Rheology – The Science

Rheology is the science of the deformation and flow of matter. In practice, the term "rheology" is generally used in relating to fluids and semi-solids, such as plastics, rubber, oil, drilling mud, cements, paints, inks, ceramic slurries, adhesives, some food products, and body fluids. Many of these materials have complex flow behaviors, in the sense that one cannot safely extrapolate from one set of flow conditions to another. The fact that many fluids of industrial significance do not behave in a classical or "Newtonian" manner leads to the need for characterization under typical process conditions. The process conditions of interest generally include shear stress, shear rate, temperature and pressure. Time effects and shear history effects may also be significant. *Viscometers*, sometimes referred to as *Rheometers*, are instruments developed for the rheological characterization of fluids.

Coaxial Cylinder Viscometers

Fann Instrument Company produces a range of true *Couette* coaxial cylinder rotational viscometers. The test fluid is contained in the annular space or shear gap between the cylinders. Rotation of the outer cylinder at known velocities is accomplished through precision gearing. The viscous drag exerted by the fluid creates a torque on the inner cylinder or bob. This torque is transmitted to a precision spring where its deflection is measured and then related to the test conditions and instrument constants. This system permits the true simulation of most significant flow process conditions encountered in industrial processing.

Direct Reading Viscometers

Fann Direct Reading Rotational Viscometers have been in continuous production for over sixty years. These viscometers have been designed so viscosity in centipoise or millipascal seconds is indicated on the scale when the standard rotor, bob and torsion spring are used at a test speed of 300 rpm. Viscosities at other test speeds are simple multipliers of the scale reading.

The torque scale has a range to 300 degrees deflection with a resolution of about 0.5 degrees. It is also possible to compute a shear stress from the dial reading with appropriate instrument constants. Likewise, a shear rate factor can be computed for a given rotor-bob combination (shear gap) to give a defined shear rate in sec^{1}.

The viscosity, sometimes called apparent viscosity or effective viscosity, can always be computed as:

$$\eta = \frac{\gamma}{\tau}$$

Alternately, the viscosity can be computed in terms of an overall instrument constant K, which can be defined for a particular combination of rotor, bob and torsion spring.

$$\eta = Kf\ \frac{\theta}{N}$$

A wide range of shear rates is made possible through selective gearing and by interchangeable rotors and bobs of various diameters. The instrument may be operated with open end rotor sleeves, which permit a gentle recirculation of material through the annulus, thereby minimizing settling of heavy particles. Optional closed end rotor cups are available for testing of smaller sample volumes.

The torsion springs are designed for ease of interchangeability, which permits the shear stress range of the instrument and, hence, the viscosity measuring range to be optimized for a given testing problem.

FANN Direct Indicating Viscometers

FANN Direct Reading Viscometers combine accuracy with simplicity of design, and are recommended for evaluating materials that are Bingham plastics. These instruments are equipped with factory installed R1 Rotor Sleeve, B1 Bob, F1 Torsion Spring, and a stainless steel sample cup for testing according to American Petroleum Institute Specification RP 13B. Other rotor-bob combinations and/or torsion springs can be substituted to extend the torque measuring range or to increase the sensitivity of the torque measurement (see Measuring Range Chart). Shear stress is read directly from a calibrated scale. Plastic viscosity and yield point of a fluid can be determined easily by making two simple subtractions from the observed data when the instrument is used with the R1-B1 combination and the standard F1 torsion spring. Carrying cases, step-down transformers and other accessories are available.

The Model 35 Viscometer

Fann Model 35 Viscometers are versatile instruments for research or production use. They can be used wherever a regulated-frequency power source is available. The Model 35 Viscometer is widely known as the ***"Standard of the Industry"*** for drilling fluid viscosity measurements.

In the six-speed models, test speeds of 600, 300, 200, 100, 6 and 3 rpm are available via synchronous motor driving through precision gearing. Any test speed can be selected without stopping rotation. The shear stress is displayed continuously on the calibrated scale, so that time-dependent viscosity characteristics can be observed as a function of time. The Model 35A is powered by a 60-Hz motor; Model 35SA by a 50-Hz motor.

