OMEGA ENGINEERING, INC.
An OMEGA Technologies Company
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FL-100 SERIES, FL-110, FL-120

Now Available

COMPUTERIZED FLOW TABLES

FOR OMEGA® ROTAMETERS

A new R & D project at Omega Instruments has produced a new computerized procedure for generating complete flow tables for any suitable fluid of known viscosity and density.

- **Tables of flow are available for calibrated and correlated flowmeters at every scale division from 1 to 100.**
- **Similar tables are available for compact flowmeters at every direct flow reading of scale.**
- **Volume flow rates are given at the conditions of flow and corrected to volumes measured at standard conditions.**
- **Each chart for a correlated and calibrated flowmeter is specific to the actual serialized meter and float material.**
- **The flow rate can be given in any units desired including mass flow.**
- **New correlation method uses complex analytical equations programmed to achieve maximum accuracy.**
- **Resultant accuracy is at least twice as good as the best previous correlation developed, namely:**
  Average error = ± 2% or ± 0.5 S.D. whichever is the greater (compared to ± 4% for previous best method)
  Maximum Error = ± 6% or ± 1.5 S.D. whichever is the greater (compared to ± 12% for previous best method)

NEW CORRELATION *

The new computerized method is based on the use of the flow equation given in terms of q as a function of C_R and K_f. A new more extensive correction is used for C_R and K_f as follows:

1. From the latest available flow data and flowmeter characteristics $y(10 + \log C_R)$ is plotted as a function of $u(10 + \log K_R)$ with Parameter R, where,

$$K_R = \sqrt{\frac{St}{R^3}}$$ (we note that

K_R is independent of R and a function of the physical properties of the fluid and the flowmeter only. It is proportional to the square root of the Archimedes number (a dimensionless quantity used in fluid dynamics analysis).

2. Two new functions related to y and u are defined as,
   a. $W = \log w$, where $w = \log z - \log z_0$
   and $\log z = -\log(y_\infty - y)$
   $y_\infty = y$ as $u \to \infty$
   $z_0 = z$ at $St = 5$

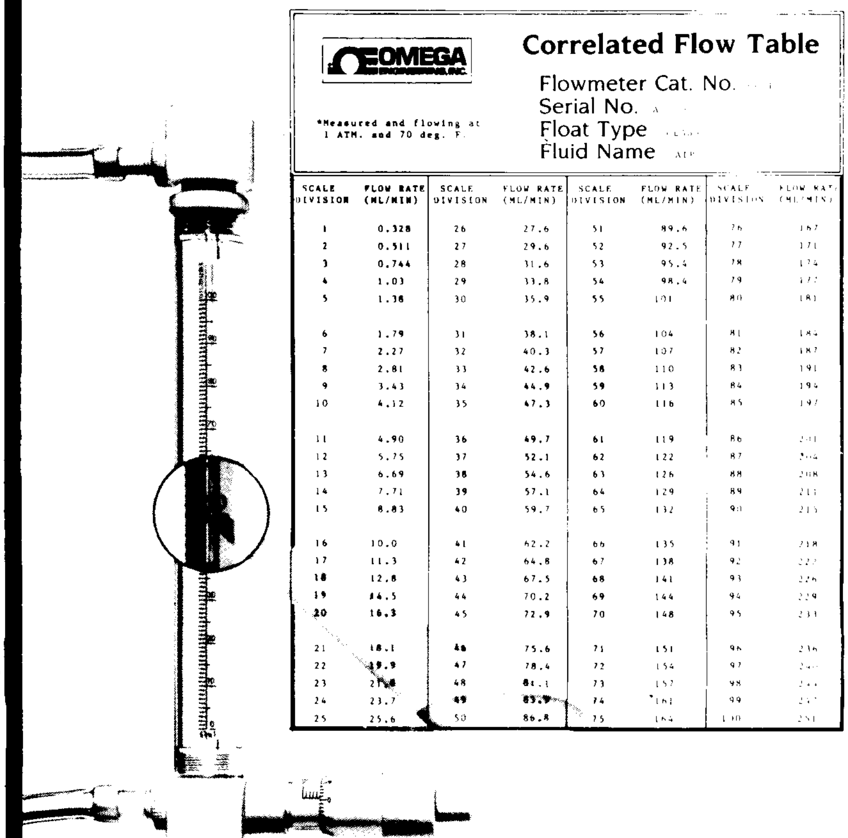
   b. $V = \log v$, where $v = u - u_0$
   and $u_0 = u$ at $St = 5$

