Departamento de Ingeniería Química - Primer Cuatrimestre 2017

76.47 Fenómenos de Transporte
76.03 Operaciones I
Ingeniería Química
Ingeniería de Alimentos

Compendio de Tablas y Gráficos

Universidad de Buenos Aires - Facultad de Ingeniería
Primer Cuatrimestre de 2017

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Tablas de Conversión de Unidades

Factores de Conversión para Unidades Comunes

Quantity	Unit	Equivalent
Mass (M)		
	1 pound mass	= 453.5924 grams
		= 0.45359 kilograms
		= 7000 grains
	1 slug	= 32.174 pounds mass
	1 ton (short)	= 2000 pounds mass
	1 ton (long)	= 2240 pounds mass
	1 ton (metric)	= 1000 kilograms
		= 2204.62 pounds mass
	1 pound mole	= 453.59 gram moles
Length (L)		
	1 foot	= 30.480 centimeters
		= 0.3048 meters
	1 inch	= 2.54 centimeters
		= 0.0254 meters
	1 mile (U.S.)	= 1.60935 kilometers
	1 yard	= 0.9144 meters
Area (L^2)		
	1 square foot	= 929.0304 square centimeters
		= 0.09290304 square meters
	1 square inch	= 6.4516 square centimeters
	1 square yard	= 0.836127 square meters
Volume (L^3)		
	1 cubic foot	= 28,316.85 cubic centimeters
		= 0.02831685 cubic meters
		= 28.31685 liters
		= 7.481 gallons (U.S.)
	1 gallon	= 3.7853 liters
		= 231 cubic inches
Time (θ)		
	1 hour	= 60 minutes
		= 3600 seconds
Temperature (T)		
	1 centigrade or Celsius degree	= 1.8 Fahrenheit degree
	Temperature, Kelvin	= T°C + 273.15
	Temperature, Rankine	= T°F + 459.7
	Temperature, Fahrenheit	= 9/5 T°C + 32
	Temperature, centigrade or Celsius	= 5/9 (T°F − 32)
	Temperature, Rankine	= 1.8 T K
Force (F)		
	1 pound force	= 444,822.2 dynes
		= 4.448222 Newtons
		= 32.174 poundals
Pressure (F/L^2)		
Normal atmospheric pressure		
	1 atm	= 760 millimeters of mercury at 0°C (density 13.5951 g/cm^3)
		= 29.921 inches of mercury at 32°F
		= 14.696 pounds force/square inch
		= 33.899 feet of water at 39.1°F
		= 1.01325×10^6 dynes/square centimeter
		= 1.01325×10^5 Newtons/square meter
Density (M/L^3)		
	1 pound mass/cubic foot	= 0.01601846 grams/cubic centimeter
		= 16.01846 kilogram/cubic meter
Energy (H or FL)		
	1 British thermal unit	= 251.98 calories
		= 1054.4 joules
		= 777.97 foot-pounds force
		= 10.409 liter-atmospheres
		= 0.2930 watt-hour
Diffusivity ($L^2/θ$)		
	1 square foot/hour	= 0.258 cm^2/s
		= 2.58×10^{-5} m^2/s
Viscosity ($M/Lθ$)		
	1 pound mass/foot hour	= 0.00413 g/cm s
		0.000413 kg/m s
	1 centipoise	= 0.01 poise
		= 0.01 g/cm s
		= 0.001 kg/m s
		= 0.000672 lbm/ft s
		= 0.0000209 lb_fs/ft^2
Thermal conductivity [$H/θL^2(T/L)$]		
	1 Btu/hr ft^2 (°F/ft)	= 0.00413 cal/s cm^2 (°C/cm)
		= 1.728 J/s m^2 (°C/m)
Heat transfer coefficient		
	1 Btu/hr ft^2 °F	= 5.678 J/s m^2 °C
Heat capacity (H/MT)		
	1 Btu/lbm °F	= 1 cal/g °C
		= 4184 J/kg °C
Gas constant		
	1.987 Btu/lbm mole °R	= 1.987 cal/mol K
		= 82.057 atm cm^3/mol K
		= 0.7302 atm ft^3/lb mole °F
		= 10.73 (lb_f/in.^{2}) (ft^3)/lb mole °R
		= 1545 (lb_f/ft^2) (ft^3)/lb mole °R
		= 8.314 (N/m^2) (m^3)/mol K
Gravitational acceleration		
	g	= 9.8066 m/s^2
		= 32.174 ft/s^2

Conversión Unidades

To convert from	To	Multiply by	To convert from	To	Multiply by
Acres	Square feet	43,560	B.t.u. (60°F.) per degree Fahrenheit	Calories per degree centigrade	453.6
Acres	Square meters	4074	Bushels (U.S. dry)	Cubic feet	1.2444
Acres	Square miles	0.001563	Bushels (U.S. dry)	Cubic meters	0.03524
Acre-feet	Cubic meters	1233	Calories, gram	B.t.u.	3.968×10^{-3}
Ampere-hours (absolute)	Coulombs (absolute)	3600	Calories, gram	Foot-pounds	3.087
Angstrom units	Inches	3.937×10^{-9}	Calories, gram	Joules	4.1868
Angstrom units	Meters	1×10^{-10}	Calories, gram	Liter-atmospheres	4.130×10^{-2}
Angstrom units	Microns	1×10^{-4}	Calories, gram	Horsepower-hours	1.5591×10^{-6}
Atmospheres	Millimeters of mercury at 32°F	760	Calories, gram, per gram per degree C.	Joules per kilogram per degree Kelvin	4186.8
Atmospheres	Dynes per square centimeter	1.0133×10^{6}	Calories, kilogram	Kilowatt-hours	0.0011626
Atmospheres	Newtons per square meter	101,325	Calories, kilogram per second	Kilowatts	4.185
Atmospheres	Feet of water at 39.1°F	33.90	Candle power (spherical)	Lumens	12.556
Atmospheres	Grams per square centimeter	1033.3	Carats (metric)	Grams	0.2
Atmospheres	Inches of mercury at 32°F	29.921	Centigrade heat units	B.t.u.	1.8
Atmospheres	Pounds per square foot	2116.3	Centimeters	Angstrom units	1×10^{8}
Atmospheres	Pounds per square inch	14.696	Centimeters	Feet	0.03281
Bags (cement)	Pounds (cement)	94	Centimeters	Inches	0.3937
Barrels (cement)	Pounds (cement)	376	Centimeters	Meters	0.01
Barrels (oil)	Cubic meters	0.15899	Centimeters	Microns	10,000
Barrels (oil)	Gallons	42	Centimeters of mercury at 0°C.	Atmospheres	0.013158
Barrels (U.S. liquid)	Cubic meters	0.11924	Centimeters of mercury at 0°C.	Feet of water at 39.1°F.	0.4460
Barrels (U.S. liquid)	Gallons	31.5	Centimeters of mercury at 0°C	Newtons per square meter	1333.2
Barrels per day	Gallons per minute	0.02917	Centimeters of mercury at 0°C.	Pounds per square foot	27.845
Bars	Atmospheres	0.9869	Centimeters of mercury at 0°C.	Pounds per square inch	0.19337
Bars	Newtons per square meter	1×10^{5}	Centimeters per second	Feet per minute	1.9685
Bars	Pounds per square inch	14.504	Centimeters of water at 4°C.	Newtons per square meter	98.064
Board feet	Cubic feet	$\frac{1}{12}$	Centistokes	Square meters per second	1×10^{-6}
Boiler horsepower	B.t.u. per hour	33,480	Circular mils	Square centimeters	5.067×10^{-6}
Boiler horsepower	Kilowatts	9.803	Circular mils	Square inches	7.854×10^{-7}
B.t.u.	Calories (gram)	252	Circular mils	Square mils	0.7854
B.t.u.	Centigrade heat units (c.h.u. or p.c.u.)	0.55556	Cords	Cubic feet	128
B.t.u.	Foot-pounds	777.9	Cubic centimeters	Cubic feet	3.532×10^{-5}
B.t.u.	Horsepower-hours	3.929×10^{-4}	Cubic centimeters	Gallons	2.6417×10^{-4}
B.t.u.	Joules	1055.1	Cubic centimeters	Ounces (U.S. fluid)	0.03381
B.t.u.	Liter-atmospheres	10.41	Cubic centimeters	Quarts (U.S. fluid)	0.0010567
B.t.u.	Pounds carbon to CO_2	6.88×10^{-5}	Cubic feet	Bushels (U.S.)	0.8036
B.t.u.	Pounds water evaporated from and		Cubic feet	Cubic centimeters	28,317
	at 212°F	0.001036	Cubic feet	Cubic meters	0.028317
B.t.u.	Cubic foot-atmospheres	0.3676	Cubic feet	Cubic yards	0.03704
B.t.u.	Kilowatt-hours	2.930×10^{-4}	Cubic feet	Gallons	7.481
B.t.u. per cubic foot	Joules per cubic meter	37,260	Cubic feet	Liters	28.316
B.t.u. per hour	Watts	0.29307	Cubic foot-atmospheres	Foot-pounds	2116.3
B.t.u. per minute	Horsepower	0.02357	Cubic foot-atmospheres	Liter-atmospheres	28.316
B.t.u. per pound	Joules per kilogram	2326	Cubic feet of water (60°F.)	Pounds	62.37
B.t.u. per pound per degree	Calories per gram per degree		Cubic feet per minute	Cubic centimeters per second	472.0
Fahrenheit	centigrade	1	Cubic feet per minute	Gallons per second	0.1247
B.t.u. per pound per degree	Joules per kilogram per degree	4186.8	Cubic feet per second	Gallons per minute	448.8
Fahrenheit	Kelvin		Cubic feet per second	Million gallons per day	0.64632
B.t.u. per second	Watts	1054.4	Cubic inches	Cubic meters	1.6387×10^{-5}
B.t.u. per square foot per hour	Joules per square meter per second	3.1546	Cubic yards	Cubic meters	0.76456
B.t.u. per square foot per minute	Kilowatts per square foot	0.1758	Curies	Disintegrations per minute	2.2×10^{12}
B.t.u. per square foot per second	Calories, gram (15°C.), per square cen-	1.2405	Curies	Coulombs per minute	1.1×10^{12}
for a temperature gradient of	timeter per second for a tempera-		Degrees	Radians	0.017453
1°F. per inch	ture gradient of 1°C. per centimeter		Drams (apothecaries' or troy)	Grams	3.888

To convert from	To	Multiply by
Drams (avoirdupois)	Grams	1.7719
Dynes	Newtons	1×10^{-5}
Ergs	Joules	1×10^{-7}
Faradays	Coulombs (abs.)	96,500
Fathoms	Feet	6
Feet	Meters	0.3048
Feet per minute	Centimeters per second	0.5080
Feet per minute	Miles per hour	0.011364
Feet per (second)^2	Meters per (second)^2	0.3048
Feet of water at 39.2°F.	Newtons per square meter	2989
Foot-poundals	B.t.u.	3.995×10^{-5}
Foot-poundals	Joules	0.04214
Foot-poundals	Liter-atmospheres	4.159×10^{-4}
Foot-pounds	B.t.u.	0.0012856
Foot-pounds	Calories, gram	0.3239
Foot-pounds	Foot-poundals	32.174
Foot-pounds	Horsepower-hours	5.051×10^{-7}
Foot-pounds	Kilowatt-hours	3.766×10^{-7}
Foot-pounds	Liter-atmospheres	0.013381
Foot-pounds force	Joules	1.3558
Foot-pounds per second	Horsepower	0.0018182
Foot-pounds per second	Kilowatts	0.0013558
Furlongs	Miles	0.125
Gallons (U.S. liquid)	Barrels (U.S. liquid)	0.03175
Gallons	Cubic meters	0.003785
Gallons	Cubic feet	0.13368
Gallons	Gallons (Imperial)	0.8327
Gallons	Liters	3.785
Gallons	Ounces (U.S. fluid)	128
Gallons per minute	Cubic feet per hour	8.021
Gallons per minute	Cubic feet per second	0.002228
Grains	Grams	0.06480
Grains	Pounds	1/7000
Grains per cubic foot	Grams per cubic meter	2.2884
Grains per gallon	Parts per million	17.118
Grams	Drams (avoirdupois)	0.5644
Grams	Drams (troy)	0.2572
Grams	Grains	15.432
Grams	Kilograms	0.001
Grams	Pounds (avoirdupois)	0.0022046
Grams	Pounds (troy)	0.002679
Grams per cubic centimeter	Pounds per cubic foot	62.43

To convert from	To	Multiply by
Horsepower (British)	Pounds water evaporated per hour at 212°F	2.64
Horsepower (metric)	Foot-pounds per second	542.47
Horsepower (metric)	Kilogram-meters per second	75.0
Hours (mean solar)	Seconds	3600
Inches	Meters	0.0254
Inches of mercury at 60°F	Newtons per square meter	3376.9
Inches of water at 60°F	Newtons per square meter	248.84
Joules (absolute)	B.t.u. (mean)	9.480×10^{-4}
Joules (absolute)	Calories, gram (mean)	0.2389
Joules (absolute)	Cubic foot-atmospheres	0.3485
Joules (absolute)	Foot-pounds	0.7376
Joules (absolute)	Kilowatt-hours	2.7778×10^{-7}
Joules (absolute)	Liter-atmospheres	0.009869
Kilocalories	Joules	4186.8
Kilograms	Pounds (avoirdupois)	2.2046
Kilograms force	Newtons	9.807
Kilograms per square centimeter	Pounds per square inch	14.223
Kilometers	Miles	0.6214
Kilowatt-hours	B.t.u.	3414
Kilowatt-hours	Foot-pounds	2.6552×10^{6}
Kilowatts	Horsepower	1.3410
Knots (international)	Meters per second	0.5144
Knots (nautical miles per hour)	Miles per hour	1.1516
Lamberts	Candles per square inch	2.054
Liter-atmospheres	Cubic foot-atmospheres	0.03532
Liter-atmospheres	Foot-pounds	74.74
Liters	Cubic feet	0.03532
Liters	Cubic meters	0.001
Liters	Gallons	0.26418
Lumens	Watts	0.001496
Micromicrons	Microns	1×10^{-6}
Microns	Angstrom units	1×10^{4}
Microns	Meters	1×10^{-6}
Miles (nautical)	Feet	6080
Miles (nautical)	Miles (U.S. statute)	1.1516
Miles	Feet	5280
Miles	Meters	1609.3
Miles per hour	Feet per second	1.4667
Miles per hour	Meters per second	0.4470
Milliliters	Cubic centimeters	1
Millimeters	Meters	0.001

Grams per cubic centimeter	Pounds per gallon	8.345	Millimeters of mercury at 0°C.	Newtons per square meter	133.32
Grams per liter	Grains per gallon	58.42	Millimicrons	Microns	0.001
Grams per liter	Pounds per cubic foot	0.0624	Mils	Inches	0.001
Grams per square centimeter	Pounds per square foot	2.0482	Mils	Meters	2.54×10^{-5}
Grams per square centimeter	Pounds per square inch	0.014223	Minims (U.S.)	Cubic centimeters	0.06161
Hectares	Acres	2.471	Minutes (angle)	Radians	2.909×10^{-4}
Hectares	Square meters	10,000	Minutes (mean solar)	Seconds	60
Horsepower (British)	B.t.u. per minute	42.42	Newtons	Kilograms	0.10197
Horsepower (British)	B.t.u. per hour	2545	Ounces (avoirdupois)	Kilograms	0.02835
Horsepower (British)	Foot-pounds per minute	33,000	Ounces (avoirdupois)	Ounces (troy)	0.9115
Horsepower (British)	Foot-pounds per second	550	Ounces (U.S. fluid)	Cubic meters	2.957×10^{-5}
Horsepower (British)	Watts	745.7	Ounces (troy)	Ounces (apothecaries')	1.000
Horsepower (British)	Horsepower (metric)	1.0139	Pints (U.S. liquid)	Cubic meters	4.732×10^{-4}
Horsepower (British)	Pounds carbon to CO_2 per hour	0.175	Poundals	Newtons	0.13826
Pounds (avoirdupois)	Grains	7000	Square feet	Square meters	0.0929
Pounds (avoirdupois)	Kilograms	0.45359	Square feet per hour	Square meters per second	2.581×10^{-5}
Pounds (avoirdupois)	Pounds (troy)	1.2153	Square inches	Square centimeters	6.452
Pounds per cubic foot	Grams per cubic centimeter	0.016018	Square inches	Square meters	6.452×10^{-4}
Pounds per cubic foot	Kilograms per cubic meter	16.018	Square yards	Square meters	0.8361
Pounds per square foot	Atmospheres	4.725×10^{-4}	Stokes	Square meters per second	1×10^{-4}
Pounds per square foot	Kilograms per square meter	4.882	Tons (long)	Kilograms	1016
Pounds per square inch	Atmospheres	0.06805	Tons (long)	Pounds	2240
Pounds per square inch	Kilograms per square centimeter	0.07031	Tons (metric)	Kilograms	1000
Pounds per square inch	Newtons per square meter	6894.8	Tons (metric)	Pounds	2204.6
Pounds force	Newtons	4.4482	Tons (metric)	Tons (short)	1.1023
Pounds force per square foot	Newtons per square meter	47.88	Tons (short)	Kilograms	907.18
Pounds water evaporated from and at 212°F.	Horsepower-hours	0.379	Tons (short)	Pounds	2000
			Tons (refrigeration)	B.t.u. per hour	12,000
Pound-centigrade units (p.c.u.)	B.t.u.	1.8	Tons (British shipping)	Cubic feet	42.00
Quarts (U.S. liquid)	Cubic meters	9.464×10^{-4}	Tons (U.S. shipping)	Cubic feet	40.00
Radians	Degrees	57.30	Torr (mm. mercury, 0°C.)	Newtons per square meter	133.32
Revolutions per minute	Radians per second	0.10472	Watts	B.t.u. per hour	3.413
Seconds (angle)	Radians	4.848×10^{-6}	Watts	Joules per second	1
Slugs	Gee pounds	1	Watts	Kilogram-meters per second	0.10197
Slugs	Kilograms	14.594	Watt-hours	Joules	3600
Slugs	Pounds	32.17	Yards	Meters	0.9144
Square centimeters	Square feet	0.0010764			

Constante Universal de los Gases

Temp. scale	Press. units	Vol. units	Wt. units	Energy units	R
Kelvin			g-moles	calories	1.9872
			g-moles	joules (abs)	8.3144
			g-moles	joules (int)	8.3130
	atm.	cm^3	g-moles	atm cm^3	82.057
	atm.	liters	g-moles	atm liters	0.08205
	mm. Hg	liters	g-moles	mm Hg-liters	62.361
	bar	liters	g-moles	bar-liters	0.08314
	kg/cm^2	liters	g-moles	$kg/(cm^2)$(liters)	0.08478
	atm	ft^3	lb-moles	atm-ft^3	1.314
	mm Hg	ft^3	lb-moles	mm Hg-ft^3	998.9
			lb-moles	chu or pcu	1.9872
Rankine			lb-moles	Btu	1.9872
			lb-moles	hp-hr	0.0007805
			lb-moles	kw-hr	0.0005819
	atm	ft^3	lb-moles	atm-ft^3	0.7302
	in Hg	ft^3	lb-moles	in Hg-ft^3	21.85
	mm Hg	ft^3	lb-moles	mm Hg-ft^3	555.0
	lb/in^2abs	ft^3	lb-moles	$(lb)(ft^3)/in^2$	10.73
	lb/ft^2abs	ft^3	lb-moles	ft-lb	1545.0

Fórmulas para la Conversión de Temperaturas

$°F = °C \cdot 9/5 + 32$
$°C = (°F - 32) \cdot 5/9$
$R = °F + 459{,}69$
$K = °C + 273{,}15$
$K = R \cdot 5/9$

