe Length, ft
½	0.5	1
¾	0.75	1.5
1	1.0	2.0
1¼	1.25	2.75
1½	1.5	3.5
2	2.0	4.5
3	3.0	6.5
4	4.0	9.0
6	6.25	14.0

TABLE 2.5.23 Pump Classes and Types

Type		Classes	
Centrifugal	Volute	Open impeller Semi-enclosed impeller Enclosed impeller	Single stage Multi-stage
	Diffuser		
	Axial flow (propeller)		
	Mixed flow		
	Turbine		
Rotary	Cam and piston		
	Screw		
	Vane		
	Gear		
	Lobe		
	Roller flexible tube		
Reciprocating	Piston		
	Plunger		
	Diaphragm		
Miscellaneous	Air lift		
	Hydraulic ram		
	Jet		
	Submersible		

TABLE 2.5.24 Flow Characteristics of Pumps

	Centrifugal	Rotary	Reciprocating
Discharge flow	Steady	Steady	Pulsating
Usual max. suction lift, m	4.6	6.7	6.7
Liquids handled	- Low viscosity - Clean - Dirty abrasive liquids with some solids[1] - Slurries with low solid content (diluted manure)	Viscous nonabrasive Agricultural chemicals.	- Low to med. viscosity - Clean - Dirty liquids with high solid content - Slurries (manure)
Discharge pressure range	Low to high	Medium	Low to highest produced
Capacity range	Smallest to largest produced	Small to medium	Usually small
How an increase in head affects			
- Capacity	Decrease	None	None to small
- Power	Usually increases but depends on the pump characteristics.	Increase	Increase
Priming	Usually requires priming[2]	Not normally required	Not normally required

[1]Impeller wear may be excessive when pumping abrasive liquids with closed impeller pumps.

[2]Small self priming centrifugal pumps are available.

2.5.4.2 Centrifugal Pumps

Volute Type Pumps - With this type of pump the impeller discharges into a progressively expanding spiral case, so proportioned that the velocity of the liquid is gradually reduced. Thus, most of the kinetic energy is converted to static pressure. Most volute pumps used in the agricultural industry have a single axial inlet and a single radial discharge. Figure 2.5.3 illustrates the volute or more commonly called centrifugal pump.

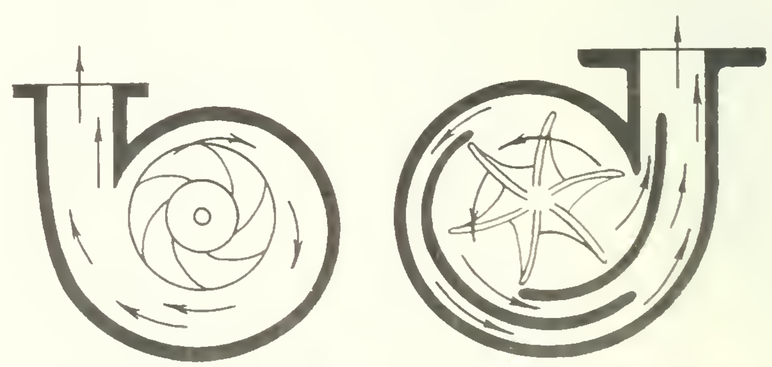


Figure 2.5.3 Volute or centrifugal pumps.

Diffuser-type Pump - This pump is similar to the volute pump but is equipped with stationary guide vanes surrounding the impeller. Their purpose is to assist in changing the direction of flow of liquids into the expanding pump case and improve efficiency. This principle is used in multi-stage pumps to redirect the flow from one stage to the next.

Mixed and Axial Flow Pumps, Figure 2.5.4 - These pumps develop their head by a combination of centrifugal force

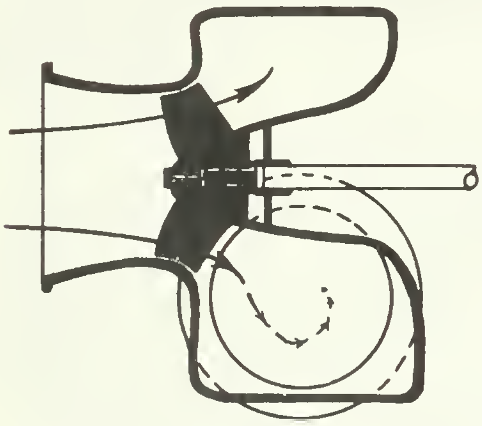


Figure 2.5.4 Mixed flow pump.

and by the lift the rotor vanes have on the liquid. Mixed flow pumps have an axial inlet and a radial discharge similar to the volute pump. Axial flow pumps have an axial inlet and an axial discharge.

Vertical shaft single or multi-stage radial or mixed flow pumps with the pumping element suspended from the discharge pipe have been referred to as deep well turbine, borehole or vertical turbine pumps. These pumps do not resemble the regenerative pump and should not be confused with it.

Turbine or Regenerative Pump, Figure 2.5.5 - These are small pumps having a multiblade impeller. The blades are cut in the rim of the impeller and rotate in an annular race chamber. Liquid enters the chamber in a tangential manner to the impeller and after making almost a complete revolution is stripped from the impeller and guided into the pump discharge opening.

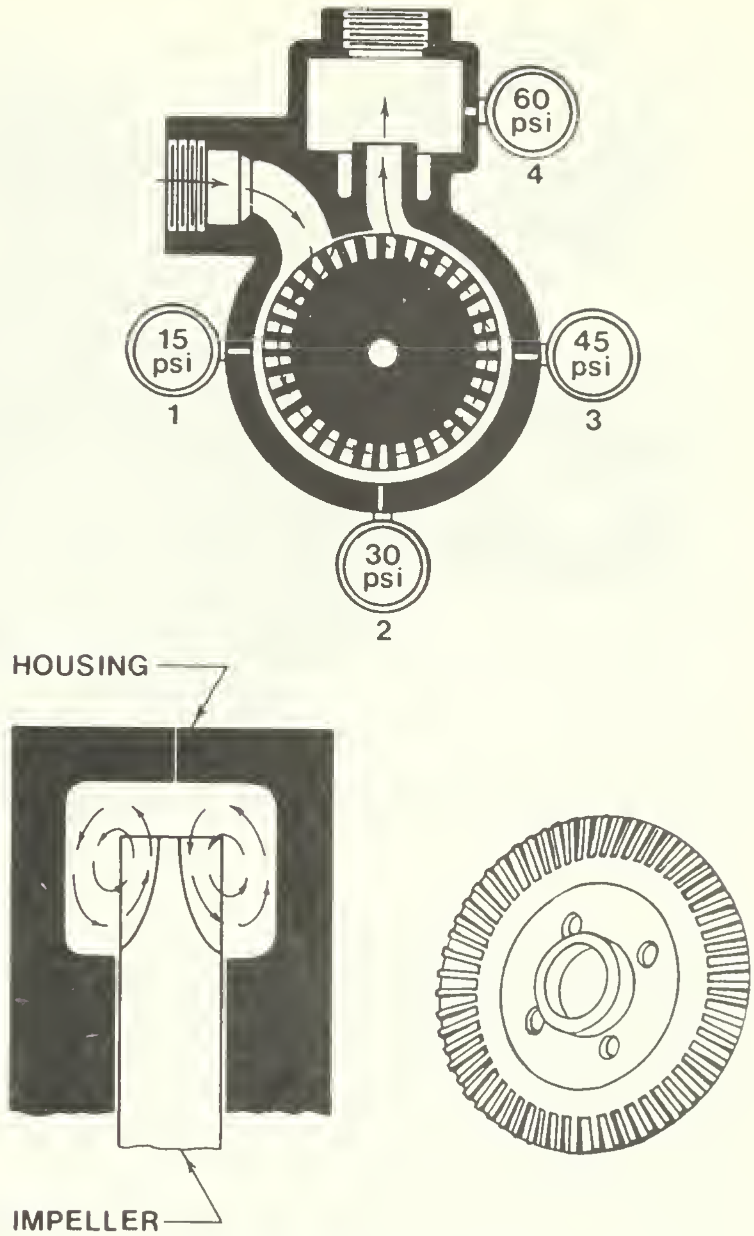


Figure 2.5.5 Turbine or regenerative pump.

2.5.4.3 **Rotary Pumps**

Rotary pumps are usually positive displacement units consisting of a fixed casing containing gears, screws, lobes, vanes or rollers which operate with a minimum of clearance. In operation, rotary pumps trap the liquid at the inlet and carry it around to the discharge nozzle where it is released. However, unlike the piston pump, the discharge is a smooth flow. While rotary pumps are usually associated with viscous liquids, their application in agriculture is by no means confined to this service. They will handle almost any liquid provided it is free from abrasives and solids.

Cam and Piston or Rotary Plunger Pumps - Cam and piston or rotary plunger pumps consist of an eccentric which activates several pistons. Figure 2.5.6 shows a multiplunger pump where each plunger has a set of inlet and discharge valves. This pump will operate at discharge pressures up to 600 psi.

Screw Pumps - Screw pumps may contain one, two or three screw-like rotors so arranged that the rotors turn in an annular space. The space between the rotors and the

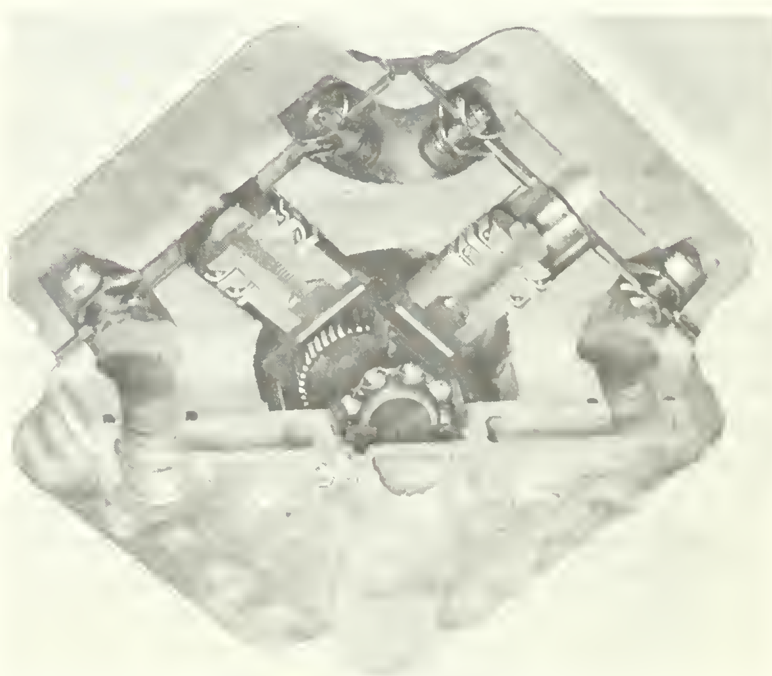


Figure 2.5.6 Multiplunger cam and piston pump.
Courtesy: Seeger-Wanner Corp.

