Encyclopedia of Chemical Processing and Design

33

Executive Editor John J. McKetta

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EXECUTIVE EDITOR John J. McKetta
ASSOCIATE EDITOR William A. Cunningham

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Organic Liquids, Thermal Conductivity Estimation to Peat Supply–Demand Relationships

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Contributors to Volume 33

P. W. Allen Senior Engineering Associate, Intermediates Technology Division, Exxon Chemical Company, Baton Rouge, Louisiana: *Oxo Process Alcohols*

Peter A. Bergh Manager Pulp & Paper Division, Foxboro Company, The Netherlands: *Paper and Pulp, Retrofitting with Advanced Control*

Terry L. Blevins Senior Technologist, Fisher Controls International, Inc., Austin, Texas: *Paper and Pulp, Energy Management; Paper and Pulp, Retrofitting with Advanced Control*

Gilbert K. Chen, Ph.D. Vice President, Technology, Glitsch, Inc., Dallas, Texas: *Packed Towers, Design; Packed Towers, Internals*

Chun H. Cho, Ph.D. Senior Technical Consultant, Fisher Controls International, Inc., Marshalltown, Iowa: *Paper and Pulp, Energy Management*

Richard A. Corbett, P.E. Refining/Petrochemical Editor, Oil & Gas Journal, Houston, Texas: *Packings and Gaskets, Substitute Materials*

Ralph M. Cox, P.E. Vice President-Engineering, Industrial Handling Engineers, Inc., Houston, Texas: *Packaging, Chemicals*

Charles L. Davis, Ph.D. Bureau of Mines, Branch of Chemical Materials, Washington, D.C.: *Peat Supply—Demand Relationships*

L. Dev, Ph.D. Weyerhauser Company, Tacoma, Washington: *Paper and Pulp, Steam Stripping of Condensates*

John L. Dunlap Manager, Applications Engineering, Fisher Controls International, Inc., Austin, Texas: *Paternering and Life Cycle Procurement; Parts Inventory*

Ken R. Ferguson Lead Design & Construction Engineer, Chevron, U.S.A, Snyder, Texas: *Orifice Meter Accuracy, High Flow Rates*

Andrew Garner Director, Process Physics Division, Pulp and Paper Research Institute of Canada, Pointe Claire, Quebec, Canada: *Paper and Pulp Industry, Alloy Selection*

Timothy L. Holmes, Ph.D. Director, Research & Development, Otto H. York, Co., Inc., Fairfield, New Jersey: *Packed Towers, Design*

Jerry R. Johanson, Ph.D. President, JR Johanson, Inc., San Luis Obispo, California: *Particle Segregation, Prevention*

Emrys H. Jones, Jr., Ph.D. Senior Engineering Associate, Chevron Oil Field Research Co., La Habra, California: *Orifice Meter Accuracy, High Flow Rates*

J. B. Joshi Department of Chemical Technology, University of Bombay, Matunga, Bombay, India: *Packed Towers Shortcuts, Pressure Drop Estimation*

P. W. Kelso Weyerhauser Company, Tacoma, Washington: *Paper and Pulp, Steam Stripping of Condensates*

Jerry M. Keys Brown, Maroney, Rose, Barber & Dye, Austin, Texas: *Patents*

Robert Lowrie, Ph.D. Consulting Engineer, The BOC Group Technical Center, Murray Hill, New Jersey: *Oxygen Service, Materials for*

Mileta Mikasinovic, P.E. Ontario Hydro, Toronto, Ontario Canada: *Orifices, Cavitation Prevention; Orifices, Throttling, Sizing of*

William J. Moltz Brown, Maroney, Rose, Barber & Dye, Austin, Texas: *Patents*

Kathleen F. Morris Director, Delta Consulting Group, Inc., New York, New York: *Performance Appraisal*

Malcolm G. Murray, Jr., P.E. Owner, Murray & Garig Tool Works, Baytown, Texas: *O-Rings*

