Encyclopedia of Chemical Processing and Design

EXECUTIVE EDITOR **John J. McKetta**

ASSOCIATE EDITOR **Guy E. Weismantel**

67 Water and Wastewater Treatment, Protective Coating System to Zeolites

MARCEL DEKKER

MARCEL DEKKER, INC. NEW YORK • BASEL

Library of Congress Cataloging in Publication Data
Main entry under title:

Encyclopedia of chemical processing and design.

Includes bibliographic references.
1. Chemical engineering—Dictionaries 2. Chemistry, Technical—Dictionaries. I. McKetta, John J. II. Cunningham, William Aaron.
Tp9.E66 660.2′8′003 75-40646
ISBN: 0-8247-2618-9

Headquarters
Marcel Dekker, Inc.
270 Madison Avenue, New York, NY 10016
tel: 212-696-9000; fax: 212-685-4540

Eastern Hemisphere Distribution
Marcel Dekker AG
Hutgasse 4, Postfach 812, CH-4001 Basel, Switzerland
tel: 41-61-261-8482; fax: 41-61-261-8896

World Wide Web
http://www.dekker.com

MARCEL DEKKER, INC.
270 Madison Avenue, New York, New York, 10016

Current printing (last digit):
10 9 8 7 6 5 4 3 2 1

PRINTED IN THE UNITED STATES OF AMERICA

International Advisory Board

International Advisory Board

Contributors to Volume 67

Joann C. Armstead Group Leader, Specialty Minerals, Easton, Pennsylvania: *Whiting (Calcium Carbonate)*

Richard E. Avery, P.E. Consultant to the Nickel Development Institute, Londonderry, New Hampshire: *Welds, Dissimilar Metals, Guidelines*

Chen-Yen Cheng Heist Engineering Technology, Houston, Texas: *Xylene Separation*

J. Michael Cherry SGD Project Manager, Department of Genetics, Stanford University, Stanford, California: *Yeasts*

J. W. Dangerfield Consulting Engineer, Houston, Texas: *Weighing Accuracy*

Thomas P. Delany Industrial Coatings Consultant, Valspur/Ameron Inc., Maple Shade, New Jersey: *Water and Wastewater Treatment, Protective Coating System*

James P. Diebold Principle Chemical Engineer, National Renewable Energy Laboratory, Golden, Colorado: *Wood, Conversion to Gasoline*

Franklin T. Dodge, Ph.D. Institute Engineer, Southwest Research Institute, San Antonio, Texas: *Wetting of Surfaces*

Richard D. French American Welding Society, Miami, Florida: *Welding*

Paula D. Gaymon Technical Representative, the NutraSweet Kelco Company, a Unit of Monsanto, San Diego, California: *Xanthan Gum*

James Heist President, Heist Engineering Technology, Houston, Texas: *Xylene Separation*

Wolfgang A. Hochleitner Senior Process Engineer, Air Products and Chemicals Inc., Allentown, Pennsylvania: *Wet Oxidation Reactor Data, Analysis of; Wet Oxidation Residue Used in Brick Manufacture*

Jerry R. Johanson, Ph.D. JR Johanson, Inc., San Luis Obispo, California: *Wear Properties, Measuring and Use of*

Vineet Kumar, Ph.D. Research Associate, School of Biochemical Engineering, Institute of Technology, Banaras Hindu University, Varanasi, India: *Wetted Surface Absorbers*

James McAllister Manager, Special Projects and Applied Research, Arkansas Power and Light, Little Rock, Arkansas: *Wire Mesh Screens, Openings Estimate; Wiring, Voltage Drops*

Takeyoshi Nagaoka Director, Nagaoka USA, Houston, Texas: *Well Screens*

William E. Nasser Canyon Consulting Company, Clayton, Missouri: *Waxes, Natural and Synthetic*

B. N. Rai, Ph.D. Lecturer, Department of Chemical Engineering & Technology, Institute of Technology, Banaras Hindu University, Varanasi, India: *Wetted Surface Absorbers*

T. Anthony Royal Research Engineer, Jenike and Johanson, Inc., North Billerica, Massachusetts: *Wear Properties, Measuring and Use of*

James W. Scahill Chemical Engineer, National Renewable Energy Laboratory, Golden, Colorado: *Wood, Conversion to Gasoline*

Sonoma County Wineries Association Sonoma, California: *Wine and Wine Making*

Robert E. Trent Director of Adsorption Technology, Zeochem, Louisville, Kentucky: *Zeolites*

Gopal Tripathi, Sc.D. Former Professor, Department of Chemical Engineering & Technology, Institute of Technology, Banaras Hindu University, Varanasi, India: *Wetted Surface Absorbers*

United States International Trade Commission Washington, D.C.: *Xylene and Other Primary Aromatics; Yarn, Man-Made Fibers*