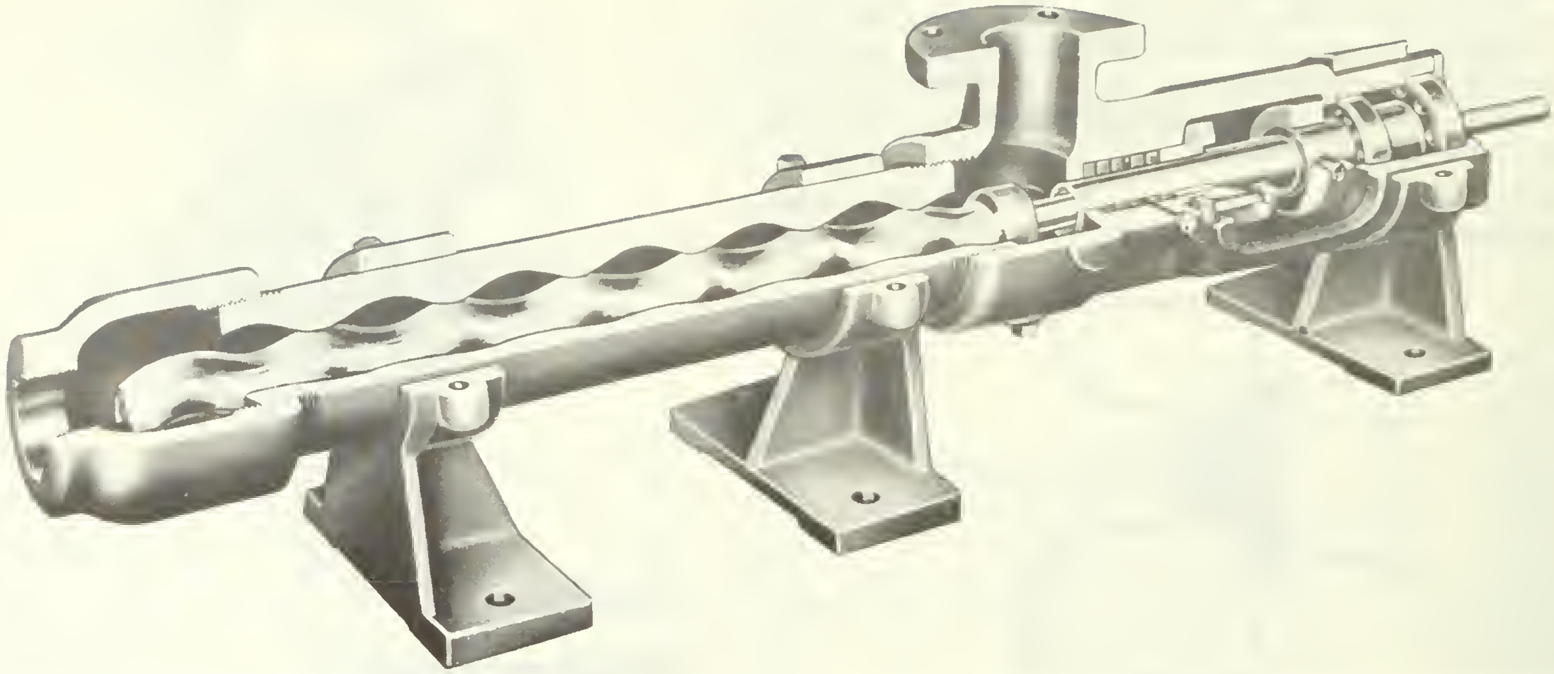


Figure 2.5.7 Modified helical or screw pump (Moyno pump). Courtesy: Robbins and Myers, Brantford, Ont.

guides fills with liquid which is displaced axially as the rotors mesh. The "Moyno Pump" shown in Figure 2.5.7, is a type of screw pump which has a flexible rubber stator and a single metal spiral rotor. The liquid in these pumps is displaced axially by the action of the helical formed rotor. Pumps of this type have been used to spread liquid manure using large volume irrigation spray nozzles.

Vane Pumps - Vane pumps consist of a rotor mounted inside a casing which is machined eccentrically in relation to the rotor axis. The rotor is fitted with a series of vanes, blades or rollers which follow the bore of the casing. Several arrangements are used.

1. Sliding vane pumps (Figure 2.5.8) consist of a series of vanes which follow the casing bore. These vanes are usually flat with parallel sides. Pumps of this type are used in handling lubricating and hydraulic oil.

2. An arrangement where the vanes are equipped with rubber or nylon rollers is used for pumping agricultural chemicals such as insecticide and herbicide sprays. (Figure 2.5.9)

3. The "Flex Rotor" pump (Figure 2.5.10) has flexible rubber vanes which rotate inside an eccentric case. It is used to handle liquids at low pressures and is self-priming at lifts up to 3 m.

Gear Pumps - Gear pumps consist of two or more gears enclosed in a closely fitted casing and so arranged that as the gears unmesh liquid fills the resulting space, it is then carried around in the tooth space to the opposite side where it is displaced when the teeth again mesh. Two arrangements of gear pumps are:

External gear pumps (Figure 2.5.11 a) have all gear teeth cut externally. They may have spur or helical cut gears; the helical cut gears reduce pumps noise.

Internal gear pumps (Figure 2.5.11 b) have one rotor with external cut teeth in mesh with an internal cut gear. A crescent shaped filler piece between the gears prevents liquid from bypassing back to the inlet.

Lobular Pumps - Lobular pumps (Figure 2.5.12) usually consist of two rotors each having two or three lobes. The rotors are driven by a system of timing gears so that some clearance is maintained between lobes. These pumps are used to handle air or other vapors which supply little or no lubrication for the internal pump parts.

Flexible Tube Pump - The flexible tube pump (sometimes called 'peristaltic' pump) is a simple device which isolates the liquid from the pump parts. One type, shown in Figure 2.5.13, has a loop of tubing which is compressed when rollers which are mounted on a rotor turn, thus forcing the trapped liquid towards the discharge.

2.5.4.4. **Reciprocating Pumps**

Piston and Plunger Pumps - Piston and plunger pumps are positive displacement pumps, a given volume being displaced with each stroke of the pump. Plunger pumps are differentiated from piston pumps by the location of the discharge valves. Plunger pumps, commonly used for deep well service, have the discharge valve incorporated in the plunger. Piston pumps have the suction and discharge valves built into the pump casing. Piston pumps have been used for domestic water systems and for high pressure sprayers (Figure 2.5.14).

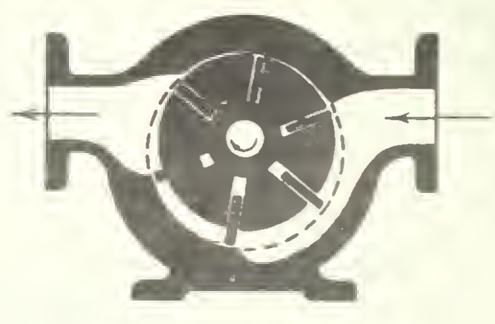


Figure 2.5.8 Sliding vane pump.

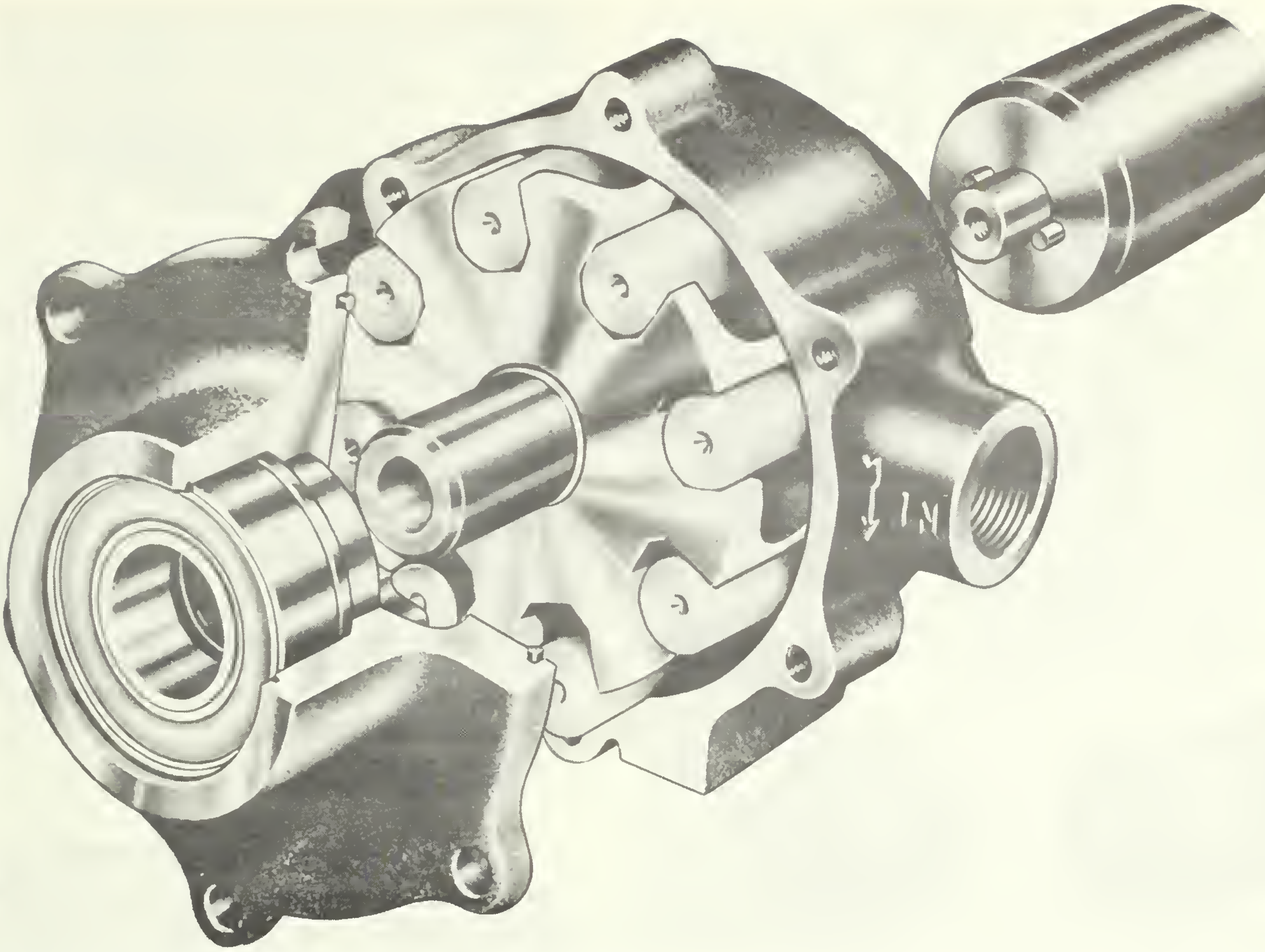


Figure 2.5.9 Nylon roller pump. Courtesy: Hypro Inc.