Robert B. Neveril Gard, Inc., Niles, Illinois: *Particle Emissions Control Costs*

K. Niranjan Department of Chemical Technology, University of Bombay, Matunga, Bombay, India: *Packed Towers Shortcuts, Pressure Drop Estimation*

Ernest O. Ohsol, Sc.D., P.E. Technical Director, OPR Technical Associates, Houston, Texas: *Oxidation of Aromatics; Paper Manufacture*

V. G. Pangarkar Department of Chemical Technology, University of Bombay, Matunga, Bombay, India: *Packed Towers Shortcuts, Pressure Drop Estimation*

R. L. Pruett Chief Scientist (retired), Intermediates Technology Division, Exxon Chemical Company, Baton Rouge, Louisiana: *Oxo Process Alcohols*

Joseph F. Reilly, Jr., P.E., C.M.C. President, Industrial Handling Engineers, Inc., Houston, Texas: *Packaging, Chemicals*

B. Tammami Superior Hard-Surfacing Co., Inc., Tulsa, Oklahoma: *Partial Condensor, Flooding Prevention*

Tom C. Tsai, Ph.D., P.E. Consulting Engineer, TDS Associates, Houston, Texas: *Packed Towers Shortcuts, Computer Calculation*

Patrick C. Tung, P.E. Ontario Hydro, Toronto, Ontario, Canada: *Orifices, Cavitation Prevention; Orifices, Throttling, Sizing of*

William M. Vatavuk, P.E. Senior Chemical Engineer, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina: *Particle Emissions Control Costs*

Guy E. Weismantel President, Weismantel International, Kingwood, Texas: *Paints and Coatings*

E. J. Wickson President, Wickson Product Research Ltd., Baton Rouge, Louisiana: *Oxo Process Alcohols*

E. John Wilkinson, Ph.D. Manager, Government Affairs, Vulcan Chemicals, Division of Vulcan Materials Company, Washington, D.C.: *Pentachlorophenol*

Adam Zanker, Ch.E., M.Sc. Senior Research Engineer, Oil Refineries, Ltd., Haifa, Israel: *Organic Liquids, Thermal Conductivity Estimation; Orifices, Air Flow Estimation; Packed Towers Shortcuts, Diameter, Optimum; Packed Towers Shortcuts, Efficiency; Packed Towers Shortcuts, Liquid Holdup and Pressure Drop; Packed Towers Shortcuts, Liquid Velocity, Linear; Particle Size Distribution Estimation;*

Frederick A. Zenz, Ph.D. Technical Director, Particulate Solid Research, Inc., Riverdale Station, Bronx, New York: *Particulate Technology*

Conversion to SI Units

To convert from	To	Multiply by
acre	square meter (m^2)	4.046×10^3
angstrom	meter (m)	1.0×10^{-10}
are	square meter (m^2)	1.0×10^2
atmosphere	newton/square meter (N/m^2)	1.013×10^5
bar	newton/square meter (N/m^2)	1.0×10^5
barrel (42 gallon)	cubic meter (m^3)	0.159
Btu (International Steam Table)	joule (J)	1.055×10^3
Btu (mean)	joule (J)	1.056×10^3
Btu (thermochemical)	joule (J)	1.054×10^3
bushel	cubic meter (m^3)	3.52×10^{-2}
calorie (International Steam Table)	joule (J)	4.187
calorie (mean)	joule (J)	4.190
calorie (thermochemical)	joule (J)	4.184
centimeter of mercury	newton/square meter (N/m^2)	1.333×10^3
centimeter of water	newton/square meter (N/m^2)	98.06
cubit	meter (m)	0.457
degree (angle)	radian (rad)	1.745×10^{-2}
denier (international)	kilogram/meter (kg/m)	1.0×10^{-7}
dram (avoirdupois)	kilogram (kg)	1.772×10^{-3}
dram (troy)	kilogram (kg)	3.888×10^{-3}
dram (U.S. fluid)	cubic meter (m^3)	3.697×10^{-6}
dyne	newton (N)	1.0×10^{-5}
electron volt	joule (J)	1.60×10^{-19}
erg	joule (J)	1.0×10^{-7}
fluid ounce (U.S.)	cubic meter (m^3)	2.96×10^{-5}
foot	meter (m)	0.305
furlong	meter (m)	2.01×10^2
gallon (U.S. dry)	cubic meter (m^3)	4.404×10^{-3}
gallon (U.S. liquid)	cubic meter (m^3)	3.785×10^{-3}
gill (U.S.)	cubic meter (m^3)	1.183×10^{-4}
grain	kilogram (kg)	6.48×10^{-5}
gram	kilogram (kg)	1.0×10^{-3}
horsepower	watt (W)	7.457×10^2
horsepower (boiler)	watt (W)	9.81×10^3
horsepower (electric)	watt (W)	7.46×10^2
hundred weight (long)	kilogram (kg)	50.80
hundred weight (short)	kilogram (kg)	45.36
inch	meter (m)	2.54×10^{-2}
inch mercury	newton/square meter (N/m^2)	3.386×10^3
inch water	newton/square meter (N/m^2)	2.49×10^2
kilogram force	newton (N)	9.806

