Section TECH-D
Properties of Liquids

TECH-D-1 Viscosity

The viscosity of a fluid is that property which tends to resist a shearing force. It can be thought of as the internal friction resulting when one layer of fluid is made to move in relation to another layer.

Consider the model shown in Fig. 1, which was used by Isaac Newton in first defining viscosity. It shows two parallel planes of fluid of area A separated by a distance dx and moving in the same direction at different velocities V_1 and V_2.

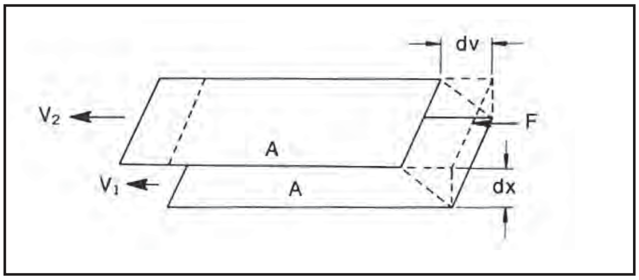


Fig. 1

The velocity distribution will be linear over the distance dx, and experiments show that the velocity gradient, $\frac{dv}{dx}$, is directly proportional to the force per unit area, $\frac{f}{a}$.

$\frac{f}{A} = n \times \frac{dv}{dx}$ Where *n* is constant for a given liquid and is called its viscosity.

The velocity gradient, $\frac{dv}{dx}$, describes the shearing experienced by the intermediate layers as they move with respect to each other. Therefore, it can be called the "rate of shear." S. Also, the force per unit area, $\frac{F}{A}$, can be simplified and called the "shear force" or "shear stress," F. With these simplified terms, viscosity can be defined as follows:

$$F = n \times S$$

$$\text{Viscosity} = n = \frac{F}{S} = \frac{\text{shear stress}}{\text{rate of shear}}$$

Isaac Newton made the assumption that all materials have, at a given temperature, a viscosity that is independent of the rate of shear. In other words, a force twice as large would be required to move a liquid twice as fast. Fluids which behave this way are called Newtonian fluids. There are, of course, fluids which do not behave this way, in other words their viscosity is dependent on the rate of shear. These are known as Non-Newtonian fluids.

Fig. 2 shows graphically the relationships between shear Stress (F,) rate of shear (S,) and viscosity (n) for a Newtonian liquid. The viscosity remains constant as shown in sketch 2, and in absolute units, the viscosity is the inverse slope of the line in sketch 1. Water and light oils are good examples of Newtonian liquids.

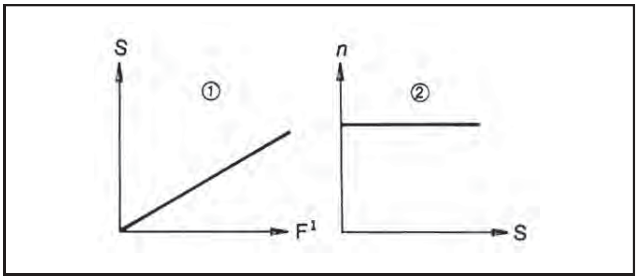
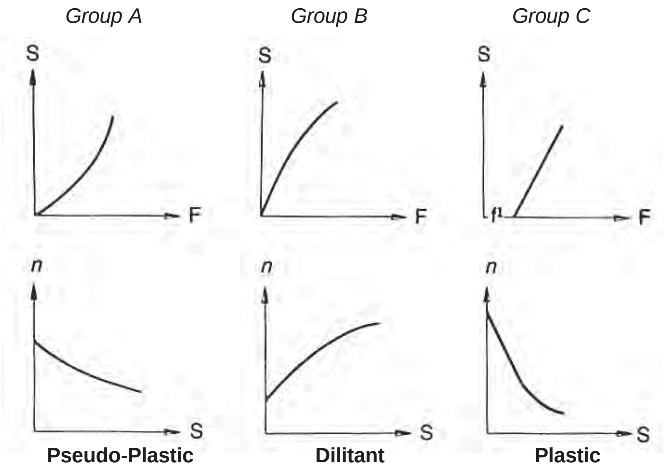


Fig. 2 Newtonian Liquid

Fig. 3 shows graphically the three most common types of Non-Newtonian liquids. Group A shows a decreasing viscosity with an increasing rate of shear. This is known as a **pseudo-plastic** material. Examples of this type are grease, molasses, paint, soap, starch, and most emulsions. They present no serious pumping problems since they tend to thin out with the high rates of shear present in a pump.

Group B shows a **dilatant** material or one in which the viscosity increases with an increasing rate of shear. Clay slurries and candy compounds are examples of dilatant liquids. Pumps must be selected with extreme care since these liquids can become almost solid if the shear rate is high enough. The normal procedure would be to oversize the pump somewhat and open up the internal clearances in an effort to reduce the shear rate.

Group C shows a **plastic** material, The viscosity decreases with increasing rate of shear. However, a certain force must be applied before any movement is produced. This force is called the yield value of the material. Tomato catsup is a good example of this type of material. It behaves similar to a pseudo-plastic material from a pumping standpoint.


Group A *Group B* *Group C*

Pseudo-Plastic **Dilitant** **Plastic**

Fig. 3 Non-Newtonian Liquids

The viscosity of some Non-Newtonian liquids is dependent upon time as well as shear rate. In other words, the viscosity at any particular time depends upon the amount of previous agitation or shearing of the liquid. A liquid whose viscosity decreases with time at a given shear rate is called a thixotropic liquid. Examples are asphalts, glues, molasses, paint, soap, starch, and grease. Liquids whose viscosity increases with time are called rheopectic liquids, but they are seldom encountered in pumping applications.

There are two basic viscosity parameters: dynamic (or absolute) viscosity and kinematic viscosity. Dynamic viscosities are given in terms of force required to move a unit area a unit distance. This is usually expressed in pound-seconds per square foot in the English system which is equal to slugs per foot-second. The Metric system is more commonly used, however, in which the unit is the dyne-second per square centimeter called the Poise. This is numerically equal to the gram per centimeter-second. For convenience, numerical values are normally expressed in centipoise, which are equal to one-hundredth of a poise.

Most pipe friction charts and pump correction charts list kinematic viscosity. The basic unit of kinematic viscosity is the stoke which is equal to a square centimeter per second in the Metric system. The corresponding English unit is square foot per second. The centistoke which is one-hundredth of a stoke is normally used in the charts. The following formula is used to obtain the kinematic viscosity when the dynamic or absolute viscosity is known:

$$\text{centistokes} = \frac{\text{centipoise}}{\text{sp. gr.}}$$

There are numerous types of viscometers available for determining liquid viscosities, most of which are designed for specific liquids or viscosity ranges. The Saybolt viscometers are probably the most widely used in the United States. The Saybolt Universal Viscometer measures low to medium viscosity, and the Saybolt Furol Viscometer measures high viscosities. The corresponding units are the SSU (Seconds Saybolt Universal) and the SSF (Seconds Saybolt Furol). These units are found on most pipe friction and pump correction charts in addition to centistokes. A conversion chart for these and other units is shown in Figs. 4A and 4B.

TECH-D-2A Viscosity Conversion Table

The following table will give an approximate comparison of various viscosity ratings so that if the viscosity is given in terms other than Saybolt Universal, it can be translated quickly by following horizontally to the Saybolt Universal column.

Seconds Saybolt Universal ssu	Kine-matic Viscosity Centi-stokes*	Seconds Saybolt Furol ssf	Seconds Red-wood 1 (Stan-dard)	Seconds Red-wood 2 (Admir-alty)	Degrees Engler	Degrees Barbey	Seconds Parlin Cup #7	Seconds Parlin Cup #10	Seconds Parlin Cup #15	Seconds Parlin Cup #20	Seconds Ford Cup #3	Seconds Ford Cup #4
31	1.00	-	29	-	1.00	6200	-	-	-	-	-	-
35	2.56	-	32.1	-	1.16	2420	-	-	-	-	-	-
40	4.30	-	36.2	5.10	1.31	1440	-	-	-	-	-	-
50	7.40	-	44.3	5.83	1.58	838	-	-	-	-	-	-
60	10.3	-	52.3	6.77	1.88	618	-	-	-	-	-	-
70	13.1	12.95	60.9	7.60	2.17	483	-	-	-	-	-	-
80	15.7	13.70	69.2	8.44	2.45	404	-	-	-	-	-	-
90	18.2	14.44	77.6	9.30	2.73	348	-	-	-	-	-	-
100	20.6	15.24	85.6	10.12	3.02	307	-	-	-	-	-	-
150	32.1	19.30	128	14.48	4.48	195	-	-	-	-	-	-
200	43.2	23.5	170	18.90	5.92	144	40	-	-	-	-	-
250	54.0	28.0	212	23.45	7.35	114	46	-	-	-	-	-
300	65.0	32.5	254	28.0	8.79	95	52.5	15	6.0	3.0	30	20
400	87.60	41.9	338	37.1	11.70	70.8	66	21	7.2	3.2	42	28
500	110.0	51.6	423	46.2	14.60	56.4	79	25	7.8	3.4	50	34
600	132	61.4	508	55.4	17.50	47.0	92	30	8.5	3.6	58	40
700	154	71.1	592	64.6	20.45	40.3	106	35	9.0	3.9	67	45
800	176	81.0	677	73.8	23.35	35.2	120	39	9.8	4.1	74	50
900	198	91.0	762	83.0	26.30	31.3	135	41	10.7	4.3	82	57
1000	220	100.7	896	92.1	29.20	28.2	149	43	11.5	4.5	90	62
1500	330	150	1270	138.2	43.80	18.7	-	65	15.2	6.3	132	90
2000	440	200	1690	184.2	58.40	14.1	-	86	19.5	7.5	172	118
2500	550	250	2120	230	73.0	11.3	-	108	24	9	218	147
3000	660	300	2540	276	87.60	9.4	-	129	28.5	11	258	172
4000	880	400	3380	368	117.0	7.05	-	172	37	14	337	230
5000	1100	500	4230	461	146	5.64	-	215	47	18	425	290
6000	1320	600	5080	553	175	4.70	-	258	57	22	520	350
7000	1540	700	5920	645	204.5	4.03	-	300	67	25	600	410
8000	1760	800	6770	737	233.5	3.52	-	344	76	29	680	465
9000	1980	900	7620	829	263	3.13	-	387	86	32	780	520
10000	2200	1000	8460	921	292	2.82	-	430	96	35	850	575
15000	3300	1500	13700	-	438	2.50	-	650	147	53	1280	860
20000	4400	2000	18400	-	584	1.40	-	860	203	70	1715	1150

Fig. 4A

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***Kinematic Viscosity (in centistokes)**
= Absolute Viscosity (in centipoises)
Density

When the Metric System terms centistokes and centipoises are used, the density is numerically equal to the specific gravity. Therefore, the following expression can be used which will be sufficiently accurate for most calculations:

***Kinematic Viscosity (in centistokes)**
= Absolute Viscosity (in centipoises)
Specific Gravity

When the English System units are used, the density must be used rather than the specific gravity.

For values of 70 centistokes and above, use the following conversion:

SSU = centistokes x 4.635

Above the range of this table and within the range of the viscosimeter, multiply the particular value by the following approximate factors to convert to SSU:

Viscosimeter	Factor	Viscosimeter	Factor
Saybolt Furol	10.	Parlin cup #15	98.2
Redwood Standard	1.095	Parlin cup #20	187.0
Redwood Admiralty	10.87	Ford cup #4	17.4
Engler – Degrees	34.5		

TECH-D-2B Viscosity Conversion Table

The following table will give an approximate comparison of various viscosity ratings so that if the viscosity is given in terms other than Saybolt Universal, it can be translated quickly by following horizontally to the Saybolt Universal column.

Seconds Saybolt Universal ssu	Kinematic Viscosity Centistokes*	Approx. Seconds Mac Michael	Approx. Gardner Holt Bubble	Seconds Zahn Cup #1	Seconds Zahn Cup #2	Seconds Zahn Cup #3	Seconds Zahn Cup #4	Seconds Zahn Cup #5	Seconds Demmier Cup #1	Seconds Demmier Cup #10	Approx. Seconds Stormer 100 gpm Load	Seconds Pratt and Lambert "F"
31	1.00	-	-	-	-	-	-	-	-	-	-	-
35	2.56	-	-	-	-	-	-	-	-	-	-	-
40	4.30	-	-	-	-	-	-	-	1.3	-	-	-
50	7.40	-	-	-	-	-	-	-	2.3	-	2.6	-
60	10.3	-	-	-	-	-	-	-	3.2	-	3.6	-
70	13.1	-	-	-	-	-	-	-	4.1	-	4.6	-
80	15.7	-	-	-	-	-	-	-	4.9	-	5.5	-
90	18.2	-	-	-	-	-	-	-	5.7	-	6.4	-
100	20.6	125	-	38	18	-	-	-	6.5	-	7.3	-
150	32.1	145	-	47	20	-	-	-	10.0	1.0	11.3	-
200	43.2	165	A	54	23	-	-	-	13.5	1.4	15.2	-
250	54.0	198	A	62	26	-	-	-	16.9	1.7	19	-
300	65.0	225	B	73	29	-	-	-	20.4	2.0	23	-
400	87.0	270	C	90	37	-	-	-	27.4	2.7	31	7
500	110.0	320	D	-	46	-	-	-	34.5	3.5	39	8
600	132	370	F	-	55	-	-	-	41	4.1	46	9
700	154	420	G	-	63	22.5	-	-	48	4.8	54	9.5
800	176	470	-	-	72	24.5	-	-	55	5.5	62	10.8
900	198	515	H	-	80	27	18	-	62	6.2	70	11.9
1000	220	570	I	-	88	29	20	13	69	6.9	77	12.4
1500	330	805	M	-	-	40	28	18	103	10.3	116	16.8
2000	440	1070	Q	-	-	51	34	24	137	13.7	154	22
2500	550	1325	T	-	-	63	41	29	172	17.2	193	27.6
3000	660	1690	U	-	-	75	48	33	206	20.6	232	33.7
4000	880	2110	V	-	-	-	63	43	275	27.5	308	45
5000	1100	2635	W	-	-	-	77	50	344	34.4	385	55.8
6000	1320	3145	X	-	-	-	-	65	413	41.3	462	65.5
7000	1540	3760	-	-	-	-	-	75	481	48	540	77
8000	1760	4170	Y	-	-	-	-	86	550	55	618	89
9000	1980	4700	-	-	-	-	-	96	620	62	695	102
10000	2200	5220	Z	-	-	-	-	-	690	69	770	113
15000	3300	7720	Z2	-	-	-	-	-	1030	103	1160	172
20000	4400	10500	Z3	-	-	-	-	-	1370	137	1540	234

Fig. 4B

Above the range of this table and within the range of the viscosimeter, multiply the particular value by the following approximate factors to convert to SSU:

Viscosimeter	Factor
Mac Michael	1.92 (approx.)
Demmier #1	14.6
Demmier #10	146.
Stormer	13. (approx.)