Diferencia de Temperatura, ΔT
$°F = °C \cdot 9/5$

Correlaciones, Tablas y Gráficos de Propiedades Termofísicas Seleccionadas

Propiedades Físicas del Aire

T (K)	ρ (kg/m^3)	$c_p \times 10^{-3}$ (J/kg · K)	$\mu \times 10^5$ (Pa · seg)	$\nu \times 10^5$ (m^2/seg)	$k \times 10^2$ (W/m · K)	$\alpha \times 10^5$ (m^2/seg)	Pr	$g\beta\rho^2/\mu^2$ (1/K · m^3)
Aire								
250	1.4133	1.0054	1.5991	1.1315	2.2269	1.5672	0.722	2.5768×10^{11}
260	1.3587	1.0054	1.6503	1.2146	2.3080	1.6896	0.719	1.4292
280	1.2614	1.0057	1.7503	1.3876	2.4671	1.9448	0.713	1.0085
300	1.1769	1.0063	1.8464	1.5689	2.6240	2.2156	0.708	0.7371
320	1.1032	1.0073	1.9391	1.7577	2.7785	2.5003	0.703	0.5523
340	1.0382	1.0085	2.0300	1.9553	2.9282	2.7967	0.699	0.4168
360	0.9805	1.0100	2.1175	2.1596	3.0779	3.1080	0.695	0.3238
400	0.8822	1.0142	2.2857	2.5909	3.3651	3.7610	0.689	0.2031
440	0.8021	1.0197	2.4453	3.0486	3.6427	4.4537	0.684	0.1330
480	0.7351	1.0263	2.5963	3.5319	3.9107	5.1836	0.681	9.0410×10^{9}
520	0.6786	1.0339	2.7422	4.0410	4.1690	5.9421	0.680	6.4201
580	0.6084	1.0468	2.9515	4.8512	4.5407	7.1297	0.680	3.9962
700	0.5040	1.0751	3.3325	6.6121	5.2360	9.6632	0.684	1.7833
800	0.4411	1.0988	3.6242	8.2163	5.7743	11.9136	0.689	1.0024
1000	0.3529	1.1421	4.1527	11.1767	6.7544	16.7583	0.702	0.4462

Propiedades Termofísicas del Agua Saturada

Temp., K	Pressure, bar*	Volume, m³/kg		Enthalpy, kJ/kg		Entropy, kJ/(kg·K)		Specific heat, C_p, kJ/(kg·K)		Viscosity, Ns/m²		Thermal conductivity, W/(m·K)		Prandtl no.		Surface tension, N/m	Temp., K
		Condensed†	Vapor	Condensed†	Vapor	Condensed†	Vapor	Condensed†	Vapor	Condensed†	Vapor	Condensed†	Vapor	Condensed†	Vapor	Condensed†	
150	6.30.−11	1.073.−3	9.55.+9	−539.6	2273	−2.187	16.54	1.155				3.73					150
160	7.72.−10	1.074.−3	9.62.+8	−525.7	2291	−2.106	15.49	1.233				3.52					160
170	7.29.−9	1.076.−3	1.08.+8	−511.7	2310	−2.026	14.57	1.311				3.34					170
180	5.38.−8	1.077.−3	1.55.+7	−497.8	2328	−1.947	13.76	1.389				3.18					180
190	3.23.−7	1.078.−3	2.72.+6	−483.8	2347	−1.868	13.03	1.467				3.04					190
200	1.62.−6	1.079.−3	5.69.+5	−467.5	2366	−1.789	12.38	1.545				2.91					200
210	7.01.−6	1.081.−3	1.39.+5	−451.2	2384	−1.711	11.79	1.623				2.79					210
220	2.65.−5	1.082.−3	3.83.+4	−435.0	2403	−1.633	11.20	1.701				2.69					220
230	8.91.−5	1.084.−3	1.18.+4	−416.3	2421	−1.555	10.79	1.779				2.59					230
240	3.72.−4	1.085.−3	4.07.+3	−400.1	2440	−1.478	10.35	1.857				2.50					240
250	7.59.−4	1.087.−3	1.52.+3	−381.5	2459	−1.400	9.954	1.935				2.42					250
255	1.23.−3	1.087.−3	956.4	−369.8	2468	−1.361	9.768	1.974				2.38					255
260	1.96.−3	1.088.−3	612.2	−360.5	2477	−1.323	9.590	2.013				2.35					260
265	3.06.−3	1.089.−3	400.4	−351.2	2486	−1.281	9.461	2.052				2.31					265
270	4.69.−3	1.090.−3	265.4	−339.6	2496	−1.296	9.255	2.091				2.27					270
273.15	6.11.−3	1.091.−3	206.3	−333.5	2502	−1.221	9.158	2.116				2.26					273.15
273.15	0.00611	1.000.−3	206.3	0.0	2502	0.000	9.158	4.217	1.854	1750.−6	8.02.−6	0.569	0.0182	12.99	0.815	0.0755	273.15
275	0.00697	1.000.−3	181.7	7.8	2505	0.028	9.109	4.211	1.855	1652.−6	8.09.−6	0.574	0.0183	12.22	0.817	0.0753	275
280	0.00990	1.000.−3	130.4	28.8	2514	0.104	8.980	4.198	1.858	1422.−6	8.29.−6	0.582	0.0186	10.26	0.825	0.0748	280
285	0.01387	1.000.−3	99.4	49.8	2523	0.178	8.857	4.189	1.861	1225.−6	8.49.−6	0.590	0.0189	8.81	0.833	0.0743	285
290	0.01917	1.001.−3	69.7	70.7	2532	0.251	8.740	4.184	1.864	1080.−6	8.69.−6	0.598	0.0193	7.56	0.841	0.0737	290
295	0.02617	1.002.−3	51.94	91.6	2541	0.323	8.627	4.181	1.868	959.−6	8.89.−6	0.606	0.0195	6.62	0.849	0.0727	295
300	0.03531	1.003.−3	39.13	112.5	2550	0.393	8.520	4.179	1.872	855.−6	9.09.−6	0.613	0.0196	5.83	0.857	0.0717	300
305	0.04712	1.005.−3	27.90	133.4	2559	0.462	8.417	4.178	1.877	769.−6	9.29.−6	0.620	0.0201	5.20	0.865	0.0709	305
310	0.06221	1.007.−3	22.93	154.3	2568	0.530	8.318	4.178	1.882	695.−6	9.49.−6	0.628	0.0204	4.62	0.873	0.0700	310
315	0.08132	1.009.−3	17.82	175.2	2577	0.597	8.224	4.179	1.888	631.−6	9.69.−6	0.634	0.0207	4.16	0.883	0.0692	315
320	0.1053	1.011.−3	13.98	196.1	2586	0.649	8.151	4.180	1.895	577.−6	9.89.−6	0.640	0.0210	3.77	0.894	0.0683	320
325	0.1351	1.013.−3	11.06	217.0	2595	0.727	8.046	4.182	1.903	528.−6	10.09.−6	0.645	0.0213	3.42	0.901	0.0675	325
330	0.1719	1.016.−3	8.82	237.9	2604	0.791	7.962	4.184	1.911	489.−6	10.29.−6	0.650	0.0217	3.15	0.908	0.0666	330
335	0.2167	1.018.−3	7.09	258.8	2613	0.854	7.881	4.186	1.920	453.−6	10.49.−6	0.655	0.0220	2.88	0.916	0.0658	335
340	0.2713	1.021.−3	5.74	279.8	2622	0.916	7.804	4.188	1.930	420.−6	10.69.−6	0.660	0.0223	2.66	0.925	0.0649	340
345	0.3372	1.024.−3	4.683	300.7	2630	0.977	7.729	4.191	1.941	389.−6	10.89.−6	0.665	0.0226	2.45	0.933	0.0641	345
350	0.4163	1.027.−3	3.846	321.7	2639	1.038	7.657	4.195	1.954	365.−6	11.09.−6	0.668	0.0230	2.29	0.942	0.0632	350
355	0.5100	1.030.−3	3.180	342.7	2647	1.097	7.588	4.199	1.968	343.−6	11.29.−6	0.671	0.0233	2.14	0.951	0.0623	355
360	0.6209	1.034.−3	2.645	363.7	2655	1.156	7.521	4.203	1.983	324.−6	11.49.−6	0.674	0.0237	2.02	0.960	0.0614	360
365	0.7514	1.038.−3	2.212	384.7	2663	1.214	7.456	4.209	1.999	306.−6	11.69.−6	0.677	0.0241	1.91	0.969	0.0605	365
370	0.9040	1.041.−3	1.861	405.8	2671	1.271	7.394	4.214	2.017	289.−6	11.89.−6	0.679	0.0245	1.80	0.978	0.0595	370
373.15	1.0133	1.044.−3	1.679	419.1	2676	1.307	7.356	4.217	2.029	279.−6	12.02.−6	0.680	0.0248	1.76	0.984	0.0589	373.15
375	1.0815	1.045.−3	1.574	426.8	2679	1.328	7.333	4.220	2.036	274.−6	12.09.−6	0.681	0.0249	1.70	0.987	0.0586	375
380	1.2869	1.049.−3	1.337	448.0	2687	1.384	7.275	4.226	2.057	260.−6	12.29.−6	0.683	0.0254	1.61	0.995	0.0576	380
385	1.5233	1.053.−3	1.142	469.2	2694	1.439	7.218	4.232	2.080	248.−6	12.49.−6	0.685	0.0258	1.53	1.004	0.0566	385
390	1.794	1.058.−3	0.980	490.4	2702	1.494	7.163	4.239	2.104	237.−6	12.69.−6	0.686	0.0263	1.47	1.013	0.0556	390
400	2.455	1.067.−3	0.731	532.9	2716	1.605	7.058	4.256	2.158	217.−6	13.05.−6	0.688	0.0272	1.34	1.033	0.0536	400
410	3.302	1.077.−3	0.553	575.6	2729	1.708	6.959	4.278	2.221	200.−6	13.42.−6	0.688	0.0282	1.24	1.054	0.0515	410
420	4.370	1.088.−3	0.425	618.6	2742	1.810	6.865	4.302	2.291	185.−6	13.79.−6	0.688	0.0293	1.16	1.075	0.0494	420
430	5.699	1.099.−3	0.331	661.8	2753	1.911	6.775	4.331	2.369	173.−6	14.14.−6	0.685	0.0304	1.09	1.10	0.0472	430

440	7.333	1.110.–3	0.261	705.3	2764	2.011	6.689	4.36	2.46	162.–6	14.50.–6	0.682	0.0317	1.04	1.12	0.0451	440
450	9.319	1.123.–3	0.208	749.2	2773	2.109	6.607	4.40	2.56	152.–6	14.85.–6	0.678	0.0331	0.99	1.14	0.0429	450
460	11.71	1.137.–3	0.167	793.5	2782	2.205	6.528	4.44	2.68	143.–6	15.19.–6	0.673	0.0346	0.95	1.17	0.0407	460
470	14.55	1.152.–3	0.136	838.2	2789	2.301	6.451	4.48	2.79	136.–6	15.54.–6	0.667	0.0363	0.92	1.20	0.0385	470
480	17.90	1.167.–3	0.111	883.4	2795	2.395	6.377	4.53	2.94	129.–6	15.88.–6	0.660	0.0381	0.89	1.23	0.0362	480
490	21.83	1.184.–3	0.0922	929.1	2799	2.479	6.312	4.59	3.10	124.–6	16.23.–6	0.651	0.0401	0.87	1.25	0.0339	490
500	26.40	1.203.–3	0.0766	975.6	2801	2.581	6.233	4.66	3.27	118.–6	16.59.–6	0.642	0.0423	0.86	1.28	0.0316	500
510	31.66	1.222.–3	0.0631	1023	2802	2.673	6.163	4.74	3.47	113.–6	16.95.–6	0.631	0.0447	0.85	1.31	0.0293	510
520	37.70	1.244.–3	0.0525	1071	2801	2.765	6.093	4.84	3.70	108.–6	17.33.–6	0.621	0.0475	0.84	1.35	0.0269	520
530	44.58	1.268.–3	0.0445	1119	2798	2.856	6.023	4.95	3.96	104.–6	17.72.–6	0.608	0.0506	0.85	1.39	0.0245	530
540	52.38	1.294.–3	0.0375	1170	2792	2.948	5.953	5.08	4.27	101.–6	18.1.–6	0.594	0.0540	0.86	1.43	0.0221	540
550	61.19	1.323.–3	0.0317	1220	2784	3.039	5.882	5.24	4.64	97.–6	18.6.–6	0.580	0.0583	0.87	1.47	0.0197	550
560	71.08	1.355.–3	0.0269	1273	2772	3.132	5.808	5.43	5.09	94.–6	19.1.–6	0.563	0.0637	0.90	1.52	0.0173	560
570	82.16	1.392.–3	0.0228	1328	2757	3.225	5.733	5.68	5.67	91.–6	19.7.–6	0.548	0.0698	0.94	1.59	0.0150	570
580	94.51	1.433.–3	0.0193	1384	2737	3.321	5.654	6.00	6.40	88.–6	20.4.–6	0.528	0.0767	0.99	1.68	0.0128	580
590	108.3	1.482.–3	0.0163	1443	2717	3.419	5.569	6.41	7.35	84.–6	21.5.–6	0.513	0.0841	1.05	1.84	0.0105	590
600	123.5	1.541.–3	0.0137	1506	2682	3.520	5.480	7.00	8.75	81.–6	22.7.–6	0.497	0.0929	1.14	2.15	0.0084	600
610	137.3	1.612.–3	0.0115	1573	2641	3.627	5.318	7.85	11.1	77.–6	24.1.–6	0.467	0.103	1.30	2.60	0.0063	610
620	159.1	1.705.–3	0.0094	1647	2588	3.741	5.259	9.35	15.4	72.–6	25.9.–6	0.444	0.114	1.52	3.46	0.0045	620
625	169.1	1.778.–3	0.0085	1697	2555	3.805	5.191	10.6	18.3	70.–6	27.0.–6	0.430	0.121	1.65	4.20	0.0035	625
630	179.7	1.856.–3	0.0075	1734	2515	3.875	5.115	12.6	22.1	67.–6	28.0.–6	0.412	0.130	2.0	4.8	0.0026	630
635	190.9	1.935.–3	0.0066	1783	2466	3.950	5.025	16.4	27.6	64.–6	30.0.–6	0.392	0.141	2.7	6.0	0.0015	635
640	202.7	2.075.–3	0.0057	1841	2401	4.037	4.912	26	42	59.–6	32.0.–6	0.367	0.155	4.2	9.6	0.0008	640
645	215.2	2.351.–3	0.0045	1931	2292	4.223	4.732	90		54.–6	37.0.–6	0.331	0.178	12	26	0.0001	645
647.3‡	221.2	3.170.–3	0.0032	2107	2107	4.443	4.443	∞	∞	45.–6	45.0.–6	0.238	0.238	∞	∞	0.0000	647.3‡

Propiedades Termodinámicas del Vapor Sobrecalentado

Temperature, K		Pressure, bar 0.1	0.5	1	5	10	20	40	60	80	100
350	v	16.12	1.027.–3	1.027.–3	1.027.–3	1.027.–3	1.026.–3	1.025.–3	1.024.–3	1.023.–3	1.023.–3
	h	2644	321.7	231.8	322.1	322.5	323.3	324.9	326.4	328.1	329.7
	s	8.327	1.037	1.037	1.037	1.037	1.036	1.035	1.034	1.032	1.031
400	v	18.44	3.67	1.827	1.067.–3	1.067.–3	1.066.–3	1.065.–3	1.064.–3	1.063.–3	1.061.–3
	h	2739	2735	2730	533.1	533.4	534.1	535.4	536.8	538.2	539.6
	s	8.581	7.831	7.502	1.601	1.600	1.599	1.597	1.595	1.593	1.592
450	v	20.75	4.14	2.063	0.410	1.124.–3	1.123.–3	1.121.–3	1.119.–3	1.118.–3	1.116.–3
	h	2835	2833	2830	2804	749.0	749.8	750.8	751.9	753.0	754.1
	s	8.811	8.061	7.736	6.949	2.110	2.107	2.105	2.102	2.099	2.097
500	v	23.07	4.61	2.298	0.452	0.221	0.104	1.201.–3	1.198.–3	1.196.–3	1.193.–3
	h	2932	2931	2929	2912.4	2891.2	2839.4	975.9	976.3	976.8	977.3
	s	9.012	8.261	7.944	7.177	6.823	6.422	2.578	2.575	2.571	2.567
600	v	27.7	5.53	2.76	0.548	0.271	0.133	0.0630	0.0396	0.0276	0.0201
	h	3131	3130	3129	3120	3109	3087	3036	2976	2906	2820
	s	9.374	8.630	8.309	7.560	7.223	6.875	6.590	6.224	5.997	5.775
700	v	32.3	6.46	3.23	0.643	0.319	0.158	0.0769	0.0500	0.0346	0.0283
	h	3335	3335	3334	3328	3322	3307	3278	3247	3214	3179
	s	9.692	8.946	8.625	7.877	7.550	7.215	6.864	6.644	6.431	6.334
800	v	36.9	7.38	3.69	0.736	0.367	0.182	0.0889	0.0589	0.0436	0.0343
	h	3547	3546	3546	3542	3537	3526	3506	3485	3464	3442
	s	9.971	9.228	8.908	8.161	7.837	7.507	7.151	6.965	6.809	6.685
900	v	41.5	8.31	4.15	0.829	0.414	0.206	0.102	0.0674	0.0501	0.0398
	h	3765	3765	3764	3761	3757	3750	3737	3719	3704	3688
	s	10.228	9.485	9.165	8.420	8.097	7.770	7.462	7.237	7.092	6.975
1000	v	46.2	9.23	4.615	0.921	0.460	0.229	0.114	0.0758	0.0564	0.0449
	h	3990	3990	3990	3987	3984	3978	3967	3955	3944	3935
	s	10.466	9.723	9.402	8.659	8.336	8.011	7.682	7.486	7.345	7.233
1500	v	69.2	13.9	6.92	1.385	0.692	0.341	0.1730	0.1153	0.0865	0.0692
	h	5231	5228	5227	5225	5224	5221	5217	5212	5207	5203
	s	11.47	10.77	10.40	9.66	9.34	9.015	8.693	8.503	8.368	8.262
2000	v	93.0	18.6	9.26	1.850	0.925	0.462	0.231	0.1543	0.1157	0.0926
	h	6832	6734	6706	6662	6649	6639	6629	6623	6619	6616
	s	12.38	11.58	11.25	10.48	10.15	9.828	9.503	9.313	9.178	9.073
2500	v	123.7	24.0	11.90	2.35	1.171	0.583	0.291	0.1942	0.1457	0.1166
	h	10417	9330	9046	8621	8504	8413	8342	8307	8285	8269
	s	13.95	12.73	12.28	11.35	10.80	10.62	10.26	10.06	9.920	9.810

*v = specific volume, m^3/kg; h = specific enthalpy, kJ/kg; s = specific entropy, kJ/(kg·K). The notation 1.027.–3 signifies 1.027×10^{-3}.