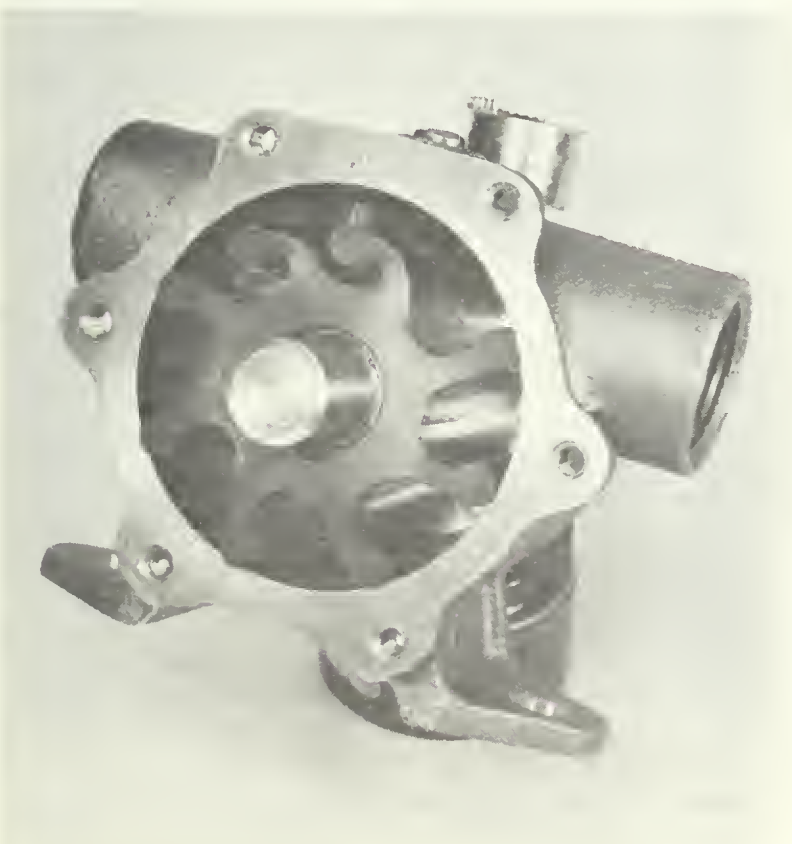


Figure 2.5.10 Flex rotor pump. Courtesy: Jabsco Products

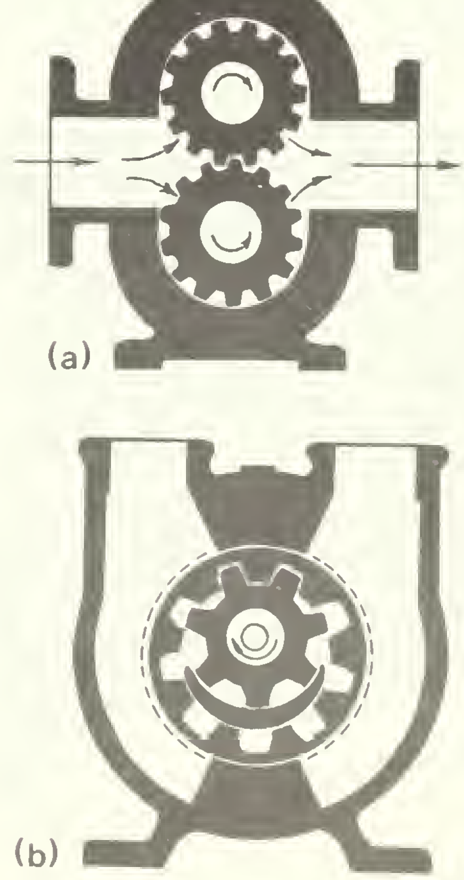


Figure 2.5.11 Gear pumps.

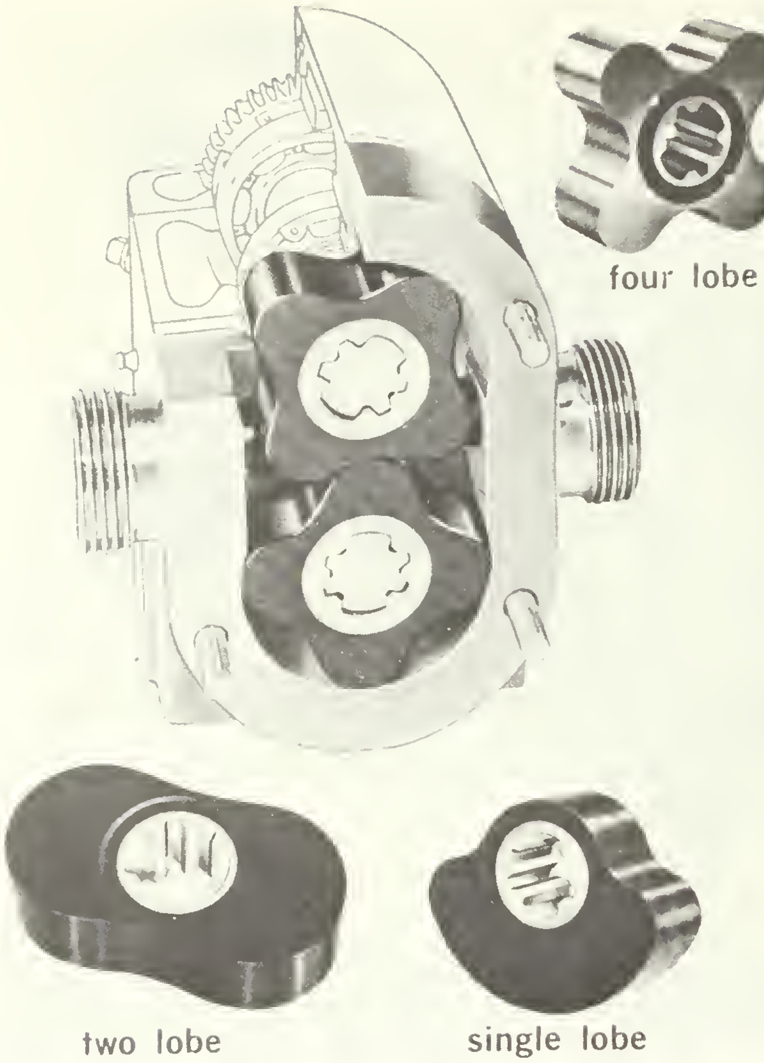


Figure 2.5.12 Lobe-type pump. Courtesy: Ladish Co.

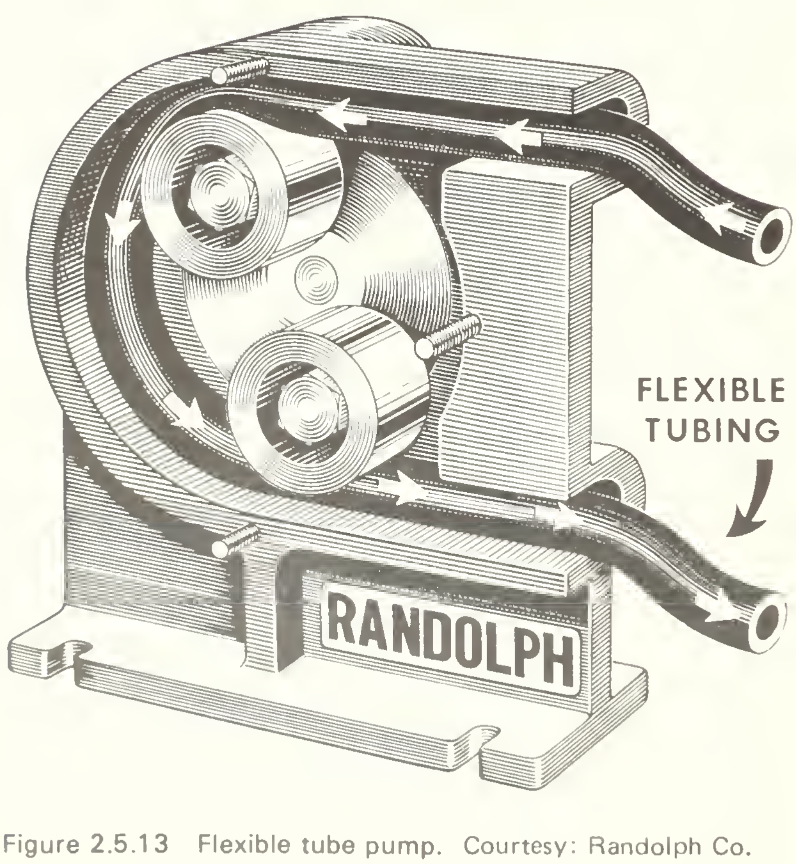


Figure 2.5.13 Flexible tube pump. Courtesy: Randolph Co.

Diaphragm Pumps - Diaphragm pumps (Figure 2.5.15) are designed to handle pulps, sewage, sludge, and corrosive materials, as well as clear liquids. A circular rubber diaphragm replaces the piston and cylinder used in other reciprocating pumps; the outer edge of the diaphragm is bolted to a flange on the pump casing. Movement of the plunger is permitted by the flexibility of the diaphragm.

2.5.4.5 **Miscellaneous Pumps.**

Air Lift Pumps - An air lift pump (Figure 2.5.16) consists of an air compressor and an air line to carry air to a diffuser located near the lower end of the discharge pipe. In operation, compressed air is injected directly into the water inside the discharge pipe at a point well below the water level. Injection of air results in the formation of a mixture of air and water which is less dense than the column of water outside the discharge pipe. Consequently, the mixture rises in the discharge pipe.

Two factors important in planning an air lift pumping system are submergence and the size of the discharge pipe. Submergence is the depth the air inlet or diffuser is located below the pumping water level. Percent submergence is expressed as:

$$S = \frac{100\ S_w}{S + L} \qquad (11)$$

where S_w is the working submergence and L is the lift.

For satisfactory operation the minimum submergence is given in Table 2.5.25. The cross section of the discharge pipe is related to the pump capacity. If the pipe is too large air will slip by, and if too small, excessive friction and inefficient expansion of air bubbles results. Suggested pipe sizes are given in Table 2.5.26. Air should be injected into the discharge pipe through a diffuser or foot piece having a large number of small holes, say 6 mm in diameter. Slip increases rapidly with an increase in bubble size.