3. The analytical relationship between W and V is given by,
$$W = n_0 + n_1V + n_2V^2 + n_3V^3$$

This polynomial expression is evaluated using the best values of the four coefficients, n_0, n_1, n_2 and n_3 determined by a graphical least squares analysis of cross plots and derivative plots. These coefficients in turn are determined by a similar analysis to yield polynominals in R as follows:

$$n_0 = a_{00} + a_{01}R + a_{02}R^2$$
$$n_1 = a_{10} + a_{11}R + a_{12}R^2$$
$$n_2 = a_{20} + a_{21}R + a_{22}R^2$$
$$n_3 = a_{30} + a_{31}R + a_{32}R^2$$

*Reference: Gilmont & Wechsler. Meas. & Control V21, No. 6, P.148 (Dec. 1987).



Correlated Flow Table

Flowmeter Cat. No.
Serial No.
Float Type
Fluid Name

*Measured and flowing at 1 ATM. and 70 deg. F.

SCALE DIVISION	FLOW RATE (ML/MIN)	SCALE DIVISION	FLOW RATE (ML/MIN)	SCALE DIVISION	FLOW RATE (ML/MIN)	SCALE DIVISION	FLOW RATE (ML/MIN)
1	0.328	26	27.6	51	89.6	76	167
2	0.511	27	29.6	52	92.5	77	171
3	0.744	28	31.6	53	95.4	78	174
4	1.03	29	33.8	54	98.4	79	177
5	1.38	30	35.9	55	101	80	181
6	1.79	31	38.1	56	104	81	184
7	2.27	32	40.3	57	107	82	187
8	2.81	33	42.6	58	110	83	191
9	3.43	34	44.9	59	113	84	194
10	4.12	35	47.3	60	116	85	197
11	4.90	36	49.7	61	119	86	201
12	5.75	37	52.1	62	122	87	204
13	6.69	38	54.6	63	126	88	208
14	7.71	39	57.1	64	129	89	211
15	8.83	40	59.7	65	132	90	215
16	10.0	41	62.2	66	135	91	218
17	11.3	42	64.8	67	138	92	222
18	12.8	43	67.5	68	141	93	226
19	14.5	44	70.2	69	144	94	229
20	16.3	45	72.9	70	148	95	233
21	18.1	46	75.6	71	151	96	236
22	19.9	47	78.4	72	154	97	[illegible]
23	[illegible]	48	81.1	73	157	98	[illegible]
24	23.7	49	83.9	74	161	99	[illegible]
25	25.6	50	86.8	75	164	100	251

NOTE: Computer charts are now supplied with all calibrated and correlated rotameters for air and water flow using glass and S.S. floats at standard conditions.

4. The above relationship is modified for a transition region defined by:
$$5 < St < St_0$$
where $St_0 = 5 + b\,R$ (b = a constant)
$V_0 = \log(\tfrac{1}{2} St_0 - .350)$
and $W_0 = n_0 + n_1V_0 + n_2V_0^2 + n_3V_0^3$
Finally, $W_T = V - V_0 + W_0$
where $W_T = W$ for the transition region

5. The relationship between C_R and St is simplified in the Stokes region as before to give:
$$C_R = .0852\sqrt{St}$$
where $St \leq 5$

6. The correction factor, K_f is defined by:
$$K_f = \left[1 - \frac{p}{p_f}\left(\frac{R}{R_f}\right)^2\right]$$
where, R_f is a simple function of v; namely,
$$\frac{100}{R_f} = m_0 + m_1 v$$

The coefficients of the linear function above are again evaluated by a graphical least squares analysis of cross plots of data to yield:
$$m_0 = m_{00} + m_{03}R^3$$
and $m_1 = m_{10} + m_{12}R^2$

From the above correlation, the computer is programmed to yield values of C_R and K_f as a function of R, which in turn is a specific function of scale division for each particular flowmeter. Substituting in

$$q = 59.8\,D_f\,C_R\sqrt{\frac{W_f(\rho_f - \rho)}{\rho_f\,\rho}}\,R\left[\frac{R}{100} + 2\right]K_f$$

yields the volumetric rate at conditions of flow, which in turn is converted to the standard rate by the program. If one attempted these computations with a scientific calculator, it would require an inordinate amount of time to obtain the complete table produced by the computer program as illustrated above.