To convert from	To	Multiply by
kip	newton (N)	4.45×10^3
knot (international)	meter/second (m/s)	0.5144
league (British nautical)	meter (m)	5.559×10^3
league (statute)	meter (m)	4.83×10^3
light year	meter (m)	9.46×10^{15}
liter	cubic meter (m^3)	0.001
micron	meter (m)	1.0×10^{-6}
mil	meter (m)	2.54×10^{-6}
mile (U.S. nautical)	meter (m)	1.852×10^3
mile (U.S. statute)	meter (m)	1.609×10^3
millibar	newton/square meter (N/m^2)	100.0
millimeter mercury	newton/square meter (N/m^2)	1.333×10^2
oersted	ampere/meter (A/m)	79.58
ounce force (avoirdupois)	newton (N)	0.278
ounce mass (avoirdupois)	kilogram (kg)	2.835×10^{-2}
ounce mass (troy)	kilogram (kg)	3.11×10^{-2}
ounce (U.S. fluid)	cubic meter (m^3)	2.96×10^{-5}
pascal	newton/square meter (N/m^2)	1.0
peck (U.S.)	cubic meter (m^3)	8.81×10^{-3}
pennyweight	kilogram (kg)	1.555×10^{-3}
pint (U.S. dry)	cubic meter (m^3)	5.506×10^{-4}
pint (U.S. liquid)	cubic meter (m^3)	4.732×10^{-4}
poise	newton second/square meter ($N \cdot s/m^2$)	0.10
pound force (avoirdupois)	newton (N)	4.448
pound mass (avoirdupois)	kilogram (kg)	0.4536
pound mass (troy)	kilogram (kg)	0.373
poundal	newton (N)	0.138
quart (U.S. dry)	cubic meter (m^3)	1.10×10^{-3}
quart (U.S. liquid)	cubic meter (m^3)	9.46×10^{-4}
rod	meter (m)	5.03
roentgen	coulomb/kilogram (c/kg)	2.579×10^{-4}
second (angle)	radian (rad)	4.85×10^{-6}
section	square meter (m^2)	2.59×10^6
slug	kilogram (kg)	14.59
span	meter (m)	0.229
stoke	square meter/second (m^2/s)	1.0×10^{-4}
ton (long)	kilogram (kg)	1.016×10^3
ton (metric)	kilogram (kg)	1.0×10^3
ton (short, 2000 pounds)	kilogram (kg)	9.072×10^2
torr	newton/square meter (N/m^2)	1.333×10^2
yard	meter (m)	0.914

Bringing Costs up to Date

Cost escalation via inflation bears critically on estimates of plant costs. Historical costs of process plants are updated by means of an escalation factor. Several published cost indexes are widely used in the chemical process industries:

Nelson Cost Indexes (*Oil and Gas J.*), quarterly
Marshall and Swift (M&S) Equipment Cost Index, updated monthly
CE Plant Cost Index (*Chemical Engineering*), updated monthly
ENR Construction Cost Index (*Engineering News-Record*), updated weekly

All of these indexes were developed with various elements such as material availability and labor productivity taken into account. However, the proportion allotted to each element differs with each index. The differences in overall results of each index are due to uneven price changes for each element. In other words, the total escalation derived by each index will vary because different bases are used. The engineer should become familiar with each index and its limitations before using it.

Table 1 compares the CE Plant Index with the M&S Equipment Cost

TABLE 1 *Chemical Engineering* and Marshall and Swift Plant and Equipment Cost Indexes since 1950

Year	CE Index	M&S Index	Year	CE Index	M&S Index
1950	73.9	167.9	1969	119.0	285.0
1951	80.4	180.3	1970	125.7	303.3
1952	81.3	180.5	1971	132.3	321.3
1953	84.7	182.5	1972	137.2	332.0
1954	86.1	184.6	1973	144.1	344.1
1955	88.3	190.6	1974	165.4	398.4
1956	93.9	208.8	1975	182.4	444.3
1957	98.5	225.1	1976	192.1	472.1
1958	99.7	229.2	1977	204.1	505.4
1959	101.8	234.5	1978	218.8	545.3
1960	102.0	237.7	1979	238.7	599.4
1961	101.5	237.2	1980	261.2	659.6
1962	102.0	238.5	1981	297.0	721.3
1963	102.4	239.2	1982	314.0	745.6
1964	103.3	241.8	1983	316.9	760.8
1965	104.2	244.9	1984	322.7	780.4
1966	107.2	252.5	1985	325.3	789.6
1967	109.7	262.9	1986	318.4	797.6
1968	113.6	273.1	1987	323.8	813.6
			1988	342.5	852.0

TABLE 2 Nelson Inflation Refinery Construction Indexes since 1946 (1946 = 100)

Date	Materials Component	Labor Component	Miscellaneous Equipment	Nelson Inflation Index
1946	100.0	100.0	100.0	100.0
1947	122.4	113.5	114.2	117.0
1948	139.5	128.0	122.1	132.5
1949	143.6	137.1	121.6	139.7
1950	149.5	144.0	126.2	146.2
1951	164.0	152.5	145.0	157.2
1952	164.3	163.1	153.1	163.6
1953	172.4	174.2	158.8	173.5
1954	174.6	183.3	160.7	179.8
1955	176.1	189.6	161.5	184.2
1956	190.4	198.2	180.5	195.3
1957	201.9	208.6	192.1	205.9
1958	204.1	220.4	192.4	213.9
1959	207.8	231.6	196.1	222.1
1960	207.6	241.9	200.0	228.1
1961	207.7	249.4	199.5	232.7
1962	205.9	258.8	198.8	237.6
1963	206.3	268.4	201.4	243.6
1964	209.6	280.5	206.8	252.1
1965	212.0	294.4	211.6	261.4
1966	216.2	310.9	220.9	273.0
1967	219.7	331.3	226.1	286.7
1968	224.1	357.4	228.8	304.1
1969	234.9	391.8	239.3	329.0
1970	250.5	441.1	254.3	364.9
1971	265.2	499.9	268.7	406.0
1972	277.8	545.6	278.0	438.5
1973	292.3	585.2	291.4	468.0
1974	373.3	623.6	361.8	522.7
1975	421.0	678.5	415.9	575.5
1976	445.2	729.4	423.8	615.7
1977	471.3	774.1	438.2	653.0
1978	516.7	824.1	474.1	701.1
1979	573.1	879.0	515.4	756.6
1980	629.2	951.9	578.1	822.8
1981	693.2	1044.2	647.9	903.8
1982	707.6	1154.2	622.8	976.9
1983	712.4	1234.8	656.8	1025.8
1984	735.3	1278.1	665.6	1061.0
1985	739.6	1297.6	673.4	1074.4
1986	730.0	1330.0	684.4	1089.9
1987	748.9	1370.0	703.1	1121.5
1988	802.8	1405.6	732.5	1164.5