The minimum pressure required is that necessary to overcome submergence;

$$P = S_w \times 9.806 \qquad P = S_w \times 0.4335 \qquad (12)$$

where P = pressure (kPa) where P = pressure (psi)
Sw = submergence (m) Sw = submergency (ft)

Increased pressures will be required for starting since the static water level will probably be above the pumping level. Table 2.5.27 lists air requirements and working pressures.

Air lift pumps are useful for emergency use or to handle water containing sand or mud, however, they are inefficient and must discharge into an open tank.

Jet Pumps - Jet pumps are a combination of a conventional pump, usually a centrifugal or turbine type and an ejector, or "jet". The jet must be located within the suction lift distance from the draw-down or pumping water level which is usually not over 6 m. Both shallow well and deep well jets are used. Shallow well jet pumps have the jet either inside or attached to the pump casing. Deep well jets are placed in the well below the pumping water level. The advantage of the deep well jet system is that the pump may be located above ground and if desirable off-set from the well. Jet pumps are less expensive than deep well turbines or submersible pumps, but are less efficient.

Referring to Figure 2.5.17, the jet pump functions by recirculating a portion of the water discharged by the

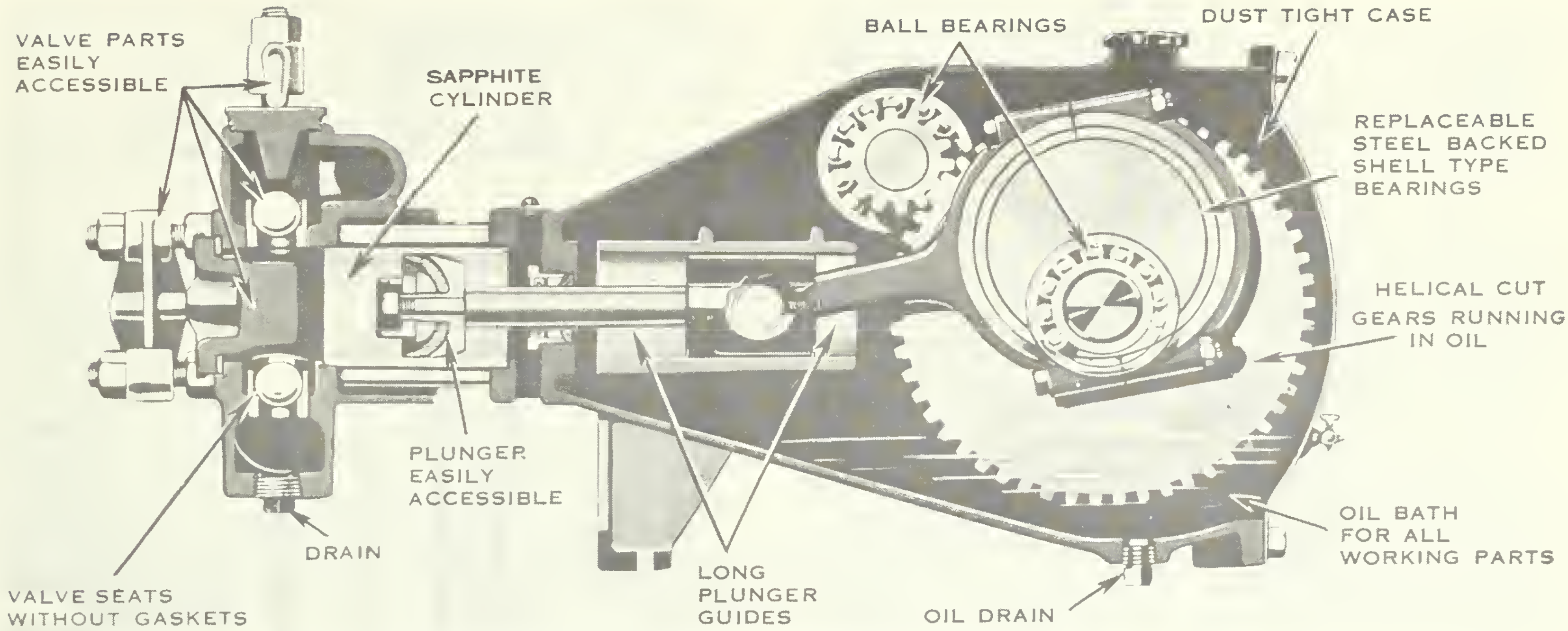


Figure 2.5.14 High-pressure piston pump. Courtesy: John Bean Division, F.M.C. Corp.

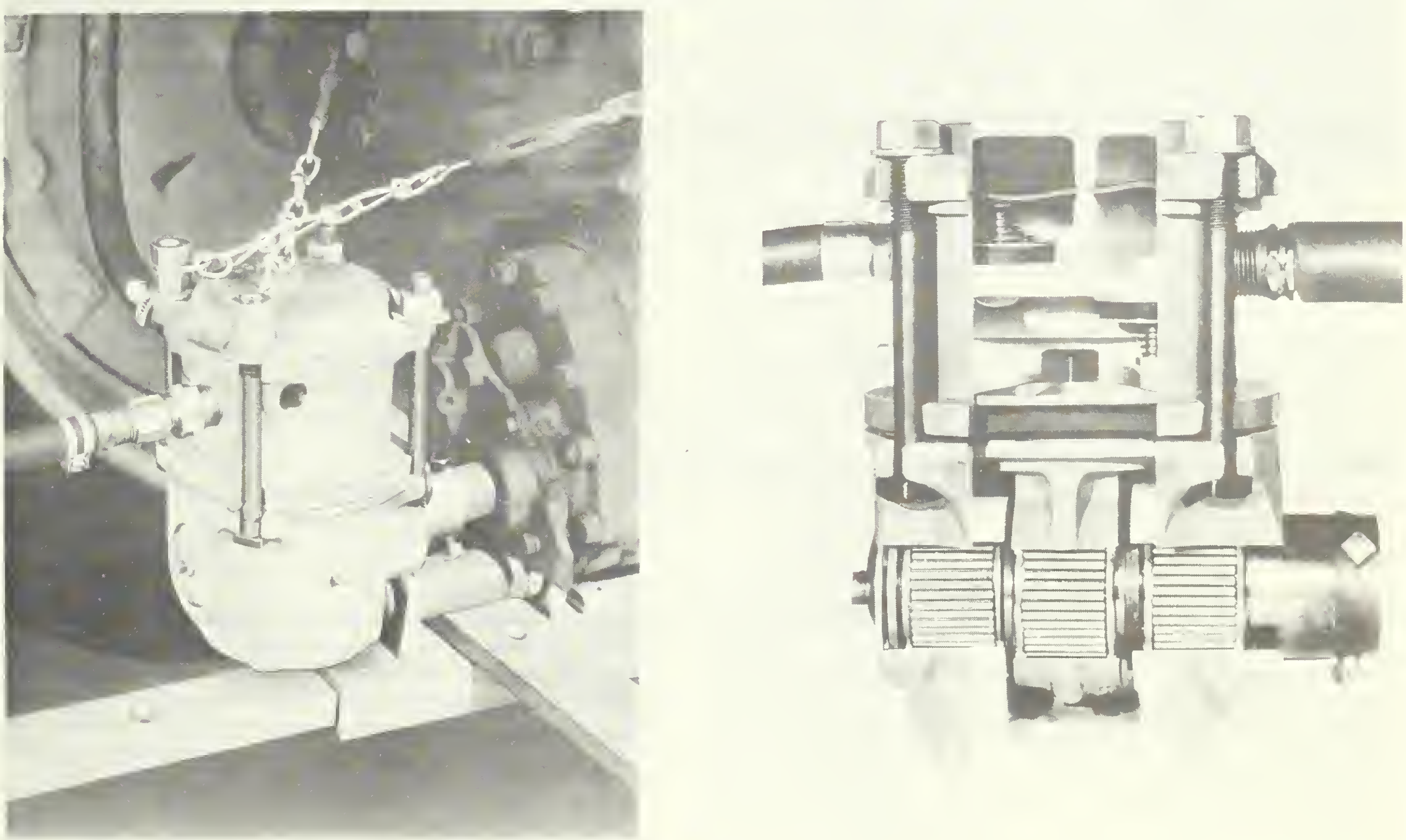


Figure 2.5.15 Diaphragm pump. Courtesy: Ace Pump Corp.

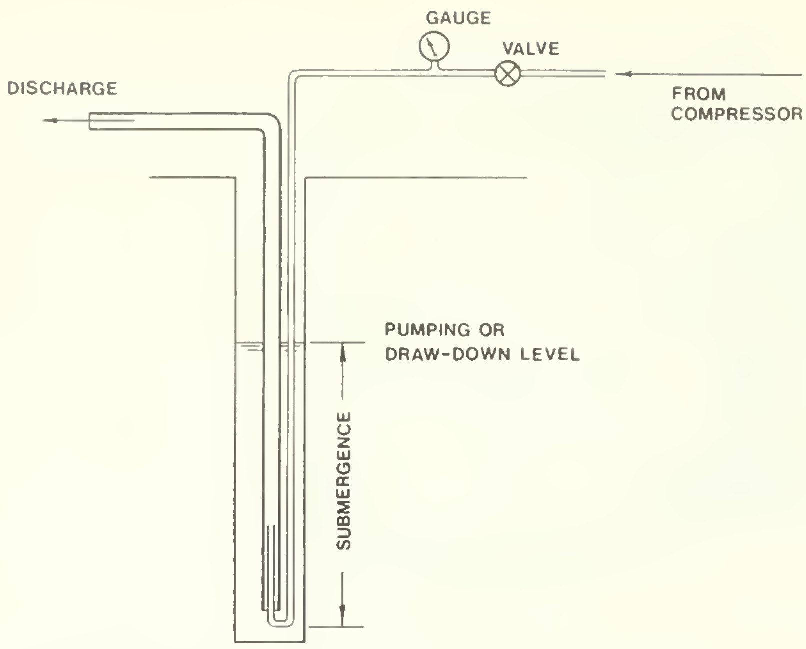


Figure 2.5.16 Air lift pump.