HOW TO ORDER

When ordering your specific computerized table please supply the following information:

1. Fluid
2. Density and viscosity
   a. At operating conditions of specified pressure and temperature
   b. At standard conditions of 1 atm. and 70°F
3. Float material
4. Flowmeter size and serial number where applicable
5. Units of flow desired

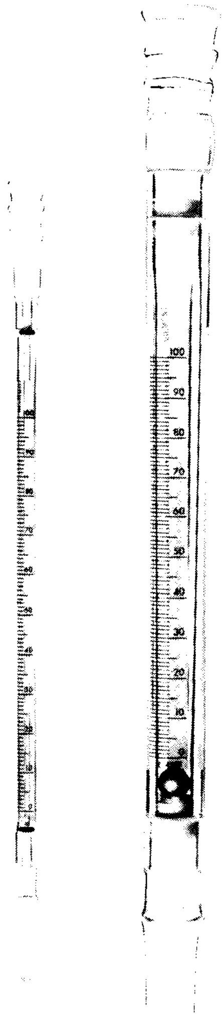
OMEGA® ROTAMETERS
HIGH-ACCURACY, UNSHIELDED

- **Computer tables are now included at no extra charge — four tables in all, air and water at standard conditions using glass and stainless steel floats. For other fluids and any conditions of flow.**
- **The standard calibration chart for air and water using the glass float now contains the values of R for use with the new generalized correlation.**
- **Calibration curves for any fluid and float can be obtained at the operating conditions of flow using the new generalized correlation. Only the density and viscosity of the fluid need be known.**
- **Each serialized meter is statistically calibrated with air at three points (an improvement over the previous two point calibration) to assure an accuracy of ± 2% or ± 1 Scale division (whichever is the greater).**
- **Readings are reproducible to ± 1% or ± 0.5 scale divisions (whichever is the greater).**
- **Other features have been maintained as follows:**
  1. Specially designed Teflon stops accept corresponding tapered joints and O-Rings to make a vacuum tight seal.
  2. Permanent black ceramic scale and white background for easy reading.
  3. Corrosion resistant-fluid comes in contact with glass and teflon only (when using glass float and plain end meter).
  4. Glass and stainless steel floats are supplied with each meter. A conversion chart indicates pressure drops for each float and converts flow rates with the glass float to those with stainless steel.

These flowmeters are manufactured from tapered precision bore tubing to ultimate tolerances (±.0001-.0002") which give maximum precision attainable for spherical float rotameters. The tolerances on the floats are of comparable magnitude.

The latest generalized correlation is based on a new dimensionless quantity K_R** (related to the Archimedes number). Prediction of fluid flows with an accuracy at least twice as good as any previous method is now possible (see page 1). See DIRECTIONS of sample calculations using graphical and analytical methods.

* U.S. Patent No. 3,183,713
** Reference: Gilmont & Maurer. Instr. & Control Sys. V.34, p.2070 (1941).
Reference: Gilmont & Wechsler. Meas. & Control V.21, No. 6, p.148 (Dec. 1987).



FL-101 FL-105
Shown with respective joint sets attached.

DIRECTIONS

The procedure for calculating the flow of any fluid of known density and viscosity are based on the new standard correlation curve supplied with the new serialized flowmeter. NOTE: Owners of old serial numbers may write for a new chart at no extra charge, by supplying us with the size and serial number of the flowmeter.

GRAPHICAL SOLUTION

1. Select the desired value of R at the corresponding value of the scale division from the calibration curve supplied.
2. Calculate the value of K_R:

$$K_R = \frac{1.021}{\mu}\left[\frac{W_f(\rho_f - \rho)\rho}{\rho_f}\right]^{0.5}$$

where, μ = viscoscity of fluid in cp
W_f = weight of float in g/cc
ρ_f = density of float in g/cc
ρ = density of fluid in g/cc
note, W_f and P_f are given in the calibration curve data.