Temperature, K		Pressure, bar										
		150	200	250	300	400	500	600	700	800	900	1000
350	v	1.020.–3	1.018.–3	1.016.–3	1.014.–3	1.009.–3	1.005.–3	1.002.–3	9.977.–4	9.937.–4	9.900.–4	9.865.–4
	h	333.7	337.7	341.7	344.7	353.8	361.8	369.7	377.7	385.7	393.7	401.7
	s	1.028	1.025	1.022	1.019	1.013	1.007	1.001	0.996	0.991	0.985	0.979
400	v	1.059.–3	1.056.–3	1.053.–3	1.050.–3	1.045.–3	1.041.–3	1.035.–3	1.031.–3	1.027.–3	1.022.–3	1.018.–3
	h	543.1	546.5	550.1	553.5	560.6	567.8	574.9	582.1	589.3	596.5	603.8
	s	1.587	1.583	1.578	1.574	1.565	1.557	1.549	1.541	1.533	1.526	1.518
450	v	1.112.–3	1.108.–3	1.105.–3	1.101.–3	1.094.–3	1.088.–3	1.082.–3	1.076.–3	1.070.–3	1.065.–3	1.059.–3
	h	756.8	759.5	762.3	765.2	771.0	776.9	783.0	789.6	795.3	801.6	807.9
	s	2.088	2.082	2.076	2.070	2.060	2.049	2.039	2.029	2.019	2.010	2.002
500	v	1.187.–3	1.181.–3	1.175.–3	1.170.–3	1.160.–3	1.151.–3	1.142.–3	1.134.–3	1.126.–3	1.119.–3	1.112.–3
	h	978.8	980.3	981.9	983.7	987.4	991.5	995.9	1000.5	1005.3	1010.3	1015.4
	s	2.558	2.549	2.541	2.533	2.517	2.502	2.488	2.474	2.461	2.449	2.437
600	v	1.519.–3	1.483.–3	1.454.–3	1.428.–3	1.392.–3	1.362.–3	1.337.–3	1.315.–3	1.296.–3	1.280.–3	1.265.–3
	h	1499	1489	1479	1472	1462	1456	1452	1449	1447	1447	1447
	s	3.501	3.469	3.443	3.419	3.379	3.346	3.316	3.290	3.266	3.244	3.223
700	v	1.724.–2	1.157.–2	7.986.–3	5.416.–3	2.630.–3	2.038.–3	1.831.–3	1.716.–3	1.639.–3	1.589.–3	1.536.–3
	h	3082	2965	2821	2635	2233	2084	2021	1986	1962	1946	1931
	s	6.037	5.770	5.494	5.179	4.554	4.308	4.192	4.116	4.058	4.012	3.972
800	v	2.195.–2	1.575.–2	1.201.–2	9.512.–3	6.391.–3	4.576.–3	3.496.–3	2.866.–3	2.484.–3	2.239.–3	2.072.–3
	h	3386	3325	3261	3193	3047	2895	2734	2648	2567	2508	2465
	s	6.444	6.252	6.086	5.934	5.654	5.397	5.175	4.998	4.864	4.761	4.701
900	v	2.590.–2	1.899.–2	1.483.–2	1.207.–2	8.619.–3	6.581.–3	5.257.–3	4.348.–3	3.704.–3	3.454.–3	2.907.–3
	h	3649	3609	3568	3526	3440	3354	3269	3188	3113	3049	2995
	s	6.755	6.587	6.449	6.327	6.119	5.940	5.780	5.637	5.510	5.399	5.305
1000	v	2.954.–2	2.186.–2	1.726.–2	1.420.–2	1.038.–2	8.102.–3	6.605.–3	5.557.–3	4.792.–3	4.212.–3	3.763.–3
	h	3904	3874	3845	3816	3756	3697	3640	3584	3532	3482	3435
	s	7.023	6.867	6.741	6.633	6.453	6.302	6.172	6.055	5.951	5.856	5.727
1500	v	0.0461	0.0346	0.0277	0.0231	0.0173	0.0139	0.0116	0.00993	0.00871	0.00776	0.00700
	h	5202	5198	5186	5180	5171	5157	5144	5133	5120	5108	5095
	s	8.074	7.936	7.827	7.738	7.597	7.484	7.391	7.310	7.239	7.176	7.118
2000	v	0.0619	0.0465	0.0372	0.0311	0.0234	0.0188	0.0157	0.0135	0.0119	0.0106	0.0096
	h	6613	6610	6608	6605	6599	6595	6590	6585	6581	6577	6574
	s	8.883	8.748	8.642	8.555	8.418	8.310	8.222	8.147	8.082	8.024	7.971
2500	v	0.0778	0.0584	0.0468	0.0391	0.0294	0.0236	0.0197	0.0170	0.0149	0.0133	0.0120
	h	8269	8269	8269	8268	8267	8265	8261	2856	8250	8244	8240
	s	9.610	9.468	9.358	9.270	9.129	9.020	8.930	8.854	8.788	8.730	8.677

Presión de Vapor del Agua líquida entre 0 y 100° C

	mmHg									
t, °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	4.579	4.613	4.647	4.681	4.715	4.750	4.785	4.820	4.855	4.890
1	4.926	4.962	4.998	5.034	5.070	5.107	5.144	5.181	5.219	5.256
2	5.294	5.332	5.370	5.408	5.447	5.486	5.525	5.565	5.605	5.645
3	5.685	5.725	5.766	5.807	5.848	5.889	5.931	5.973	6.015	6.058
4	6.101	6.144	6.187	6.230	6.274	6.318	6.363	6.408	6.453	6.498
5	6.543	6.589	6.635	6.681	6.728	6.775	6.822	6.869	6.917	6.965
6	7.013	7.062	7.111	7.160	7.209	7.259	7.309	7.360	7.411	7.462
7	7.513	7.565	7.617	7.669	7.722	7.775	7.828	7.882	7.936	7.990
8	8.045	8.100	8.155	8.211	8.267	8.323	8.380	8.437	8.494	8.551
9	8.609	8.668	8.727	8.786	8.845	8.905	8.965	9.025	9.086	9.147
10	9.209	9.271	9.333	9.395	9.458	9.521	9.585	9.649	9.714	9.779
11	9.844	9.910	9.976	10.042	10.109	10.176	10.244	10.312	10.380	10.449
12	10.518	10.588	10.658	10.728	10.799	10.870	10.941	11.013	11.085	11.158
13	11.231	11.305	11.379	11.453	11.528	11.604	11.680	11.756	11.833	11.910
14	11.987	12.065	12.144	12.223	12.302	12.382	12.462	12.543	12.624	12.706
15	12.788	12.870	12.953	13.037	13.121	13.205	13.290	13.375	13.461	13.547
16	13.634	13.721	13.809	13.898	13.987	14.076	14.166	14.256	14.347	14.438
17	14.530	14.622	14.715	14.809	14.903	14.997	15.092	15.188	15.284	15.380
18	15.477	15.575	15.673	15.772	15.871	15.971	16.071	16.171	16.272	16.374
19	16.477	16.581	16.685	16.789	16.894	16.999	17.105	17.212	17.319	17.427
20	17.535	17.644	17.753	17.863	17.974	18.085	18.197	18.309	18.422	18.536
21	18.650	18.765	18.880	18.996	19.113	19.231	19.349	19.468	19.587	19.707
22	19.827	19.948	20.070	20.193	20.316	20.440	20.565	20.690	20.815	20.941
23	21.068	21.196	21.324	21.453	21.583	21.714	21.845	21.977	22.110	22.243
24	22.377	22.512	22.648	22.785	22.922	23.060	23.198	23.337	23.476	23.616
25	23.756	23.897	24.039	24.182	24.326	24.471	24.617	24.764	24.912	25.060
26	25.209	25.359	25.509	25.660	25.812	25.964	26.117	26.271	26.426	26.582
27	26.739	26.897	27.055	27.214	27.374	27.535	27.696	27.858	28.021	28.185
28	28.349	28.514	28.680	28.847	29.015	29.184	29.354	29.525	29.697	29.870
29	30.043	30.217	30.392	30.568	30.745	30.923	31.102	31.281	31.461	31.642
30	31.824	32.007	32.191	32.376	32.561	32.747	32.934	33.122	33.312	33.503
31	33.695	33.888	34.082	34.276	34.471	34.667	34.864	35.062	35.261	35.462
32	35.663	35.865	36.068	36.272	36.477	36.683	36.891	37.099	37.308	37.518
33	37.729	37.942	38.155	38.369	33.584	38.801	39.018	39.237	39.457	39.677
34	39.898	40.121	40.344	40.569	40.796	41.023	41.251	41.480	41.710	41.942
35	42.175	42.409	42.644	42.880	43.117	43.355	43.595	43.836	44.078	44.320
36	44.563	44.808	45.054	45.301	45.549	45.799	46.050	46.302	46.556	46.811
37	47.067	47.324	47.582	47.841	48.102	48.364	48.627	48.891	49.157	49.424
38	49.692	49.961	50.231	50.502	50.774	51.048	51.323	51.600	51.879	52.160
39	52.442	52.725	53.009	53.294	53.580	53.867	54.156	54.446	54.737	55.030
40	55.324	55.61	55.91	56.21	56.51	56.81	57.11	57.41	57.72	58.03
41	58.34	58.65	58.96	59.27	59.58	59.90	60.22	60.54	60.86	61.18
42	61.50	61.82	62.14	62.47	62.80	63.13	63.46	63.79	64.12	64.46
43	64.80	65.14	65.48	65.82	66.16	66.51	66.86	67.21	67.56	67.91
44	68.26	68.61	68.97	69.33	69.69	70.05	70.41	70.77	71.14	71.51
45	71.88	72.25	72.62	72.99	73.36	73.74	74.12	74.50	74.88	75.26
46	75.65	76.04	76.43	76.82	77.21	77.60	78.00	78.40	78.80	79.20
47	79.60	80.00	80.41	80.82	81.23	81.64	82.05	82.46	82.87	83.29
48	83.71	84.13	84.56	84.99	85.42	85.85	86.28	86.71	87.14	87.58
49	88.02	88.46	88.90	89.34	89.79	90.24	90.69	91.14	91.59	92.05
t, °C	0	1	2	3	4	5	6	7	8	9
50	92.51	97.20	102.09	107.20	112.51	118.04	123.80	129.82	136.08	142.60
60	149.38	156.43	163.77	171.38	179.31	187.54	196.09	204.96	214.17	223.73
70	233.7	243.9	254.6	265.7	277.2	289.1	301.4	314.1	327.3	341.0
80	355.1	369.7	384.9	400.6	416.8	433.6	450.9	468.7	487.1	506.1
90	525.76	527.76	529.77	531.78	533.80	535.82	537.86	539.90	541.95	544.00
91	546.05	548.11	550.18	552.26	554.35	556.44	558.53	560.64	562.75	564.87
92	566.99	569.12	571.26	573.40	575.55	577.71	579.87	582.04	584.22	586.41
93	588.60	590.80	593.00	595.21	597.43	599.66	601.89	604.13	606.38	608.64
94	610.90	613.17	615.44	617.72	620.01	622.31	624.61	626.92	629.24	631.57
95	633.90	636.24	638.59	640.94	643.30	645.67	648.05	650.43	652.82	655.22
96	657.62	660.03	662.45	664.88	667.31	669.75	672.20	674.66	677.12	679.69
97	682.07	684.55	687.04	689.54	692.05	694.57	697.10	699.63	702.17	704.71
98	707.27	709.83	712.40	714.98	717.56	720.15	722.75	725.36	727.98	730.61
99	733.24	735.88	738.53	741.18	743.85	746.52	749.20	751.89	754.58	757.29
100	760.00	762.72	765.45	768.19	770.93	773.68	776.44	779.22	782.00	784.78
101	787.57	790.37	793.18	796.00	796.82	801.66	804.50	807.35	810.21	813.06

Diagrama Psicrométrico

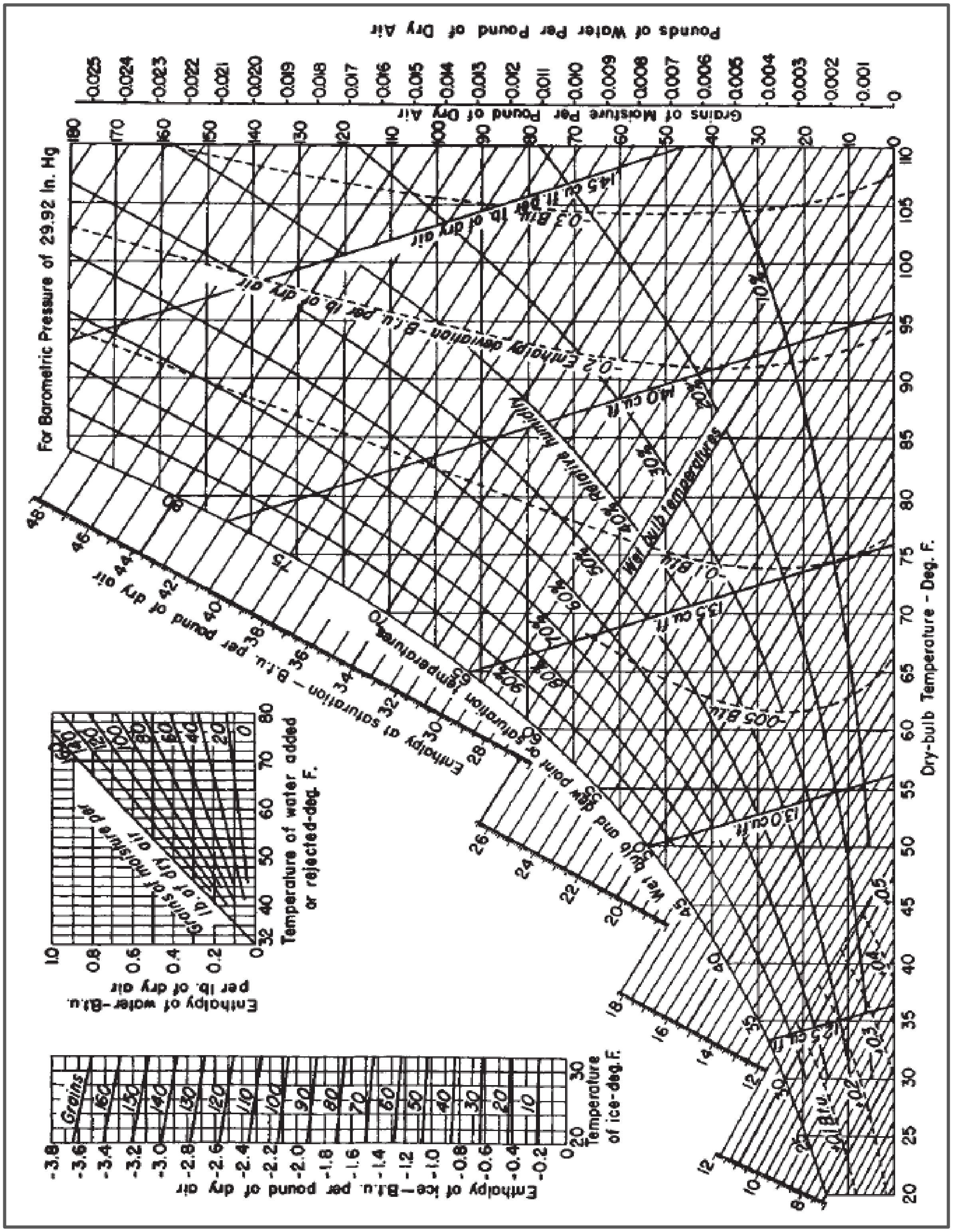
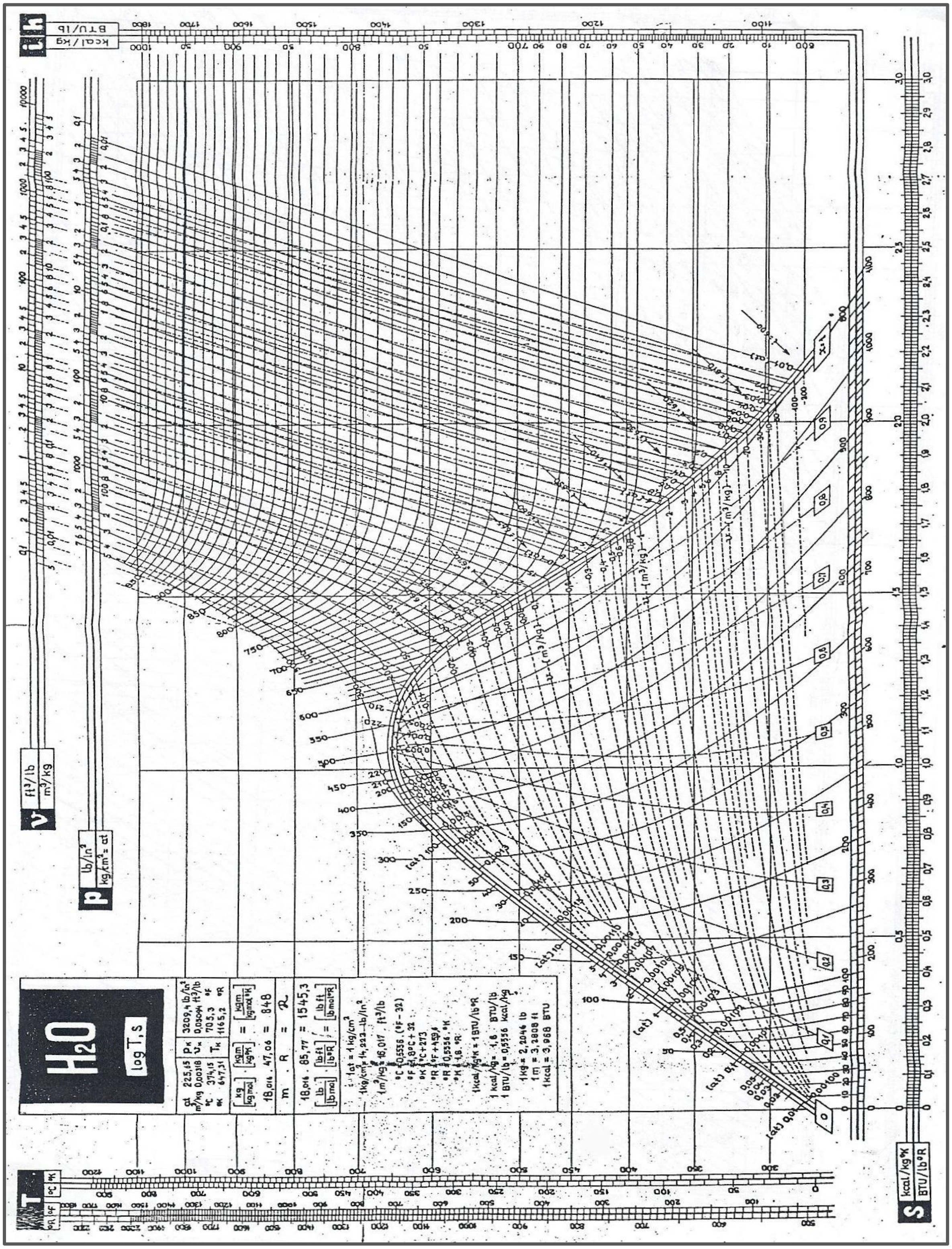
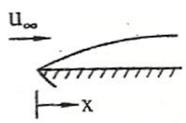
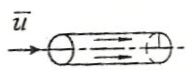
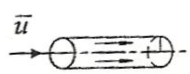
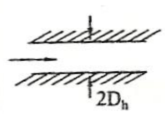
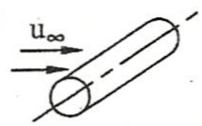
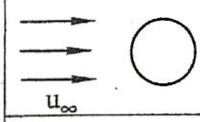
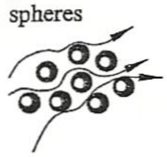
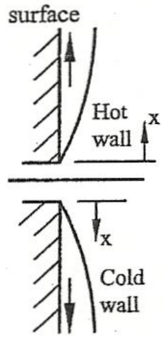
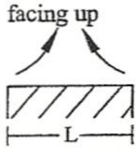


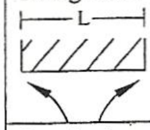
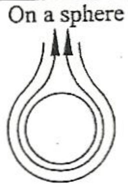
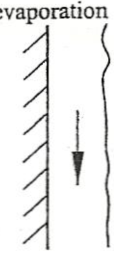
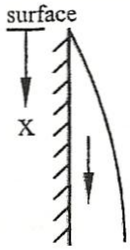
Diagrama Temperatura-Entropía para el Agua

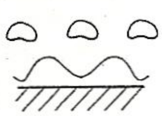


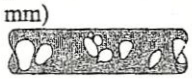
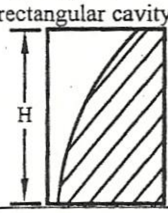
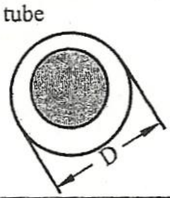
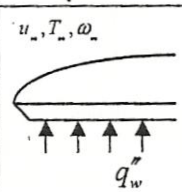
Correlaciones para el Coeficiente Pelicular de Transferencia Convectiva de Calor en Distintos Modos y Geometrías