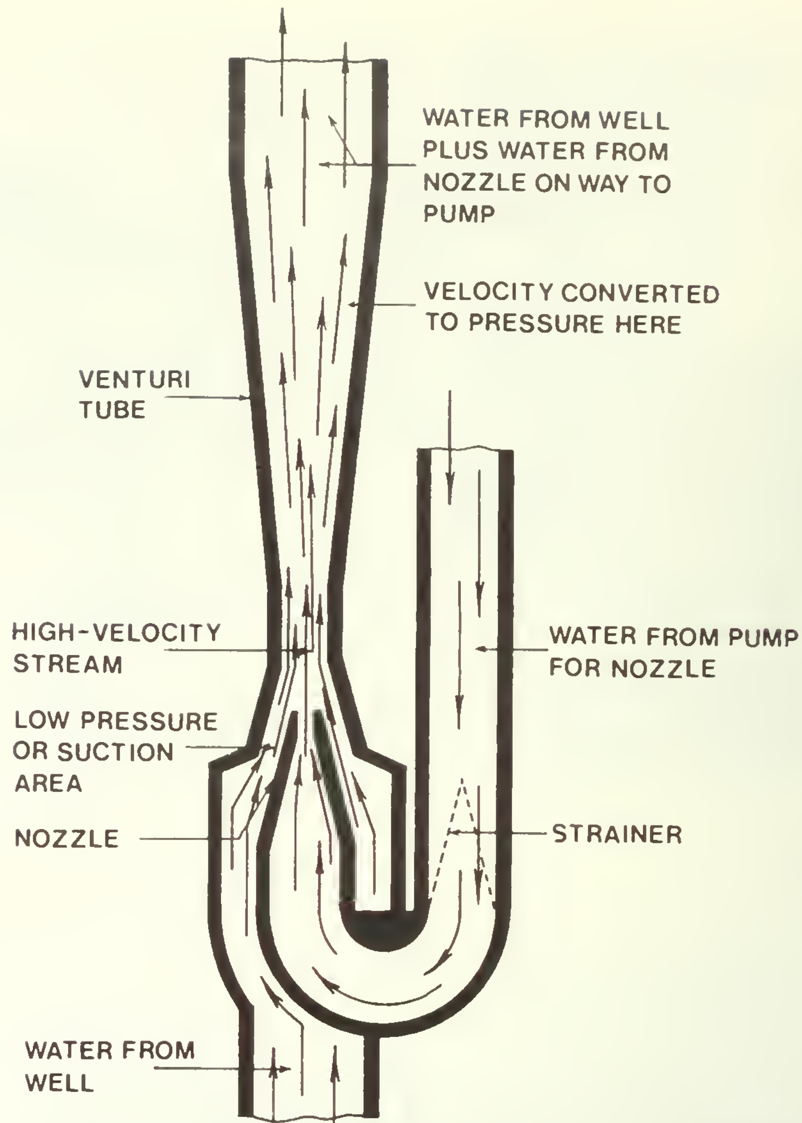


Figure 2.5.17 Jet pump.

TABLE 2.5.25 Submergence Required for Air Lift Pumping System

Depth of Well m	Submergence %
- 15	65
15 - 30	60
30 - 60	50
60 - 100	50

TABLE 2.5.26 Size of Air and Discharge Lines for Air Lift Pumping Systems

Pumping Rate	Nominal Pipe Sizes, in.		
L/s	Well Casing	Drop Pipe	Air Line
2 - 4	3½	2½	¾
4 - 5	4½	3	1
5 - 6	5	3½	1¼
6 - 10	6	4	1½
10 - 16	8	5	1½

TABLE 2.5.27 Air Volume and Working Pressure for Air Lift Pumping

Lift from Draw-Down Level m	Submergence (Depth of Air Line Below Draw-Down Level, m	Liters of Air Per Liter of Water Pumped	Working Pressure kPa
12	12	3.7	120
	24	2.5	240
18	18	4.5	180
	36	3.0	355
24	24	4.9	240
	48	3.4	475
30	30	5.6	295
	60	4.0	590
42	42	6.4	415
	85	4.7	835
60	60	7.9	590

pump through the drive pipe to the jet nozzle. The high velocity stream creates a low pressure or suction area which draws water in from the well and delivers it into a venturi tube. Water then passes up into the enlarged portion of the venturi where the pressure increases. This pressure in turn forces water up the delivery pipe to within the suction range of the pump.

Jet pumps will operate at depths of 120 m or more, however, Hicks (4) states that for lifts over 46 m other pump designs are usually better suited. For efficient operation of jet pumps the ejector must be selected to match the lift.

Two types of ejector assemblies are available for most models of jet pumps. The two-pipe assembly is most desirable and is designed to operate inside 4 in. or larger well casings. The single pipe assembly is for use in small diameter wells. It uses the well casing as the drive pipe to supply water to the ejector. Adapters are available to fit single pipe assemblies into most small well casings.

Submersible Pumps - Submersible pumps consist of a small multistage centrifugal pump close coupled to an electric motor. The pump and motor are built in one compact unit which can be suspended below the water level on the end of the discharge pipe. Insulated waterproof wires run down to the motor to supply power. Pumps are available to fit inside 4 in. and larger well casing.

Submersible pumps have several advantages, including high efficiency and exceptionally quiet operation because of being submerged. Priming is not necessary as the pump is under water and the cost of frost proofing is usually reduced. The pump has the disadvantage that, while designed for long service, the entire pump and piping must be removed from the well should it fail. Further, submersible pumps are not intended for use in wells producing sand or corrosive water.

Hydraulic Ram - The hydraulic ram is in effect a pump and a prime mover combined. For operation it requires a water supply which is elevated above the ram. The kinetic energy of the water flowing in the drive pipe from the supply is used to drive the ram. This energy produces a pressure in the ram which will force some of the water to a higher pressure than that which would be produced by the static head of the supply. The balance of the water is wasted. Rams are most useful for water supply from a stream or spring where electric power is not available.

2.5.5 PUMP AND SYSTEM CHARACTERISTICS

2.5.5.1 General

The American Society of Mechanical Engineers has developed standard procedures for testing both centrifugal and rotary pumps. These test codes are used by pump manufacturers to provide performance data on pumps. In reading pump specifications certain terms and definitions are used.

Static Head - In pump applications the height of a column of liquid acting on the pump suction or discharge is called the static head. Static head is further defined as static suction head and static discharge head.

Static Suction Head - Numerically this is the height the supply liquid surface is above the center line of a pump.

Static Suction Lift - This is the vertical distance that the liquid supply level is below the pump center line.

Static Discharge Head - This is the vertical distance between the pump center line and the point of free delivery of the liquid.

Total Static Head - This is the vertical distance between the supply and discharge levels of the liquids being handled.

Friction Head - This is the equivalent head, measured in meters (feet) of the liquid being handled that is required to overcome the resistance of pipes, valves and other fittings used in the piping system. Friction head losses occur on both the suction and discharge side of the pump and vary with the flow rate of the liquid, pipe size, interior condition of the pipe and the nature of the liquid being handled.

The resistance of pipe fittings is usually expressed in terms of equivalent length of straight pipe of the same size as the fitting. Tables 2.5.14 to 2.5.18 give friction head loss for water in various types of pipe and Tables 2.5.19 and 2.5.20 list equivalent lengths of pipe for various fittings. For viscous liquids the friction head loss can be calculated using Equation (10).

Velocity Head - Liquids must be accelerated to some average velocity within the pipe. The pump must supply this energy. Usually the velocity head for most pumping situations is small and is neglected when calculating total head.

Entrance and Exit Losses - There are frictional losses which occur when the liquid enters or exits from a piping system. Except in exceptional situations these losses are also neglected.

Pressure Head - If the discharge from a pump is into a closed tank partially filled with air, the pressure expressed in meters (feet) of the liquid is termed the pressure head.

Total Suction Head - This is the difference between the static suction head and the sum of all friction heads plus any pressure on the liquid on the suction side of the system.

Total Suction Lift - This is the sum of the static suction lift, the friction head and the velocity and inlet losses, if they are considered, minus any pressure on the suction side of the system.

Total Discharge Head - This is the sum of the static discharge head, friction head, velocity head, if it is considered, and any pressure head which may exist.

Total Head - This is the sum of the suction lift and the discharge head or if a suction head exists, it is the difference between the discharge and suction head.

2.5.5.2 System Characteristics

Graphic plots are used as an aid to pumping system analysis. This concept of plotting system loss curves in conjunction with pump characteristic curves to find the system operating conditions is adaptable not only to centrifugal pumps but also to rotary and reciprocating pumps and fans.

Example 2.5.1, 2.5.2 and 2.5.3 illustrate the development of system-head curves.

2.5.5.3 Volute or Centrifugal Pump Characteristics

Specifications for centrifugal pumps are usually given in tabular or graphic form. Table 2.5.28 illustrates one method of presenting pump performance data for a small centrifugal pump series. For pumps in this series the maximum lift is limited to about 4.6 m or 15 ft. Pump efficiencies are not tabulated but horsepower requirements are included.

Figures 2.5.18 and 2.5.19 are examples of pump performance or characteristic curves, they include:

1. Pump identification
2. Impeller diameter
3. Suction and inlet pipe size
4. Head - capacity curve
5. Horsepower curve
6. Isoefficiency curve
7. Net positive suction head (NPSH) curve

The data presented by the curves is for a small centrifugal pump having a 2 in. suction and 1½ in. discharge line. In Figure 2.5.18 the head-capacity (H-Q) curves are for constant speed and variable impeller diameter. In Figure 2.5.19 the impeller diameter is constant but the speed is changed.

If the demand on a system changes, due to a change in suction or discharge surface levels or a change in the friction characteristics in the system, the total head may increase. These conditions are illustrated by the system-head curves shown in Figure 2.5.18. Selection of the pump to permit an initial operating point at A results in a favorable operating range C, from the standpoint of pump efficiency, when the operating head increases.

Net Positive Suction Head (NPSH) - The required NPSH is a function of pump design, capacity and operating speed. It varies from one pump to the next and represents the pressure required at the pump intake to provide a stated flow through the pump. Values given by the pump manufacturer (Figures 2.5.18 and 2.5.19) are based on tests and are corrected to the pump center line.

The available NPSH can be calculated as follows:

(a) When the liquid supply is above the center line of the pump and the surface is exposed to atmospheric pressure

$$NPSH = (h_b + h_s) - (h_f + h_p) \qquad (12)$$

(b) When the liquid level is below the center line of the pump

$$NPSH = h_b \cdot (h_s + h_f + h_p) \qquad (13)$$

(c) If the liquid supply in (a) or (b) is from a closed tank substitute the tank pressure for the barometric pressure.