3. From the correlation chart on the next page obtain the value of C_R corresponding to R and K_R. When $C_R < .19$, use the equation

$$C_R = .0852 K_R R^{1.5}$$

4. Determine the value of the correction factor, K_t. For gases and values of $R < 10$, the value of K_t may be taken as unity. If not, determine K_t as follows:
   a. Calculate the value of v:
   $$v = \log K_R - .350 + \frac{3}{2}\log R$$
   b. From the Correction Factor Chart on the page following the Correlation Chart, obtain the value of $100/R_t$ corresponding to the values of R and v.
   c. Calculate the value of K_t:
   $$K_t = 1 - \frac{\rho}{\rho_f}\left[\frac{R}{R_t}\right]^2$$
5. Calculate the volumetric rate of flow, q:

$$q = C_R K_q R\left[\frac{R}{100} + 2\right]K_t$$

where,

$$K_q = 59.8\, D_f\left[\frac{W_f(\rho_f - \rho)}{\rho\rho_f}\right]^{0.5}$$

and D_f = Diam. float in inches from data.

6. The above value of q is at the conditions of flow which may be reduced to a volume measured at standard conditions, q': $q' = q\rho/\rho$ where, ρ_0 = density at standard conditions

SAMPLE CALCULATIONS

Flowmeter, Size #1, F1100, Glass Float, W_f = .00530 g, ρ_f = 2.53 g/cc, D_f = .0625 in. Water at 40 °C, μ = .653 cp., ρ = .992 g/cc, ρ_0 = .998 g/cc. Values of R at 5, 10 & 25

$$K_R = \frac{1.021}{.653}\left[\frac{.00530(2.53 - .992).992}{2.53}\right]^{0.5} = .08836,\ K_q = .2130$$

R	C_R	v	$100/R_t$	K_t	q	q'
5	.0842	—	—	1	.184	.183
10	.233	.097	4.44	.923	.962	.956
25	.526	.693	2.30	.870	5.48	5.45

FOR ANALYTICAL SOLUTION see page following the CORRELATION CHART.

CLEANING: When cleaning the meter, great care should be exercised not to lose the ball, especially for the smaller sizes. It is possible to replace the ball with negligible error because the diameter and density of the ball are held to very close tolerances. Normal methods of cleaning are recommended using mild detergents and drying with acetone.

JOINT SETS: It is recommended that short lengths of flexible tubing (such as tygon or teflon) be used on each end to hold the joints securely to the flowmeter especially with the smaller sizes (#0 and #1). To protect the tiny teflon stops of these smaller sizes a suitable needle may be inserted in the orifice upon assembly and disassembly.

SPARE PARTS LIST

SIZE No. Description	ρf	FA	FW	0 Cat. No.	1 Cat. No.	2 Cat. No.	3 Cat. No.	4 Cat. No.	5 Cat. No.
Teflon Stop, Top				F-2004	F-1104	F-1204	F-1304	F-2404	F-2504
Teflon Stop, Bottom				F-2005	F-1105	F-1205	F-1305	F-1405	F-1505
Flowmeter Tube				F-2031	F-1131	F-1231	F-1331	F-1431	F-1531
Joint, Inner				F-1133	F-1133	F-1233	F-1333	F-1433	F-1533
Joint, Outer				F-1134	F-1134	F-1234	F-1334	F-1434	F-1534
O-Ring for Joint				S-1105	S-1105	F-7032	S-1205	F-1435-V	F-1535-V
O-Ring, EPR				S-1105-E	S-1105-E	F-7032-E	S-1205-E	F-1435-E	F-1535-E
FLOAT									
Glass	2.53	1	1	F-2032	F-1132	F-1232	F-1332	F-1432	F-1532
S.S.	8.02	1.8	2.1	F-2032-S	F-1132-S	F-1232-S	V-2119-S	F-1432-S	F-1532-S
Tant.†††	16.6	2.6	3.2		F-1132-T	F-1232-T	F-1332-T		
T.C.†††	14.9	2.4	3.0	F-2032-TC				F-1432-TC	F-1532-TC

ρ_f = density, F_A and F_W are magnifying factors for air & water
††† supplied with conversion chart for flow and pressure drop

NOTE: Extremely dry gases, at low flows, may cause erratic readings due to electrostatic charge build-up.