TECH-D-3 Determination of Pump Performance When Handling Viscous Liquids

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The performance of centrifugal pumps is affected when handling viscous liquids. A marked increase in brake horsepower, a reduction in head, and some reduction in capacity occur with moderate and high viscosities.

Fig. 5 provides a means of determining the performance of a conventional centrifugal pump handling a viscous liquid when its performance on water is known. It can also be used as an aid in selecting a pump for a given application. The values shown in Fig. 5 are averaged from tests of conventional single stage pumps of 2-inch to 8-inch size, handling petroleum oils. The correction curves are, therefore, not exact for any particular pump.

When accurate information is essential, performance tests should be conducted with the particular viscous liquid to be handled.

Limitations on Use of Viscous Liquid Performance Correction Chart

Reference is made to Fig. 5. This chart is to be used only within the scales shown. Do not extrapolate.

Use only for pumps of conventional hydraulic design, in the normal operating range, with open or closed impellers. Do not use for mixed flow or axial flow pumps or for pumps of special hydraulic design for either viscous or non-uniform liquids.

Use only where adequate NPSH is available in order to avoid the effect of cavitation.

Use only on Newtonian (uniform) liquids. Gels, slurries, paper stock and other non-uniform liquids may produce widely varying results, depending on the particular characteristics of the liquids.

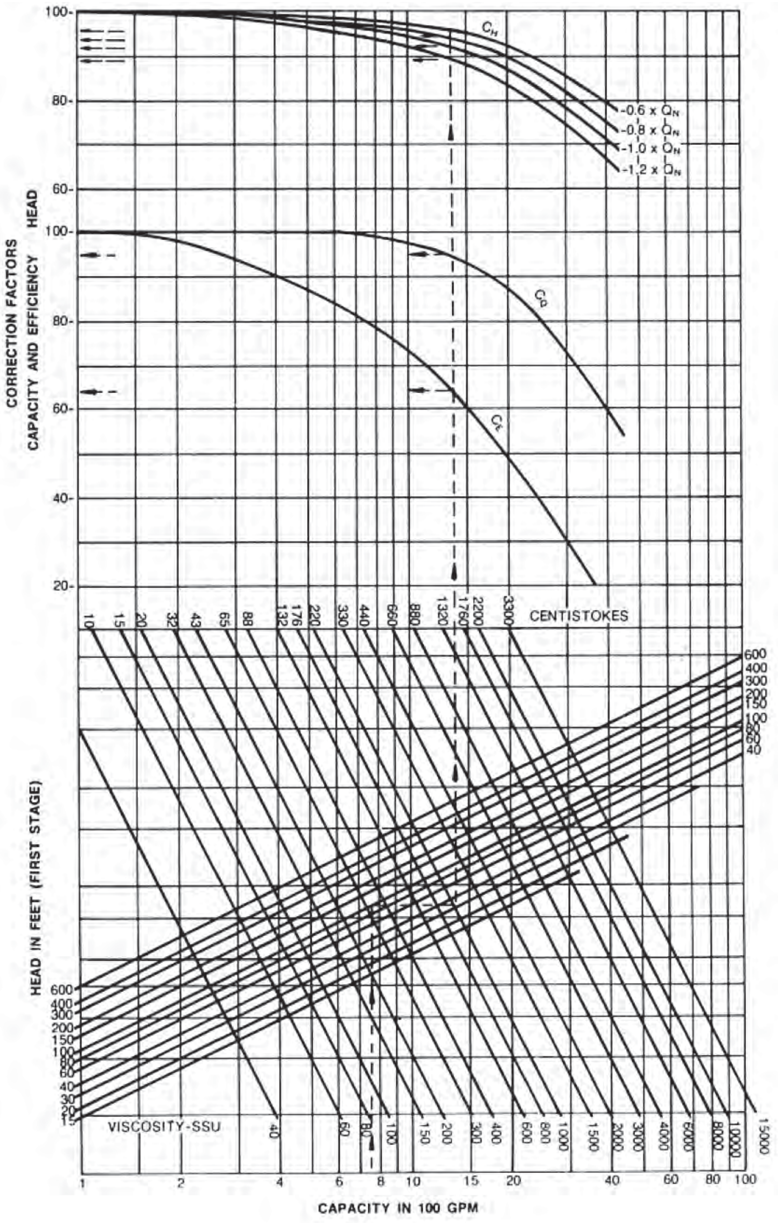

Fig. 5
Performance Correction Chart

Symbols and Definitions Used in Determination of Pump Performance When Handling Viscous Liquids.

These symbols and definitions are:

Q_{vis} = Viscous Capacity, gpm
The capacity when pumping a viscous liquid.

H_{vis} = Viscous Head, feet
The head when pumping a viscous liquid.

E_{vis} = Viscous Efficiency, per cent
The efficiency when pumping a viscous liquid.

bhp_{vis} = Viscous Brake Horsepower
The horsepower required by the pump for
the viscous conditions.

Q_W = Water Capacity, gpm
The capacity when pumping water.

H_W = Water Head, feet
The head when pumping water.

sp gr = Specific Gravity

C_Q = Capacity correction factor

C_H = Head correction factor

C_E = Efficiency correction factor

1.0 Q_w = Water Capacity at which maximum efficiency
is obtained.

The following equations are used for determining the viscous performance when the water performance of the pump is known:

$$Q_{vis} = C_Q \text{ X } Q_w$$

$$H_{vis} = C_H \times H_w$$

$$E_{vis} = C_E \times E_w$$

$$bhp_{vis} = \frac{Q_{vis} \times H_{vis} \times \text{sp gr}}{3960 \times E_{vis}}$$

C_Q, C_H and C_E are determined from Fig. 5 which is based on the water performance.

The following equations are used for approximating the water performance when the desired viscous capacity and head are given and the values of C_Q and C_H must be estimated from Fig. 5 using Q_{vis} and H_{vis}, as:

$$Q_W(\text{approx.}) = \frac{Q_{vis}}{C_Q}$$

$$H_W(\text{approx.}) = \frac{H_{vis}}{C_H}$$

Instructions for Preliminary Selection of a Pump for a Given Head-Capacity-Viscosity Condition

Given the desired capacity and head of the viscous liquid to be pumped and the viscosity and specific gravity at the pumping temperature, Fig. 5 can be used to find approximate equivalent capacity and head when pumping water.

Enter the chart (Fig. 5) at the bottom with the desired viscous capacity, (Q_{vis}) and proceed upward to the desired viscous head (H_{vis}) in feet of liquid. For multi-stage pumps, use head per stage. Proceed horizontally (either left or right) to the fluid viscosity, and then go upward to the correction curves. Divide the viscous capacity (Q_{vis}) by the capacity correction factor (C_Q) to get the approximate equivalent water capacity (Q_w approximately).

Divide the viscous head (H_{vis}) by the head correction factor (C_H) from the curve marked "1.0 x Q_w" to get the approximate equivalent water head (H_w approximately). Using this new equivalent water head-capacity point, select a pump in the usual manner.

The viscous efficiency and the viscous brake horsepower may then be calculated.

This procedure is approximate as the scales for capacity and head on the lower half of Fig. 5 are based on the water performance. However, the procedure has sufficient accuracy for most pump selection purposes. Where the corrections are appreciable, it is desirable to check the selection by the method described below.

EXAMPLE. Select a pump to deliver 750 gpm at 100 feet total head of a liquid having a viscosity of 1000 SSU and a specific gravity of 0.90 at the pumping temperature.

Enter the chart (Fig. 5) with 750 gpm, go up to 100 feet head, over to 1000 SSU, and then up to the correction factors:

C_Q = 0.95
C_H = 0.92 (for 1.0 Q_{nw})
C_E = 0.635

$$Q_w = \frac{750}{0.95} = 790 \text{ gpm}$$

$$H_w = \frac{100}{0.92} = 108.8 \quad 109 \text{ feet head}$$

Select a pump for a water capacity of 790 gpm at 109 feet head. The selection should be at or close to the maximum efficiency point for water performance. If the pump selected has an efficiency on water of 81 per cent at 790 gpm, then the efficiency for the viscous liquid will be as follows:

$$E_{vis} = 0.635 \times 81\% = 51.5 \text{ per cent}$$

The brake horsepower for pumping the viscous liquid will be:

$$bhp_{vis} = \frac{750 \times 100 \times 0.90}{3960 \times 0.515} = 33.1 \text{ hp}$$

For performance curves of the pump selected, correct the water performance as shown below.

Instructions for Determining Pump Performance on a Viscous Liquid When Performance on Water is Known

Given the complete performance characteristics of a pump handling water, determine the performance when pumping a liquid of a specified viscosity.

From the efficiency curve, locate the water capacity (1.0 x Q_w) at which maximum efficiency is obtained.

From this capacity, determine the capacities (0.6 x Q_w). (0.8 x Q_w) and (1.2 x Q_w).

Enter the chart at the bottom with the capacity at best efficiency (1.0 x Q_w), go upward to the head developed (in one stage) (H_w) at this capacity, then horizontally (either left or right) to the desired viscosity, and then proceed upward to the various correction curves.

Read the values of (C_E) and (C_Q), and of (C_H) for all four capacities.

Multiply each head by its corresponding head correction factor to obtain the corrected heads. Multiply each efficiency value by (C_E) to obtain the corrected efficiency values which apply at the corresponding corrected capacities.

Plot corrected head and corrected efficiency against corrected capacity. Draw smooth curves through these points. The head at shut-off can be taken as approximately the same as that for water.

Calculate the viscous brake horsepower (bhp_{vis}) from the formula given above.

Plot these points and draw a smooth curve through them which should be similar to and approximately parallel to the brake horsepower (bhp) curve for water.

EXAMPLE. Given the performance of a pump (Fig. 6) obtained by test on water, plot the performance of this pump when handling oil with a specific gravity of 0.90 and a viscosity of 1000 SSU at pumping temperature.

On the performance curve (Fig. 6) locate the best efficiency point which determines (Qw). In this sample this is 750 gpm. Tabulate capacity, head and efficiency for (0.6 x 750), (0.8 x 750) and (1.2 x 750).

Using 750 gpm, 100 feet head and 1000 SSU, enter the chart and determine the correction factors. These are tabulated in Table 6 of Sample Calculations. Multiply each value of head, capacity and efficiency by its correction factor to get the corrected values. Using the corrected values and the specific gravity, calculate brake horsepower. These calculations are shown on Table 6. Calculated points are plotted in Fig. 6 and corrected performance is represented by dashed curves.

