Kelair Pumps Australia Pty Ltd ABN 28 001 308 381 215 Walters Road Arndell Park NSW 2148
Ph: 1300 789 466 Fax: 02 9678 9455 Email: kelair@kelairpumps.com.au www.kelairpumps.com.au
QLD Fax: 07 3805 7309 VIC Fax: 03 9569 7866 TAS Fax: 03 6331 9102 WA Fax: 08 9248 2255

PUMP CLINIC 22

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. A detailed discussion on viscosity is a major undertaking and this article serves to provide a basic understanding of viscosity and how it impacts on pumping.

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 V1 and V2.

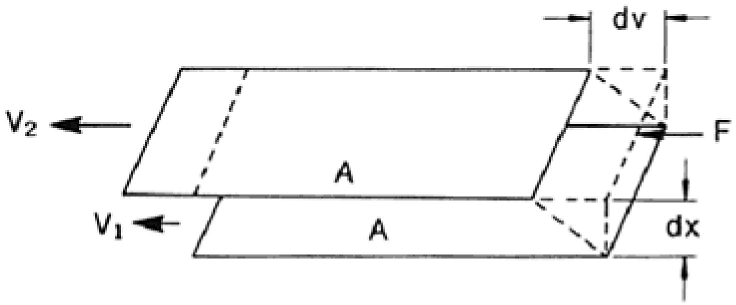

Fig. 1

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 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'.

$$F = n \times S$$

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

Newtonian Liquids

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.

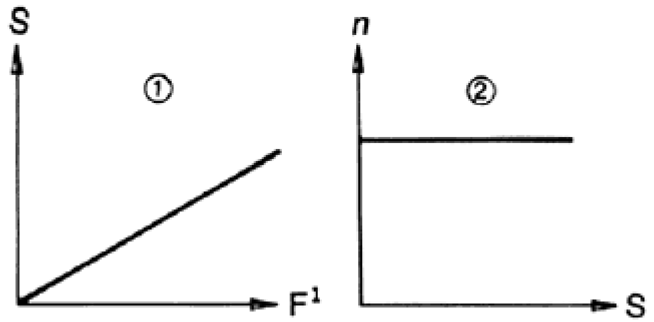

Fig. 2 Newtonian Liquid

Non-Newtonian Liquids

Fig. 3 shows graphically the three most common types of Non-Newtonian liquids. These liquids can present problems to the pump suppliers. 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 mechanical pumping problems since they tend to thin out with the high rates of shear present in a pump. They can present problems in positive displacement pump selection because slippage through clearances may increase due to the drop in viscosity and pump speeds may need to be increased to compensate.

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 sauce is a good example of this type of material. It behaves similar to a pseudo-plastic material from a pumping standpoint.

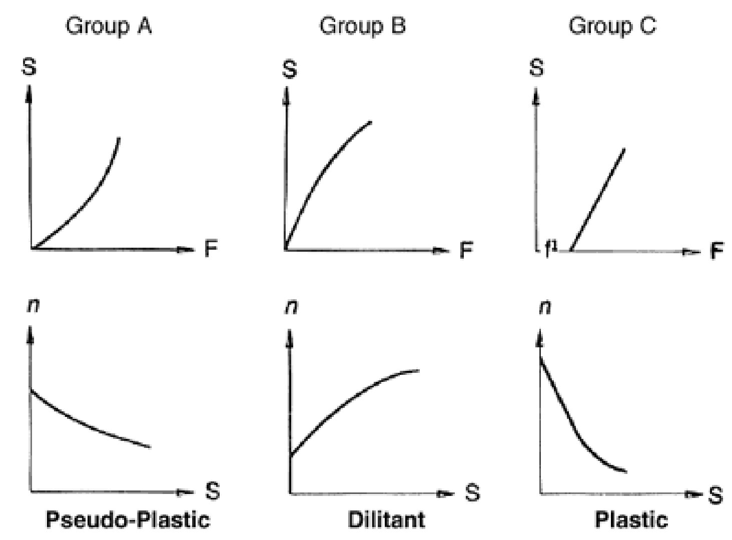

Fig. 3 Non-Newtonian Liquids

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.

Units of Viscosity

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 centimetre called the Poise. This is numerically equal to the gram per centimetre-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 centimetre 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 various units used for viscosity and these are determined by the type of viscometers utilised 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 corresponding units are the SSU (Seconds Saybolt Universal).

These units are found on most pipe friction and pump correction charts in addition to centistokes. Conversion charts for various units of viscosity are attached.

Viscosity and Pumping

1. Centrifugal pumps. Centrifugal pump performance curves are primarily based on the viscosity of water; namely 1cst. Higher viscosities affect the capacity-head performance and more significantly the pump efficiency and therefore power requirements. The water performance of pumps may be adjusted for any viscosity and this is covered in a separate Pump Clinic titled Viscosity Impact on Centrifugal Pump Performance.

   Because of the significant impact of viscosity on power requirements, there are general viscosity limits for centrifugal pumps. These are simply arbitrary figures. The PIA Handbook defines the limits based on the dimension in millimetres of the pump discharge connections and these are

< 50 mm	maximum 300 cst
>50mm but <150 mm	maximum 500 cst
>150 mm	maximum 800 cst

   Our experience has indicated that these viscosities may be a little high and better limits are;

< 50 mm	maximum 100 cst
>50mm but <150 mm	maximum 250 cst
>150 mm	maximum 400 cst

   This only shows the arbitrary nature of these limits. It is important to understand the viscosity characteristics as the liquid is sheared in particular where the viscosity increases with shear and the pump manufacturer should be consulted in these instances.

KelairPumps

Kelair Pumps Australia Pty Ltd ABN 28 001 308 381 215 Walters Road Arndell Park NSW 2148
Ph: 1300 789 466 Fax: 02 9678 9455 Email: kelair@kelairpumps.com.au www.kelairpumps.com.au
QLD Fax: 07 3805 7309 VIC Fax: 03 9569 7866 TAS Fax: 03 6331 9102 WA Fax: 08 9248 2255

2. Positive Displacement Pumps. The application of positive displacement (PD) pumps is easier as the majority of PD pump selection procedures and software programs use viscosity as one of the determining parameters for pump size, speed and motor selection. The other parameters are flow, pressure and other liquid conditions e.g. solids content.

   The change in viscosity as the product is sheared is more important with PD pump selection irrespective of whether viscosity increases or decreases. With decreasing viscosity, the impact of liquid slippage through pump clearances from pump discharge to suction may increase significantly (dependent on differential pressure across the pump) and this needs to be considered in pump size and speed selection. With increasing viscosities, mechanical issues as well a speed reduction is a major consideration. Contact the pump supplier with viscosity change information in these instances.

Section D -- Properties of Liquids

***Viscosity Conversion Table* 1**

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.

$$\text{*Kinematic Viscosity (in centistokes)} = \frac{\text{Absolute Viscosity (in centipoises)}}{\text{Density}}$$

When the Metric System terms centistokes and centipoises are 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:

$$\text{*Kinematic Viscosity (in centistokes)} = \frac{\text{Absolute Viscosity (in centipoises)}}{\text{Specific Gravity}}$$

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		

***Viscosity Conversion Table* 2**

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.)