FLOWMETERS, PLAIN ENDS / SET OF JOINTS†

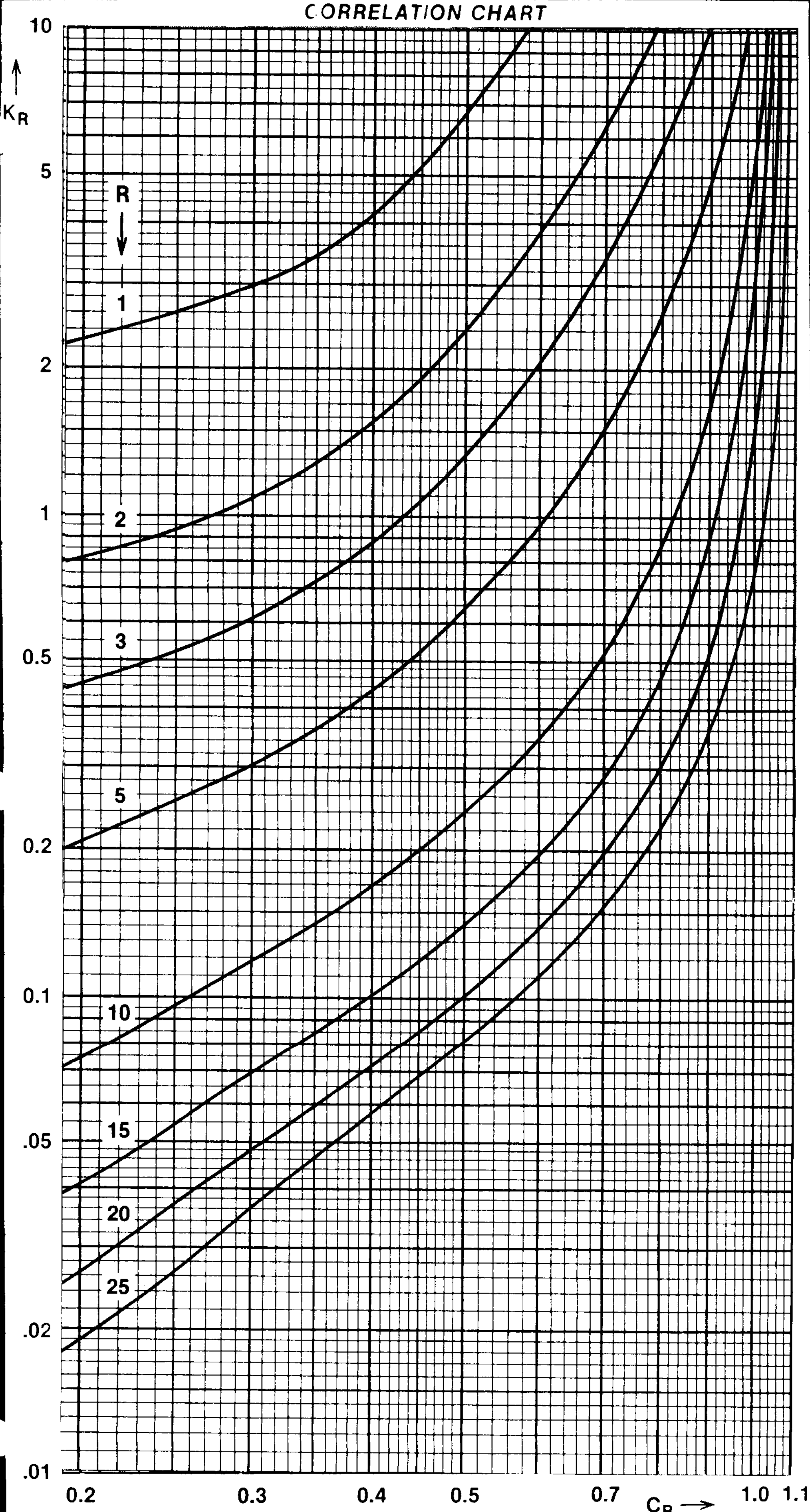
SIZE	RANGES ML/MIN †† AIR	RANGES ML/MIN †† WATER	CAT. NO.	FLOAT DIAM. "	TUBE O.D. "	TUBE LENGTH "	$	CAT. NO.
0	0.2-100	.002-1.1	FL-100	.0469	5/16	7½	10/30	FL-J1
1	1-280	.01-4.0	FL-101	.0625	5/16	7½	10/30	FL-J1
2	10-1900	0.2-36	FL-102	.125	5/16	7½	12/30	FL-J2
3	200-14,000	3-300	FL-103	.250	7/16	7½	14/35	FL-J3
4	1000-36,000	10-850	FL-104	.375	11/16	9	19/38	FL-J4
5	3000-77,000	30-1900	FL-105	.500	15/16	9	24/40	FL-J5