TECH-D-4 Viscosity Corrections for Capacities of 100 GPM or Less

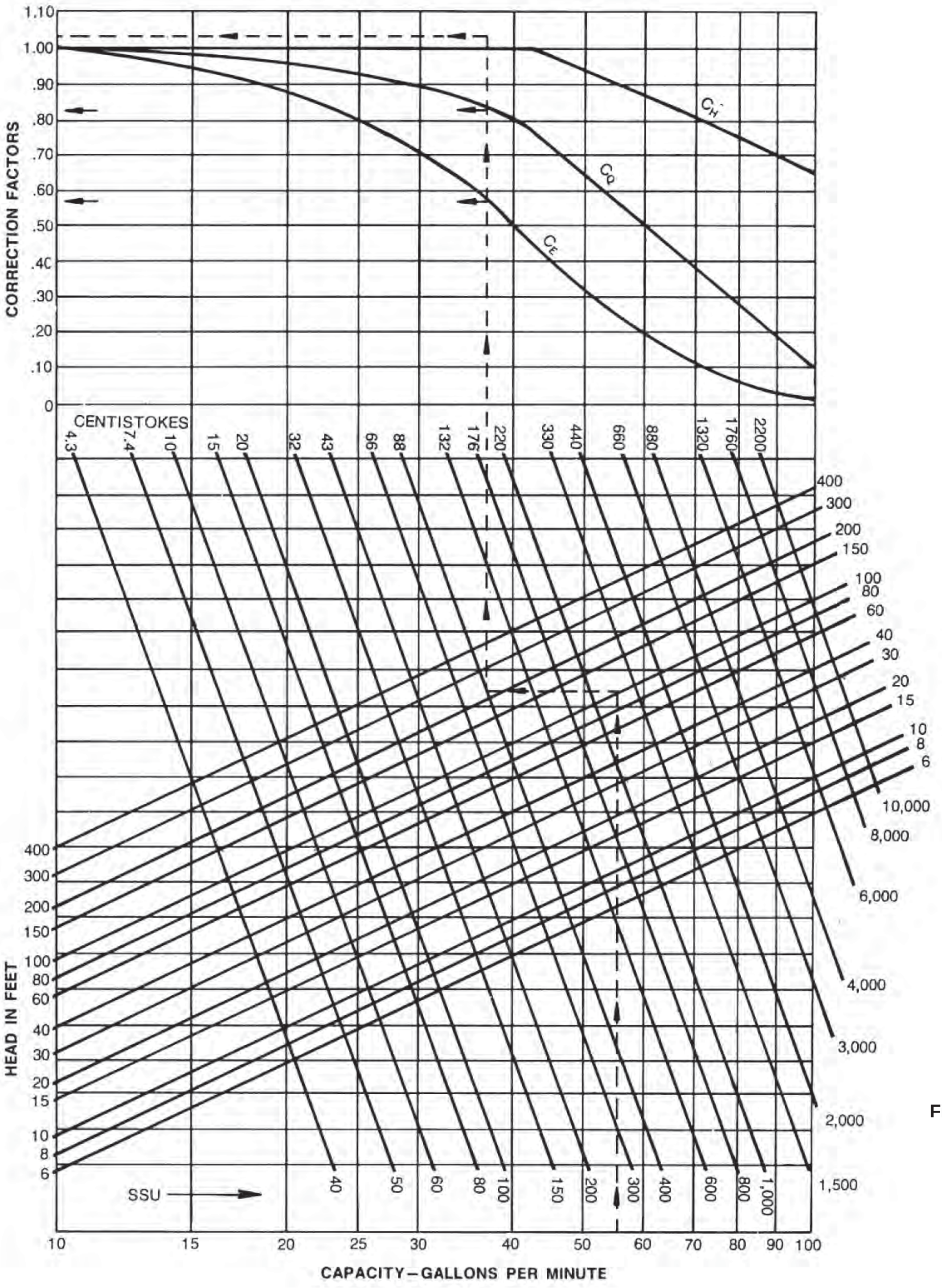

Fig. 5A

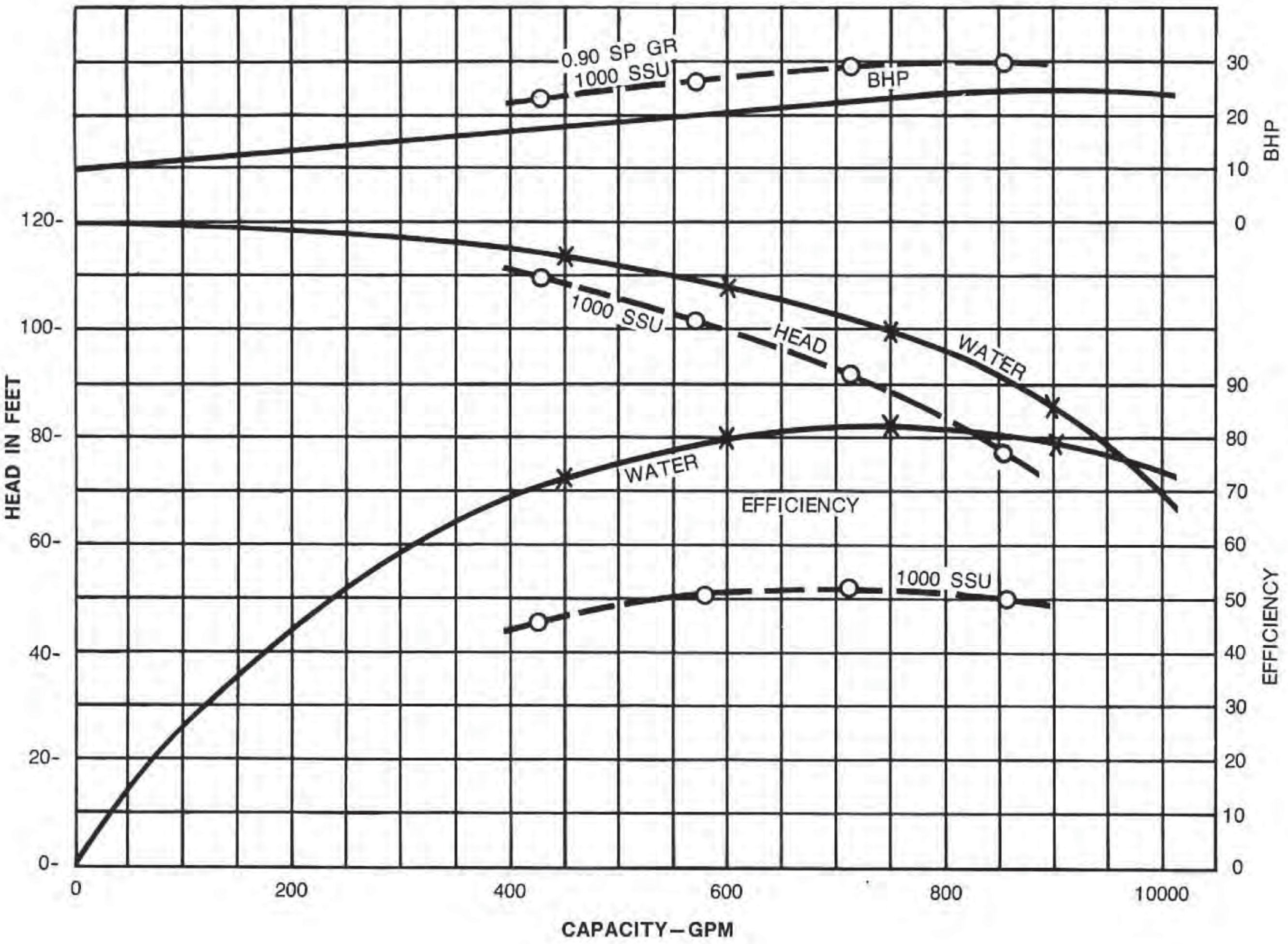

Fig. 6 Sample Performance Chart

TABLE 6

SAMPLE CALCULATIONS

	0.6 × Q_{NW}	0.8 × Q_{NW}	1.0 × Q_{NW}	1.2 × Q_{NW}
Water capacity (Q_W)	450	600	750	900
Water head in feet (H_W)	114	108	100	86
Water efficiency (E_W)	72.5	80	82	79.5
Viscosity of liquid	1000 SSU	1000 SSU	1000 SSU	1000 SSU
C_Q—from chart	0.95	0.95	0.95	0.95
C_H—from chart	0.96	0.94	0.92	0.89
C_E—from chart	0.635	0.635	0.635	0.635
Viscous capacity—$Q_W \times C_Q$	427	570	712	855
Viscous head—$H_W \times C_H$	109.5	101.5	92	76.5
Viscous efficiency—$E_W \times C_E$	46.0	50.8	52.1	50.5
Specific gravity of liquid	0.90	0.90	0.90	0.90
bhp viscous	23.1	25.9	28.6	29.4

TECH-D-5A Viscosity of Common Liquids

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Liquid	*Sp Gr at 60 F	VISCOSITY		At F
		SSU	Centistokes	
Freon	1.37 to 1.49 @ 70 F		.27-.32	70
Glycerine (100%)	1.26 @ 68F	2,950	648	68.6
		813	176	100
Glycol:				
Propylene	1.038 @ 68F	240.6	52	70
Triethylene	1.125@ 68 F	185.7	40	70
Diethylene	1.12	149.7	32	70
Ethylene	1.125	88.4	17.8	70
Hydrochloric Acid(31.5)	1.05 @ 68 F		1.9	68
Mercury	13.6		.118	70
			.11	100
Phenol (Carbonic Acid)	.95 to 1.08	65	11.7	65
Silicate of soda	40 Baume	365	79	100
	42 Baume	637.6	138	100
Sulfric Acid (100%)	1.83	75.7	14.6	68
FISH AND ANIMAL OILS:				
Bone Oil	.918	220	47.5	130
		65	11.6	212
Cod Oil	.928	**150**	32.1	100
		95	19.4	130
Lard	.96	**287**	62.1	100
		160	34.3	130
Lard Oil	.912 to .925	**190 to 220**	41 to 47.5	100
		112 to 128	23.4 to 27.1	130
Menhaddden Oil	.933	**140**	29.8	100
		90	18.2	130
Neatsfoot Oil	.917	**230**	49.7	100
		130	27.5	130
Sperm Oil	.883	**110**	23.0	100
		78	15.2	130
Whale Oil	.925	**163 to 184**	35 to 39.6	100
		97 to 112	19.9 to 23.4	130
Mineral Oils:				
Automobile Crankcase Oils (Average Midcontinent Parrafin Base)				
SAE 10	**.880 to .935	165 to 240	35.4 to 51.9	100
		90 to 120	18.2 to 25.3	130
SAE 20	**.880 to .935	240 to 400	51.9 to 86.6	100
		120 to 185	25.3 to 39.9	130
SAE 30	**.880 to .935	400 to 580	86.6 to 125.5	100
		185 to 255	39.9 to 55.1	130
SAE 40	**.880 to .935	580 to 950	125.5 to 205.6	100
		255 to	55.1 to	130
		80	15.6	210
SAE 50	**.880 to .935	950 to 1,600	205.6 to 352	100
		80 to 105	15.6 to 21.6	210
SAE 60	**.880 to .935	1,600 to 2,300	352 to 507	100
		105 to 125	21.6 to 26.2	210
SAE 70	**.880 to .935	2,300 to 3,100	507 to 682	100
		125 to 150	26.2 to 31.8	210
SAE 10W	**.880 to .935	**5,000 to 10,000**	1,100 t o2,200	0
SAE 20W	**.880 to .935	**10,000 to 40,000**	2,200 TO 8,800	0
Automobile Transmission Lubricants:				
SAE 80	**.880 to .935	**100,000 max**	**22,000 max**	0
SAE 90	**.880 to .935	**800 To 1,500**	173.2 to 324.7	100
		300 to 500	64.5 to 108.2	130
SAE 140	**.880 to .935	950 to 2,300	205.6 to 507	130
		120 to 200	25.1 to 42.9	210
SAE 250	**.880 to .935	Over 2,300	Over 507	130
		Over 200	Over 42.9	210
Crude Oils:				
Texas, Oklahoma	.81 to .916	40 to 783	4.28 to 169.5	60
		34.2 to 210	2.45 to 4.53	100
Wyoming, Montana	.86 to .88	74 to 1,215	14.1 to 263	60
		46 to 320	6.16 to 69.3	100
California	.78 to .92	40 to 4,480	4.28 to 1,063	60
		34 to 700	2.4 to 151.5	100
Pennsylvania	.8 to .85	46 to 216	6.16 to 46.7	60
		38 to 86	3.64 to 17.2	100
Diesel Engine Lubricating Oils (Based on Average Midcontinent Parafin Base):	**.880 to .935	165 to 240	35.4 to 51.9	100
Federal Specefication No. 9110		**90 to 120**	18.2 to 25.3	130

* Unless otherwise noted.

** Depends on origin or percent and type of solvent.

Liquid	*Sp Gr at 60 F	VISCOSITY		At F
		SSU	Centistokes	
Diesel Engine Lubricating Oils (Based on Average Midcontinent Parafin Base): Federal Specification No.9170	**.880 to .935	300 to 410 **140 to 180**	64.5 to 88.8 29.8 to 38.8	100 130
Federal Specification No. 9250	**.880 to .935	470 to 590 **200 to 255**	101.8 to 127.8 43.2 to 55.1	100 130
Federal Specification No. 9370	**.880 to .935	800 to 1,100 **320 to 430**	173.2 to 238.1 69.3 to 93.1	100 130
Federal Specification No. 9500	**.880 to .935	490 to 600 **92 to 105**	106.1 to 129.9 18.54 to 21.6	130 210
Diesel Fuel Oils: No. 2 D	**.82 to .95	32.6 to 45.5 39	2 to 6 1 to 3.97	100 130
No.3 D	**.82 to .95	**45.5 to 65** 39 to 48	6 to 11.75 3.97 to 6.78	100 130
No.4 D	**.82 to .95	**140 max** 70 max	29.8 max 13.1 max.	100 130
No.5 D	**.82 to .95	**400 max** 165 max	86.6 max 35.2 max	122 160
Fuel Oils: No. 1	**.82 to .95	34 to 40 **32 to 35**	2.39 to 4.28 2.69	70 100
No. 2	**.82 to .95	36 to 50 **33 to 40**	3.0 to 7.4 2.11 to 4.28	70 100
No.3	**.82 to .95	**35 to 45** 32.8 to 39	2.69 to .584 2.06 to 3.97	100 130
No.5A	**.82 to .95	**50 to 125** 42 to 72	7.4 to 26.4 4.91 to 13.73	100 130
No.5B	**.82 to .95	125 to **400** 72 to 310	26.4 to 86.6 13.63 to 67.1	100 122 130
No.6	**.82 to .95	**450 to 3,000** 175 to 780	97.4 to 660 37.5 to 172	122 160
Fuel Oil – Navy Specification	**.989 max	**110 to 225** 63 to 115	23 to 48.6 11.08 to 23.9	122 160
Fuel Oil – Navy II	1.0 max	**1,500 max** 480 max	324.7 max 104 max	122 160
Gasoline	.68 to .74		.46 to .88 .40 to .71	60 100
Gasoline (Natural)	76.5 degrees API		.41	68
Gas Oil	28 degrees Api	73 50	13.9 7.4	70 100
Insulating Oil: Transformer, switches and Circuit breakers		**65 max**	11.75 max	100
Kerosene	.78 to .82	35 32.6	2.69 2	68 100
Machine Lubricating Oil (Average Pennsylvania Parafin Base): Federal Specification No.8	**.880 to .935	112 to 160 **70 to 90**	23.4 to 34.3 13.1 to 18.2	100 130
Federal Specification No. 10	**.880 to .935	160 to 235 **90 to 120**	34.3 to 50.8 18.2 to 25.3	100 130
Federal Specification No. 20	**.880 to .935	235 to 385 **120 to 185**	50.8 to 83.4 25.3 to 39.9	100 130
Federal Specification No. 30	**.880 to .935	385 to 550 185 to 255	83.4 to 119 39.9 to 55.1	100 130
Mineral Lard Cutting Oil: Federal Specefication Grade 1		**140 to 190** 86 to 110	29.8 to 41 17.22 to 23	100 130
Federal Specification Grade 2		**190 to 220** 110 to 125	41 to 47.5 23 to 26.4	100 130
Petrolatum	.825	100 77	20.6 14.8	130 160
Turbine Lubricating Oil: Federal Specification (Penn Base)	.91 Average	400 to 440 **185 to 205**	86.6 to 95.2 39.9 to 44.3	100 130
VEGETABLE OILS: Castor Oil	.96 @ 68 F	1,200 to 1,500 **450** to 600	259.8 to 324.7 97.4 to 129.9	100 130
China Wood Oil	.943	**1,425** 580	308.5 125.5	69 100
Cocoanut Oil	.925	**140 to 148** 76 to 80	29.8 to 31.6 14.69 to 15.7	100 130
Corn Oil	.924	135 **54**	28.7 8.59	130 212
Cotton Seed Oil	.88 to .925	**176** 100	37.9 20.6	100 130

* Unless otherwise noted.

** Depends on origin or percent and type of solvent.

Liquid	*Sp Gr at 60 F	VISCOSITY		At F
		SSU	Centistokes	
VEGETABLE OILS:				
Linseed Oil, Raw	.925 to .939	**143** 93	30.5 18.94	100 130
Olive oil	.912 to .918	**200** 115	43.2 24.1	100 130
Palm oil	.924	**221** 125	47.8 26.4	100 130
Peanut Oil	.920	**195** 112	42 23.4	100 130
Rape Seed Qil	.919	**250** 145	54.1 31	100 130
Rosin Oil	.980	**1,500** 600	324.7 129.9	100 130
Rosin (Wood)	1.09 Avg	500 to **20,000** 1,000 to 50,000	108.2 to 4,400 216.4 to 11,000	200 190
Sesame Oil	.923	**184** 110	39.6 23	100 130
Soja Bean Oil	.927 to.98	**165** 96	35.4 19.64	100 130
Turpentine	.86 to .87	33 32.6	2.11 2.0	60 100
SUGARS, SYRUPS, MOLASSES, ETC.				
Corn Syrups	1.4 TO 1.47	5,000 to 500,000 1,500 to 60,000	1,1000 to 110.000 324.7 to 13,200	100 130
Glucose	1.35 to 1.44	35,000 to 100,000 4,000 to 11,000	7,700 to 22,000 880 to 2420	100 150
Honey (Raw)		340	73.6	100
Molasses “A” (First)	140.6 to 146	1,300 to 23,00 700 to 8,000	281.1 to 5,070 151.5 to 1,760	100 130
Molasses”B” (Second)	1.43 to 1.48	6,500 to 60,000 3,000 to 15,000	1,410 to 13,200 660 to 3,300	100 130
Molasses “C” (Blackstrap or final)	1.46 to 1.49	17,00 to 250,000 6,000 to 75,00	2,630 to 5,500 1,320 to 16,500	100 130
Sucrose Solutions(Sugar Syrups)				
60 Brix	1.29	230 92	49.7 18.7	70 100
62 Brix	1.30	310 111	67.1 23.2	70 100
64 Brix	1.31	440 148	95.2 31.6	70 100
66 Brix	1.326	650 195	140.7 42.0	70 100
68 Brix	1.338	1,000 275	216.4 59.5	70 100
70 Brix	1.35	1,650 400	364 86.6	70 100
72 Brix	1.36	2,700 640	595 138.6	70 100
74 Brix	1.376	5,500 1,100	1,210 238	70 100
76 Brix	1.39	10,000 2,000	2,200 440	70 100
TARS:				
Tar Coke Oven	1.12+	3,000 to 8,000 650 to 1,400	600 to 1,760 140.7 to 308	71 100
Tar Gas House	1.16 to 1.30	15,000 to 300,000 2,000 to 20,000	3,300 to 66,000 440 to 4,400	70 100
Road Tar:				
Grade RT-2	1.07+	**200 to 300** 55 to 60	43.2 to 64.9 8.77 to 10.22	122 212
Grade RT-4	1.08+	**400 to 700** 65 to 75	86.6 to 154 11.63 to 14.28	122 212
Grade RT-6	109+	**1,000 to 2,000** 85 to 125	216.4 to 440 16.83 to 26.2	122 212
Grade RT-8	1.13+	**3,000 to 8,000** 150 to 225	660 to 1,760 31.8 to 48.3	122 212
Grade RT-10	1.14+	**20,000 to 60,000** 250 to 400	4,400 to 13,200 53.7 to 86.6	122 212
Grade RT-12	1.15+	114,000 to 456,000 **500 to 800**	25,000 to 75,000 108.2 to 173.2	122 212
Pine Tar	1.06	2,500 500	559 108.2	100 132
MISCELLANEOUS				
Corn Starch Solutions:				
22 Baume	1.18	150 130	32.1 27.5	70 100
24 Baume	1.20	600 440	129.8 95.2	70 100

* Unless otherwise noted.