Twelve total test speeds let you measure over an extended shear-rate range. Test speeds of 600, 300, 200, 180, 100, 90, 60, 30, 6, 3, 1.8 and 0.9 rpm are available via a synchronous motor driving through an SR12 gear box and then through the precision gearing, as defined for Model 35. The additional 10:3 speed reduction is selectable through a two-position gear-shift lever. The SR12 gear box can be retrofitted to Model 35 Viscometers.

Fann Model 35 Viscometer
6 Speeds

Fann Model 35/SR12 Viscometer
12 Speeds

Measuring Range for FANN Model 35 Viscometers

ROTOR-BOB	R1 B1	R2 B1	R3 B1	R1 B2	R1 B3	R1 B4
BASIC DATA						
Rotor Radius, R_o, cm	1.8415	1.7588	2.5866	1.8415	1.8415	1.8415
Bob Radius, R_j, cm	1.7245	1.7245	1.7245	1.2276	0.8622	0.8622
Bob Height, L, cm	**3.800**	**3.800**	**3.800**	**3.800**	**3.800**	**1.900**
Shear Gap, in Annulus, cm	**0.1170**	**0.0343**	**0.8261**	**0.6139**	**0.9793**	**0.9793**
Radii Ratio, R_j / R_o	0.9365	0.9805	0.667	0.666	0.468	0.468
Maximum Use Temperature, °C	93	93	93	93	93	93
Minimum Use Temperature, °C	**0**	**0**	**0**	**0**	**0**	**0**
Overall Instrument Constant, K	**300.0**	**94.18**	**1355**	**2672**	**7620**	**15,200**
Standard F1 Torsion Spring $\eta = Kf\theta/N$						
SHEAR STRESS RANGE						
Shear Stress Constant for Effective Bob Surface k_2, cm^{-3}	0.01323	0.01323	0.01323	0.0261	0.0529	0.106
Shear Stress Range, dynes/cm^2 $\gamma = k_1 k_2 \theta$						
F 0.2 $\theta = 1^\circ$	1.02	1.02	1.02	2.01	4.1	8.2
F 0.2 $\theta = 300^\circ$	307	307	307	605	1225	2450
F 0.5 $\theta = 1^\circ$	**2.56**	**2.56**	**2.56**	**5.04**	**10.2**	**20.4**
F 0.5$\theta = 300^\circ$	**766**	**766**	**766**	**1510**	**3060**	**6140**
F1 $\theta = 1^\circ$	5.11	5.11	5.11	10.1	20.4	40.9
F1 $\theta = 300^\circ$	1533	1533	1533	3022	6125	12,300
F2 $\theta = 1^\circ$	**10.22**	**10.22**	**10.22**	**20.1**	**40.8**	**81.8**
F2 $\theta = 300^\circ$	**3066**	**3066**	**3066**	**6044**	**12,250**	**24,500**
F3 $\theta = 1^\circ$	15.3	15.3	15.3	30.2	61.3	123
F3 $\theta = 300^\circ$	4600	4600	4600	9067	18,400	36,800
F4 $\theta = 1^\circ$	**20.4**	**20.4**	**20.4**	**40.3**	**81.7**	**164**
F4 $\theta = 300^\circ$	**6132**	**6132**	**6132**	**12,090**	**24,500**	**49,100**
F5 $\theta = 1^\circ$	25.6	25.6	25.6	50.4	102	205
F5 $\theta = 300^\circ$	7665	7665	7665	15,100	30,600	61,400
F10 $\theta = 1^\circ$	**51.1**	**51.1**	**51.1**	**100.7**	**204**	**409**
F10 $\theta = 300^\circ$	**15330**	**15330**	**15330**	**30,200**	**61,200**	**123,000**
SHEAR RATE RANGE						
Shear Rate Constant k_3, sec^{-1} per rpm	1.7023	5.4225	0.377	0.377	0.268	0.268
Shear Rate range, sec^{-1} $\Upsilon = k_3 N$						
N = 0.9 rpm	1.5	4.9	0.4	0.4	0.24	0.24
N = 1.8 rpm	3.1	9.8	0.7	0.7	0.48	0.48
N = 3 rpm	**5.1**	**16.3**	**1.1**	**1.1**	**0.80**	**0.80**
N = 6 rpm	**10.2**	**32.5**	**2.3**	**2.3**	**1.61**	**1.61**
N = 30 rpm	51.1	163	11.3	11.3	8.0	8.0
N = 60 rpm	102	325	22.6	22.6	16.1	16.1
N = 90 rpm	**153**	**488**	**33.9**	**33.9**	**24.1**	**24.1**
N = 100 rpm	**170**	**542**	**37.7**	**37.7**	**26.8**	**26.8**
N = 180 rpm	306	976	67.9	67.9	48.2	48.2
N = 200 rpm	340	1084	75.4	75.4	53.6	53.6
N = 300 rpm	**511**	**1627**	**113**	**113**	**80.4**	**80.4**
N = 600 rpm	**1021**	**3254**	**226**	**226**	**161**	**161**
VISCOSITY RANGE IN CENTIPOISE[1]						
Minimum Viscosity[2]						
All models, 600 rpm maximum	0.5[3]	0.5[3]	2.3	4.5	12.7	25
Maximum Viscosity[4]						
For Model 35A & 35SA, 3 rpm min.	30,000	9,400	135,000	270,000	762,000	1,500,000
For Model 35A/SR 12 & 35SA/SR 12, 0.9 rpm min.	10,000	31,400	400,000	890,000	2,550,000	5,000,000

