PIPING DESIGN HANDBOOK

EDITED BY
JOHN J. McKETTA

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Preface

This book represents an encyclopedia of piping design methods. Almost every phase of piping design is covered and presented in an easy-to-read and easy-to-use format. Each article is prepared by a world expert in that particular area. For simplicity, *Piping Design Handbook* is arranged in 10 general sections to present the elements of fluid flow, fluidics, piping design, pipeline design, buried pipelines, pipeline supports, pipeline shortcut methods, operation and maintenance, pipeline failure, and the economics and costs of pipeline systems including a compendium of worldwide activity.

Every practicing professional engineer involved in piping design should have a copy of this extremely helpful handbook on his or her working shelf.

The basic principles are extremely well covered by experts in the field such as Professor Neil S. Berman. Another important section is the pipeline shortcut methods, which includes 22 articles presenting expanded rules of thumb for the piping design engineer.

I am grateful for all the help I received from the great number of experts who have contributed to this book.

JOHN J. McKETTA

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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

Conversion to SI Units

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

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
1989	829.2	1440.4	769.9	1195.9
1990	832.8	1487.7	795.5	1225.7

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):

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

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