Liquid	*Sp Gr at 60 F	VISCOSITY		At F
		SSU	Centistokes	
MISCELLANEOUS Corn Starch Solutions: 25 Baume	1.2	1400 800	303 17.2	70 100
Ink- Printers	1.00 to 1.38	2,500 to 10,000 1,100 to 3,000	550 to 2,200 238.1 to 660	100 130
Tallow	.918 Avg.	56	9.07	212
Milk	1.02 to 1.05		1.13	68
Varnish – Spar	.9	1425 650	313 143	68 100
Water- Fresh	1.0		1.13 .55	60 130

* Unless otherwise noted.

TECH-D-5B Physical Properties of Common Liquids

Liquid	Sp. Gr. 60° F (16°C)	Melting Point °F (°C)	Boiling Point °F (°C)	pH At 77° F (25°C)	VISCOSITY							
					SSU				Centipoise			
					40°F	80°F	120°F	160°F	4°C	27°C	49°C	71°C
Acetic Acid	1.05	63	244						1.6	1.2	.8	.6
Glacial		(17)	(118)									
8.8% (1N)				2.4								
.88% (.1N)	1.01			2.9								
.09 (.01N)				3.4								
Acetone	.79	- 137 (-94)	133 (56)						.4	.3	.3	.2
Alum, 0.6% (0.1N)				3.2								
Ammonia 100%	.77	-108 (-78)	-27 (-33)						.14	.1	.08	.06
26%	.91								1.8	1.2		
1.7% (1N)				11.6								
.17% (0.1N)				11.1								
.02% (.01N)				10.6								
Asphalt												
Unblended	1.1-1.5							(12,000 at 250°F)				
RS1	1.0					155-1,000	160	85		86	34	17
RC2	1.0						2,400-5,000					
RC5	1.0					500,000	45,000	8,000				
Emulsion	1.0					1000-7,000						
Benzene	.84	42 (6)	176 (80)						.8	.6	.5	.3
Benzoic Acid												
0.1% (.01N)				3.1								
Black liquor,												
50%	1.3						5,000	(80-150 at 250°F)				(15-37 at 121°C)
70%	1.5							(6,300 at 250°F)				1,400 at 121°C)
Borax	1.7 (75)	167										
1% (0.1N)				9.2								
Boric Acid		338 (171)										
0.2% (0.1N)				5.2								
Butane	.59									.18		
Calcium Carbonate Sat.				9.4								
Calcium Chloride 25%	1.23	-21 (-29)							4.5	2.1	.9	.5
Calcium Hydroxide Sat. (Slaked Lime)				12.4								
Carbolic Acid (Phenol)	1.07	109 (43)	360 (182)			60			14.5	7.3	3.9	2.1

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Liquid	**Sp. Gr. 60° F (16°C)**	**Melting Point °F (°C)**	**Boiling Point °F (°C)**	**pH At 77° F 25°C)**	**VISCOSITY**							
					SSU				**Centipoise**			
					40°F	**80°F**	**120°F**	**160°F**	**4°C**	**27°C**	**49°C**	**71°C**
Carbonic Acid Sat.				3.8								
Carbon Tetrachloride	1.58	-95 (-71)	170 (77)						1.3	.9	.7	.6
Citric Acid .6% (1n)				2.2								
Corn Oil	.92						135					
Corn Starch,												
22° Baume	1.18					150	130					
25° Baume	1.21					1,400	800					
Corn Syrup	1.4						5,000-500,000					
Cotton Seed Oil	.9						176					
Crude Oil												
Pennsylvania	.8					200	86					
Wyoming	.9					1,100	320					
48° API	.79									2.8		
32.6° API	.86									20.0		
Dowtherm A	.99	54 (12)	500 (260)									
Dowtherm C	1.1	70 (21)	600 (316)									
Ethane	.37									(.05 at 16° C.)		
Ethyl Alcohol	.79	- 173 (- 144)	173 (78)						1.6	1.0	.7	.5
Ethyl Alcohol 95%	.81								2.0	1.3	.8	.6
Ethylene Glycol	1.1	9 (- 13)	387 (198)		185	86	53	39	44	19	9	4
Ethyl Acetate	.9									.49		
Formic Acid, 1.22 100%	122	47 (8)	213 (100)						2.4	1.5	-	.8
.5% (.1N)	1.0	-	-	2.3								
Fuel Oil												
No. 1 (Kerosene)	.81				40	36	31	30	3.3	2.1	1.4	0.9
No. 2	.86				43	36	33	32	4.6	2.6	1.6	1.2
No. 3	.89				84	52	41	37	15	7	4	3
No. 6 (Bunker C)	.96					4,500-20,000	680-- 1,900	180-500		1,00	155	40
Diesel 2D	.82-.95				100	53	40	35				
3D	.82-.95				200	80	50	40				
5D	.82-.95				15,000	2,000	400	160				
Gasoline	.6-.7				30				.7	.6	.4	.3
Glucose	1.4						35,000-100,000					
Glycerine (Glycerol)	1.26	64 (18)	554 (290)		25,000	3,100	700	230	6,260	490	130	56
50%	1.13								11	5.4	2.8	1.5
Hydrochloric Acid, 38%	1.20	- 13 (-25)										
31.5%	1.15	-115 (-46)							2.5	1.8	1.4	1.1
3.6% (1N)				0.1								
.36% (0.1N)				1.1								
.04% (.01N)				2.0								
Jet Fuel	.7-.8				35							
Lactic Acid		63 (17) –	252 (122) –	2.4								
Methyl Alcohol	.80	- 144 (-98)	149 (65)						.8	.5	.4	
80%	.82								1.0	.7	.5	.4
Milk, 3.5%	1.03			6.3-6.6						1.1		
Molasses A	1.40					10,000	2,600-60,000					
Molasses C	1.49					300,000	25,000-250,000					

Liquid	Sp. Gr. 60° F (16°C)	Melting Point °F (°C)	Boiling Point °F (°C)	pH At 77° F 25°C)	VISCOSITY							
					SSU				Centipoise			
					40°F	80°F	120°F	160°F	4°C	27°C	49°C	71°C
Nitric Acid,												
95%	1.50	-44 (-44)	187 (86)						1.4	1.0	.8	.6
60%	1.37	-9 (-23)							3.4	2.2	1.5	1.0
Oil, 5W					550	160	74	51	110	30	12	7
10W	.9				1,500	265	120	64	170	50	22	11
20W	.9				2,900	500	170	80	580	98	33	14
30W	.9				5,000	870	260	110	1,200	200	60	25
50W	.9				23,000	3,600	720	225	-	400	100	45
70W	.9				120,000	10,000	1,800	500	-	4,000	-	-
Oleic Acid	0.89	13 (-11)	547 (286)							26		
Olive Oil	.9				1,500	320	150	80				
Palmetic Acid	0.85	146 (63)	520 (271)									
Parafin	.9	100 (38)	660 (349)									
Peanut Oil	.9				1,200	300	150	80				
Propane	.51										.12	
Propylene Gylcol	1.0					241						
Potassium Hydroxide												
5.7% (1N)				14.0								
0.57% (0.1N)				13.0								
0.06% (0.01N)				12.0								
Rosin	1.09							500-20,000				
Sodium Bicarbonate												
0.4% (0.1N)				8.4								
Sodium Chloride, 25%	1.19								3.3	2.1	1.3	.9
Sodium Hydroxide, 50%	1.53				950	240	84	46	250	77	26	10
30%	1.33					58				10	4.5	2.5
4% (1N)				14.0								
0.4% (0.1N)				13.0								
.04% (.01N)				12.0								
Stearic Acid	.85	157 (69)	721 (383)									
Sucrose, 60%	1.29	10 (- 12)	218 (103)		500	150	68		156	41	14	7
40 %	1.18	25 (-4)	214 (101)						120	5	2.5	1.6
Sugar Syrup												
60 Brix	1.29					230	92					
70 Brix	1.35					1,650	400					
76 Brix	1.39					10,000	2,000					
Sulfur Molten	2.06	239 (115)	832 (445)						(11 at 123°C)	(9 at 159°C)	(22 at 160°C)	(16,000 at 184°C)
Sulfric Acid												
110% (Fuming, Oleum)		92	342 (33)	(172)	280	100	55		82	41	22	12
100%	1.83	50 (10)				75						
98%	1.84	37 (3)	554 (290)		118	68	45	37	46	23	12	6
60%	1.50	-83 (-64)	282 (139)						8.9	5.8	3.9	2.7
20%	1.14	8 (-13)	218 (103)						2.5	1.4	0.8	0.6
4.9% (1N)					0.3							
.49% (.1N)					1.2							
.05 (.01N)					2.1							
Toluene	.86	-139 (-95)	231 (111)						.8	.6	.4	.4
Trichloroethylene	1.62	-99 (-72)	189 (87)						.7	.6	.5	.4
Turpentine	.86	140 (-10)	320 (160)		34	33	32	32	1.9	1.4	.9	.7
Vinegar				2.4-3.4								
Water	1.0	32 (0)	212 (100)	6.5-8.0	32				1.6	.9	.6	.4
Wines		1.03			2.8-3.8							

TECH-D-6 Friction Loss for Viscous Liquids. Loss in Feet of Liquid per 100 Feet of New Schedule 40 Steel Pipe

GPM	Nom. Pipe Size	Kinematic Viscosity – Seconds Saybolt Universal													
		Water	100	200	300	400	500	600	800	1000	1500	2000	3000	5000	10,000
3	½	10.0	25.7	54.4	83	108	135	162	218	273	411	545	820	1350	-
	¾	2.50	8.5	17.5	26.7	35.5	44	53	71	88	131	176	265	440	880
	1	0.77	3.2	6.6	10.2	13.4	16.6	20.0	26.6	34	50	67	100	167	-
5	¾	6.32	14.1	29.3	44	59	74	88	117	147	219	293	440	740	1470
	1	1.93	5.3	11.0	16.8	22.4	28	33	44	56	83	111	167	-	-
	1¼	0.51	1.8	3.7	5.5	7.6	9.5	11.1	14.8	18.5	28	37	56	94	187
10	1	6.86	11.2	22.4	33.5	45	56	66	89	112	165	223	-	-	-
	1¼	1.77	3.6	7.5	11.2	14.9	19.1	22.4	30	37	55	74	112	190	-
	1½	0.83	1.9	4.2	6.0	8.1	10.2	12.3	16.5	20.3	31	41	62	102	207
15	1	14.6	26	34	50	67	85	104	137	172	-	-	-	-	-
	1¼	3.72	6.4	11.3	16.9	22.4	29	34	45	57	84	112	167	-	-
	1½	1.73	2.8	6.2	9.2	12.4	15.3	18.4	25	30	46	61	92	152	-
20	1	25.1	46	46	67	90	111	133	180	220	-	-	-	-	-
	1½	2.94	5.3	8.1	12.2	16.2	20.3	25	33	40	61	81	122	203	-
	2	0.87	1.5	3.0	4.4	6.0	7.4	9.0	11.9	14.8	22.4	30	45	74	147
30	1½	6.26	11.6	12.2	18.2	24.3	30	37	50	61	91	122	182	-	-
	2	1.82	3.2	4.4	6.7	9.0	11.1	13.2	17.8	22.2	33	45	67	178	222
	2½	0.75	1.4	2.2	3.2	4.4	5.5	6.5	8.8	10.9	16.6	22.0	33	55	110
40	1½	10.8	19.6	20.8	24	32	40	50	65	81	121	162	243	400	810
	2	3.10	5.8	5.8	9.0	11.8	14.8	17.7	24	30	44	59	89	148	-
	2½	1.28	2.5	3.0	4.4	5.8	7.4	8.8	11.8	14.6	22.2	29	44	73	145
60	2	6.59	11.6	13.4	13.4	17.8	22.2	27	36	45	67	89	134	220	-
	2½	2.72	5.1	5.5	6.5	8.8	10.9	13.1	17.8	22.0	34	44	66	109	220
	3	0.92	1.8	1.8	2.8	3.7	4.6	5.6	7.3	9.2	13.8	18.5	27	46	92
80	2½	4.66	8.3	9.7	9.7	11.8	14.6	17.6	24	29	44	58	87	145	-
	3	1.57	3.0	3.2	3.7	4.8	6.2	7.3	9.7	12.2	18.3	24	37	61	122
	4	0.41	0.83	0.83	1.2	1.7	2.1	2.5	3.3	4.2	6.2	8.3	12.5	20.6	41
100	2½	7.11	12.2	14.1	14.8	14.8	18.5	22	29	36	55	73	109	183	-
	3	2.39	4.4	5.1	5.1	6.2	7.6	9.1	12.1	15.2	23	31	46	77	150
	4	0.62	1.2	1.3	1.5	2.1	2.5	3.1	4.1	5.1	7.8	10.4	15.5	26	51
125	3	3.62	6.5	7.8	8.1	8.1	9.7	11.5	15.3	19.4	29	39	58	97	193
	4	0.94	1.8	2.1	2.1	2.6	3.2	3.9	5.2	6.4	9.8	12.7	19.3	32	65
	6	0.12	0.25	0.28	0.39	0.52	0.63	0.78	1.0	1.3	1.9	2.6	3.9	6.4	13.0
150	3	5.14	9.2	10.4	11.5	11.5	11.5	13.7	18.4	23	35	46	69	115	230
	4	1.32	2.4	2.9	2.9	3.1	3.9	4.6	6.2	7.8	11.5	15.4	23	39	78
	6	0.18	0.34	0.39	0.46	0.62	0.77	0.9	1.2	1.5	2.3	3.0	4.6	7.6	15.2
175	3	6.9	11.7	13.8	15.8	15.8	15.8	15.9	21.4	27	40	53	80	133	-
	4	1.76	3.2	4.0	4.0	4.0	4.6	5.4	7.4	9.2	13.7	18.2	28	46	92
	6	0.23	0.44	0.52	0.54	0.7	0.9	1.1	1.4	1.8	2.6	3.5	5.3	8.8	17.8
200	3	8.90	15.0	17.8	20.3	20.3	20.3	20.3	25	31	46	61	91	152	-
	4	2.27	4.2	5.1	5.1	5.1	5.1	6.2	8.3	10.4	15.5	20.6	31	51	103
	6	0.30	0.58	0.69	0.69	0.81	1.0	1.2	1.6	2.0	3.0	3.9	6.2	9.9	20.1
250	4	3.46	6.0	7.4	8.0	8.0	8.0	8.0	10.2	12.9	19.4	26	39	64	130
	6	0.45	0.83	0.99	1.0	1.0	1.2	1.5	2.1	2.5	3.7	5.1	7.6	12.5	-
	8	0.12	0.21	0.28	0.28	0.35	0.42	0.51	0.67	0.83	1.2	1.7	2.5	4.2	8.3
300	6	1.09	8.5	9.9	11.6	11.6	11.6	11.6	12.4	15.5	23	31	46	77	155
	8	0.28	1.2	1.4	1.5	1.5	1.5	1.8	2.5	3.0	4.6	6.0	9.1	15.0	30
	10	0.09	0.30	0.39	0.39	0.42	0.51	0.61	0.82	1.0	1.5	2.0	3.0	5.1	9.9
400	6	1.09	1.9	2.3	2.5	2.8	2.8	2.8	3.2	3.9	6.0	8.1	12.1	20.1	-
	8	0.28	0.53	0.62	0.67	0.67	0.67	0.81	1.1	1.3	2.0	2.8	4.1	6.7	13.5
	10	0.09	0.18	0.21	0.23	0.23	0.28	0.32	0.43	0.53	0.81	1.1	1.6	2.8	5.3
600	6	2.34	4.2	5.1	5.3	5.5	6.0	6.2	6.2	6.2	9.0	12.0	18.5	-	-
	8	0.60	1.1	1.3	1.4	1.5	1.5	1.5	1.7	2.0	3.0	3.9	6.2	9.9	20
	10	0.19	0.37	0.42	0.46	0.51	0.51	0.51	0.65	0.81	1.2	1.6	2.4	4.2	8.1
800	6	4.03	6.5	8.1	8.5	9.2	9.7	11.1	11.1	11.1	12.0	16.0	-	-	-
	8	1.02	1.8	2.2	2.3	2.5	2.8	2.8	2.8	2.8	3.9	5.3	8.2	13.4	-
	10	0.33	0.60	0.69	0.78	0.88	0.92	0.92	0.92	1.1	1.6	2.1	3.2	5.3	10.9
1000	8	1.56	2.5	3.2	3.5	3.7	4.2	4.4	4.4	4.4	5.1	6.7	10.2	16.6	-
	10	0.50	0.88	1.0	1.2	1.3	1.4	1.4	1.4	1.4	2.0	2.8	4.0	6.7	13.4
	12	0.21	0.39	0.46	0.51	0.55	0.58	0.58	0.58	0.67	1.0	1.3	2.0	3.5	6.7