Where,

h_b = barometric pressure

h_s = static suction head

h_f = friction head loss in the suction line

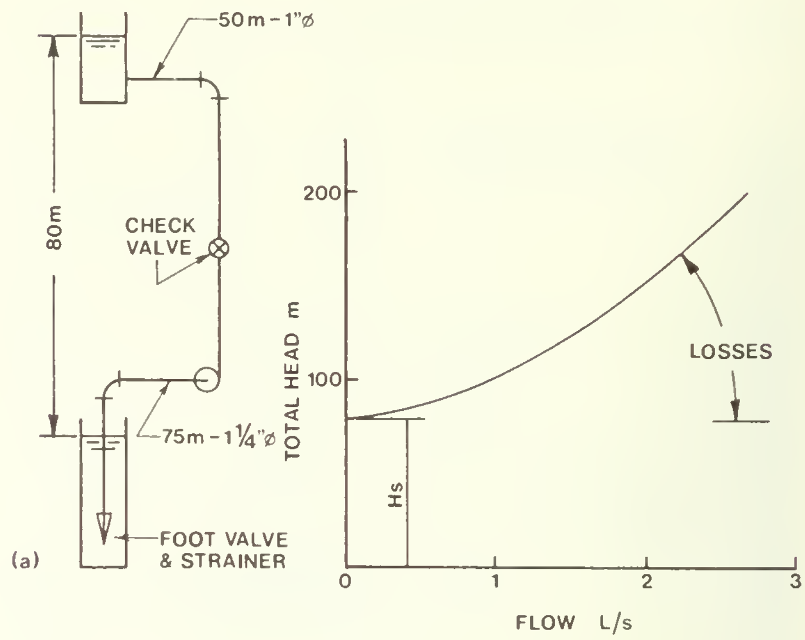
h_p = vapor pressure of the liquid

Note: All pressures are expressed in meters (feet) of the liquid being pumped.

Failure to provide adequate NPSH will reduce pump capacity and efficiency and can lead to cavitation problems, noise and damage to the pump. When the pump in Figure 2.5.18 is discharging 140 gpm the required NPSH is 9 feet of water.

Values for the vapor pressure of water are given in Table 2.5.29.

EXAMPLE 2.5.1 Develop a system-head curve for the piping arrangement at (a)



Friction loss calculations for a flow rate of 1.5 L/s suction pipe head loss

Suction pipe 1¼ in.	75.0 m	
1 - 90° elbow	3.0	Table 2.5.19
1 - Foot valve	2.1	Table 2.5.19
1 - Strainer	4.9	Table 2.5.19
	84.0 m	

From Table 2.5.14 friction head loss from 1¼ in. pipe and 1.5 L/s flow rate is 15.2 m/100m of pipe

Friction loss = (84/100) 15.2 = 12.8 m

Discharge pipe head loss

Discharge pipe 1 in.	50.0 m
1 - 90° elbow	1.6
1 - Check valve	3.4
	55.0 m

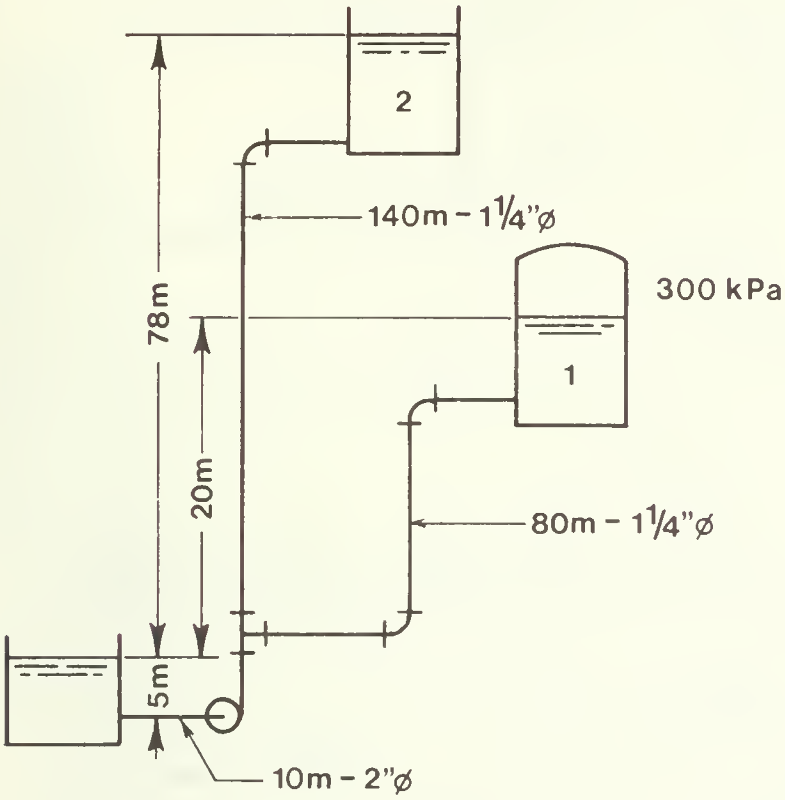
Friction loss = (55/100) 57.9 = 31.8 m

Total friction head 44.6 m

Similar calculations may be made for other flow rates

Flow Rate L/s	Total Static Head m	Friction Head m
0.5	80	5.9
1.0	80	21.1
1.5	80	44.6
2.0	80	76.0
2.5	80	114.9

EXAMPLE 2.5.2 System-head curve with two discharge pipes



System-head curves are plotted independently for the two pipes when the discharge heads are different. The combined system-head curve is obtained by adding the flow rates for the two pipes at the same head.

Assume flow rate 2.0 L/s

Discharge pipe head loss, system 1

Discharge pipe 1¼ in.	140.0
1 - 90° elbow	2.0
1 - T line flow	1.4
	143.4 m

Friction loss (143.4/100) 25.9 = 37.1 m

Discharge pipe head loss, system 2

Discharge pipe 1¼ in.	80.0
2 - 90° elbows	4.0
1 - T branch flow	2.7
	86.7 m

Friction loss (86.7/100) 25.9 = 22.5 m

Suction pipe head loss

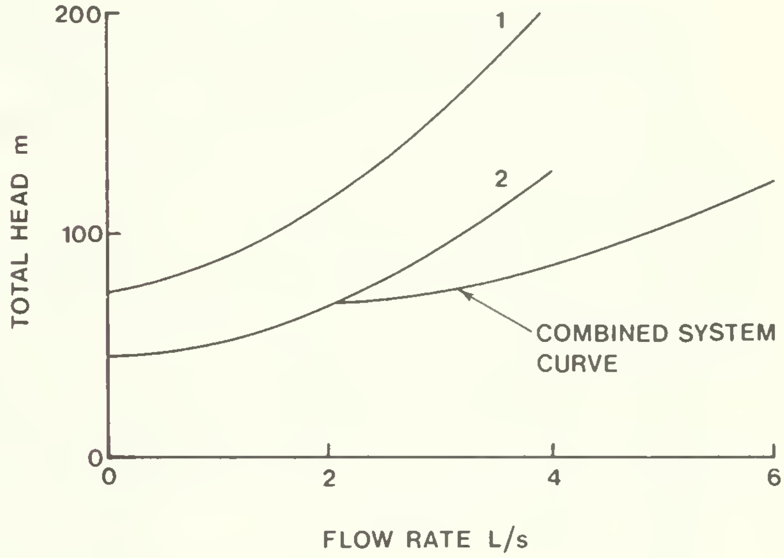
Suction pipe - 10 m
Friction loss (10/100) 3.6 = 0.4 m

System 1	m
Static suction head	-5
Static discharge head	78
Friction head 37.1 + 0.4 =	37.4
Total head	110.4

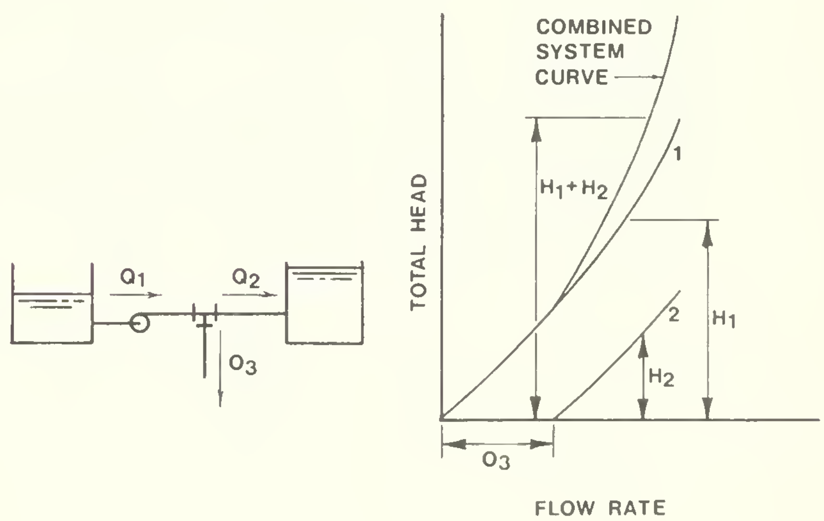
System 2	m
Static suction head	-5
Static discharge head	20
Friction head 22.5 + 0.4 =	22.9
Pressure head 300/9.806	30.4
Total head	68.3

Total head vs flow rate

Flow Rate L/s	Total Head 1 m	Total Head 2 m
1.0	83.4	51.7
2.0	110	68.2
3.0	153	93.9
4.0	208	128



EXAMPLE 2.5.3 System-head curve with diverted flow



In this case a constant quantity Q_3 is diverted at an intermediate point from the line. Plot the system-head curve for Q_1 in the normal manner. The curve for Q_2 is displaced an amount equal to Q_3 since this is the quantity passing lines 1 and 3 but not line 2. The combined system-head curve is obtained by adding the head loss for 1 and 2 at the same flow rate.

TABLE 2.5.28 Pump Performance Data. Model Series 9 (3450 rpm)

Pump Figure No	Motor hp Rating	Dist. Pipe Size	Suc. Pipe Size	Total Head, Ft 50	60	70	80	90	100	110	120	140	160	180	200	220	Shut Off Head
				Capacity, gal per min (U.S.)													
3	3	2	3	165	150	130	110	75									100
5	5	2	3			190	185	175	160	145	125	55					145
7.5	7.5	2	3							200	195	175	140	90			195
10	10	2	3									205	195	170	140	95	240

Maximum recommended suction lift is 15 ft.