Each meter is supplied with complete directions and correlation charts for calculating the calibration curve for any fluid whose density and viscosity are known. Owners of serialized flowmeter made prior to the new computerized correlation, may order any one of the four computer tables. Just supply us with flowmeter size and serial number and specify desired tables.

†Consists of one inner and outer joint plus two O-rings.

††Flow ranges for glass float stated above may be extended by factors of approx 2 to 3 by using heavier floats. See Spare Parts List.

CORRELATION CHART



FOR $C_R < 0.19$, $C_R = .0852\ K_R R^{1.5}$

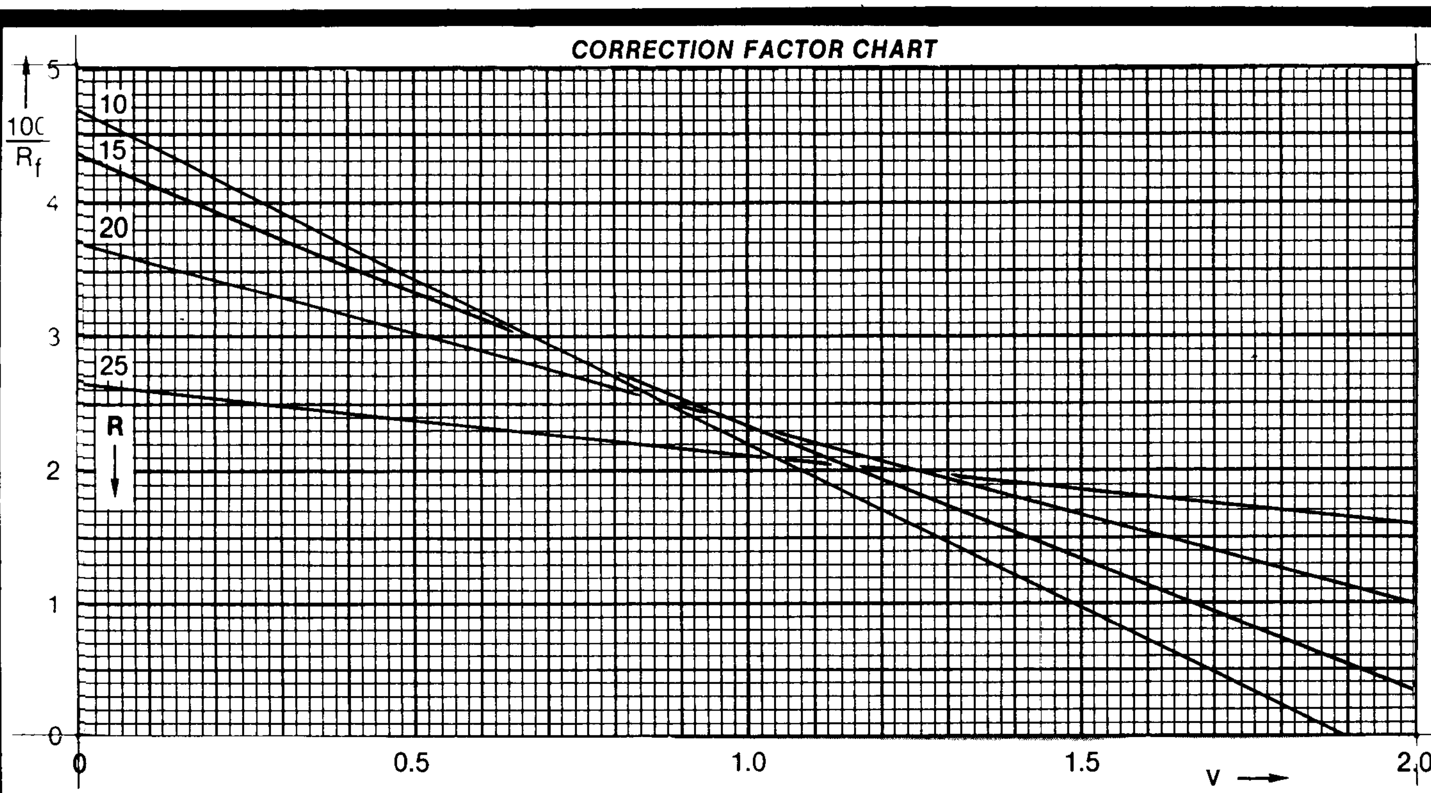
Density & Viscosity of Gases at 70°F & 1 atm