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TECH-D-7 Pumping Liquids with Entrained Gas

Pump applications in many industrial processes involve handling liquid and gas mixtures. The entrained gas may be an essential part of an industrial process, or it may be unwanted. The Pulp and Paper industry, for example, injects from between 4% and 10% air into a dilute pulp slurry as part of the ink removal process in a flote cell used in paper recycling. Many chemical and petrochemical processes also involve pumping a two phase flow. Unwanted entrained gas can result from excess agitation or vortexing due to inadequate submergence on the suction of a pump.

The proper selection of a centrifugal pump for liquid and gas (two phase) mixtures is highly dependent on the amount of gas and the characteristics of the liquid. The presence of entrained gases will reduce the output of centrifugal pumps and can potentially cause loss of prime. Conventional pump designs can be used for low percentages by volume (up to 4%), while special modified impellers can be used effectively for up to 10% gas by volume. Performance corrections are required in all cases with gas content above approximately 2%. Gas concentrations above 10% can also be handled, but only with special design pumps (pumps with inducers, vortex pumps, or pumps with gas extraction).

Virtually any type of centrifugal pump can handle some amount of entrained gas. The problem to be addressed is the tendency for the gas to accumulate in the pump suction inhibiting flow and head generation. If gas continues to accumulate, the pump may lose prime. Fig. 1 shows how the performance of a standard end suction pump is affected by various amounts of air. With a minor performance correction, this type of pump is reasonably efficient in handling up to approximately 4% entrained gas.

As the percentage of gas exceeds 4% by volume, the performance of a conventional pump begins to degrade drastically (Fig. 1) until the pump becomes unstable, eventually losing prime. It has been found beneficial to increase the impeller running clearance (0.090 to 0.180 in.) allowing for greater leakage. This is effective in preventing loss of prime with gas concentrations up to 10%. Fig. 2 shows a standard end suction open impeller pump with clearances opened for gas handling.

Numerous tests have been conducted in an effort to quantify the performance corrections for various gas concentrations for both standard pumps and pumps with open clearances. The performance corrections are affected by many variables, including pump specific speed, operating speed, impeller design and number of vanes, operating point on the curve, and suction pressure. Performance correction charts are not presented here due to the numerous variables, but Goulds Applications Engineers can make recommendations and selections for most specific applications.

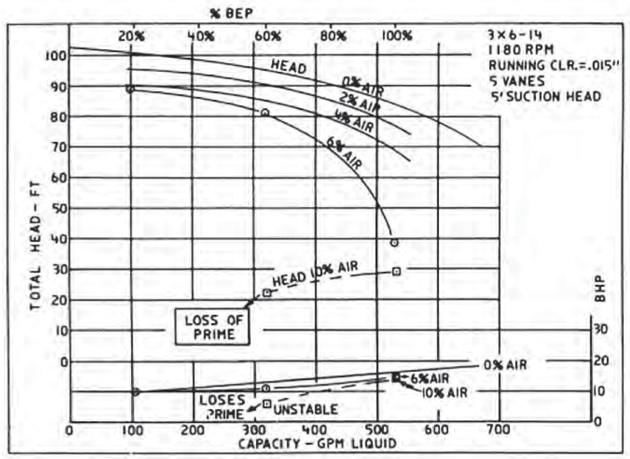
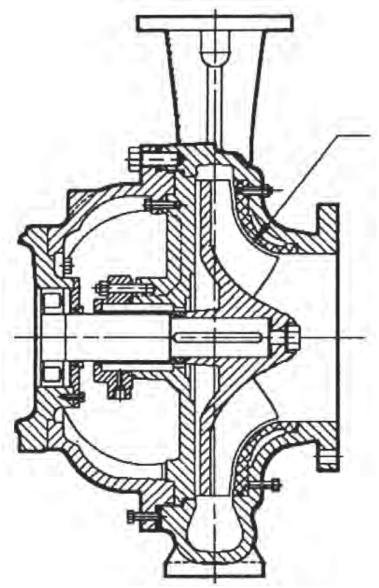


Fig. 1 Head and Power vs Capacity Zero to Ten Percent Air by Volume for Normal Running Clearance



Standard Clearance (Typically .015")

Increased Running Clearance (Typically .090" - .180")

Fig. 2 Open Impeller End Suction Pump with Normal Running Clearance and Increased Running Clearance.

TECH-D-8A Solids and Slurries - Definition of Terms

APPARENT VISCOSITY

The viscosity of a non-Newtonian slurry at a particular rate of shear, expressed in terms applicable to Newtonian fluids.

CRITICAL CARRYING VELOCITY

The mean velocity of the specific slurry in a particular conduit, above which the solids phase remains in suspension, and below which solid-liquid separation occurs.

EFFECTIVE PARTICLE DIAMETER

The single or average particle size used to represent the behavior of a mixture of various sizes of particles in a slurry. This designation is used to calculate system requirements and pump performance.

FRICTION CHARACTERISTIC

A term used to describe the resistance to flow which is exhibited by solid-liquid mixtures at various rates of flow.

HETEROGENEOUS MIXTURE

A mixture of solids and a liquid in which the solids are net uniformly distributed.

HOMOGENEOUS FLOW
(FULLY SUSPENDED SOLIDS)

A type of slurry flow in which the solids are thoroughly mixed in the flowing stream and a negligible amount of the solids are sliding along the conduit wall.

HOMOGENEOUS MIXTURE

A mixture of solids and a liquid in which the solids are uniformly distributed.

NON-HOMOGENEOUS FLOW
(PARTIALLY SUSPENDED SOLIDS)

A type of slurry flow in which the solids are stratified, with a portion of the solids sliding along the conduit wall. Sometimes called "heterogeneous flow" or "flow with partially suspended solids."

NON-SETTLING SLURRY

A slurry in which the solids will not settle to the bottom of the containing vessel or conduit, but will remain in suspension, without agitation, for long periods of time.

PERCENT SOLIDS BY VOLUME

The actual volume of the solid material in a given volume of slurry, divided by the given volume of slurry, multiplied by 100.

PERCENT SOLIDS BY WEIGHT

The weight of dry solids in a given volume of slurry, divided by the total weight of that volume of slurry, multiplied by 100.

SALTATON

A condition which exists in a moving stream of slurry when solids settle in the bottom of the stream in random agglomerations which build up and wash away with irregular frequency.

SETTLING SLURRY

A slurry in which the solids will move to the bottom of the containing vessel or conduit at a discernible rate, but which will remain in suspension if the slurry is agitated constantly.

SETTLING VELOCITY

The rate at which the solids in a slurry will move to the bottom of a container of liquid that is not in motion. (Not to be confused with the velocity of a slurry that is less than the critical carrying velocity as defined above.)

SQUARE ROOT LAW

A rule used to calculate the approximate increase in critical carrying velocity for a given slurry when pipe size is increased. It states:

$$V_L = V_s = \left(\frac{D_L}{D_s}\right)^{1/2}$$

Where:

V_L = Critical carrying velocity in larger pipe
D_L = Diameter of larger pipe
V_S = Critical carrying velocity in smaller pipe
D_S = Diameter of smaller pipe

NOTE: This rule should not be used when pipe size is decreased.

VISCOSITY TYPES

(For definitions of the various types of viscosities applicable to slurries, see Rheological Definitions.)

YIELD VALUE (STRESS)

The stress at which many non-Newtonian slurries will start to deform and below which there will be no relative motion between adjacent particles in the slurry.

TECH-D-8B Solids and Slurries - Slurry Pump Applications

Determining the *when* to use a slurry style centrifugal pump can be a challenging decision. Often the cost of a slurry pump is many times that of a standard water pump and this can make the decision to use a slurry pump very difficult. One problem in selecting a pump type is determining whether or not the fluid to be pumped is actually a slurry. We can define a slurry as any fluid which contains more solids than that of potable water. Now, this does not mean that a slurry pump must be used for every application with a trace amount of solids, but at least a slurry pump should be considered.

Slurry pumping in its simplest form can be divided into three categories: the light, medium and heavy slurry. In general, **light slurries** are slurries that are not intended to carry solids. The presence of the solids occurs more by accident than design. On the other hand, **heavy slurries** are slurries that are designed to transport material from one location to another. Very often the carrying fluid in a heavy slurry is just a necessary evil in helping to transport the desired material. The **medium slurry** is one that falls somewhere in between. Generally, the percent solids in a medium slurry will range from 5% to 20% by weight.

After a determination has been made as to whether or not you are dealing with a heavy, medium, or light slurry, it is then time to match a pump to the application. Below is a general listing of the different characteristics of a light, medium, and heavy slurry.

Light Slurry Characteristics:

- Presence of solids is primarily by accident
- Solids Size < 200 microns
- Non-settling slurry
- The slurry specific gravity < 1.05
- Less than 5% solids by weight

Medium Slurry Characteristics:

- Solids size 200 microns to 1/4 inch (6.4mm)
- Settling or non-settling slurry
- The slurry specific gravity < 1.15
- 5% to 20% solids by weight

Heavy Slurry Characteristics:

- Slurry's main purpose is to transport material
- Solids > 1/4 inch (6.4mm)
- Settling or non-settling slurry
- The slurry specific gravity > 1.15
- Greater than 20% solids by weight

The previous listing is just a quick guideline to help classify various pump applications. Other considerations that need to be addressed when selecting a pump model are:

- Abrasive hardness
- Particle shape
- Particle size
- Particle velocity and direction
- Particle density
- Particle sharpness

The designers of slurry pumps have taken all of the above factors into consideration and have designed pumps to give the end user maximum expected life. Unfortunately, there are some compromises that are made in order to provide an acceptable pump life. The following short table shows the design feature, benefit, and compromise of the slurry pump.

SLURRY PUMP DESIGN		
Design Feature	**Benefit**	**Compromise**
Thick Wear Sections	Longer component life	Heavier, more expensive parts
Larger Impellers	Slower pump speeds longer component life	Heavier, more expensive parts
Specialty Materials	Longer component life	Expensive parts
Semi Volute or Concentric Casing	Improved pump life	Loss in efficiency
Extra Rigid Power Ends	Improved bearing lives	More expensive shafts and bearings

Although selecting the proper slurry pump for a particular application can be quite complex, the selection task can be broken down into a simplified three-step process:

1. Determine which group of possible pump selections best matches your specific application.
2. Plot the system curve depicting the required pump head at various capacities.
3. Match the correct pump performance curve with the system curve.

Slurry pumps can be broken down into two main categories. The rubber-lined pump and the hard metal pump. However, because of the elastomer lining, the rubber-lined pumps have a somewhat limited application range. Below is a general guideline which helps distinguish when to apply the rubber-lined pumps.

Rubber Lined	Hard Metal Pump
Solids < 1/2 inch (13mm)	Solids > 1/4 inch (6.4mm)
Temperature < 300° F (150°C)	Temperature < 250° F (120°C)
Low Head service < 150 feet (46m)	Heads above 150 feet (46m)
Rounded particles	Sharp/Jagged particles
Complete pH range	pH range from 4 to 12
	Hydrocarbon based slurry

It should be noted, however, that a hard metal pump can also be used for services that are outlined for the rubber-lined pump. After a decision has been made whether to use a hard metal pump or a rubber-lined pump, it is then time to select a particular pump model. A pump model should be selected by reviewing the application and determining which model pump will work best in the service.