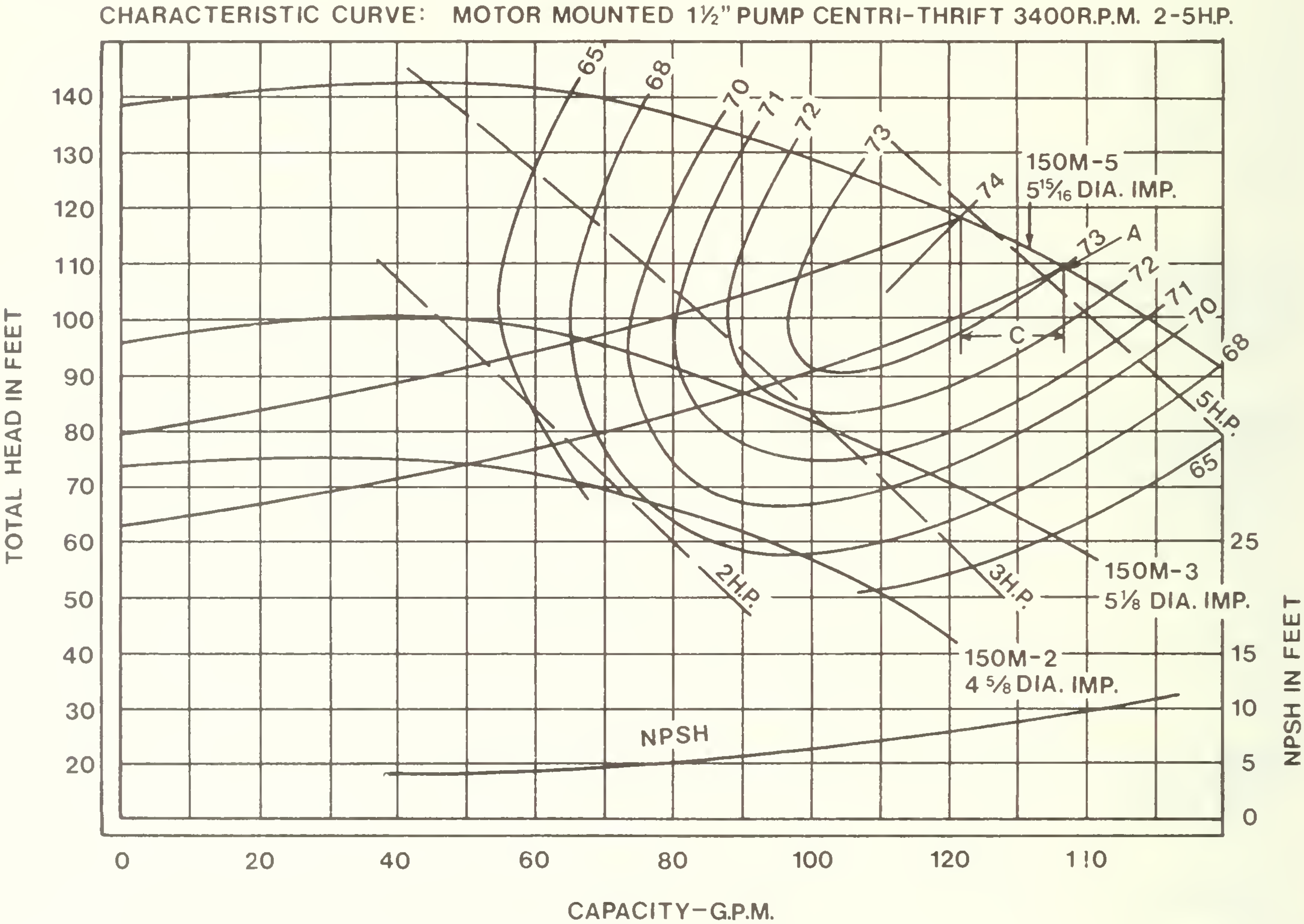


Figure 2.5.18 Performance curves for a small motor-mounted centrifugal pump.

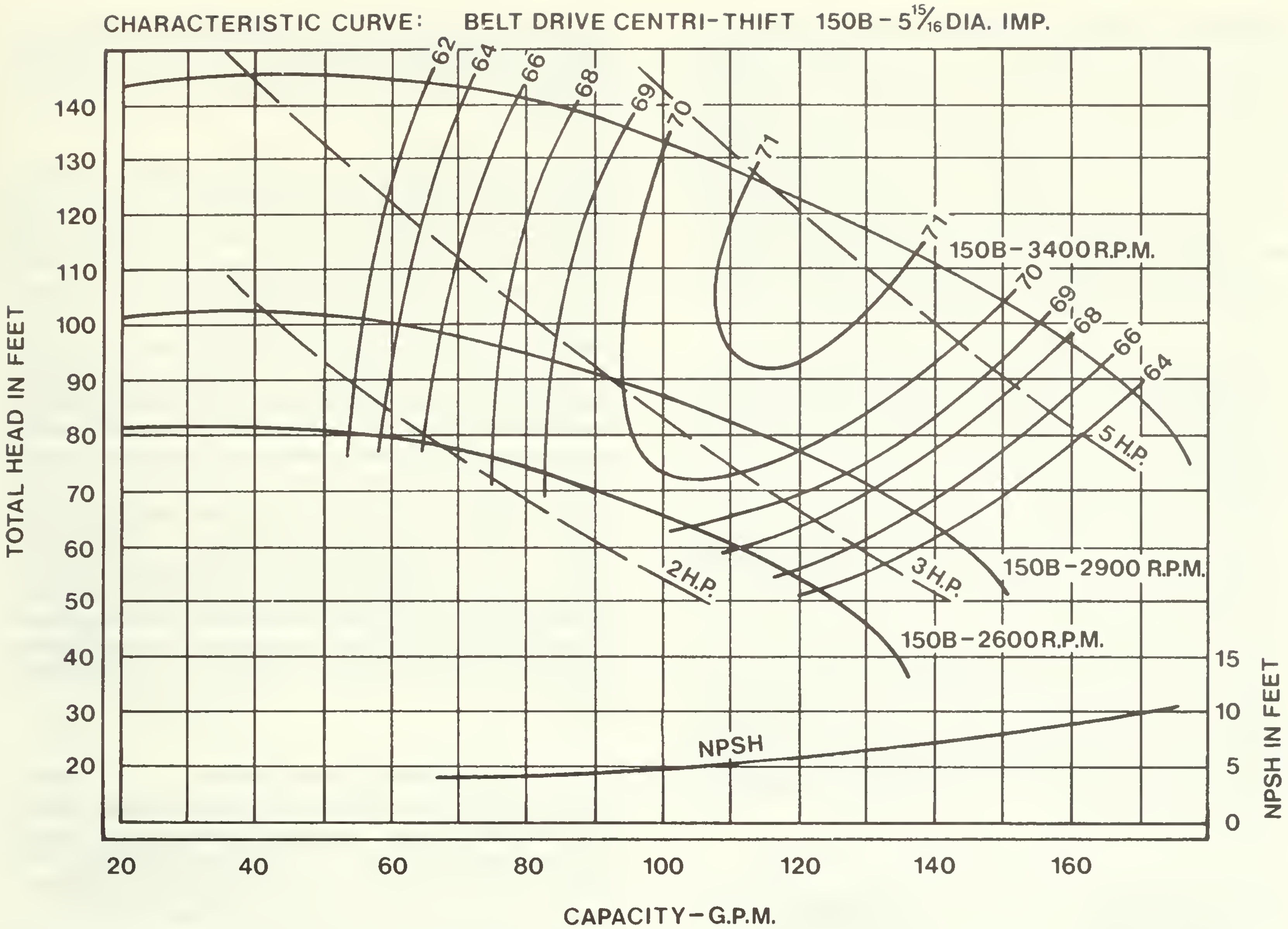


Figure 2.5.19 Performance curves for a small belt-driven centrifugal pump.

TABLE 2.5.29 Vapor Pressure of Water

Temperature	Specific Gravity	Vapor Pressure		
°C	G	m	ft	kPa
10	0.999	0.125	0.411	1.23
20	0.998	0.238	0.782	2.34
30	0.995	0.433	1.42	4.24
40	0.992	0.752	2.47	7.38
50	0.988	1.26	4.13	12.3
60	0.985	2.03	6.66	19.9
70	0.977	3.18	10.4	31.2
80	0.971	4.83	15.8	47.3
90	0.965	7.15	23.4	70.1
100	0.958	10.3	33.9	101.3

Cavitation - When centrifugal pumps are operated at abnormally high suction lifts or with high temperature liquids, insufficient NPSH may be available and cavitation within the pump can occur. While the cavitation process is complex what appears to occur is the formation of bubbles when the liquid flashes to vapor at the point of lowest pressure at the back of the impeller blades. These bubbles move toward a high pressure area near the blade tips where they collapse. The bubbles collapse so rapidly and the liquid hits the impeller so hard that metal may be gouged out of the impeller, resulting in pitting. The noise associated with cavitation is caused by the collapse of the bubbles.

Impeller Design - Among the variables associated with pump selection is the impeller design. Several types have been developed for specific uses, they are usually classified by vane detail, how the liquid enters the impeller and by application. The types for domestic and agricultural use include:

1. Open impellers (Figure 2.5.20 a) have the vanes completely exposed. They are used in sump dewatering pumps where they are expected to handle dirty water at low heads. They are also used in laundry pumps and similar inexpensive units.

2. Semi-enclosed impellers (Figure 2.5.20 b) have a shroud on one side of the vanes. They are used to handle sewage, liquid manure and similar types of materials.

3. Closed impellers (Figure 2.5.20 c) have a shroud on both side of the vanes. They are designed to handle clear liquids at high heads.

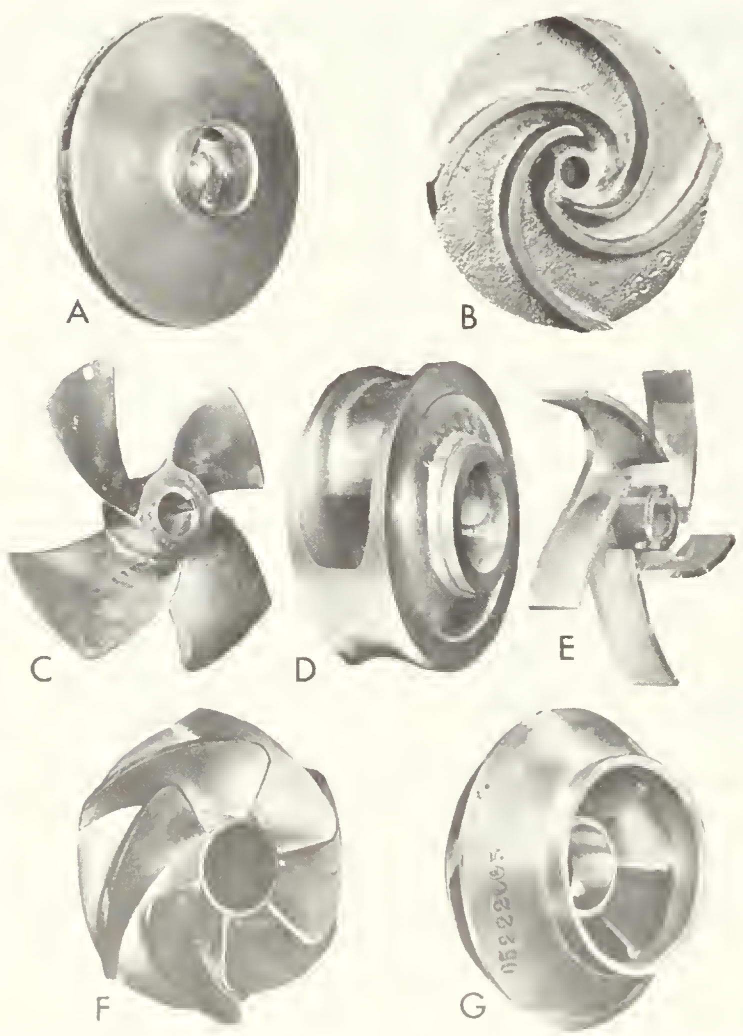


Figure 2.5.20 Typical pump impellers. (A & D closed impellers, B semi-open impeller, C axial flow impeller, F & G mixed flow impellers.