Index. Table 2 shows the Nelson Inflation Petroleum Refinery Construction Indexes since 1946. It is recommeded that the CE Index be used for updating total plant costs, and the M&S Index or Nelson Index for updating equipment costs. The Nelson Indexes are better suited for petroleum refinery materials, labor, equipment, and general refinery inflation.

Since

$$C_B = C_A(B/A)^n \tag{1}$$

Here, A = the size of units for which the cost is known, expressed in terms of capacity, throughput, or volume; B = the size of unit for which a cost is required, expressed in the units of A; $n = 0.6$ (i.e., the six-tenths exponent); C_A = actual cost of unit A; and C_B = the cost for B being sought for the same time period as cost C_A.

To approximate a current cost, multiply the old cost by the ratio of the current index value to the index at the date of the old cost:

$$C_B = C_A I_B / I_A \tag{2}$$

Here, C_A = old cost; I_B = current index value; and I_A = index value at the date of old cost.

Combining Eqs. (1) and (2):

$$C_B = C_A(B/A)^n(I_B/I_A) \tag{3}$$

For example, if the total investment cost of Plant A was $25,000,000 for 200-million-lb/yr capacity in 1974, find the cost of Plant B at a throughput of 300 million lb/yr on the same basis for 1986. Let the sizing exponent, n, be equal to 0.6.

From Table 1, the CE Index for 1986 was 318.4, and for 1974 it was 165.4. Via Eq. (3):

$$C_B = C_A(B/A)^n(I_B/I_A)$$

$$= 25.0(300/200)^{0.6}(318.4/165.4)$$

$$= \$61{,}200{,}000$$

JOHN J. McKETTA

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Organic Liquids, Thermal Conductivity Estimation

A study on the prediction of thermal conductivity of organic liquids has been performed by Narasimhan and collaborators [1]. The authors checked the six existing and widely used correlations for thermal conductivity prediction, and found that an average error of prediction (based on over 80 specimens checked) ranges from 8.8 to 14.8%.

The authors presented a new correlation for which the average error does not exceed ±3% of measured value for the 84 liquids tested. This correlation is valid for a wide range of organic liquids, including hydrocarbons, alcohols, and halogenated hydrocarbons (aromatic and aliphatic) in a relatively narrow temperature range. This new correlation is

$$K = (0.877 \times 10^{-3}) C_p \rho^{0.83} (293/T)^{0.38}$$

where K = the thermal conductivity of an organic liquid, cal/s · cm · °C
C_p = the heat capacity of an organic liquid, cal/g · °C
ρ = the density of a liquid at 20°C, g/cm^3
T = the absolute temperature, °K

Calculation of thermal conductivity is easily made since it involves only knowledge of the density at 20°C and the heat capacity at 20°C, both of which are very easily obtainable. On the other hand, the calculation is troublesome because it involves the use of fractional powers.

Therefore, a nomograph (Fig. 1) is presented which solves this equation rapidly through the use of only two movements of a ruler.

How to Use the Nomograph. Although the temperature is expressed in °K in the original formula, the nomograph is graduated in degrees centigrade for greater convenience.

The Procedure

1. Connect the known values of ρ and t on the appropriate scales with a ruler. Mark the point of intersection of the ruler with the Reference Line.
2. Connect this point to the known value of C_p on the appropriate scale with the ruler. Read the final result from the intersection point of the ruler with the K scale.

Example. Given an organic liquid having a density (ρ) at 20°C of 0.9 g/cm^3 and a heat capacity (C_p) at 20°C of 0.5 cal/g · °C. Find the thermal conductivity of this liquid at a temperature t = +60°C.