S. N. Upadhyay, Ph.D. Professor, Department of Chemical Engineering & Technology, Institute of Technology, Banaras Hindu University, Varanasi, India: *Wetted Surface Absorbers*

Morris Anthony Vivona, P.E. Director, Water and Wastewater, ICF Kaiser Engineering, Inc., Houston, Texas: *Water and Wastewater Treatment, Protective Coating System*

Robert L. Virta Physical Scientist, U.S. Geological Survey, Reston, Virginia: *Wollastonite Supply—Demand Relationships*

John W. Ward Manager Engineering Sales, Refinery Technology, Haldor Topsøe, Inc., Houston, Texas: *Wet Gas Sulfuric Acid Process*

Jeffrey D. Weber Managing Director Publication Services, American Welding Society, Miami, Florida: *Welding*

William Weinberger President, Visual Edge Company, Houston, Texas: *X-Ray Technology*

Guy E. Weismantel President, Weismantel International, Kingwood, Texas: *Weaving, Industrial Application; Whiting (Calcium Carbonate); Xanthates; Xylene Isomerization; Xylene Separation*

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)	kologram (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
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}

To convert from	To	Multiply by
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
Vatavuk Air Pollution Control Cost Indexes (VAPCCI) (*Chemical Engineering*), updated quarterly

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,

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	1973	144.1	344.1
1951	80.4	180.3	1974	165.4	398.4
1952	81.3	180.5	1975	182.4	444.3
1953	84.7	182.5	1976	192.1	472.1
1954	86.1	184.6	1977	204.1	505.4
1955	88.3	190.6	1978	218.8	545.3
1956	93.9	208.8	1979	238.7	599.4
1957	98.5	225.1	1980	261.2	659.6
1958	99.7	229.2	1981	297.0	721.3
1959	101.8	234.5	1982	314.0	745.6
1960	102.0	237.7	1983	316.9	760.8
1961	101.5	237.2	1984	322.7	780.4
1962	102.0	238.5	1985	325.3	789.6
1963	102.4	239.2	1986	318.4	797.6
1964	103.3	241.8	1987	323.8	813.6
1965	104.2	244.9	1988	342.5	852.0
1966	107.2	252.5	1989	355.4	895.1
1967	109.7	262.9	1990	357.6	915.1
1968	113.6	273.1	1991	361.3	930.6
1969	119.0	285.0	1992	358.2	943.1
1970	125.7	303.3	1993	359.2	964.2
1971	132.3	321.3	1994	368.1	993.4
1972	137.2	332.0	1995	381.1	1027.5
			1996	381.7	1039.2
			1997	386.5	1056.8

TABLE 2 Nelson-Farrar Inflation Petroleum 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
1989	829.2	1440.4	769.9	1195.9
1990	832.8	1487.7	797.5	1225.7
1991	832.3	1533.3	827.5	1252.9

TABLE 2 Continued

Date	Materials Component	Labor Component	Miscellaneous Equipment	Nelson Inflation Index
1992	824.6	1579.2	837.6	1277.3
1993	846.7	1620.2	842.8	1310.8
1994	877.2	1664.7	851.1	1349.7
1995	918.0	1708.1	879.5	1392.1
1996	917.1	1753.5	903.5	1418.9
1997	923.9	1799.5	910.5	1449.2

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 Index. Table 2 shows the Nelson-Farrar Inflation Petroleum Refinery Construction Indexes since 1946. It is recommended that the CE Index be used for updating total plant costs and the M&S Index or Nelson-Farrar Index for updating equipment costs. The Nelson-Farrar 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 of 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),

TABLE 3 Vatavuk Air Pollution Control Cost Indexes (VAPCCI). First Quarter 1994 = 100.0 (index values have been rounded to the nearest tenth).

Control Device	1994 (Avg.)	1995 (Avg.)	1996 (Avg.)
Carbon adsorbers	101.2	110.7	106.4
Catalytic incinerators	102.0	107.1	107.0
Electrostatic precipitators	102.8	108.2	108.0
Fabric filters	100.5	102.7	104.5
Flares	100.5	107.5	104.9
Gas absorbers	100.8	105.6	107.8
Mechanical collectors	100.3	103.0	103.3
Refrigeration systems	100.5	103.0	104.4
Regenerative thermal oxidizers	101.4	104.4	106.3
Thermal incinerators	101.3	105.9	108.2
Wet scrubbers	101.3	112.5	119.8

$$\begin{aligned} C_B &= C_A(B/A)^n(I_B/I_A) \\ &= 25.0(300/200)^{0.6}(318.4/165.4) \\ &= \$61{,}200{,}000 \end{aligned}$$

Table 3 shows the Vatavuk Air Pollution Control Cost Indexes (VAPCCI) since 1994. For details, see the Vatavuk Air Pollution Control Cost Indexes article in volume 61.

Editor's note: For a more thorough explanation of updating costs, see the article, "Tower Cost Updating" in volume 58.

JOHN J. McKETTA

Contents of Volume 67