Heat transfer mode	Geometry	Nusselt number	Comments and restrictions	Dimensionless numbers
	Flow parallel to a flat plate 	$Nu_x = 0.332\,Re_x^{1/2}\,Pr^{1/3}$ $(Pr > 0.6)$ $Nu_x = 0.565\,Re_x^{1/2}\,Pr^{1/2}$ $(Pr \leq 0.05)$	Isothermal surface $Re_x < 5\times10^5$ (laminar)	$Nu_x = \frac{hx}{k}$ $Re_x = \frac{u_\infty x}{\nu}$
		$\overline{Nu} = 0.037(Re_L^{0.8} - 871)Pr^{0.33}$ $(0.6 \leq Pr \leq 60)$	$5\times10^5 < Re_L < 10^8$ (Turbulent)	$\overline{Nu} = \frac{\bar{h}L}{k}$ $Re_L = \frac{u_\infty L}{\nu}$
	Flow in a pipe (conventional size) 	$\overline{Nu} = 3.66 + \frac{0.0668(D/L)Re\,Pr}{1+0.04[(D/L)Re\,Pr]^{2/3}}$	Isothermal surface $Re \leq 2300$ Thermal entry region	$\overline{Nu} = \frac{\bar{h}D}{k}$ $Re = \frac{\bar{u}D}{\nu}$ $\bar{u}$ is mean velocity
Forced convection		$Nu = 0.027\,Re^{0.8} \times Pr^{0.33}(\mu/\mu_w)^{0.14}$ $(0.7 \leq Pr \leq 16700)$	$L/D \geq 10$ $Re > 10{,}000$ (Fully developed turbulent) μ_w is viscosity evaluated at T_w	
	Flow in a pipe (miniature) 	$\overline{Nu} = (1+F) \times \frac{(f/8)(Re-1000)Pr}{1+12.7(f/8)^{0.5}(Pr^{2/3}-1)}$ $f = [1.82\log(Re) - 1.64]^{-2}$ $F = 7.6\times10^{-5}\,Re \times [1-(D/D_0)^2]$	D_0=1.164 mm is reference diameter. Correlation was obtained for water at D=0.102, 0.76 and 1.09 mm.	$\overline{Nu} = \frac{\bar{h}D}{k}$ $Re = \frac{\bar{u}D}{\nu}$
	Flow between parallel plates 	$\overline{Nu} = 7.54 + \frac{0.03(D_h/L)Re\,Pr}{1+0.016[(D_h/L)Re\,Pr]^{2/3}}$	Isothermal surface $Re \leq 2800$ (Laminar)	$\overline{Nu} = \frac{\bar{h}D_h}{k}$ $Re = \frac{\bar{u}D_h}{\nu}$
		$\overline{Nu} = 0.023\,Re^{0.8}\,Pr^{0.33}$ $(Pr > 0.5)$	$Re > 10{,}000$ (Turbulent)	

Heat transfer mode	Geometry	Nusselt number	Comments and restrictions	Dimensionless numbers
Forced convection	Flow across a circular cylinder 	$\overline{Nu} = 0.3 + \frac{0.62 Re^{1/2} Pr^{1/3}}{[1+(0.4/Pr)^{2/3}]^{1/4}} \times \left[1+\left(\frac{Re}{282000}\right)^{5/8}\right]^{4/5}$	$Re\,Pr > 0.2$ (Both laminar and turbulent)	$\overline{Nu} = \frac{\bar{h}D}{k}$ $Re = \frac{u_\infty D}{\nu}$
	Flow across a sphere 	$\overline{Nu} = 2 + (0.4 Re^{0.5} + 0.06 Re^{2/3}) Pr^{0.4} (\mu/\mu_w)^{\frac{1}{4}}$	$3.5 < Re < 76000$ $0.71 \le Pr \le 380$ μ_w is viscosity evaluated at T_w	
	Flow through a packed bed of spheres 	$\overline{Nu} = 1.625 Re^{1/2} Pr^{1/3}$	$15 \le Re \le 120$ D – diameter of sphere A – bed cross-sectional area	$\overline{Nu} = \frac{\bar{h}D}{k}$ $Re = \frac{\dot{m}D}{A\mu}$
Free convection	On a vertical surface 	$\overline{Nu}^{1/2} = 0.825 + \frac{0.387 Ra^{1/6}}{[1+(0.492/Pr)^{9/16}]^{8/27}}$	$\Delta T = \lvert T_w - T_\infty \rvert$ Applicable to both laminar and turbulent	$\overline{Nu} = \frac{\bar{h}L}{k}$ $Ra = \frac{g\beta\Delta T L^3}{\nu\alpha}$
	On a horizontal heated square facing up 	$\overline{Nu} = 0.54 (Gr\,Pr)^{1/4}$	Isothermal surface $10^5 \le Gr \le 7\times10^7$ For rectangle, use shorter side of L	$\overline{Nu} = \frac{\bar{h}L}{k}$ $Gr = \frac{g\beta\Delta T L^3}{\nu^2}$

Heat transfer mode	Geometry	Nusselt number	Comments and restrictions	Dimensionless numbers
Free convection	On a horizontal heated square facing down 	$\overline{Nu} = 0.27(Gr\,Pr)^{1/4}$	Isothermal surface $3\times10^5 \le Gr \le 3\times10^{10}$ For rectangle, use shorter side of L	$\overline{Nu} = \frac{\bar{h}L}{k}$ $Gr = \frac{g\beta\Delta T L^3}{\nu^2}$
	On a horizontal cylinder 	$\overline{Nu}^{1/2} = 0.60 + \frac{0.387 Ra^{1/6}}{[1+(0.559/Pr)^{9/16}]^{8/27}}$	$Ra < 10^{12}$	$\overline{Nu} = \frac{\bar{h}D}{k}$ $Ra = \frac{g\beta\Delta T D^3}{\nu\alpha}$
	On a sphere 	$\overline{Nu} = 2 + \frac{0.589 Ra^{1/4}}{[1+(0.469/Pr)^{9/16}]^{4/9}}$	$\Delta T = T_w - T_\infty$ $Ra < 10^{11}$ $Pr \ge 0.7$	$\overline{Nu} = \frac{\bar{h}D}{k}$ $Ra = \frac{g\beta\Delta T D^3}{\nu\alpha}$
Evaporation	Falling film evaporation 	Laminar $Nu = 1.10 Re_\delta^{-1/3}$ $(Re_\delta \le 30)$ Wavy laminar $Nu = 0.828 Re_\delta^{-0.22}$ $(30 \le Re_\delta \le 1800)$ Turbulent $Nu = 0.0038 Re_\delta^{0.4} Pr^{0.65}$ $(Re_\delta > 1800)$	Nu – local Nusselt number Γ – mass flow rate per unit width of the vertical surface	$Nu = \frac{h(\nu_l^2/g)^{\frac{1}{3}}}{k}$ $Re_\delta = \frac{4\Gamma}{\mu}$
Condensation	On a vertical surface 	Laminar (Nusselt) $Nu = 1.10 Re_\delta^{-1/3}$ $(Re_\delta \le 30)$ Wavy laminar $Nu = \frac{Re_\delta}{Re_\delta^{1.22} - 5.22}$ $(30 \le Re_\delta \le 1800)$ Turbulent $Nu = 0.023 Re_\delta^{0.25} Pr^{-0.5}$	Nu – local Nusselt number Γ – mass flow rate per unit width of the vertical surface	$Nu = \frac{h(\nu_l^2/g)^{\frac{1}{3}}}{k}$ $Re_\delta = \frac{4\Gamma}{\mu}$

Heat transfer mode	Geometry	Nusselt number	Comments and restrictions	Dimensionless numbers
Condensation	On tubes 	$\overline{Nu} = 0.729 \times \left[\frac{D^3 h_{\ell v} g(\rho_\ell - \rho_v)}{n k_\ell \nu_\ell \Delta T}\right]^{\frac{1}{4}}$	$\Delta T = T_{sat} - T_w$ n – number of tubes	$\overline{Nu} = \frac{\bar{h} D}{k_\ell}$
	In microscale channel ($D_h < 1.5$mm) 	$\mathrm{Nu} = \mathrm{We}^{-\mathrm{Ja}} \mathrm{Re} \mathrm{Pr}^Y$	$Y = 1.3$ for $\mathrm{Re} \le 65$ $Y = (0.5D_h - 1)$ $/(2D_h)$ for $\mathrm{Re} > 65$	$\mathrm{We} = \frac{\rho_\ell V^2 L}{\sigma}$ $\mathrm{Ja} = \frac{c_{p\ell}(T_{sat} - T_w)}{h_{\ell v}}$ $\mathrm{Re} = \frac{\dot{m}'' D_h}{\mu_\ell}$ $\dot{m}''$ –mass flux (kg/s-m^2)
Boiling	Nucleate, saturated pool boiling 	$\overline{\mathrm{Nu}} = \frac{\mathrm{Ja}_\ell^2}{C^3 \mathrm{Pr}_\ell^m}$	m=2 for water m=4.1 for other fluids C=0.013 water-copper or stainless steel C=0.006 for water-nickel or brass	$\overline{Nu} = \frac{\bar{h} L_c}{k_\ell}$ $L_c = \sqrt{\frac{\sigma_\ell}{g(\rho_\ell - \rho_v)}}$ $\mathrm{Ja}_\ell = \frac{c_{p,\ell} \Delta T}{h_{\ell v}}$ $\Delta T = T_w - T_{sat}$
	Film boiling on a horizontal plate 	$\overline{\mathrm{Nu}} = 0.425 \times \left[Gr \mathrm{Pr}_v \left(\frac{1 + 0.4 Ja_v}{Ja_v}\right)\right]^{\frac{1}{4}}$	Term in parentheses accounts for sensible heating effect in vapor film	$\overline{Nu} = \frac{\bar{h} L_c}{k_v}$ $L_c = \sqrt{\frac{\sigma_\ell}{g(\rho_\ell - \rho_v)}}$ $Gr = \frac{g[(\rho_\ell - \rho_v)/\rho_v] L_c^3}{\nu_v^2}$ $\mathrm{Ja}_v = \frac{c_{p,v} \Delta T}{h_{\ell v}}$

Heat transfer mode	Geometry	Nusselt number	Comments and restrictions	Dimensionless numbers
Boiling	Film boiling on a horizontal cylinder 	$\overline{\mathrm{Nu}} = 0.62 \times \left[\mathrm{Gr}\,\mathrm{Pr}_v \left(\frac{1+0.4Ja_v}{Ja_v} \right) \right]^{\frac{1}{4}}$	$D \gg$ film thickness	$\overline{Nu} = \frac{\bar{h}D}{k_v}$ $\mathrm{Gr} = \frac{g[(\rho_l - \rho_v)/\rho_v]D^3}{\nu_v^2}$ $\mathrm{Ja}_v = \frac{c_{p,v}\Delta T}{h_{fg}}$
	Film boiling on a sphere 	$\overline{\mathrm{Nu}} = 0.4 \times \left[\mathrm{Gr}\,\mathrm{Pr}_v \left(\frac{1+0.4\mathrm{Ja}_v}{\mathrm{Ja}_v} \right) \right]^{\frac{1}{3}}$	$D \gg$ film thickness	
	Boiling in microchannel (D=1.39 – 1.69 mm) 	$\mathrm{Nu} = 30\,\mathrm{Re}^{0.857} \times \mathrm{Bo}^{0.714}(1-x)^{-0.143}$	Correlation obtained by using Freon ® 141 x is quality	$\overline{Nu} = \frac{\bar{h}D}{k_\ell}$ $\mathrm{Bo} = \frac{q''}{h_{\ell v}\dot{m}''}$ $\dot{m}''$ – mass flux (kg/s-m^2)
Melting	Melting in a rectangular cavity 	$\mathrm{Nu} = (2\tau)^{-1/2}$ $+[c_1\mathrm{Ra}^{1/4} - (2\tau)^{-1/2}]$ $\times[1 + (c_2\mathrm{Ra}^{3/4}\tau^{3/2})^n]^{1/n}$ $c_1 = 0.35, c_2 = 0.175$ $n = -2$	Nusselt number is function of time	$\overline{Nu} = \frac{\bar{h}H}{k}$ $\mathrm{Ra} = \frac{g\beta\Delta T H^3}{\nu\alpha}$ $\tau = \mathrm{SteFo}$ $\mathrm{Fo} = \frac{\alpha_\ell t}{H^2}$
Solidification	Solidification around a horizontal tube 	$\overline{\mathrm{Nu}} = 0.52\mathrm{Ra}^{1/4}$	D is transient equivalent outer diameter of the solid $Ra \le 10^9$	$\overline{Nu} = \frac{\bar{h}D}{k}$ $\mathrm{Ra} = \frac{g\beta\Delta T D^3}{\nu\alpha}$
Sublimation		$\mathrm{Nu}_x = 0.458\,\mathrm{Re}_x^{1/2}\,\mathrm{Pr}^{1/3}$ $\mathrm{Sh}_x = 0.459\,\mathrm{Re}_x^{1/2}\,\mathrm{Sc}^{1/3}$	Uniform heat flux surface $\mathrm{Re}_x < 5\times10^5$	$\mathrm{Nu}_x = \frac{hx}{k}$ $\mathrm{Sh}_x = \frac{h_m x}{D}$

Correlación de McAdams para Convección Forzada alrededor de un Cilindro Horizontal

$$\frac{hD}{k_f} = c\left(\frac{VD\rho_f}{\mu_f}\right)^n (\mathrm{Pr}_f)^{1/3}$$

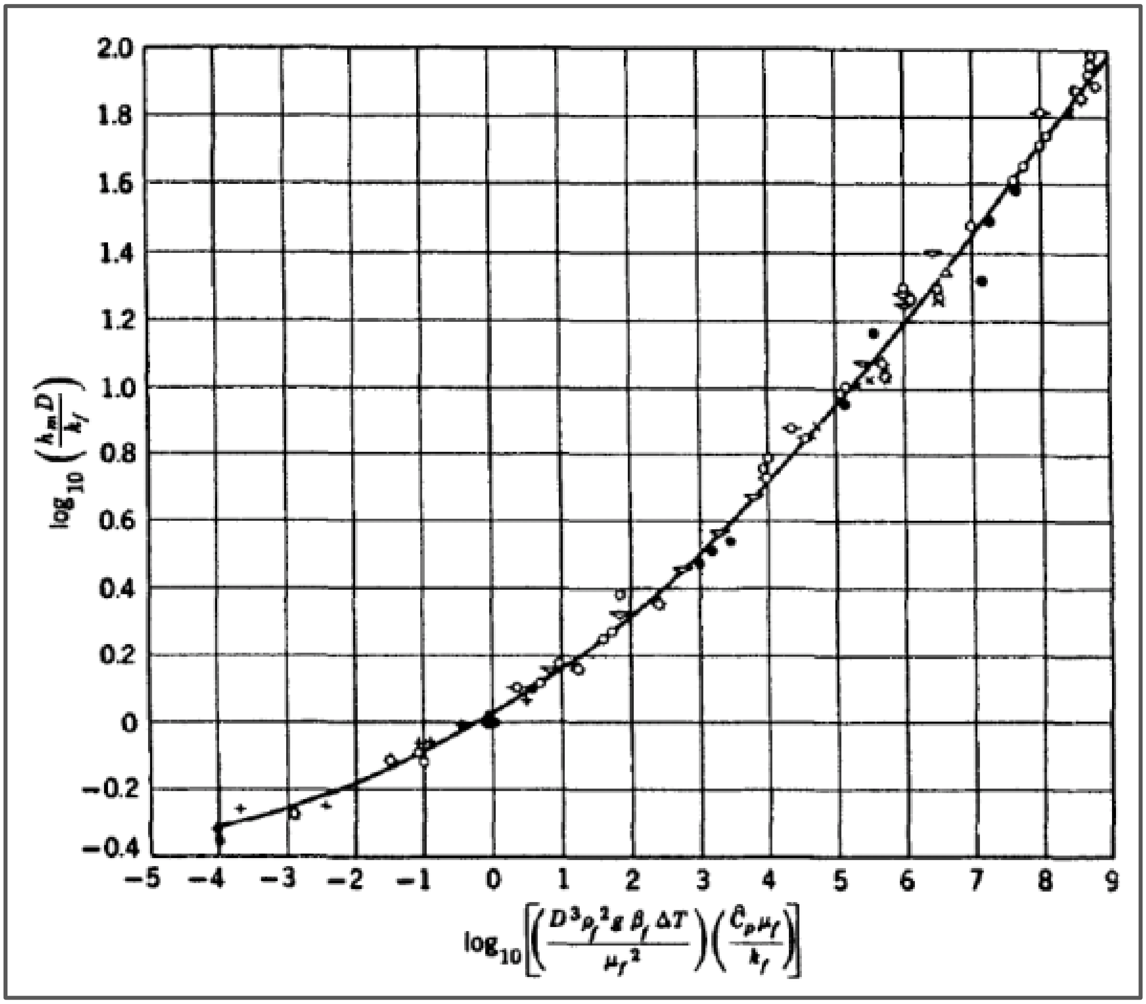
Las constantes c y n son funciones del número de Reynolds. Las propiedades físicas y el número de Reynolds deben ser evaluados a la temperatura de film ($T_f = (T_0 + T_\infty)/2$).

Valores de c y n para utilizarlos en la ecuación:

$\mathrm{Re}_{d_f}^{a}$	C	n
0.4–4	0.989	0.330
4–40	0.911	0.385
40–4,000	0.683	0.466
4,000–40,000	0.193	0.618
40,000–400,000	0.0266	0.805

[a] The Reynolds number is based on the cylinder diameter and the film temperature.