	Slurry Pump Break Down	
Light Slurries	**Medium Slurries**	**Heavy Slurries**
AF	AF	5150
HS	HS	RX
HSU	HSU	CKX
HSUL	HSUL	5500
VHS	VHS	SRL-C
JC	JC	SRL-XT
JCU	JCU	
VJC	VJC	
	5150	
	RX	
	SRL	
	CW	

NOTES:

The Model HS pump is a unique pump in that it is a recessed impeller or "vortex" pump. This style pump is well suited to handle light pulpy or fibrous slurries. The recessed impeller used in the HS family of pumps will pass large stringy fibers and should be considered when pump plugging is a concern.

The Model AF is a specialized pump with an axial flow design. This design of pump is built specifically for high flow, low head applications.

In general, slurry pumps have been designed to handle fluids with abrasive solids and will give extended lives over standard water or process pumps. Although many features have been designed into the slurry pump, there are still two factors which directly relate to the pump's life that can be determined. The first choice to make is determining the metallurgy of the pump. In most cases, a hard metal slurry pump will be constructed of some hardened metal with a Brinell hardness of at least 500. Goulds standard slurry pump material is a 28% chrome iron with a minimum hardness of 600 Brinell. This material is used for most abrasive services and can also be used in some corrosive fluids as well. If a more corrosive resistant material is required, then the pump may be constructed out of a duplex Stainless Steel such as CD4MCu. Please check with your nearest Goulds sales office if you are unsure what material will be best suited for a particular application.

PUMP RUNNING SPEED

The other factor that can be controlled by the sales or end user engineer is the pump running speed. The running speed of a slurry pump is one of the most important factors which determines the life of the pump. Through testing, it has been proven that a slurry pump's wear rate is proportional to the speed of the pump raised to the $2^1/_2$ power.

EXAMPLE:

If Pump (A) is running at 1000 RPM and
Pump (B) is running at 800 RPM,

then the life factor for Pump (B) as compared to Pump (A) is $(1000/800)^{2.5}$ or Pump (B) will last 1.75 times as long as Pump (A).

With the above ratio in mind, it can be shown that by cutting a slurry pump speed in half, you get approximately 6 times the wear life. For this reason, most slurry pumps are V-belt driven with a full diameter impeller. This allows the pump to run at the slowest possible running speed and, therefore, providing the maximum pump life.

WHY USE A V-BELT DRIVE?

In most ANSI pump applications it is a reasonable practice to control condition point by trimming the impeller and direct connecting the motor. However, this is not always sound practice in slurry applications. The abrasive solids present, wear life is enhanced by applying the pump at the slowest speed possible.

Another situation where V-belts are beneficial is in the application of axial flow pumps. Axial flow pumps cannot be trimmed to reduce the condition point because they depend on close clearances between the vane tips and the casing for their function. The generally low RPM range for axial flow application also makes it beneficial to use a speed reduction from the point of view of motor cost.

The types of V-belt drives available for use in pump applications are termed fixed speed, or fixed pitch, and variable speed. The fixed pitch drive consists of two sheaves; each machined to a specific diameter, and a number of belts between them to transmit the torque. The speed ratio is roughly equal to the diameter ratio of the sheaves. The variable speed drive is similar to the fixed speed except that the motor sheave can be adjusted to a range of effective or *pitch* diameters to achieve a band of speed ratios. This pitch adjustment is made by changing the width of the *V*grooves on the sheave. Variable speed drives are useful in applications where an exact flow rate is required or when the true condition point is not well defined at the time that the pump is picked.

V-belt drives can be applied up to about 2000 horsepower, but pump applications are usually at or below 350 HP.

TECH-D-8C Solids and Slurries - Useful Formulas

a. The formula for specific gravity of a solids-liquids mixture or slurry, S_m is:

$$S_m = \frac{S_s \times S_1}{S_s + C_w (S_1 - S_s)}$$

where,

S_m = specific gravity of mixture or slurry
S_1 = specific gravity of liquid phase
S_s = specific gravity of solids phase
C_w = concentration of solids by weight
C_v = concentration of solids by volume

EXAMPLE: if the liquid has a specific gravity of 1.2 and the concentration of solids by weight is 35% with the solids having a specific gravity of 2.2, then:

$$S_m = \frac{2.2 \times 1.2}{2.2 + .35\,(1.2 - 2.2)} = 1.43$$

b. Basic relationships among concentration and specific gravities of solid liquid mixtures are shown below:

In Terms of	**S_s, S_m, S_1**	**C_v**	**C_w**
C_v	$\frac{S_m - S_1}{S_s - S_1}$		$C_w \frac{S_m}{S_s}$
C_w	$\frac{(S_m - S_1)}{(S_s - S_1)} \times \frac{S_s}{S_m}$	$C_v \frac{S_s}{S_m}$	

Where pumps are to be applied to mixtures which are both corrosive and abrasive, the predominant factor causing wear should be identified and the materials of construction selected accordingly. This often results in a compromise and in many cases can only be decided as a result of test or operational experience.

For any slurry pump application, a complete description of the mixture components is required in order to select the correct type of pump and materials of construction.

$$C_W = \frac{\text{weight of dry solids}}{\text{weight of dry solids + weight of liquid phase}}$$

$$C_v = \frac{\text{volume of dry solids}}{\text{volume of dry solids + volume of liquid phase}}$$

See nomograph for the relationship of concentration to specific gravity of dry solids in water shown in Fig. B.

c. Slurry flow requirements can be determined from the expression:

$$Q_m = \frac{4 \text{ x dry solids (tons per hour)}}{C_w = S_m}$$

where,

Q_m = slurry flow (U.S. gallons per minute)
1 ton = 2000 lbs.

EXAMPLE: 2,400 tons of dry solids is processed in 24 hours in water with a specific gravity of 1.0 and the concentration of solids by weight is 30% with the solids having a specific gravity of 2.7 then:

$$S_m = \frac{2.7 \times 1.0}{2.7 + .3\,(1\text{-}2.7)} = .123$$

$$Q_m = \frac{4 \times 100}{.3 \times 1.23} = 1{,}084 \text{ } \textit{U.S. GPM}$$

d. Abrasive wear: Wear on metal pumps increases rapidly when the particle hardness exceeds that of the metal surfaces being abraded. If an elastomer lined pump cannot be selected, always select metals with a higher relative hardness to that of the particle hardness. There is little to be gained by increasing the hardness of the metal unless it can be made to exceed that of the particles. The effective abrasion resistance of any metal will depend on its position on the mohs or knoop hardness scale. The relationships of various common ore minerals and metals is shown in Fig. A.

Wear increases rapidly when the particle size increases. The life of the pump parts can be extended by choosing the correct materials of construction.

Sharp angular particles cause about twice the wear of rounded particles.

Austenetic maganese steel is used when pumping large dense solids where the impact is high.

Hard irons are used to resist erosion and, to a lesser extent, impact wear.

Castable ceramic materials have excellent resistance to cutting erosion but impeller tip velocities are usually restricted to 100 ft./sec.

Elastomer lined pumps offer the best wear life for slurries with solids under $^1/_4$" for the SRL/SRL-C and under $^1/_2$" for the SRL-XT.

Several Elastomers are available for different applications. Hypalon is acceptable in the range of 1-14 pH. There is a single stage head limitation of about 150' due to tip speed limitations of elastomer impellers.

See the Classification of Pumps according to Solids Size chart (Fig. C) and Elastomer Quick Selection Guide (Section TECH-B-2) for more information.

Solids and Slurries

Approximate Comparison of Hardness Values of Common Ores and Minerals

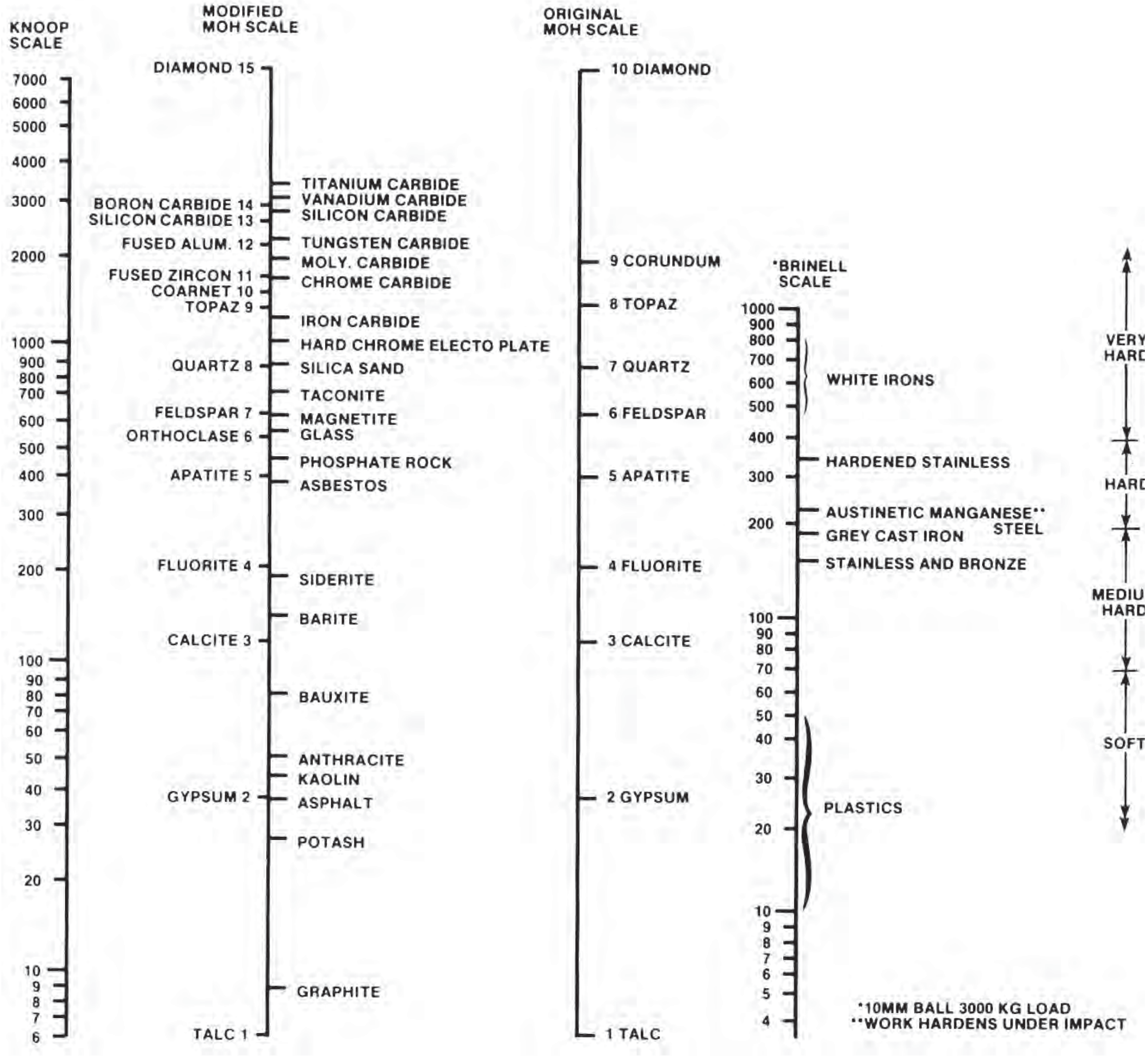


Fig. A

Solids and Slurries

Nomograph of the Relationship of Concentration to Specific Gravity in Aqueous Slurries