GAS	ρ in g/Li	μ in cp
Acetylene	1.087	.0101
Air	1.200	.0181
Ammonia	.7155	.00986
Argon	1.655	.0221
Butane (n)	2.510	.0076
Butane (iso)	2.481	.0076
Carbon dioxide	1.835	.0148
Carbon monoxide	1.160	.0174
Chlorine	2.989	.0133
Ethane	1.259	.00913
Ethylene	1.170	.0101
Helium	.1657	.0194
Hydrogen	.0834	.0087
Hydrogen chloride	1.522	.0144
Hydrogen sulfide	1.429	.0126
Krypton	3.382	.02514
Methane	.6653	.0109
Methyl chloride	2.139	.0107
Neon	.8358	.0312
Nitric oxide	1.244	.0188
Nitrogen	1.161	.0175
Nitrous oxide	1.836	.0144
Oxygen	1.326	.0203
Propane	1.875	.00803
Sulfur dioxide	2.717	.0125
Xenon	5.307	.0226

TABLE II

Density & Viscosity of Liquids at 70°F & 1 atm

LIQUID	ρ in g/ml	μ in cp
Acetic Acid	1.049	1.221
Acetone	.790	.32
Aniline	1.022	4.40
Benzene	.879	.652
Butyl Acetate	.883	.732
n-butanol	.810	2.948
CCl_4	1.594	.969
Chlorobenzene	1.106	.799
Chloroform	1.483	.58
Diethyl Ether	.714	.233
Ethyl Acetate	.900	.455
Ethanol	.789	1.20
Ethylene Br	1.460	1.72
Ethylene Cl	.898	.79
Ethylene Glycol	1.109	19.90
Fluorobenzene	1.023	.598
Heptane	.684	.409
Methyl Acetate	.933	.381
Methanol	.791	.597
Nitrobenzene	1.204	2.03
n-octane	.703	.542
Propanol	.804	2.256
Toluene	.867	.590
o-xylene	.880	.810
m-xylene	.864	.620
p-xylene	.861	.648
Aqueous Solutions (% by weight)		
10% HCl	1.048	1.159
30% HCl	1.149	1.702
10% HNO_3	1.054	1.042
40% HNO_3	1.247	1.558
10% H_2SO_4	1.066	1.228
60% H_2SO_4	1.499	5.905