Gráfica del Número de Nusselt en convección natural alrededor de un cilindro horizontal



Ecuación de Continuidad para una Fase de Densidad ρ en Distintos Sistemas de Coordenadas

- Coordenadas rectangulares (x , y , z):

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial y}(\rho v_y) + \frac{\partial}{\partial z}(\rho v_z) = 0$$

- Coordenadas cilíndricas (r , θ , z):

$$\frac{\partial \rho}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(\rho r v_r) + \frac{1}{r}\frac{\partial}{\partial \theta}(\rho v_\theta) + \frac{\partial}{\partial z}(\rho v_z) = 0$$

- Coordenadas esféricas (r , θ , ϕ):

$$\frac{\partial \rho}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r}(\rho r^2 v_r) + \frac{1}{r \operatorname{sen}\theta}\frac{\partial}{\partial \theta}(\rho v_\theta \operatorname{sen}\theta) + \frac{1}{r \operatorname{sen}\theta}\frac{\partial}{\partial \phi}(\rho v_\phi) = 0$$

Transferencia de Cantidad de Movimiento

La Ecuación de Movimiento en Coordenadas Rectangulares (x, y, z)

En función de τ :

Componente x)
$$\rho\left(\frac{\partial v_x}{\partial t}+v_x\frac{\partial v_x}{\partial x}+v_y\frac{\partial v_x}{\partial y}+v_z\frac{\partial v_x}{\partial z}\right)=-\frac{\partial p}{\partial x}-\left(\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{yx}}{\partial y}+\frac{\partial \tau_{zx}}{\partial z}\right)+\rho g_x$$

Componente y)
$$\rho\left(\frac{\partial v_y}{\partial t}+v_x\frac{\partial v_y}{\partial x}+v_y\frac{\partial v_y}{\partial y}+v_z\frac{\partial v_y}{\partial z}\right)=-\frac{\partial p}{\partial y}-\left(\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{zy}}{\partial z}\right)+\rho g_y$$

Componente z)
$$\rho\left(\frac{\partial v_z}{\partial t}+v_x\frac{\partial v_z}{\partial x}+v_y\frac{\partial v_z}{\partial y}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial p}{\partial z}-\left(\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}\right)+\rho g_z$$

En función de los gradientes de velocidad para un fluido newtoniano de ρ y μ constantes:

Componente x)
$$\rho\left(\frac{\partial v_x}{\partial t}+v_x\frac{\partial v_x}{\partial x}+v_y\frac{\partial v_x}{\partial y}+v_z\frac{\partial v_x}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 v_x}{\partial x^2}+\frac{\partial^2 v_x}{\partial y^2}+\frac{\partial^2 v_x}{\partial z^2}\right)+\rho g_x$$

Componente y)
$$\rho\left(\frac{\partial v_y}{\partial t}+v_x\frac{\partial v_y}{\partial x}+v_y\frac{\partial v_y}{\partial y}+v_z\frac{\partial v_y}{\partial z}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v_y}{\partial x^2}+\frac{\partial^2 v_y}{\partial y^2}+\frac{\partial^2 v_y}{\partial z^2}\right)+\rho g_y$$

Componente z)
$$\rho\left(\frac{\partial v_z}{\partial t}+v_x\frac{\partial v_z}{\partial x}+v_y\frac{\partial v_z}{\partial y}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 v_z}{\partial x^2}+\frac{\partial^2 v_z}{\partial y^2}+\frac{\partial^2 v_z}{\partial z^2}\right)+\rho g_z$$

La Ecuación de Movimiento en Coordenadas Cilíndricas (r, θ, z)

En función de τ :

Componente r [a])

$$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}-\frac{v_\theta^{2}}{r}+v_z\frac{\partial v_r}{\partial z}\right)=-\frac{\partial p}{\partial r}-\left(\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rr})+\frac{1}{r}\frac{\partial \tau_{r\theta}}{\partial \theta}-\frac{\tau_{\theta\theta}}{r}+\frac{\partial \tau_{rz}}{\partial z}\right)+\rho g_r$$

Componente θ [b])

$$\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_r v_\theta}{r}+v_z\frac{\partial v_\theta}{\partial z}\right)=-\frac{1}{r}\frac{\partial p}{\partial \theta}-\left(\frac{1}{r^2}\frac{\partial}{\partial r}(r^2\tau_{r\theta})+\frac{1}{r}\frac{\partial \tau_{\theta\theta}}{\partial \theta}+\frac{\partial \tau_{\theta z}}{\partial z}\right)+\rho g_\theta$$

Componente z)

$$\rho\left(\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial p}{\partial z}-\left(\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rz})+\frac{1}{r}\frac{\partial \tau_{\theta z}}{\partial \theta}+\frac{\partial \tau_{zz}}{\partial z}\right)+\rho g_z$$

En función de los gradientes de velocidad para un fluido newtoniano de ρ y μ constantes:

Componente r [a])

$$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}-\frac{v_\theta^{2}}{r}+v_z\frac{\partial v_r}{\partial z}\right)=-\frac{\partial p}{\partial r}+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_r)\right)+\frac{1}{r^2}\frac{\partial^2 v_r}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta}+\frac{\partial^2 v_r}{\partial z^2}\right]+\rho g_r$$

Componente θ [b])

$$\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_r v_\theta}{r}+v_z\frac{\partial v_\theta}{\partial z}\right)=-\frac{1}{r}\frac{\partial p}{\partial \theta}+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_\theta)\right)+\frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial v_r}{\partial \theta}+\frac{\partial^2 v_\theta}{\partial z^2}\right]+\rho g_\theta$$

Componente z)

$$\rho\left(\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left[\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 v_z}{\partial \theta^2}+\frac{\partial^2 v_z}{\partial z^2}\right)\right]+\rho g_z$$

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[a] El término $\rho v_\theta^{2}/r$ representa la *fuerza centrífuga*.

[b] El término $\rho v_r v_\theta / r$ representa la *fuerza de Coriolis*.

La Ecuación de Movimiento en Coordenadas Esféricas (r, θ, ϕ)

En función de τ :

Componente r)

$$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}+\frac{v_\phi}{r\,\mathrm{sen}\,\theta}\frac{\partial v_r}{\partial \phi}-\frac{v_\theta{}^2+v_\phi{}^2}{r}\right)$$

$$=-\frac{\partial p}{\partial r}-\left(\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\tau_{rr}\right)+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial}{\partial \theta}\left(\tau_{r\theta}\,\mathrm{sen}\,\theta\right)\right.$$

$$\left.+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial \tau_{r\phi}}{\partial \theta}-\frac{\tau_{\theta\theta}+\tau_{\phi\phi}}{r}\right)+\rho g_r$$

Componente θ)

$$\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_\phi}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\theta}{\partial \phi}+\frac{v_r v_\theta}{r}-\frac{v_\phi{}^2\cot\theta}{r}\right)$$

$$=-\frac{1}{r}\frac{\partial p}{\partial \theta}-\left(\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\tau_{r\theta}\right)+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial}{\partial \theta}\left(\tau_{\theta\theta}sen\theta\right)+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial \tau_{\theta\phi}}{\partial \phi}\right.$$

$$\left.+\frac{\tau_{r\theta}}{r}-\frac{\cot\theta}{r}\tau_{\phi\phi}\right)+\rho g_\theta$$

Componente ϕ)

$$\rho\left(\frac{\partial v_\phi}{\partial t}+v_r\frac{\partial v_\phi}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\phi}{\partial \theta}+\frac{v_\phi}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\phi}{\partial \phi}+\frac{v_\phi v_r}{r}+\frac{v_\theta v_\phi}{r}\cot\theta\right)$$

$$=-\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial p}{\partial \phi}-\left(\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\tau_{r\phi}\right)+\frac{1}{r}\frac{\partial \tau_{\theta\phi}}{\partial \theta}+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial \tau_{\phi\phi}}{\partial \phi}\right.$$

$$\left.+\frac{\tau_{r\phi}}{r}-\frac{2\cot\theta}{r}\tau_{\theta\phi}\right)+\rho g_\phi$$

En función de los gradientes de velocidad para un fluido newtoniano de ρ y μ constantes[c]:

Componente r)

$$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}+\frac{v_\phi}{r\,\mathrm{sen}\,\theta}\frac{\partial v_r}{\partial \phi}-\frac{v_\theta{}^2+v_\phi{}^2}{r}\right)$$

$$=-\frac{\partial p}{\partial r}+\mu\left(\nabla^2 v_r-\frac{2}{r^2}v_r-\frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta}-\frac{2}{r^2}v_\theta\cot\theta\right.$$

$$\left.-\frac{2}{r^2\,\mathrm{sen}\,\theta}\frac{\partial v_\phi}{\partial \phi}\right)+\rho g_r$$

Componente θ)

$$\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_\phi}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\theta}{\partial \phi}+\frac{v_r v_\theta}{r}-\frac{v_\phi{}^2\cot\theta}{r}\right)$$

$$=-\frac{1}{r}\frac{\partial p}{\partial \theta}+\mu\left(\nabla^2 v_\theta+\frac{2}{r^2}\frac{\partial v_r}{\partial \theta}-\frac{v_\theta}{r^2\,\mathrm{sen}^2\,\theta}-\frac{2\cos\theta}{r^2\,\mathrm{sen}^2\,\theta}\frac{\partial v_\phi}{\partial \phi}\right)+\rho g_\theta$$

Componente ϕ)

$$\rho\left(\frac{\partial v_\phi}{\partial t}+v_r\frac{\partial v_\phi}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\phi}{\partial \theta}+\frac{v_\phi}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\phi}{\partial \phi}+\frac{v_\phi v_r}{r}+\frac{v_\theta v_\phi}{r}\cot\theta\right)$$

$$=-\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial p}{\partial \phi}+\mu\left(\nabla^2 v_\phi-\frac{v_\phi}{r^2\,\mathrm{sen}^2\,\theta}+\frac{2}{r^2\,\mathrm{sen}^2\,\theta}\frac{\partial v_r}{\partial \phi}\right.$$

$$\left.+\frac{2\cos\theta}{r^2\,\mathrm{sen}^2\,\theta}\frac{\partial v_\theta}{\partial \phi}\right)+\rho g_\phi$$

[c] En estas ecuaciones:

$$\nabla^2=\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right)+\frac{1}{r^2\,\mathrm{sen}\,\theta}\frac{\partial}{\partial \theta}\left(\mathrm{sen}\,\theta\frac{\partial}{\partial \theta}\right)+\frac{1}{r^2\,\mathrm{sen}^2\,\theta}\left(\frac{\partial^2}{\partial \phi^2}\right)$$

Componentes del Tensor Esfuerzo en Función de μ y v para un Fluido Newtoniano en Coordenadas Rectangulares (x, y, z)

$$\tau = \begin{bmatrix} \tau_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \tau_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \tau_{zz} \end{bmatrix}$$

$$\tau_{xx} = -\mu\left[2\frac{\partial v_x}{\partial x} - \tfrac{2}{3}(\nabla \cdot v)\right]$$

$$\tau_{yy} = -\mu\left[2\frac{\partial v_y}{\partial y} - \tfrac{2}{3}(\nabla \cdot v)\right]$$

$$\tau_{zz} = -\mu\left[2\frac{\partial v_z}{\partial z} - \tfrac{2}{3}(\nabla \cdot v)\right]$$

$$\tau_{xy} = \tau_{yx} = -\mu\left[\frac{\partial v_x}{\partial y} + \frac{\partial v_y}{\partial x}\right]$$

$$\tau_{yz} = \tau_{zy} = -\mu\left[\frac{\partial v_y}{\partial z} + \frac{\partial v_z}{\partial y}\right]$$

$$\tau_{zx} = \tau_{xz} = -\mu\left[\frac{\partial v_z}{\partial x} + \frac{\partial v_x}{\partial z}\right]$$

$(\nabla \cdot v)$: Divergencia del vector velocidad en coordenadas cartesianas

$$(\nabla \cdot v) = \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z}$$

Componentes del Tensor Esfuerzo en Función de μ y v para un Fluido Newtoniano en Coordenadas Cilíndricas (r, θ, z)

$$\tau = \begin{bmatrix} \tau_{rr} & \tau_{r\theta} & \tau_{rz} \\ \tau_{\theta r} & \tau_{\theta\theta} & \tau_{\theta z} \\ \tau_{zr} & \tau_{z\theta} & \tau_{zz} \end{bmatrix}$$

$$\tau_{rr} = -\mu\left[2\frac{\partial v_r}{\partial r} - \tfrac{2}{3}(\nabla \cdot v)\right]$$

$$\tau_{\theta\theta} = -\mu\left[2\left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r}{r}\right) - \tfrac{2}{3}(\nabla \cdot v)\right]$$

$$\tau_{zz} = -\mu\left[2\frac{\partial v_z}{\partial z} - \tfrac{2}{3}(\nabla \cdot v)\right]$$

$$\tau_{r\theta} = \tau_{\theta r} = -\mu\left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right) + \frac{1}{r}\frac{\partial v_r}{\partial \theta}\right]$$

$$\tau_{\theta z} = \tau_{z\theta} = -\mu\left[\frac{\partial v_\theta}{\partial z} + \frac{1}{r}\frac{\partial v_z}{\partial \theta}\right]$$

$$\tau_{zr} = \tau_{rz} = -\mu\left[\frac{\partial v_z}{\partial r} + \frac{\partial v_r}{\partial z}\right]$$

$(\nabla \cdot v)$: Divergencia del vector velocidad en coordenadas cilíndricas

$$(\nabla \cdot v) = \frac{1}{r}\frac{\partial}{\partial r}(r v_r) + \frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{\partial v_z}{\partial z}$$

Componentes del Tensor Esfuerzo en Función de μ y v para un Fluido Newtoniano en Coordenadas Esféricas (r, θ, ϕ)

$$\tau = \begin{bmatrix} \tau_{rr} & \tau_{r\theta} & \tau_{r\phi} \\ \tau_{\theta r} & \tau_{\theta\theta} & \tau_{\theta\phi} \\ \tau_{\phi r} & \tau_{\phi\theta} & \tau_{\phi\phi} \end{bmatrix}$$

$$\tau_{rr} = -\mu\left[2\frac{\partial v_r}{\partial r} - \tfrac{2}{3}(\nabla \cdot v)\right]$$

$$\tau_{\theta\theta} = -\mu\left[2\left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r}{r}\right) - \tfrac{2}{3}(\nabla \cdot v)\right]$$

$$\tau_{\phi\phi} = -\mu\left[2\left(\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\phi}{\partial \phi} + \frac{v_r}{r} + \frac{v_\theta \cot\theta}{r}\right) - \tfrac{2}{3}(\nabla \cdot v)\right]$$

$$\tau_{r\theta} = \tau_{\theta r} = -\mu\left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right) + \frac{1}{r}\frac{\partial v_r}{\partial \theta}\right]$$

$$\tau_{\theta\phi} = \tau_{\phi\theta} = -\mu\left[\frac{\mathrm{sen}\,\theta}{r}\frac{\partial}{\partial \theta}\left(\frac{v_\phi}{\mathrm{sen}\,\theta}\right) + \frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\theta}{\partial \phi}\right]$$

$$\tau_{\phi r} = \tau_{r\phi} = -\mu\left[\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_r}{\partial \phi} + r\frac{\partial}{\partial r}\left(\frac{v_\phi}{r}\right)\right]$$

$(\nabla \cdot v)$: Divergencia del vector velocidad en coordenadas esféricas

$$(\nabla \cdot v) = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 v_r\right) + \frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial}{\partial \theta}\left(v_\theta\,\mathrm{sen}\,\theta\right) + \frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\phi}{\partial \phi}$$

La función $-(\tau:\nabla v) = \mu\phi_v$ para Fluidos Newtonianos en Distintas Coordenadas

Rectangular:

$$\phi_v = 2\left[\left(\frac{\partial v_x}{\partial x}\right)^2 + \left(\frac{\partial v_y}{\partial y}\right)^2 + \left(\frac{\partial v_z}{\partial z}\right)^2\right]$$
$$+\left[\frac{\partial v_y}{\partial x} + \frac{\partial v_x}{\partial y}\right]^2 + \left[\frac{\partial v_z}{\partial y} + \frac{\partial v_y}{\partial z}\right]^2 + \left[\frac{\partial v_x}{\partial z} + \frac{\partial v_z}{\partial x}\right]^2$$
$$-\frac{2}{3}\left[\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z}\right]^2$$

Cilíndrica:

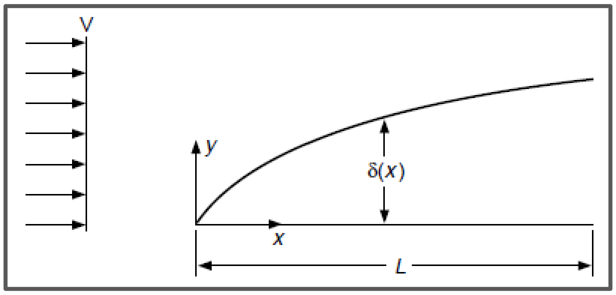
$$\phi_v = 2\left[\left(\frac{\partial v_r}{\partial r}\right)^2 + \left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r}{r}\right)^2 + \left(\frac{\partial v_z}{\partial z}\right)^2\right]$$
$$+\left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right) + \frac{1}{r}\frac{\partial v_r}{\partial \theta}\right]^2 + \left[\frac{1}{r}\frac{\partial v_z}{\partial \theta} + \frac{\partial v_\theta}{\partial z}\right]^2$$
$$+\left[\frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r}\right]^2$$
$$-\frac{2}{3}\left[\frac{1}{r}\frac{\partial}{\partial r}(r v_r) + \frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{\partial v_z}{\partial z}\right]^2$$

Esférica:

$$\phi_v = 2\left[\left(\frac{\partial v_r}{\partial r}\right)^2 + \left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r}{r}\right)^2\right.$$
$$\left.+\left(\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\phi}{\partial \phi} + \frac{v_r}{r} + \frac{v_\theta \cot\theta}{r}\right)^2\right]$$
$$+\left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right) + \frac{1}{r}\frac{\partial v_r}{\partial \theta}\right]^2$$
$$+\left[\frac{\mathrm{sen}\,\theta}{r}\frac{\partial}{\partial \theta}\left(\frac{v_\phi}{\mathrm{sen}\,\theta}\right) + \frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\theta}{\partial \phi}\right]^2$$
$$+\left[\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_r}{\partial \phi} + r\frac{\partial}{\partial r}\left(\frac{v_\phi}{r}\right)\right]^2$$
$$-\frac{2}{3}\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 v_r\right) + \frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial}{\partial \theta}\left(v_\theta\,\mathrm{sen}\,\theta\right) + \frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\phi}{\partial \phi}\right]^2$$

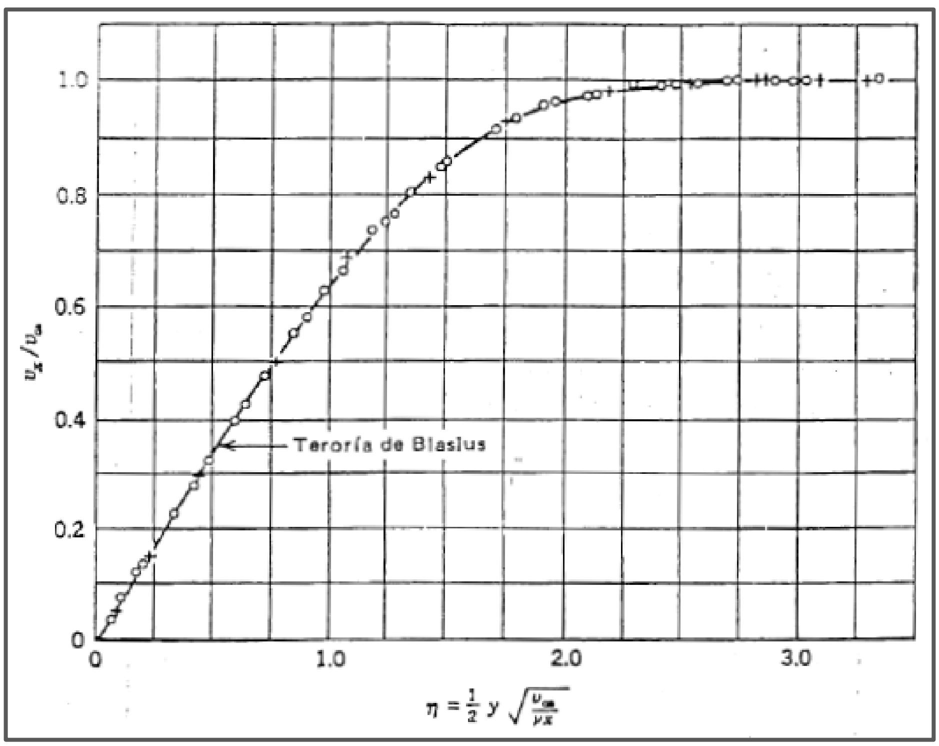
Transporte de Cantidad de Movimiento en la Interfase

Placa Plana



$$Re_x = \frac{x v_\infty \rho}{\mu}$$

Distribución de la velocidad en la capa límite laminar sobre una placa plana. Datos experimentales proporcionados por J. Nikuradse (monograph, Zentrale F. wiss. Berichtswesen, Berlín, 1942) para la magnitud del número de Reynolds de $1{,}08.10^5$ a $7{,}28.10^5$.