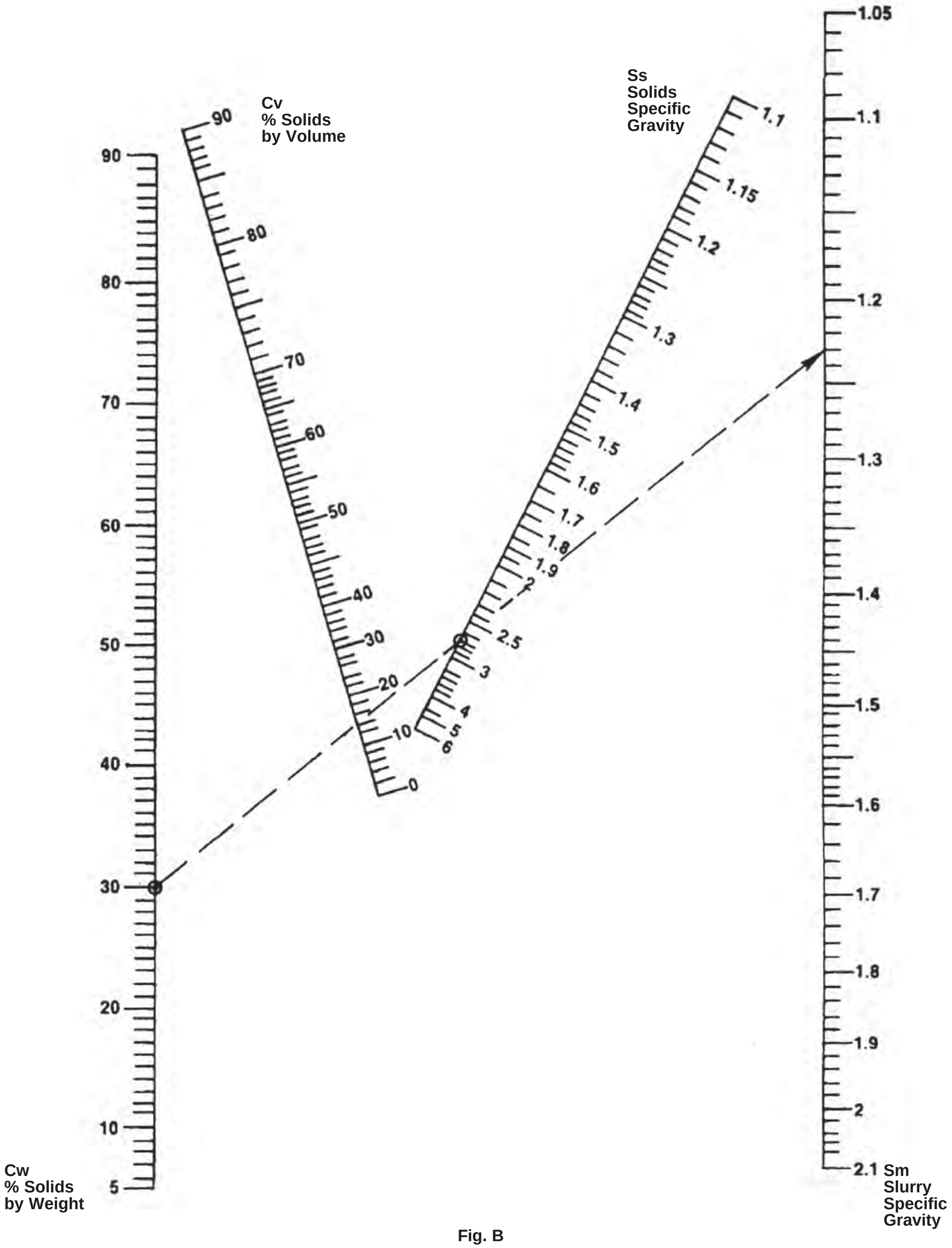
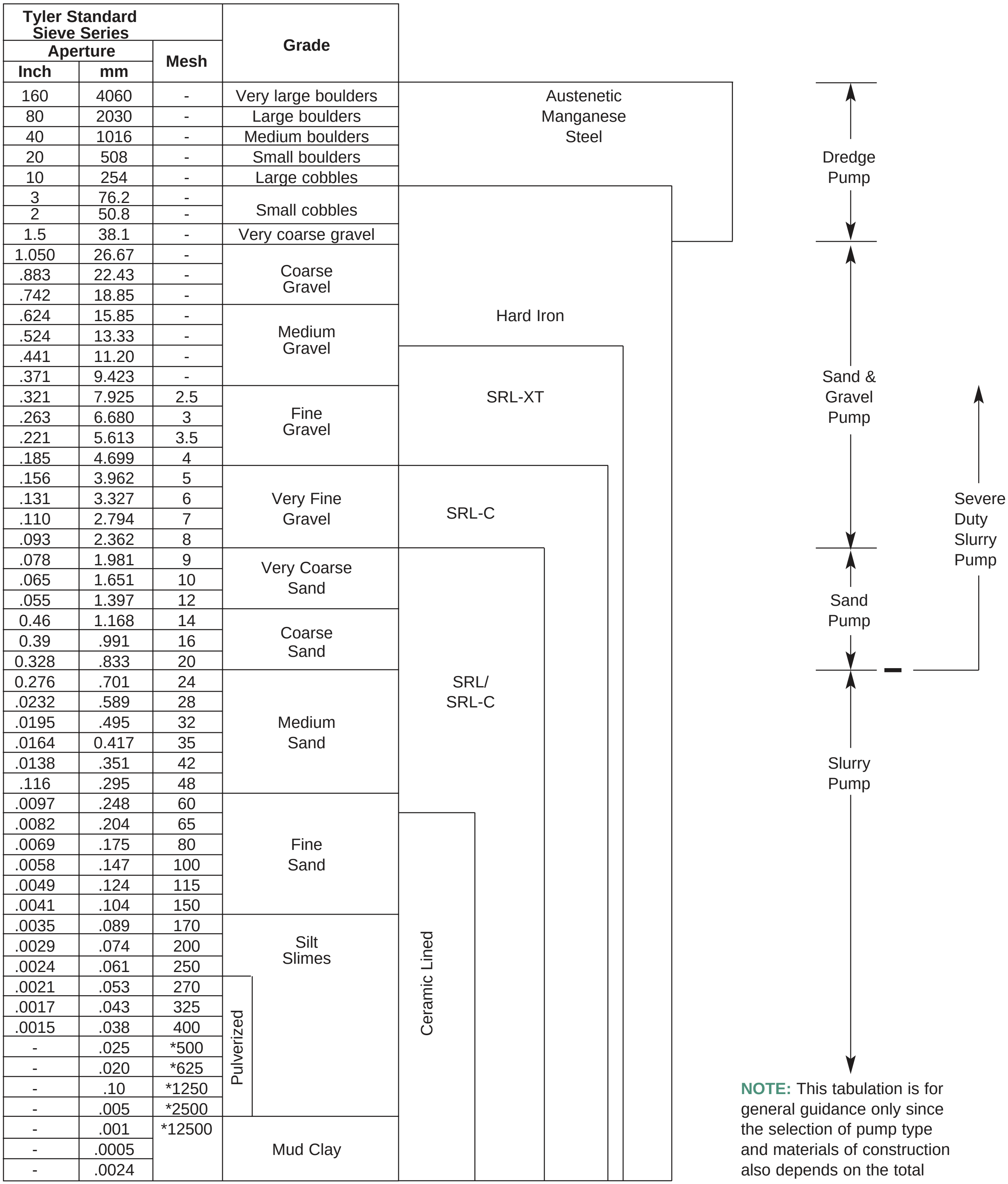


Fig. B

Solids and Slurries

Classification of Pumps According to Solid Size



Tyler Standard Sieve Series		Mesh	Grade
Aperture			
Inch	mm		
160	4060	-	Very large boulders
80	2030	-	Large boulders
40	1016	-	Medium boulders
20	508	-	Small boulders
10	254	-	Large cobbles
3	76.2	-	Small cobbles
2	50.8	-	
1.5	38.1	-	Very coarse gravel
1.050	26.67	-	Coarse Gravel
.883	22.43	-	
.742	18.85	-	
.624	15.85	-	Medium Gravel
.524	13.33	-	
.441	11.20	-	
.371	9.423	-	
.321	7.925	2.5	Fine Gravel
.263	6.680	3	
.221	5.613	3.5	
.185	4.699	4	
.156	3.962	5	Very Fine Gravel
.131	3.327	6	
.110	2.794	7	
.093	2.362	8	
.078	1.981	9	Very Coarse Sand
.065	1.651	10	
.055	1.397	12	
0.46	1.168	14	Coarse Sand
0.39	.991	16	
0.328	.833	20	
0.276	.701	24	Medium Sand
.0232	.589	28	
.0195	.495	32	
.0164	0.417	35	
.0138	.351	42	
.116	.295	48	
.0097	.248	60	Fine Sand
.0082	.204	65	
.0069	.175	80	
.0058	.147	100	
.0049	.124	115	
.0041	.104	150	
.0035	.089	170	Silt Slimes
.0029	.074	200	
.0024	.061	250	
.0021	.053	270	Pulverized
.0017	.043	325	
.0015	.038	400	
-	.025	*500	
-	.020	*625	
-	.10	*1250	
-	.005	*2500	
-	.001	*12500	Mud Clay
-	.0005		
-	.0024		

* Theoretical values   Micron = .001 mm

NOTE: This tabulation is for general guidance only since the selection of pump type and materials of construction also depends on the total head to be generated and the abrasivity of the slurry i.e. concentration, solids specific gravity, etc.

Fig. C

Solids and Slurries

Standard Screen Sizes Comparison Chart

U.S. Bureau of Standard Screens			Tyler Screens				British Standard Screens			I.M.M. Screens		
	Aperture			Aperture				Apeture			Aperture	
Mesh	Inches	mm	Mesh	Inches	mm	Mesh Double Tyler Series	Mesh	Inches	mm	Mesh	Inches	mm
			$2\frac{1}{2}$	.321	7.925							
3	.265	6.73	3	.263	6.680							
$3\frac{1}{2}$	.223	5.66		.221	5.613	$3\frac{1}{2}$						
4	.187	4.76	4	.185	4.699							
5	.157	4.00		.156	3.962	5						
6	.132	3.36	6	.131	3.327		5	.1320	3.34			
7	.111	2.83		.110	2.794	7	6	.1107	2.81			
8	.0937	2.38	8	.093	2.362		7	.0949	2.41	5	.100	2.54
10	.0787	2.00		.078	1.981	9	8	.0810	2.05			
12	.0661	1.68	10	.065	1.651		10	0.660	1.67			
										8	.062	1.574
14	.0555	1.41		.055	1.397	12	12	.0553	1.40			
										10	.050	1.270
16	.0469	1.19	14	.046	1.168		14	.0474	1.20			
										12	.0416	1.056
18	.0394	1.00		.039	.991	16	16	.0395	1.00			
20	.0331	.84	20	.0328	.883		18	.0336	.85			
										16	.0312	.792
25	.0280	.71		.0276	.701	24	22	.0275	.70			
										20	.025	.635
30	.0232	.59	28	.0232	.589		25	.0236	.60			
35	.0197	.50		.0195	.495	32	30	.0197	.50	25	.020	.508
40	.0165	.42	35	.0164	.417		36	.0166	.421	30	.0166	.421
45	.0138	.35		.0138	.351	42	44	.0139	.353	35	.0142	.361
										40	.0125	.317
50	.0117	.297	48	.0116	.295		52	.0166	.295			
60	.0098	.250		.0097	.246	60	60	.0099	.252	50	.01	.254
70	.0083	.210	65	.0082	.208		72	.0083	.211	60	.0083	.211
80	.0070	.177		.0069	.175	80	85	.0070	.177	70	.0071	.180
100	.0059	.149	100	.0058	.147		100	.0060	.152	80	.0062	.157
										90	.0055	.139
120	.0049	.125		.0049	.124	115	120	.0049	.125	100	.0050	.127
140	.0041	.105	150	.0041	.104		150	.0041	.105	120	.0042	.107
170	.0035	.088		.0035	.088	170	170	.0035	.088	150	.0033	.084
200	.0029	.074	200	.0029	.074		200	.0030	.076	170	.0029	.074
230	.0024	.062		.0024	.061	250	240	.0026	.065	200	.0025	.063
270	.0021	.053	270	.0021	.053		300	.0021	.053			
325	.0017	.044		.0017	.043	325						
			400	.0015	.037							

Fig. D

Solids and Slurries

Specific Gravities of Rocks, Minerals and Ores

Material	Specific Gravity	Mohs Hardness
Aluminum	2.55- 2.75	1-2
Amber	1.06-1.11	
Ambylgonite	3-3.1	5.5-6
Andesine	2.66- 2.94	6-6.5
Aragonite, CaCO3	2.94-2.95	3.5-4
Argentite	7.2-7.4	2-2.5
Asbestos	2.1-2.4	2
Asphaltum	1.1-1.5	
Asphalt Rock	2.41	
Barite	4.5	3-3.5
Basalt	2.4-3.1	8-9
Bauxite	2.55-2.73	
Bentonite	1.6	
Bertrandite	2.6	6
Beryl	2.66- 2.83	7.5-8
Biotite	2.7-3.1	2.5-3
Bone	1.7-2	
Borax	1.71-1.73	2-2.5
Bornite	5.06-5.08	3
Braggite	10	
Braunite	4.72- 4.83	6-6.5
Brick	1.4-2.2	
Calcite	2.72-2.94	3
Carnotite	2.47	1-2
Cassiterite	6.99-7.12	6-7
Carbon, Amorphous Graphitic	1.88-2.25	
Celluloid	1.4	
Cerussite	6.5- 6.57	3-3.5
Chalcocite	5.5-5.8	2.5-3
Chalcopyrite	4.1-4.3	3.5-4
Chalk	1.9-2.8	
Charcoal, Pine	0.28-0.44	
Charcoal, Oak	0.47-0.57	
Chromite	4.5	5.5
Chrysoberyl	3.65-3.85	8.5
Cinnabar	8.09	2-2.5
Clay	1.8-2.6	2
Coal, Anthracite	1.4-1.8	2
Coal, Bituminous	1.2-1.5	
Coal, Lignite	1.1-1.4	
Cobaltite	6.2	5.5
Coke	1-1.7	
Colemanite	1.73	4.5
Columbite	5.15-5.25	6
Copper	8.95	2.5-3
Cork	0.22-0.26	
Covellite	4.6-4.76	1.5-2
Cuprite	6	3.5-4
Diabase	2.94	
Diatomaceous Earth	0.4-0.72	
Diorite	2.86	
Dolomite	2.8-2.86	3.5-4
Enargite	4.4-4.5	3
Epidote	3.25-3.5	6
Feldspar	2.55-2.75	
Fluorite	3.18	4
Fly Ash	2.07	
Galena	7.3-7.6	2.5-2.75
Glass	2.4-2.8	7
Goethite	3.3-4.3	5-5.5
Gold	19.3	2.5-3
Granite	2.6-2.9	
Graphite	2.2-2.72	1-2
Gravel, Dry	1.55	4-5
Gravel, Wet	2	
Gypsum	2.3-2.37	2
Halite	2.2	2.5
Hausmannite	4.83-4.85	5.5
Helvite	3.2-3.44	6
Hematite	4.9-5.3	5-6
Hessite	8.24- 8.45	2-3
Ice	0.917	
Ilmenite	4.68-4.76	5-6
Iron, Slag	2.5-3	
Lepidolite	2.8-2.9	2.5-4
Lime, slaked	1.3- 1.4	
Limestone	2.4-2.7	2-5
Limonite	3.6-4	
Linnaeite	4.89	
Magnetite	4.9-5.2	5.5-6.5
Manganite	4.3-4.4	4
Marble	2.5-2.78	4
Marl	2.23	
Millerite	5.3-5.7	3-3.5
Monazite	5.1	5
Molybdenite	4.62-4.73	1-1.5
Muscovite	2.77- 2.88	2.5-3
Niccolite	7.784	5-5.5
Orpiment	3.5	1.5-2
Pentlandite	4.8	2.5-3
Petalite	2.412-2.422	6.5
Phosophite	3.21	
Phosphorus, white	1.83	
Polybasite	6-6.2	2.3
	Porphyry	2.6-2.9
Potash	2.2	
Powellite	4.21-4.25	3.5-4
Proustiie	5.57	2-2.5
Psilomelane	4.71	5-6
Pumice	0.37-0.9	
Pyragyrite	5.85	2.5
Pyrites	4.95-5.1	3.5-4.5
Pyrolusite	4.8	6-6.5
Quartz	2.5-2.8	7-8
Quartzite	2.68	7
Realgar	3.56	1.5-2
Rhodochrosite	3.7	3.5-4
Rhodonite	3.57-3.76	5.5-6.5
Rutile	4.2-5.5	6-6.5
Sand (see Quartz)	1.7-3.2	7
Sandstone	2-3.2	7
Scheelite	6.08-6.12	4.5-5
Schist	2.6-3	
Serpentine	2.5	2.5-3.5
Shale	1.6-2.9	
Siderite	3.9-4	4-4.5
Silica, fused trans.	2.21	
Slag, Furnace	2-3.9	
Slate	2.8-2.9	
Smaltite	6.48	
Soapstone, talc	2.6-2.8	2
Sodium Nitrate	2.2	
Sperrylite	10.58	6-7
Spodumene	3.03-3.22	6.5-7
Sphalerite	3.9-4.1	3.5-4
Stannite	4.3-4.5	4
Starch	1.53	
Stibnite	4.61-4.65	2
Sugar	1.59	
Sulfur	1.93-2.07	1.5-2.5
Sylvanite	8.161	1.5-2
Taconite	3.18	
Tallow, beef	0.94	
Tantalite	7.9-8	6.5
Tetrahedrite	4.6-5.1	3-4.5
Titanite	3.5	
Trap Rock	2.79	
Uraninite	8-11	5-6
Witherite	4.29-4.3	3.5
Wolframite	7.12-7.51	4-4.5
Zinc Blende	4.02	4
Zincite	5.64-5.68	4