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"The Original Testing Equipment Company"

Viscosity Computation

Viscosity can be computed in several ways:

1. In terms of an overall instrument constant

$$\eta = Kf \frac{\theta}{N}$$

where K is the overall instrument constant

$$\left(\frac{\text{dyne sec}}{\text{cm}^2}\right) \quad \left(\frac{\text{rpm}}{\text{degrees deflection}}\right)$$

f	is the torsion spring
θ	is the Fann Viscometer reading
N	is the rate of revolution of the outer cylinder
h	will be in centipoise

2. In terms of three instrument constants for torsion spring, bob surface, and shear gap.

$$\eta = \frac{k_1 k_2}{k_3} (100) \frac{\theta}{N}$$

where K_1 is the torsion constant in dyne cm/degree deflection

k_2	is the shear stress constant for the effective bob surface, cm^3
k_3	is the shear rate constant, sec^{-1} per rpm
100	is a conversion factor 1 poise = 100 cP
η	will be in centipoise

3. In terms of shear stress divided by shear rate

$$\eta = \frac{\gamma}{\tau}$$

where τ is the shear stress in dynes/cm^2

τ	$= k_1 k_2 \theta$
γ	=shear rate in sec^{-1}
γ	$= k_3 N$
η	will be in poise 1 poise = 100 cP

Conversion Factors

SI Units	Symbol	Unit	Abbreviation	Conversion
Shear Stress	τ	Pascal 1 Pascal = 1 Newton/meter^2	Pa	1 Pa = 10 dynes/cm^2
Shear Rate	γ	Reciprocal Second	s-1	1 s^{-1} (no change)
Viscosity	η	Pascal Second or Milli Pascal Second	Pa · s mPa · s	1 Pa · s = 10 poise mPa · s = 1 cP
OILFIELD UNITS (R-1 Rotor, B-1 Bob and F-1 Torsion Spring)				
Shear Stress (exact)	τ	dynes/cm^2	---	1° Fann = 5.11 dynes/cm^2
Shear Stress (exact)		lb/100 ft^2	---	1° Fann = 1.065 lb/100 ft^2
Shear Stress (approx.)		lb/100 ft^2	---	1° Fann $\cong$ 1 lb/100 ft^2
Shear Rate	γ	Reciprocal Second	1/sec	1/sec = 1.7023 N (R1, B1)
Viscosity	μ	centipoise	cP	$\mu = \frac{5.11\theta}{1.70N} (100) = 300 \frac{\theta}{N}$ (R1, B1)
Effective Viscosity	μ_e	centipoise	cP	$\mu_e = 300 \frac{\theta}{N}$
Plastic Viscosity	PV	centipoise	cP	$PV = \theta_{600} - \theta_{300}$
Yield Point	YP	lb/100 ft^2	---	$YP = \theta_{300} - PV$

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