ANALYTICAL SOLUTION OF FLUID FLOW

1. Same as step 1 of GRAPHICAL SOLUTION on previous page
2. Same as step 2 of GRAPHICAL SOLUTION
3. Calculate the following:
   a) $St = K_R^2 R^3$
   b) $St_0 = 5 + .777R$
4. Determine the region of flow as follows:
   a) If $St < 5$ region is Stokes, skip to step 9
   b) If $St_0 \geq St \geq 5$ region is transitional, skip to step 6
   c) If $St > St_0$ region is turbulent, proceed to step 5
5. For the turbulent region, calculate the following:
   a) $V = \log[\log K_R - .350 + 1.5 \log R]$ (K_R from step 2)
   b) $W_c = n_0 + n_1 V + n_2 V^2 + n_3 V^3$
   where, $n_0 = -.197 + .00418R - .000155R^2$
   $n_1 = 1.065 - .0189R + .001375R^2$
   $n_2 = .929 - .1510R + .004025R^2$
   $n_3 = .542 - .06185R$, skip to step 7
6. For the transitional region calculate the following:
   a) $V_0 = \log[0.5 \log St_0 - .350]$ (St_0 from step 3b)
   b) $W_0 = n_0 + n_1 V_0 + n_2 V_0^2 + n_3 V_0^3$ (coeff. the same as in 5b)
   c) $W_c = W_0 - V_0 + V$ (V as calculated in Step 5a)
7. Calculate the following:
   a) $w_c = \log^{-1} W_c$
   b) $z_c = \log^{-1}(w_c + 0.1193)$
   c) $y_c = 10.040 - (1/z_c)$
   d) $C_R = \log^{-1}(y_c - 10)$
8. Determine the value of K_f as follows: ($K_f = 1$ for gases)
   a) $v = \log^{-1} V$ (V from step 5a)
   b) $R_f = \dfrac{100}{m_0 + m_1 v}$

   where, $m_0 = 4.81 - .138 \dfrac{R^3}{1000}$

   $m_1 = -2.82 + .369 \dfrac{R^2}{100}$

   c) $K_f = 1 - \dfrac{\rho}{\rho_f}\left[\dfrac{R}{R_f}\right]^2$ Skip to step 10
9. For the Stokes region calculate:
   a) $C_R = .0852(St)^{0.5}$
   b) $K_f = 1 - \dfrac{\rho}{\rho_f}\left[\dfrac{m_0 R}{100}\right]^2$ (m_0 from step 8b)
10. Calculate the volumetric flow at the conditions of flow:

    $$q = C_R K_q R\left[\frac{R}{100} + 2\right] K_f$$

    where, $K_q = 59.8\, D_f \left[\dfrac{W_f(\rho_f - \rho)}{\rho \rho_f}\right]^{0.5}$
11. The above flow (q) may be reduced to a volume measured at standard conditions (q^1) as follows:

    $q' = q \dfrac{\rho}{\rho_0}$ where, ρ_0 = density at std. cond.

SAMPLE CALCULATIONS FOR ANALYTICAL SOLUTION

Step		R = 5	R = 10	R = 25
1.	R :	5	10	25
2.	K_R = .08836 for all values of R			
3.	St = .00781 R^3			
a)	St :	.975	7.81	122.0
b)	St_0 :	8.885	12.77	24.4
4.	Region:	Stokes	transitional	turbulent
5. a)	V :			−.1592
b)	W_c :			−.4249
	n_0 :		−.1707	−.1894
	n_1 :		1.0315	1.4519
	n_2 :		−.1785	−.3304
	n_3 :		−.0765	−1.0043
6. a)	V_0 :		−.6923	
b)	W_0 :		−.9325	
	V :		−1.0613	
c)	W_c :		−1.2565	
7. a)	w_c :		.0554	.3760
b)	z_c :		1.495	3.128
c)	y_c :		9.371	9.72
d)	C_R :		.235	.525
8. a)	v :		.09632	.6931
b)	R_f :		22.54	43.52
	m_0 :		4.672	2.654
	m_1 :		−2.451	−.5138
c)	K_f :		.923	.871
9. a)	C_R :	.0842		
b)	m_0 :	4.79		
	K_f :	.977		
10.	K_q = .2130 for all values of R			
	q :	.180	.970	5.48
11.	q' :	.179	.964	5.45

*** NOTE: For size #0 and S.S. Float multiply by an additional factor K_f^1:**

$$K_f^1 := \left[1 - \left(\frac{\rho}{\rho_f}\right)^2\right]\left(1 - \frac{R}{R_f'}\right)^2$$

Where: R_f' = 700 for gases
R_f' = 355 - 51.5 R + 2.37 R^2 for Liquids