Soluciones de Blasius para capa límite laminar ($0 < \mathrm{Re} < 5.10^5$):

$$\delta_{(x)} = \frac{5x}{\sqrt{\mathrm{Re}_x}} \qquad \left.\frac{\partial v_x}{\partial y}\right|_{y=0} = 0{,}332 v_\infty \sqrt{\frac{\rho v_\infty}{\mu \cdot x}}$$

$$\Rightarrow \qquad \tau_{Placa} = -\mu 0{,}332 v_\infty \sqrt{\frac{\rho v_\infty}{\mu \cdot x}}$$

Coeficiente de fricción superficial puntual para capa límite laminar ($0 < \mathrm{Re} < 5.10^5$)[d]:

$$C_{D_x} = \frac{0{,}664}{\sqrt{\mathrm{Re}_x}}$$

Coeficiente de fricción superficial puntual para capa límite turbulenta ($5.10^5 < \mathrm{Re} < 10^7$)[d]:

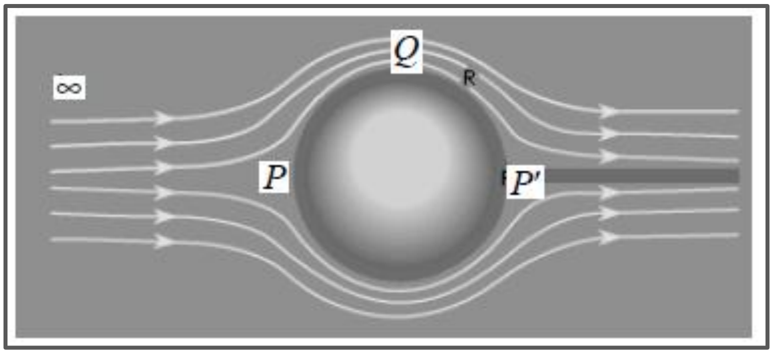
$$C_{D_x} = \frac{0{,}0576}{\mathrm{Re}_x^{1/5}}$$

[d] El subíndice "x" en estas expresiones indica que los coeficientes son locales.

Flujo Reptante alrededor de Esferas

Se define el número de Reynolds como: $\mathrm{Re} = \dfrac{D v_{\infty} \rho}{\mu}$

Flujo Reptante $\Rightarrow \mathrm{Re} < 0{,}1$

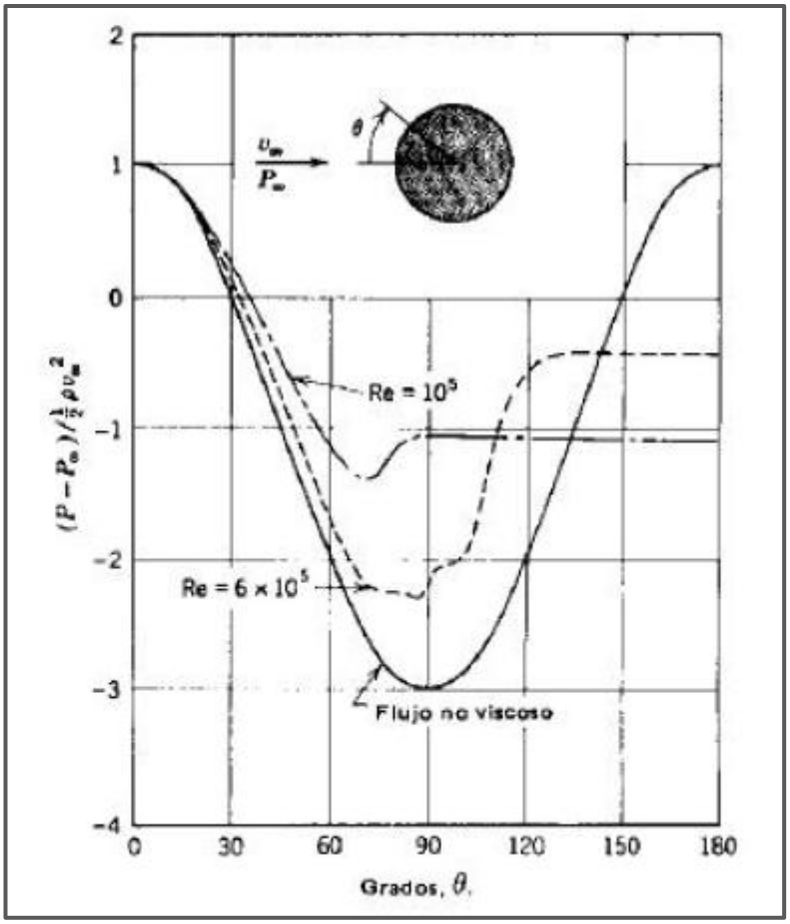


$$\boxed{F_{Fluido/\,Sólida} = F_D = 3\pi D\mu \cdot v_{\infty}}$$

Los resultados se pueden extender hasta $\mathrm{Re} \approx 1$

Distribuciones de Presión alrededor de Cilindros

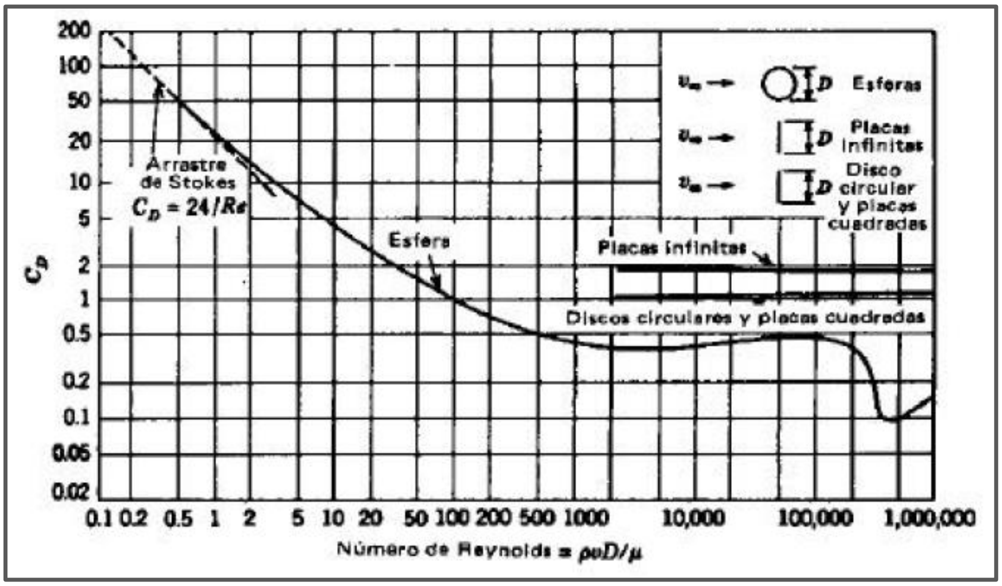
Distribución de presiones sobre un cilindro circular para varios valores del número de Reynolds:



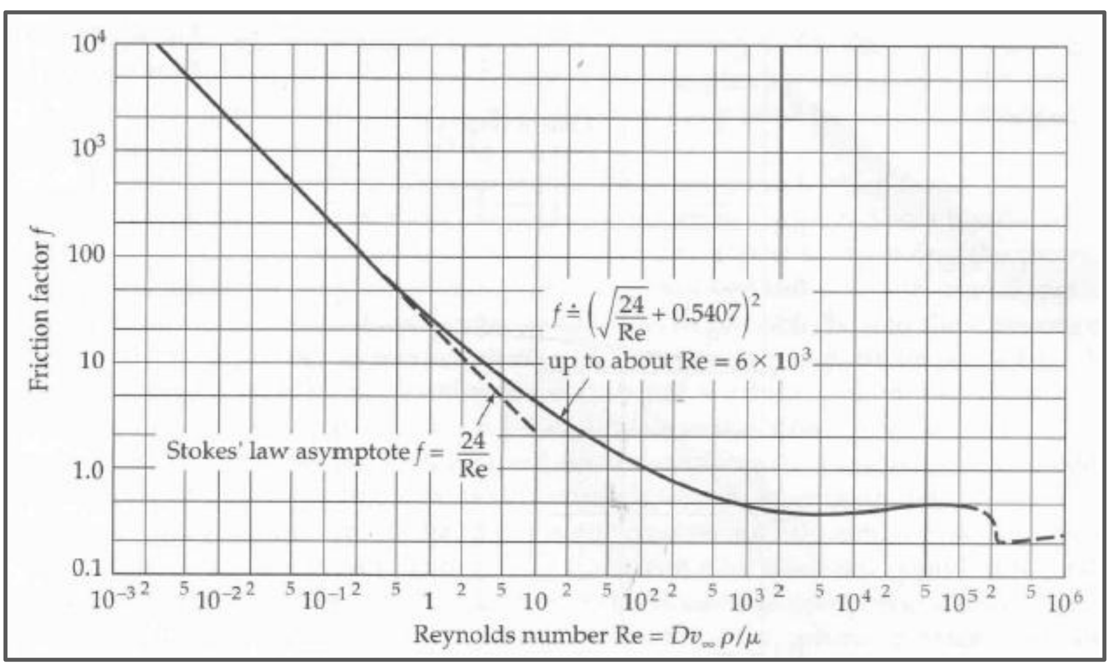
Coeficientes de Arrastre

Definición de Factores de Fricción: $\left|\overline{F}_{f\to s}\right| = f \cdot A_{Característica} \cdot \rho \dfrac{v^2}{2}$

- Coeficiente de arrastre para diversas geometrías (esferas, placas infinitas, discos circulares y placas cuadradas) en función del número de Reynolds:



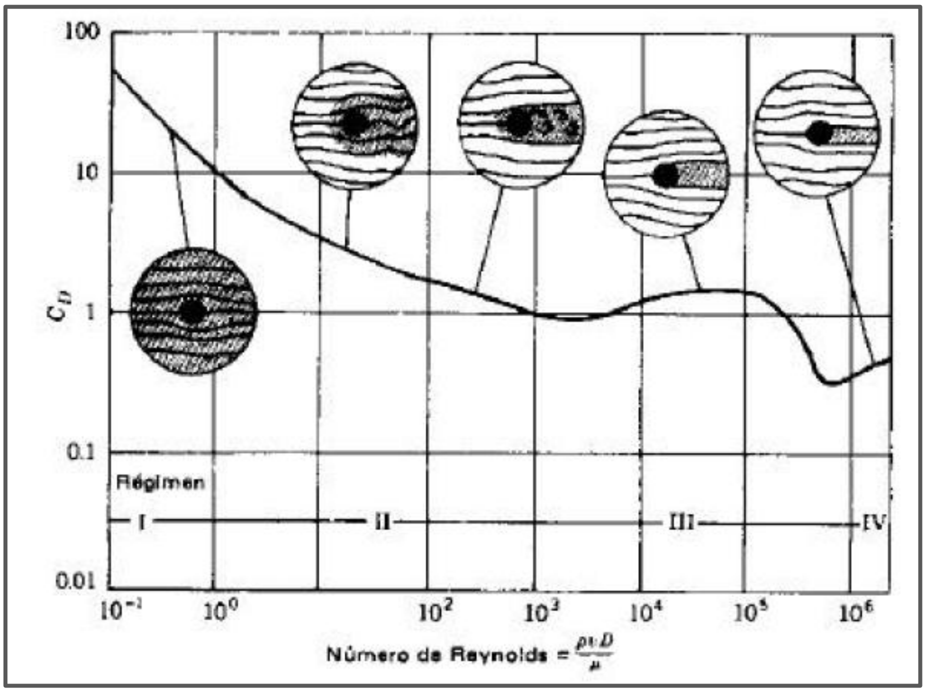
- Coeficiente de arrastre para esferas:



- Expresión empírica del coeficiente de arrastre para esferas:

$$\begin{cases} \mathrm{Re} < 1 & \rightarrow \quad C_D = \dfrac{24}{\mathrm{Re}} \\ 1 < \mathrm{Re} < 10^3 & \rightarrow \quad C_D = \left(\dfrac{24}{\mathrm{Re}}\right)\left(1 + 0{,}15\,\mathrm{Re}^{0{,}69}\right) \\ 10^3 < \mathrm{Re} < 3.10^5 & \rightarrow \quad C_D = 0{,}47 \\ \mathrm{Re} > 3.10^5 & \rightarrow \quad C_D = 0{,}2 \end{cases}$$

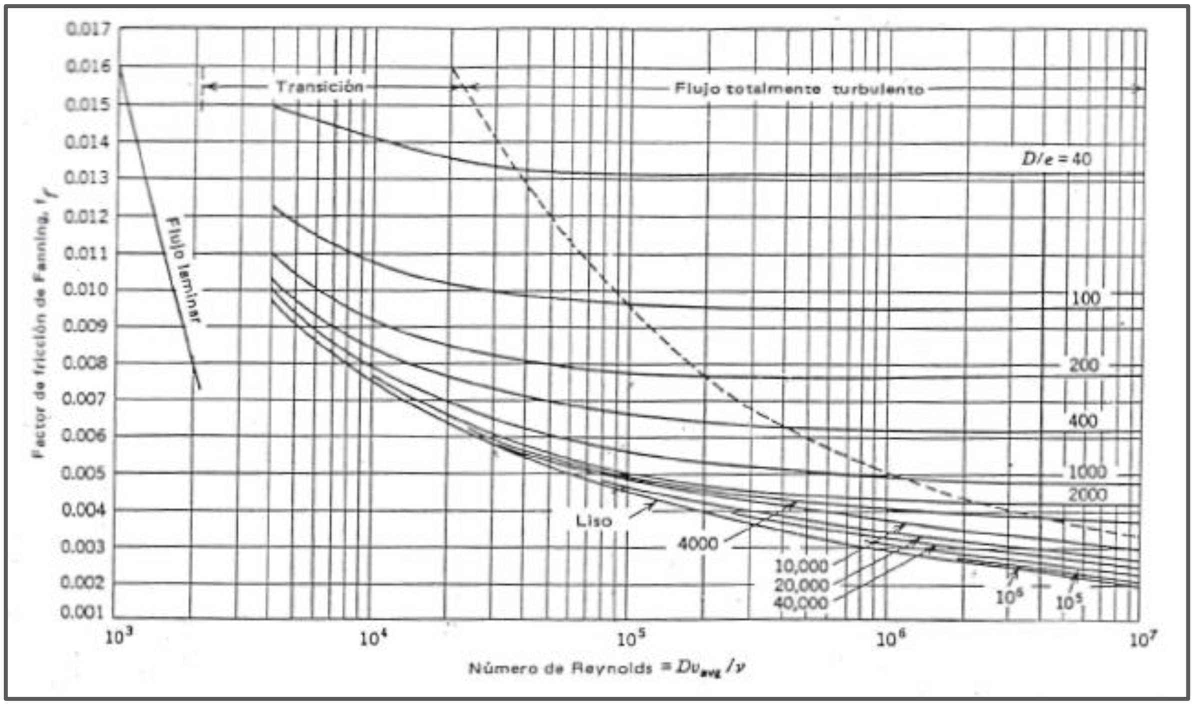
- Coeficiente de arrastre para cilindros circulares en función del número de Reynolds:



Las regiones sombreadas señalan las áreas donde el esfuerzo cortante ejerce influencia.

Factor de Fricción de Fanning

Gráfica del factor de fricción de Fanning para el flujo en un tubo:



- Correlación de Blasius para tubos hidráulicamente lisos:

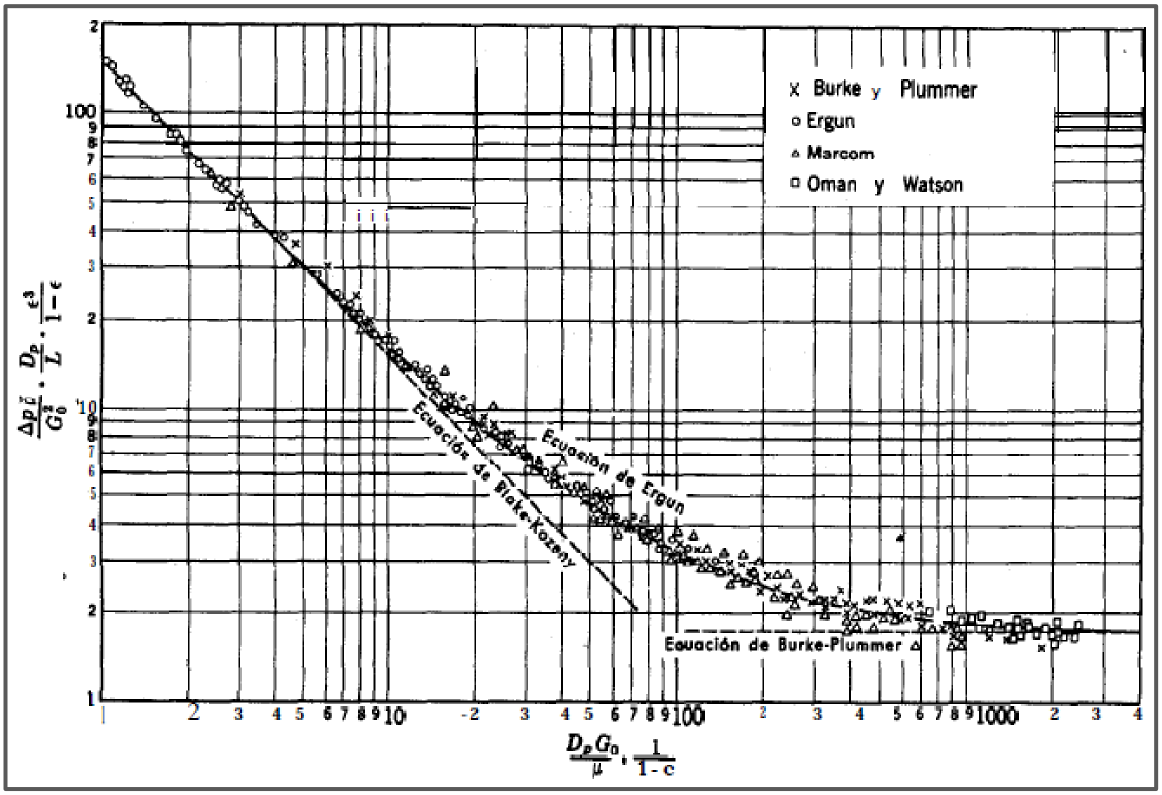
$$f_F = \frac{0{,}0791}{\mathrm{Re}^{1/4}} \qquad\qquad 2.10^3 < \mathrm{Re} < 10^5$$

- Correlación de Haaland para tubos rugosos:

$$\frac{1}{\sqrt{f_F}} = -3{,}6\log_{10}\left[\frac{6{,}9}{\mathrm{Re}} + \left(\frac{e}{3{,}7D}\right)^{10/9}\right] \qquad\qquad \left[\begin{array}{l} 10^3 < \mathrm{Re} < 10^8 \\ \dfrac{e}{D} < 0{,}05 \end{array}\right.$$

Factores de Fricción para Columnas de Relleno

La ecuación de Ergun para flujo en lechos rellenos y las dos asíntotas relacionadas, la ecuación de Blake-Kozeny y la ecuación de Burke-Plummer en función del Reynolds de partícula:



- Ecuación de Blake-Kozeny para flujo laminar:

$$\frac{P_0 - P_L}{L} = 150\left(\frac{\mu v_o}{D_p^2}\right)\frac{(1-\varepsilon)^2}{\varepsilon^3} \qquad \text{válida para } \mathrm{Re}_p < 10 \text{ y } \varepsilon < 0{,}5$$

- Ecuación de Ergun para la región de transición:

$$\frac{P_0 - P_L}{L} = 150\left(\frac{\mu v_o}{D_p^2}\right)\frac{(1-\varepsilon)^2}{\varepsilon^3} + \frac{7}{4}\left(\frac{\rho v_o^2}{D_p}\right)\frac{1-\varepsilon}{\varepsilon^3}$$

- Ecuación de Burke-Plummer para flujo altamente turbulento:

$$\frac{P_0 - P_L}{L} = \frac{7}{4}\left(\frac{\rho v_o^2}{D_p}\right)\frac{1-\varepsilon}{\varepsilon^3} \qquad \text{válida para } \mathrm{Re}_p > 1000$$

Reynolds de Partícula: $\mathrm{Re}_p = \dfrac{D_p v_o \rho}{(1-\varepsilon)\mu}$ siendo v_o la velocidad superficial.