Fig. E

Solids and Slurries

Hardness Conversion Table for Carbon and Alloy Steels

Brinell Hardness Number (Carbide Ball)	Rockwell Hardness Numbers					Tensile Strength	
	C Scale	A Scale	15N Scale Superficial	B Scale	30T Scale Superficial	ksl	MPa
	66	84.5	92.5				
722	64	83.4	91.8				
688	62	82.3	91.1				
654	60	81.2	90.2				
615	58	80.1	89.3				
577	56	79	88.3			313	2160
543	54	78	87.4			292	2010
512	52	76.8	86.4			273	1880
481	50	75.9	85.5			255	1760
455	48	74.7	84.5			238	1640
443	47	74.1	83.9			229	1580
432	46	73.6	83.5			221	1520
421	45	73.1	83			215	1480
409	44	72.5	82.5			208	1430
400	43	72	82			201	1390
309	42	71.5	81.5			194	1340
381	41	70.9	80.9			188	1300
371	40	70.4	80.4			182	1250
362	39	69.9	79.9			177	1220
353	38	69.4	79.4			171	1180
344	37	68.9	78.8			166	1140
336	36	68.4	78.3			161	1110
327	35	67.9	77.7			156	1080
319	34	67.4	77.2			152	1050
311	33	66.8	76.6			149	1030
301	32	66.3	76.1			146	1010
294	31	65.8	75.6			141	970
286	30	65.3	75			138	950
279	29	64.6	74.5			135	930
271	28	64.3	73.9			131	900
264	27	63.8	73.3			128	880
258	26	63.3	72.8			125	860
253	25	62.8	72.2			123	850
247	24	62.4	71.6			119	820
243	23	62	71			117	810
240				100	83.1	116	800
234				99	82.5	114	785
222				97	81.1	104	715
210				95	79.8	100	690
200				93	78.4	94	650
195				92	77.8	92	635
185				90	76.4	89	615
176				88	75.1	86	590
169				86	73.8	83	570

Fig. F

Solids and Slurries

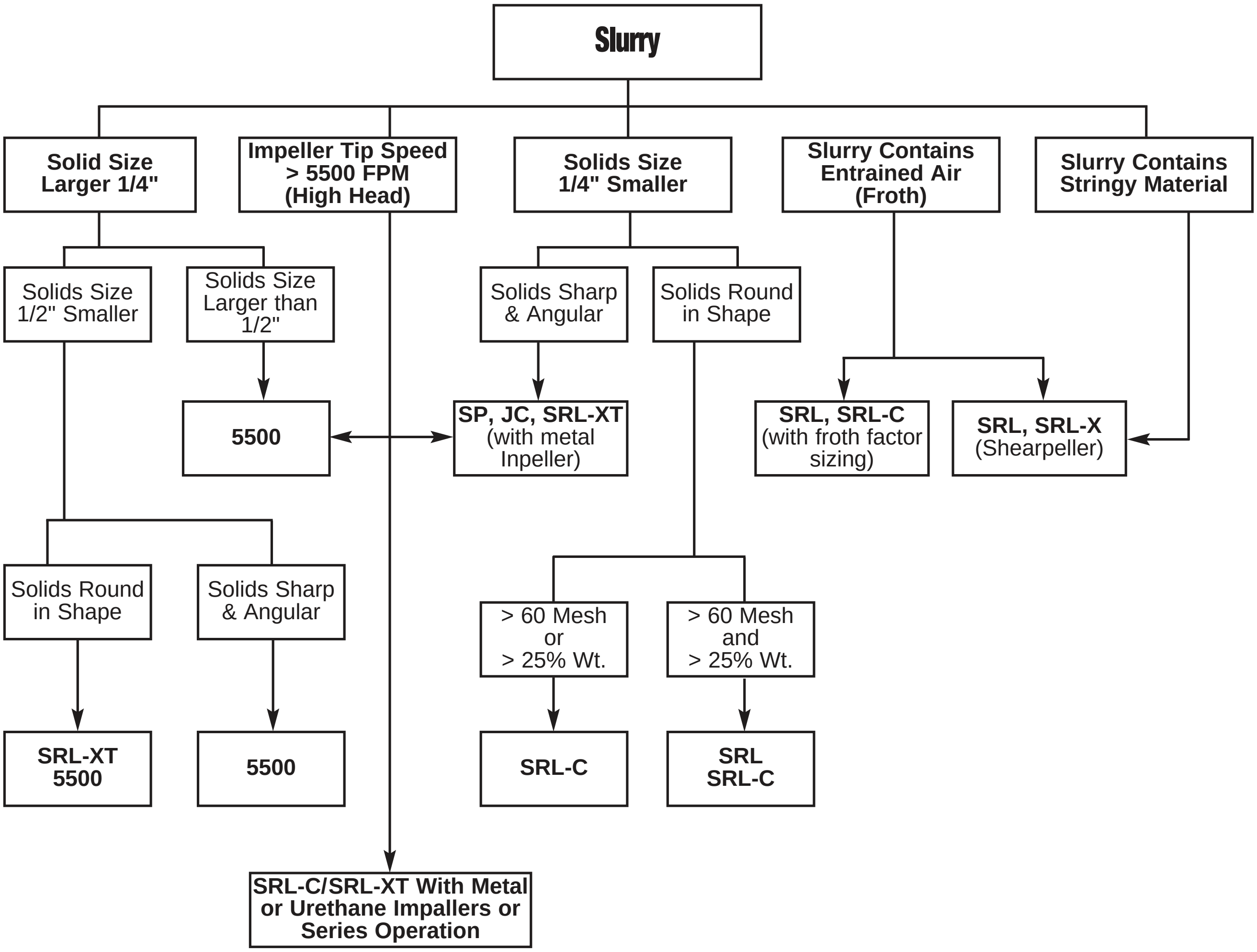
Slurry Pump Materials

MTL CODE	COMMON NAME	ASTM NUMBER	BRINELL HARDNESS	CHARACTERISTICS AND TYPICAL APPLICATIONS	pH RANGE
1002	Cast Iron	A48 Cl. 35B	196-228	Offers moderate resistance to abrasion and corrosion. It is suitable for light slurry applications, particularly those for intermittent service.	6-9
1228	HC600	A532 Cl. III Type A	550-650	Hardened HC600 (High Chromium Iron)	5-12
1245	316SS	A743 GR. CF-8M	159-190	Used for high corrosive, mildly abrasive applications.	3-11
1247	CD4MCu	A734 Gr. CD4MCu	224-325	This is a high strength corrosion resistant alloy for mildly abrasive applications.	

MTL CODE	PRINCIPAL ALLOYING ELEMENTS (%, Bal Fe)						
	Cr	Ni	C	Mn	Si	Mo	Others
1002	-	-	3.25-3.35	0.45-0.70	1.70-1.90	-	-
1228	23.0-28.0	15 Max	2.3-3.0	0.5-1.5	1.0 Max	1.5 Max	-
1245	18.0-21.0	9.0-12.0	0.08 Max	1.5 Max	2.0 Max	2.0-3.0	-
1247	25.0-27.0	5.0-6.0	0.4 Max	-	-	2.0	Cu 3.0

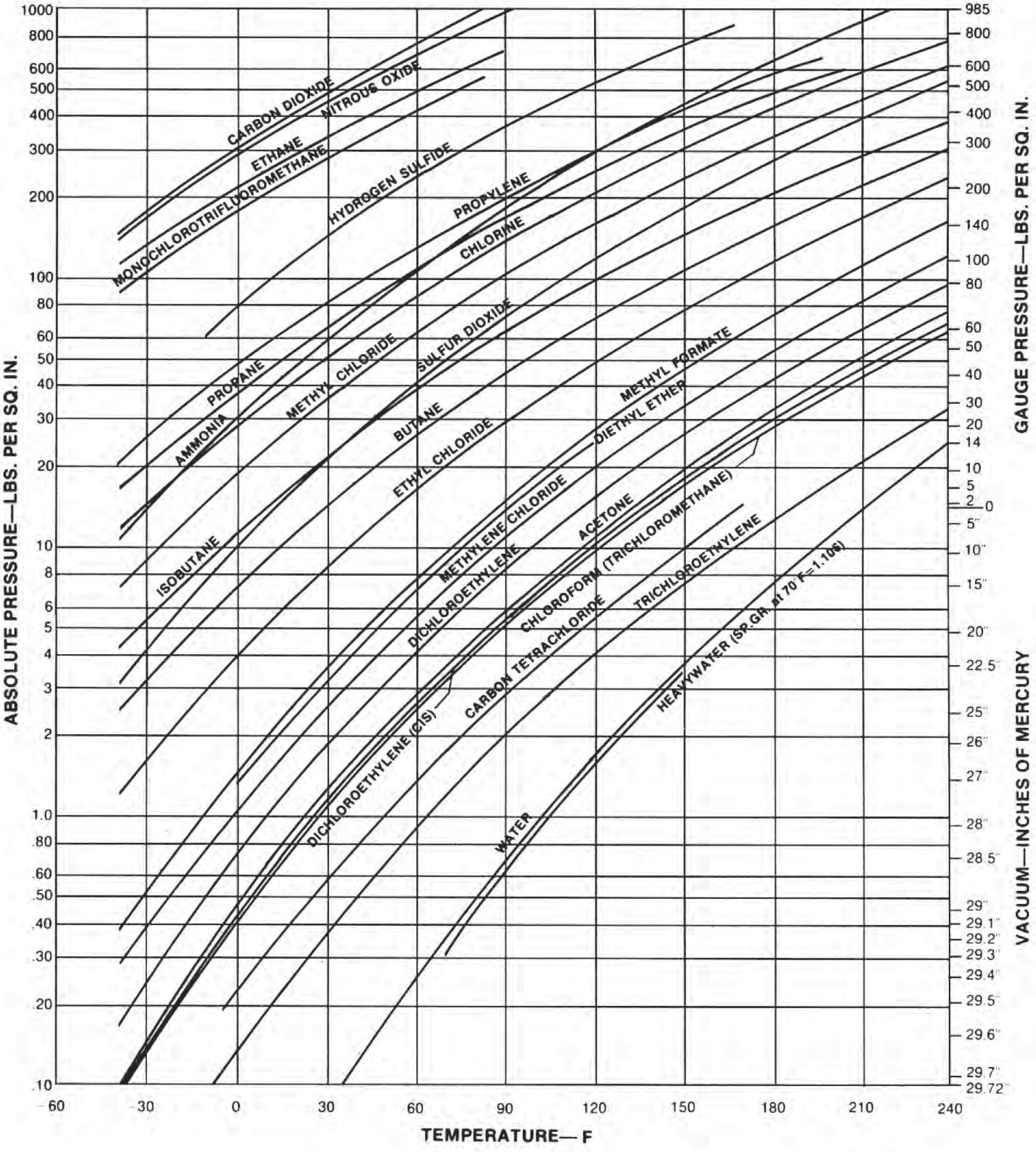
Fig. G

Slurry Pump Application Guidelines



TECH-D-9A Vapor Pressure – Various Liquids

Chart 1 –60° to 240°F



TECH-D-9A Vapor Pressure – Various Liquids

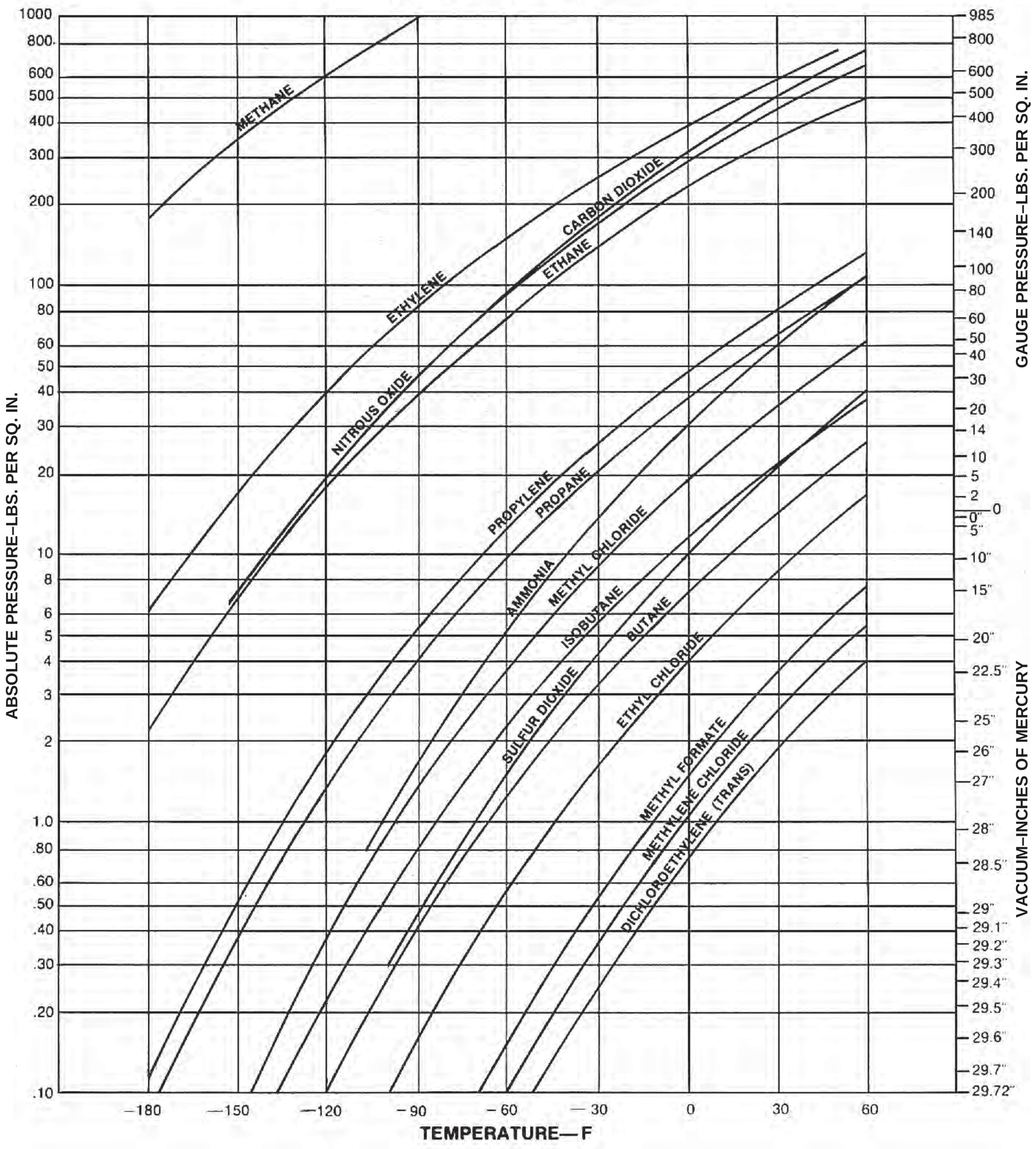


Chart 2 –180° to 60°F