4. Other configurations include propeller and mixed flow impellers usually used in high capacity pumps. Special self-cleaning and non-clogging types are also made. The non-clogging type will handle solids up to a specified diameter.

Series and parallel operation - Where a wide range of demand occurs two or more pumps may be operated in series or parallel when demands are high and only one used for low demands. In order to evaluate the performance of the system under varying conditions the system head curve should be plotted in conjunction with the performance curves for the pumps.

When two or more pumps operate in series plot the composite curve by adding the heads for the same capacity. When the pumps are operated in parallel add the capacities at the same head. To predict the operating point superimpose the system head curve on the composite plot.

Viscous Liquid - Centrifugal pumps will handle viscous liquids; however, the pump will develop a lower head, capacity will be decreased and the horsepower input will be higher. For most applications rotary pumps are more satisfactory for handling clear viscous liquids. For detail on handling viscous liquids in centrifugal pumps refer to Standards of the Hydraulic Institute (5) or Hicks and Edwards (4).

2.5.5.4 **Rotary Pump Characteristics**

The advantage of the rotary pump is that beside a steady flow, the discharge, neglecting leakage, is almost constant regardless of the discharge head and the capacity for low viscosity liquids is proportional to speed. Also, most rotary pumps are self-priming.

Slip or loss of capacity caused by clearance between the casing and rotating elements is a function of fluid viscosity and discharge pressure. It results in a reduction in pump efficiency.

As with centrifugal pumps, manufacturers supply rating tables for rotary pumps. Pertinent data such as pump capacity, power input, head and fluid viscosity should be included. Most manufacturers also tend to emphasize application rather than pump class. Typical applications include sprayers, food handling, milk handling, hydraulic power transmission, oil burners and many other industrial uses.

TABLE 2.5.30 Recommended Speed Reductions for Rotary Pumps Handling Viscous Liquids

Liquid Viscosity		Speed Reduction
cSt (mm^2/s)	SSU	% of Rated Pump Speed
130	600	2
170	800	6
220	1000	10
320	1500	12
420	2000	14
850	4000	20
1350	6000	30
1700	8000	40
2200	10000	50
4250	20000	55
6300	30000	57
8500	40000	60

As a guide to handling viscous liquids such as oil, honey or molasses, Table 2.5.30 lists recommended speed reductions for rotary pumps as a function of viscosity.

2.5.5.5 Reciprocating Pump Characteristics

The discharge from reciprocating pumps is pulsating. The characteristic of the pulsations depend on the type of pump (single acting, double acting, multiplunger) and whether or not a cushion chamber is used.

The use of reciprocating pumps in the agricultural industry is limited to high pressure field and orchard sprayers and use in washing pens in livestock buildings. More recently, large 200 to 250 mm diameter piston pumps have been developed for handling semiliquid manure from barns to storage piles. Plunger pumps still find some application in deep wells; however they have been largely replaced by jet and submersible pumps.

2.5.5.6 Pump Power Requirements

The power required to drive any type or class of pump handling non-viscous incompressible liquids can be computed by:

$$P = \frac{9.81 a \alpha h_t}{e} \qquad (14)$$

where

a = flow rate, L/s
α = liquid density, kg/L
h_t = total head, m
e = pump efficiency
P = power, kW

In the British system:

$$P = \frac{q \alpha h_t}{33{,}000e} \qquad (15)$$

where,

q = flow rate, gpm
α = weight per gallon, lb/g
h_t = total head, ft
e = pump efficiency
P = power, hp

2.5.5.7 Pumping Volatile Liquids

Volatile liquids such as gasoline, refrigerants, propane and similar liquids which vaporize readily at normal atmospheric pressures and temperatures can cause pumping difficulties. The problem encountered is one of maintaining sufficient NPSH. The available NPSH must be equal to or greater than that required by the pump, otherwise the liquid will vaporize in the suction line.

2.5.5.8 Pump Capacity Determination

In the absence of a weigh tank or other flow measuring device the discharge from a pump or pipe can be estimated using the technique described in Figure 2.5.21.

2.5.6 WATER HAMMER

Water hammer can occur in a closed pipe system when the velocity of the liquid changes suddenly due to a pump starting or stopping or a sudden opening or closing of a flow control device such as a valve. The pressure developed may be sufficient to damage the pump or piping.

The magnitude of the pressure rise may be estimated from:

$$h = Vr/g \qquad (16)$$

where,

h = pressure rise, m
V = velocity of the pressure wave in the pipe $= 1420/\sqrt{1 + KR}$, m/s
r = the reduction in liquid velocity, m/s
g = 9.81 m/s
K = elastic modulus of water/elastic modulus of the pipe material
R = pipe diameter/wall thickness

The time required for the pressure wave to travel the length of the pipe is given by:

$$t = L/V$$

where,

L = pipe length between the pump and the device causing water hammer, m
t = time, s

Values for K for common pipe materials are: steel 0.010; wrought iron 0.0107; cement-asbestos 0.088; wood 0.20; and PVC (rigid) 0.83.

EXAMPLE 2.5.4 Determine the pressure rise in 800 m of 4 in. steel pipe if a valve at the discharge end is snapped shut when the liquid velocity is 2.41 m/s and R = 19.

Velocity of the pressure wave:

$$V = 1420/\sqrt{1 + 0.01 \times 19} = 1301.7 \text{ m/s}$$

Increase in pressure above the normal pressure:

$$h = \frac{1301.7 \times 2.41}{9.81} = 320 \text{ m}$$

Solutions to the problem of water hammer involves; (a) lengthening the time to stop flow to several intervals of t; (b) bleeding some water from the system; and (c) designing the system for low flow rates. Lengthening the flow stopping time of the pump requires some type of flywheel on the pump or its drive. A simpler solution is to mount a small surge tank near the pump discharge or other device causing water hammer. The tank will bleed water from the pipe and thus dampen the surge.

2.5.7 REFERENCES

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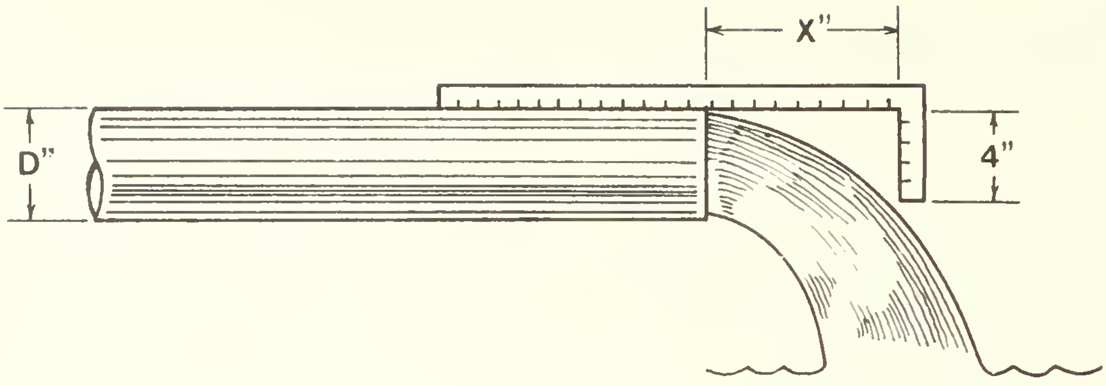

Discharge Rate (gal/min)													
Horiz. Dist. X	Nominal Pipe Diameter												Average Velocity
(Inches)	1"	1¼"	1½"	2"	2½"	3"	4"	5"	6"	8"	10"	12"	
4	5.7	9.8	13.3	22.0	31.3	48.5	83.5						2.1
5	7.1	12.2	16.6	27.5	39.0	61.0	104	163					2.6
6	8.5	14.7	20.0	33.0	47.0	73.0	125	195	285				3.1
7	10.0	17.1	23.2	38.5	55.0	85.0	146	228	334	580			3.7
8	11.3	19.6	26.5	44.0	62.5	97.5	166	260	380	665	1060		4.2
9	12.8	22.0	29.8	49.5	70.0	110	187	293	430	750	1190	1660	4.7
10	14.2	24.5	33.2	55.5	78.2	122	208	326	476	830	1330	1850	5.3
11	15.6	27.0	36.5	60.5	86.0	134	229	360	525	915	1460	2200	5.8
12	17.0	29.0	40.0	66.0	94.0	146	250	390	570	1000	1600	2220	6.2
13	18.5	31.5	43.0	71.5	102	158	270	425	620	1080	1730	2400	6.9
14	20.0	34.0	46.5	77.0	109	170	292	456	670	1160	1860	2590	7.4
15	21.3	36.3	50.0	82.5	117	183	312	490	710	1250	2000	2780	7.9
16	22.7	39.0	53.0	88.0	125	196	334	520	760	1330	2120	2960	8.4
17		41.5	56.5	93.0	133	207	355	550	810	1410	2260	3140	9.1
18			60.0	99.0	144	220	375	590	860	1500	2390	3330	9.7
19				110	148	232	395	620	910	1580	2520	3500	10.4
20					156	244	415	650	950	1660	2660	3700	10.6
21						256	435	685	1000	1750	2800		11.4
22							460	720	1050	1830	2920		11.8
23								750	1100	1910	3060		12.4
24									1140	2000	3200		13.0

For other than standard diameter pipes the flow may be determined by using the following formula:
Q gpm = $1.28D^2$ where D = Inside pipe diameter
X = Horizontal open flow for drop of 4".

Figure 2.5.21 Determination of pump capacity by the horizontal discharge method. To estimate the flow rate from a horizontal pipe construct an L-shaped measuring instrument as shown above. Measure the distance X that the top surface of the water discharging from the pipe must travel before it drops 4 in. Refer to the table to estimate the flow rate in gal/min (US).

4. Hicks, T.G. and Edwards, T.W. 1971. Pump application engineering - McGraw Hill Co. New York, N.Y.
5. Hydraulic Institute. 1955. Standards of the Hydraulic Institute. New York, N.Y.
6. Moody, I.F. 1944. Friction factors for pipe flow. Am. Soc. Mech. Engns. Trans. 66: 671-684.
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