Fricción en Accesorios en Régimen Turbulento

- Cálculo de la pérdida de carga en accesorios por el método de la constante (K_{acc}):

$$h_f = K_{acc} \frac{\langle v \rangle^2}{2|\vec{g}|}$$

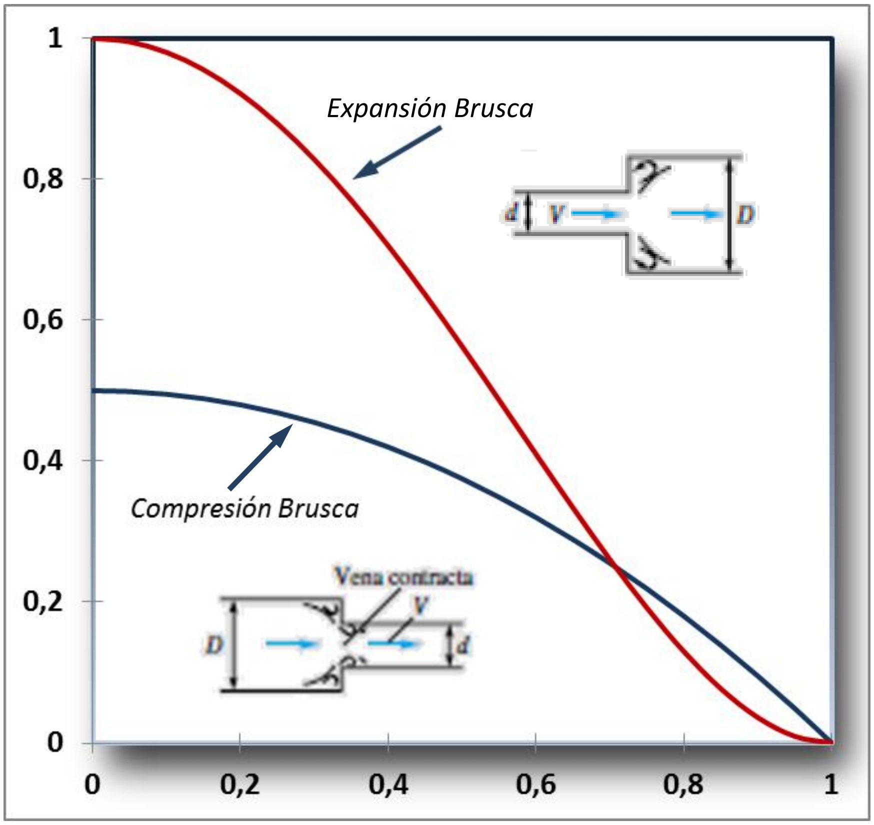
- Cálculo de la pérdida de carga en accesorios por el método de la longitud equivalente (L_{eq}):

$$h_f = 4 f_F \frac{L_{eq}}{D} \frac{\langle v \rangle^2}{2|\vec{g}|}$$

- Factores de pérdidas debidas a la fricción de varios accesorios para tubos:

Accesorio	K	L_{eq}/D
Válvula del globo, totalmente abierta	7.5	350
Válvula de cuña, totalmente abierta	3.8	170
Válvula de compuerta, totalmente abierta	0.15	7
Válvula de compuerta, abierta 3/4	0.85	40
Válvula de compuerta, abierta 1/2	4.4	200
Válvula de compuerta, abierta 1/4	20	900
Codo a 90°, estándar	0.7	32
Codo a 90°, de radio corto	0.9	41
Codo a 90°, de radio largo	0.4	20
Codo a 45°, estándar	0.35	15
Tubo en T, conducto con salida lateral	1.5	67
Tubo en T, conducto recto	0.4	20
	1.6	75

- Compresión y Expansión Brusca:



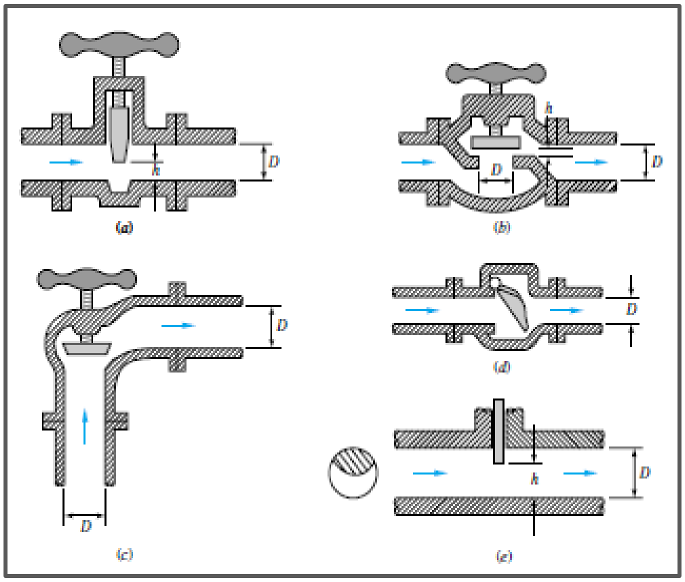
Expansión Brusca: $$K_{EB} = \left(1 - \frac{d^2}{D^2}\right)^2$$

Compresión Brusca: $$K_{CB} = 0{,}5\left(1 - \frac{d^2}{D^2}\right)$$

- Valores típicos de K_{acc} y L_{eq}/D de varios accesorios para tubos:

Type of fitting or valve	Additional friction loss, equivalent no. of velocity heads, K
45° ell, standard[b,c,d,e,f]	0.35
45° ell, long radius[c]	0.2
90° ell, standard[b,c,e,f,g,h]	0.75
Long radius[b,c,d,e]	0.45
Square or miter[h]	1.3
180° bend, close return[b,c,e]	1.5
Tee, standard, along run, branch blanked off[e]	0.4
Used as ell, entering run[g,i]	1.0
Used as ell, entering branch[c,g,i]	1.0
Branching flow[i,j,k]	1[l]
Coupling[c,e]	0.04
Union[e]	0.04
Gate valve,[b,e,m] open	0.17
¾ open[n]	0.9
½ open[n]	4.5
¼ open[n]	24.0
Diaphragm valve,[o] open	2.3
¾ open[n]	2.6
½ open[n]	4.3
¼ open[n]	21.0
Globe valve,[e,m]	
Bevel seat, open	6.0
½ open[n]	9.5
Composition seat, open	6.0
½ open[n]	8.5
Plug disk, open	9.0
¾ open[n]	13.0
½ open[n]	36.0
¼ open[n]	112.0
Angle valve,[b,e] open	2.0
Y or blowoff valve,[b,m] open	3.0
Plug cock[p]	
θ = 5°	0.05
θ = 10°	0.29
θ = 20°	1.56
θ = 40°	17.3
θ = 60°	206.0
Butterfly valve[p]	
θ = 5°	0.24
θ = 10°	0.52
θ = 20°	1.54
θ = 40°	10.8
θ = 60°	118.0
Check valve,[b,e,m] swing	2.0[q]
Disk	10.0[q]
Ball	70.0[q]
Foot valve[e]	15.0
Water meter,[h] disk	7.0[r]
Piston	15.0[r]
Rotary (star-shaped disk)	10.0[r]
Turbine-wheel	6.0[r]

- Geometría típica de los distintos tipos válvulas:



(a) Válvula Compuerta (tipo aguja).

(b) Válvula Globo.

(c) Válvula de ángulo.

(d) Válvula Anti-Retorno.

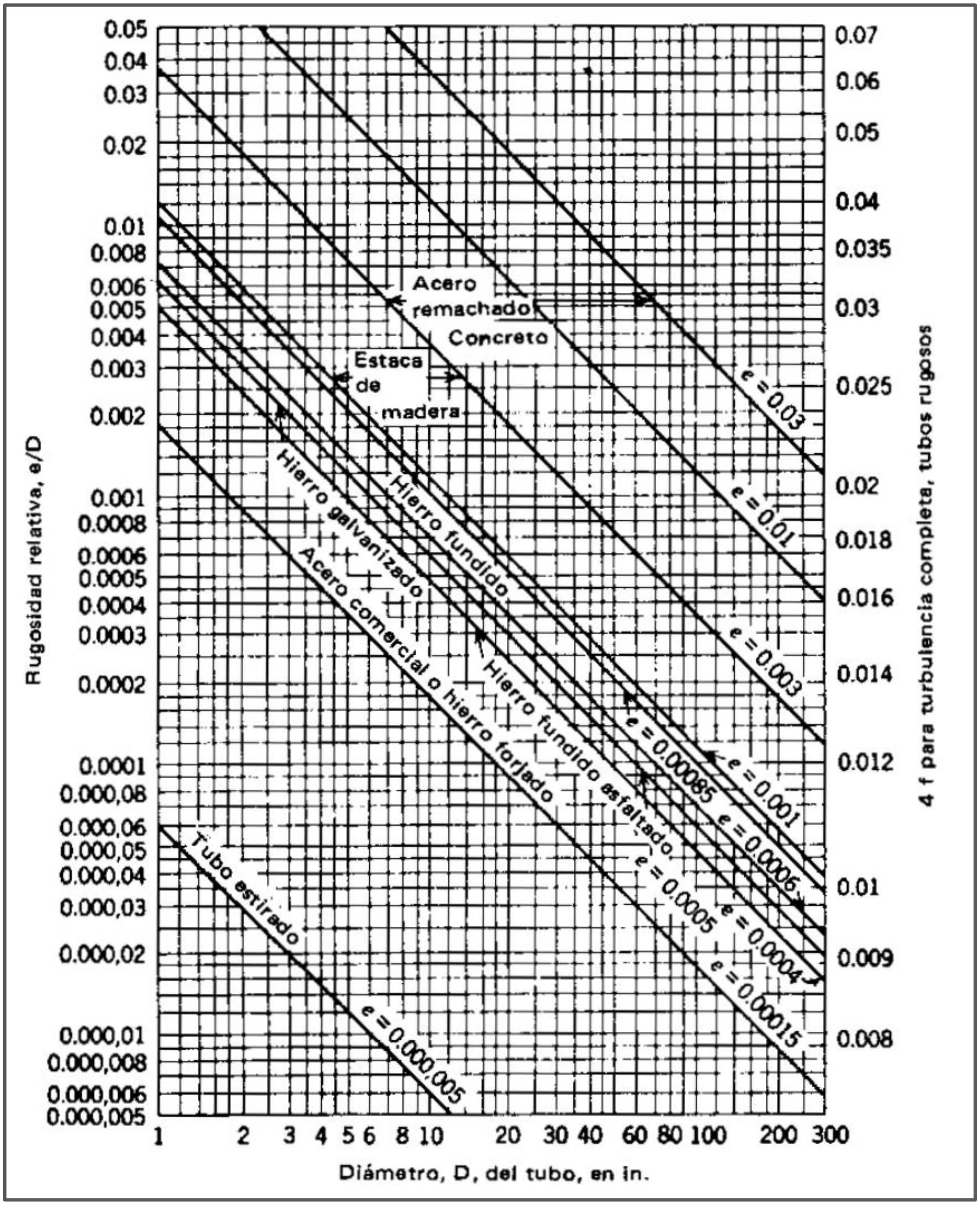
(e) Válvula Compuerta (tipo disco).

- Valores de K_{acc} para válvulas totalmente abiertas, codos y tes en función del diámetro nominal de la tubería:

	Nominal diameter, in								
	Screwed				Flanged				
	$\frac{1}{2}$	1	2	4	1	2	4	8	20
Valves (fully open):									
Globe	14	8.2	6.9	5.7	13	8.5	6.0	5.8	5.5
Gate	0.30	0.24	0.16	0.11	0.80	0.35	0.16	0.07	0.03
Swing check	5.1	2.9	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Angle	9.0	4.7	2.0	1.0	4.5	2.4	2.0	2.0	2.0
Elbows:									
45° regular	0.39	0.32	0.30	0.29					
45° long radius					0.21	0.20	0.19	0.16	0.14
90° regular	2.0	1.5	0.95	0.64	0.50	0.39	0.30	0.26	0.21
90° long radius	1.0	0.72	0.41	0.23	0.40	0.30	0.19	0.15	0.10
180° regular	2.0	1.5	0.95	0.64	0.41	0.35	0.30	0.25	0.20
180° long radius					0.40	0.30	0.21	0.15	0.10
Tees:									
Line flow	0.90	0.90	0.90	0.90	0.24	0.19	0.14	0.10	0.07
Branch flow	2.4	1.8	1.4	1.1	1.0	0.80	0.64	0.58	0.41

Rugosidad de Materiales Empleados en Conductos y Tubos

Parámetros de rugosidad de conductos y tubos (los valores de *e* están dados en ft):



Propiedades de las Tuberías de Acero

TABLE 10-18 Properties of Steel Pipe

Nominal pipe size, in	Outside diameter, in	Schedule no.	Wall thickness, in	Inside diameter, in	Cross-sectional area		Circumference, ft, or surface, ft²/ft of length		Capacity at 1-ft/s velocity		Weight of plain-end pipe, lb/ft
					Metal, in²	Flow, ft²	Outside	Inside	U.S. gal/min	lb/h water	
⅛	0.405	10S	0.049	0.307	0.055	0.00051	0.106	0.0804	0.231	115.5	0.19
		40ST, 40S	.068	.269	.072	.00040	.106	.0705	.179	89.5	.24
		80XS, 80S	.095	.215	.093	.00025	.106	.0563	.113	56.5	.31
¼	0.540	10S	.065	.410	.097	.00092	.141	.107	.412	206.5	.33
		40ST, 40S	.088	.364	.125	.00072	.141	.095	.323	161.5	.42
		80XS, 80S	.119	.302	.157	.00050	.141	.079	.224	112.0	.54
⅜	0.675	10S	.065	.545	.125	.00162	.177	.143	.727	363.5	.42
		40ST, 40S	.091	.493	.167	.00133	.177	.129	.596	298.0	.57
		80XS, 80S	.126	.423	.217	.00098	.177	.111	.440	220.0	.74
½	0.840	5S	.065	.710	.158	.00275	.220	.186	1.234	617.0	.54
		10S	.083	.674	.197	.00248	.220	.176	1.112	556.0	.67
		40ST, 40S	.109	.622	.250	.00211	.220	.163	0.945	472.0	.85
		80XS, 80S	.147	.546	.320	.00163	.220	.143	0.730	365.0	1.09
		160	.188	.464	.385	.00117	.220	.122	0.527	263.5	1.31
		XX	.294	.252	.504	.00035	.220	.066	0.155	77.5	1.71
¾	1.050	5S	.065	.920	.201	.00461	.275	.241	2.072	1036.0	0.69
		10S	.083	.884	.252	.00426	.275	.231	1.903	951.5	0.86
		40ST, 40S	.113	.824	.333	.00371	.275	.216	1.665	832.5	1.13
		80XS, 80S	.154	.742	.433	.00300	.275	.194	1.345	672.5	1.47
		160	.219	.612	.572	.00204	.275	.160	0.917	458.5	1.94
		XX	.308	.434	.718	.00103	.275	.114	0.461	230.5	2.44
1	1.315	5S	.065	1.185	.255	.00768	.344	.310	3.449	1725	0.87
		10S	.109	1.097	.413	.00656	.344	.287	2.946	1473	1.40
		40ST, 40S	.133	1.049	.494	.00600	.344	.275	2.690	1345	1.68
		80XS, 80S	.179	0.957	.639	.00499	.344	.250	2.240	1120	2.17
		160	.250	0.815	.836	.00362	.344	.213	1.625	812.5	2.84
		XX	.358	0.599	1.076	.00196	.344	.157	0.878	439.0	3.66
1¼	1.660	5S	.065	1.530	0.326	.01277	.435	.401	5.73	2865	1.11
		10S	.109	1.442	0.531	.01134	.435	.378	5.09	2545	1.81
		40ST, 40S	.140	1.380	0.668	.01040	.435	.361	4.57	2285	2.27
		80XS, 80S	.191	1.278	0.881	.00891	.435	.335	3.99	1995	3.00
		160	.250	1.160	1.107	.00734	.435	.304	3.29	1645	3.76
		XX	.382	0.896	1.534	.00438	.435	.235	1.97	985	5.21
1½	1.900	5S	.065	1.770	0.375	.01709	.497	.463	7.67	3835	1.28
		10S	.109	1.682	0.614	.01543	.497	.440	6.94	3465	2.09
		40ST, 40S	.145	1.610	0.800	.01414	.497	.421	6.34	3170	2.72
		80XS, 80S	.200	1.500	1.069	.01225	.497	.393	5.49	2745	3.63
		160	.281	1.338	1.429	.00976	.497	.350	4.38	2190	4.86
		XX	.400	1.100	1.885	.00660	.497	.288	2.96	1480	6.41
2	2.375	5S	.065	2.245	0.472	.02749	.622	.588	12.34	6170	1.61
		10S	.109	2.157	0.776	.02538	.622	.565	11.39	5695	2.64
		40ST, 40S	.154	2.067	1.075	.02330	.622	.541	10.45	5225	3.65
		80ST, 80S	.218	1.939	1.477	.02050	.622	.508	9.20	4600	5.02
		160	.344	1.687	2.195	.01552	.622	.436	6.97	3485	7.46
		XX	.436	1.503	2.656	.01232	.622	.393	5.53	2765	9.03
2½	2.875	5S	.083	2.709	0.728	.04003	.753	.709	17.97	8985	2.48
		10S	.120	2.635	1.039	.03787	.753	.690	17.00	8500	3.53
		40ST, 40S	.203	2.469	1.704	.03322	.753	.647	14.92	7460	5.79
		80XS, 80S	.276	2.323	2.254	.02942	.753	.608	13.20	6600	7.66
		160	.375	2.125	2.945	.02463	.753	.556	11.07	5535	10.01
		XX	.552	1.771	4.028	.01711	.753	.464	7.68	3840	13.69
3	3.500	5S	.083	3.334	0.891	.06063	.916	.873	27.21	13,605	3.03
		10S	.120	3.260	1.274	.05796	.916	.853	26.02	13,010	4.33
		40ST, 40S	.216	3.068	2.228	.05130	.916	.803	23.00	11,500	7.58
		80XS, 80S	.300	2.900	3.016	.04587	.916	.759	20.55	10,275	10.25
		160	.438	2.624	4.213	.03755	.916	.687	16.86	8430	14.32
		XX	.600	2.300	5.466	.02885	.916	.602	12.95	6475	18.58
3½	4.0	5S	.083	3.834	1.021	.08017	1.047	1.004	35.98	17,990	3.48
		10S	.120	3.760	1.463	.07711	1.047	0.984	34.61	17,305	4.97
		40ST, 40S	.226	3.548	2.680	.06870	1.047	0.929	30.80	15,400	9.11
		80XS, 80S	.318	3.364	3.678	.06170	1.047	0.881	27.70	13,850	12.50
4	4.5	5S	.083	4.334	1.152	.10245	1.178	1.135	46.0	23,000	3.92
		10S	.120	4.260	1.651	.09898	1.178	1.115	44.4	22,200	5.61
		40ST, 40S	.237	4.026	3.17	.08840	1.178	1.054	39.6	19,800	10.79
		80XS, 80S	.337	3.826	4.41	.07986	1.178	1.002	35.8	17,900	14.98

TABLE 10-18 Properties of Steel Pipe *(Continued)*

Nominal pipe size, in	Outside diameter, in	Schedule no.	Wall thickness, in	Inside diameter, in	Cross-sectional area		Circumference, ft, or surface, ft²/ft of length		Capacity at 1-ft/s velocity		Weight of plain-end pipe, lb/ft
					Metal, in²	Flow, ft²	Outside	Inside	U.S. gal/min	lb/h water	
		120	0.438	3.624	5.58	0.07170	1.178	0.949	32.2	16,100	19.00
		160	.531	3.438	6.62	.06647	1.178	0.900	28.9	14,450	22.51
		XX	.674	3.152	8.10	.05419	1.178	0.825	24.3	12,150	27.54
5	5.563	5S	.109	5.345	1.87	.1558	1.456	1.399	69.9	34,950	6.36
		10S	.134	5.295	2.29	.1529	1.456	1.386	68.6	34,300	7.77
		40ST, 40S	.258	5.047	4.30	.1390	1.456	1.321	62.3	31,150	14.62
		80XS, 80S	.375	4.813	6.11	.1263	1.456	1.260	57.7	28,850	20.78
		120	.500	4.563	7.95	.1136	1.456	1.195	51.0	25,500	27.04
		160	.625	4.313	9.70	.1015	1.456	1.129	45.5	22,750	32.96
		XX	.750	4.063	11.34	.0900	1.456	1.064	40.4	20,200	38.55
6	6.625	5S	.109	6.407	2.23	.2239	1.734	1.677	100.5	50,250	7.60
		10S	.134	6.357	2.73	.2204	1.734	1.664	98.9	49,450	9.29
		40ST, 40S	.280	6.065	5.58	.2006	1.734	1.588	90.0	45,000	18.97
		80XS, 80S	.432	5.761	8.40	.1810	1.734	1.508	81.1	40,550	28.57
		120	.562	5.501	10.70	.1650	1.734	1.440	73.9	36,950	36.39
		160	.719	5.187	13.34	.1467	1.734	1.358	65.9	32,950	45.34
		XX	.864	4.897	15.64	.1308	1.734	1.282	58.7	29,350	53.16
8	8.625	5S	.109	8.407	2.915	.3855	2.258	2.201	173.0	86,500	9.93
		10S	.148	8.329	3.941	.3784	2.258	2.180	169.8	84,900	13.40
		20	.250	8.125	6.578	.3601	2.258	2.127	161.5	80,750	22.36
		30	.277	8.071	7.265	.3553	2.258	2.113	159.4	79,700	24.70
		40ST, 40S	.322	7.981	8.399	.3474	2.258	2.089	155.7	77,850	28.55
		60	.406	7.813	10.48	.3329	2.258	2.045	149.4	74,700	35.64
		80XS, 80S	.500	7.625	12.76	.3171	2.258	1.996	142.3	71,150	43.39
		100	.594	7.437	14.99	.3017	2.258	1.947	135.4	67,700	50.95
		120	.719	7.187	17.86	.2817	2.258	1.882	126.4	63,200	60.71
		140	.812	7.001	19.93	.2673	2.258	1.833	120.0	60,000	67.76
		XX	.875	6.875	21.30	.2578	2.258	1.800	115.7	57,850	72.42
		160	.906	6.813	21.97	.2532	2.258	1.784	113.5	56,750	74.69
10	10.75	5S	.134	10.482	4.47	.5993	2.814	2.744	269.0	134,500	15.19
		10S	.165	10.420	5.49	.5922	2.814	2.728	265.8	132,900	18.65
		20	.250	10.250	8.25	.5731	2.814	2.685	257.0	128,500	28.04
		30	.307	10.136	10.07	.5603	2.814	2.655	252.0	126,000	34.24
		40ST, 40S	.365	10.020	11.91	.5475	2.814	2.620	246.0	123,000	40.48
		80S, 60XS	.500	9.750	16.10	.5185	2.814	2.550	233.0	116,500	54.74
		80	.594	9.562	18.95	.4987	2.814	2.503	223.4	111,700	64.43
		100	.719	9.312	22.66	.4729	2.814	2.438	212.3	106,150	77.03
		120	.844	9.062	26.27	.4479	2.814	2.372	201.0	100,500	89.29
		140, XX	1.000	8.750	30.63	.4176	2.814	2.291	188.0	94,000	104.13
		160	1.125	8.500	34.02	.3941	2.814	2.225	177.0	88,500	115.64
12	12.75	5S	0.156	12.438	6.17	.8438	3.338	3.26	378.7	189,350	20.98
		10S	0.180	12.390	7.11	.8373	3.338	3.24	375.8	187,900	24.17
		20	0.250	12.250	9.82	.8185	3.338	3.21	367.0	183,500	33.38
		30	0.330	12.090	12.88	.7972	3.338	3.17	358.0	179,000	43.77
		ST, 40S	0.375	12.000	14.58	.7854	3.338	3.14	352.5	176,250	49.56
		40	0.406	11.938	15.74	.7773	3.338	3.13	349.0	174,500	53.52
		XS, 80S	0.500	11.750	19.24	.7530	3.338	3.08	338.0	169,000	65.42
		60	0.562	11.626	21.52	.7372	3.338	3.04	331.0	165,500	73.15
		80	0.688	11.374	26.07	.7056	3.338	2.98	316.7	158,350	88.63
		100	0.844	11.062	31.57	.6674	3.338	2.90	299.6	149,800	107.32
		120, XX	1.000	10.750	36.91	.6303	3.338	2.81	283.0	141,500	125.49
		140	1.125	10.500	41.09	.6013	3.338	2.75	270.0	135,000	139.67
		160	1.312	10.126	47.14	.5592	3.338	2.65	251.0	125,500	160.27
14	14	5S	0.156	13.688	6.78	1.0219	3.665	3.58	459	229,500	23.07
		10S	0.188	13.624	8.16	1.0125	3.665	3.57	454	227,000	27.73
		10	0.250	13.500	10.80	0.9940	3.665	3.53	446	223,000	36.71
		20	0.312	13.376	13.42	0.9750	3.665	3.50	438	219,000	45.61
		30, ST	0.375	13.250	16.05	0.9575	3.665	3.47	430	215,000	54.57
		40	0.438	13.124	18.66	0.9397	3.665	3.44	422	211,000	63.44
		XS	0.500	13.000	21.21	0.9218	3.665	3.40	414	207,000	72.09
		60	0.594	12.812	25.02	0.8957	3.665	3.35	402	201,000	85.05
		80	0.750	12.500	31.22	0.8522	3.665	3.27	382	191,000	106.13
		100	0.938	12.124	38.49	0.8017	3.665	3.17	360	180,000	130.85
		120	1.094	11.812	44.36	0.7610	3.665	3.09	342	171,000	150.79
		140	1.250	11.500	50.07	0.7213	3.665	3.01	324	162,000	170.21
		160	1.406	11.188	55.63	0.6827	3.665	2.93	306	153,000	189.11
16	16	5S	0.165	15.670	8.21	1.3393	4.189	4.10	601	300,500	27.90
		10S	0.188	15.624	9.34	1.3314	4.189	4.09	598	299,000	31.75
		10	0.250	15.500	12.37	1.3104	4.189	4.06	587	293,500	42.05

TABLE 10-18 Properties of Steel Pipe *(Concluded)*

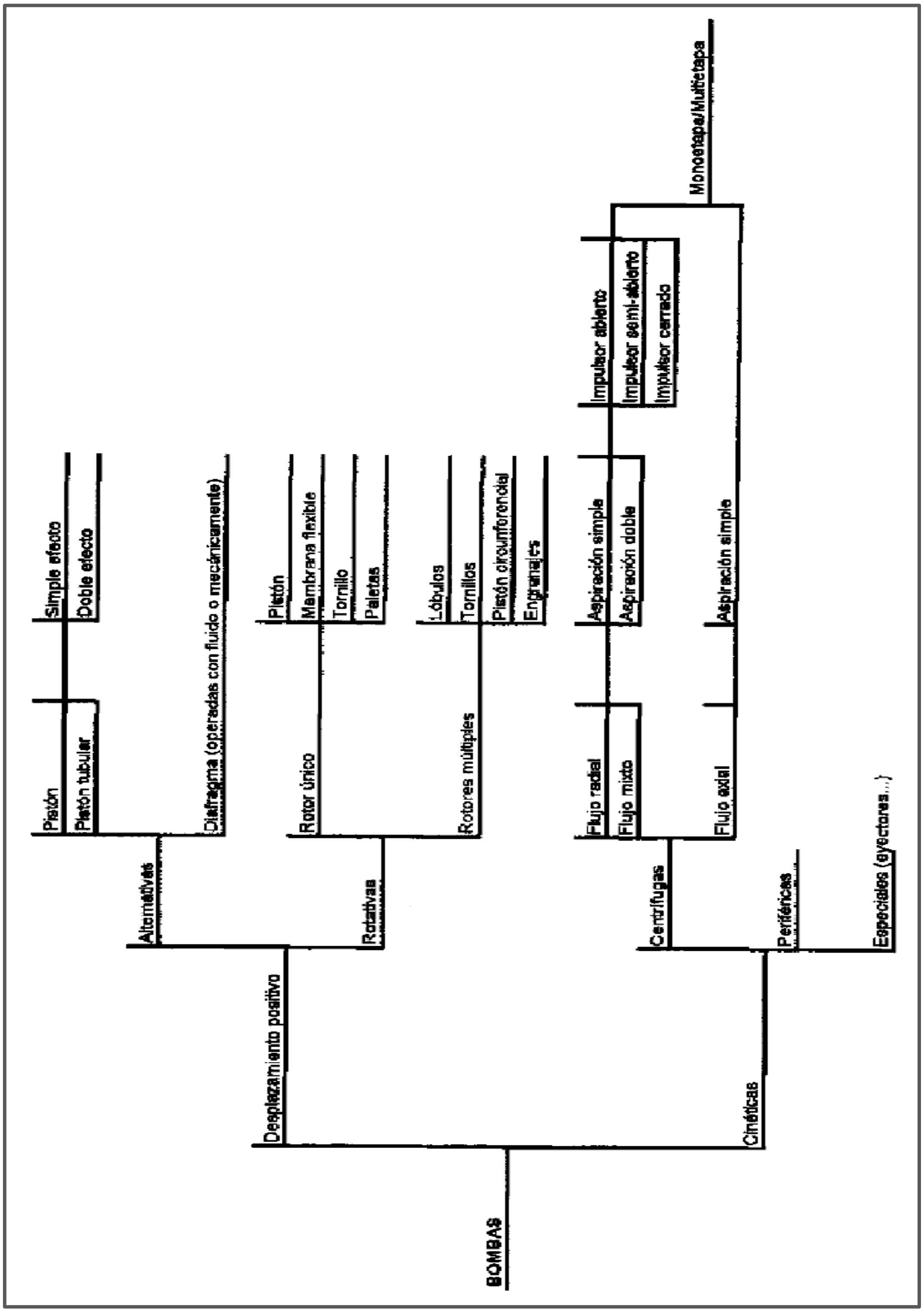
Nominal pipe size, in	Outside diameter, in	Schedule no.	Wall thickness, in	Inside diameter, in	Cross-sectional area		Circumference, ft, or surface, ft^2/ft of length		Capacity at 1-ft/s velocity		Weight of plain-end pipe, lb/ft
					Metal, in^2	Flow, ft^2	Outside	Inside	U.S. gal/min	lb/h water	
		20	0.312	15.376	15.38	1.2985	4.189	4.03	578	289,000	52.27
		30, ST	0.375	15.250	18.41	1.2680	4.189	3.99	568	284,000	62.58
		40, XS	0.500	15.000	24.35	1.2272	4.189	3.93	550	275,000	82.77
		60	0.656	14.688	31.62	1.1766	4.189	3.85	528	264,000	107.50
		80	0.844	14.312	40.19	1.1171	4.189	3.75	501	250,500	136.61
		100	1.031	13.938	48.48	1.0596	4.189	3.65	474	237,000	164.82
		120	1.219	13.562	56.61	1.0032	4.189	3.55	450	225,000	192.43
		140	1.438	13.124	65.79	0.9394	4.189	3.44	422	211,000	223.64
		160	1.594	12.812	72.14	0.8953	4.189	3.35	402	201,000	245.25
18	18	5S	0.165	17.670	9.25	1.7029	4.712	4.63	764	382,000	31.43
		10S	0.188	17.624	10.52	1.6941	4.712	4.61	760	379,400	35.76
		10	0.250	17.500	13.94	1.6703	4.712	4.58	750	375,000	47.39
		20	0.312	17.376	17.34	1.6468	4.712	4.55	739	369,500	58.94
		ST	0.375	17.250	20.76	1.6230	4.712	4.52	728	364,000	70.59
		30	0.438	17.124	24.16	1.5993	4.712	4.48	718	359,000	82.15
		XS	0.500	17.000	27.49	1.5763	4.712	4.45	707	353,500	93.45
		40	0.562	16.876	30.79	1.5533	4.712	4.42	697	348,500	104.67
		60	0.750	16.500	40.64	1.4849	4.712	4.32	666	333,000	138.17
		80	0.938	16.124	50.28	1.4180	4.712	4.22	636	318,000	170.92
		100	1.156	15.688	61.17	1.3423	4.712	4.11	602	301,000	207.96
		120	1.375	15.250	71.82	1.2684	4.712	3.99	569	284,500	244.14
		140	1.562	14.876	80.66	1.2070	4.712	3.89	540	270,000	274.22
		160	1.781	14.438	90.75	1.1370	4.712	3.78	510	255,000	308.50
20	20	5S	0.188	19.624	11.70	2.1004	5.236	5.14	943	471,500	39.78
		10S	0.218	19.564	13.55	2.0878	5.236	5.12	937	467,500	46.06
		10	0.250	19.500	15.51	2.0740	5.236	5.11	930	465,000	52.73
		20, ST	0.375	19.250	23.12	2.0211	5.236	5.04	902	451,000	78.60
		30, XS	0.500	19.000	30.63	1.9689	5.236	4.97	883	441,500	104.13
		40	0.594	18.812	36.21	1.9302	5.236	4.92	866	433,000	123.11
		60	0.812	18.376	48.95	1.8417	5.236	4.81	826	413,000	166.40
		80	1.031	17.938	61.44	1.7550	5.236	4.70	787	393,500	208.87
		100	1.281	17.438	75.33	1.6585	5.236	4.57	744	372,000	256.10
		120	1.500	17.000	87.18	1.5763	5.236	4.45	707	353,500	296.37
		140	1.750	16.500	100.3	1.4849	5.236	4.32	665	332,500	341.09
		160	1.969	16.062	111.5	1.4071	5.236	4.21	632	316,000	397.17
24	24	5S	0.218	23.564	16.29	3.0285	6.283	6.17	1359	679,500	55.37
		10, 10S	0.250	23.500	18.65	3.012	6.283	6.15	1350	675,000	63.41
		20, ST	0.375	23.250	27.83	2.948	6.283	6.09	1325	662,500	94.62
		XS	0.500	23.000	36.90	2.885	6.283	6.02	1295	642,500	125.49
		30	0.562	22.876	41.39	2.854	6.283	5.99	1281	640,500	140.68
		40	0.688	22.624	50.39	2.792	6.283	5.92	1253	626,500	171.29
		60	0.969	22.062	70.11	2.655	6.283	5.78	1192	596,000	238.35
		80	1.219	21.562	87.24	2.536	6.283	5.64	1138	569,000	296.58
		100	1.531	20.938	108.1	2.391	6.283	5.48	1073	536,500	367.39
		120	1.812	20.376	126.3	2.264	6.283	5.33	1016	508,000	429.39
		140	2.062	19.876	142.1	2.155	6.283	5.20	965	482,500	483.12
		160	2.344	19.312	159.5	2.034	6.283	5.06	913	456,500	542.13
30	30	5S	0.250	29.500	23.37	4.746	7.854	7.72	2130	1,065,000	79.43
		10, 10S	0.312	29.376	29.10	4.707	7.854	7.69	2110	1,055,000	98.93
		ST	0.375	29.250	34.90	4.666	7.854	7.66	2094	1,048,000	118.65
		20, XS	0.500	29.000	46.34	4.587	7.854	7.59	2055	1,027,500	157.53
		30	0.625	28.750	57.68	4.508	7.854	7.53	2020	1,010,000	196.08

5S, 10S, and 40S are extracted from Stainless Steel Pipe, ANSI B36.19—1976, with permission of the publisher, the American Society of Mechanical Engineers, New York. ST = standard wall, XS = extra strong wall, XX = double extra strong wall, and Schedules 10 through 160 are extracted from Wrought-Steel and Wrought-Iron Pipe, ANSI B36.10—1975, with permission of the same publisher. Decimal thicknesses for respective pipe sizes represent their nominal or average wall dimensions. Mill tolerances as high as ±12½ percent are permitted.

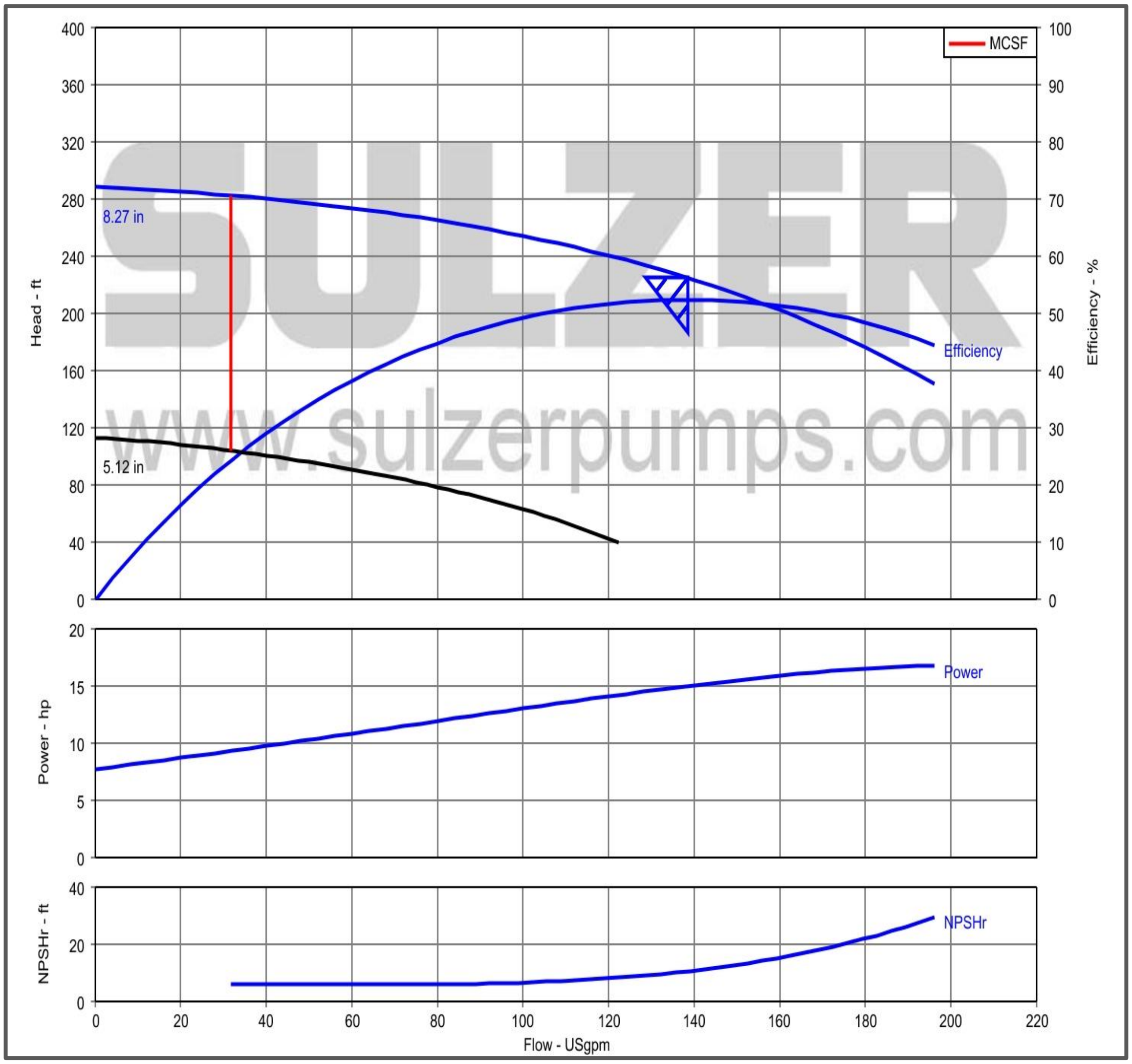
Plain-end pipe is produced by a square cut. Pipe is also shipped from the mills threaded, with a threaded coupling on one end, or with the ends beveled for welding, or grooved or sized for patented couplings. Weights per foot for threaded and coupled pipe are slightly greater because of the weight of the coupling, but it is not available larger than 12 in or lighter than Schedule 30 sizes 8 through 12 in, or Schedule 40 6 in and smaller.

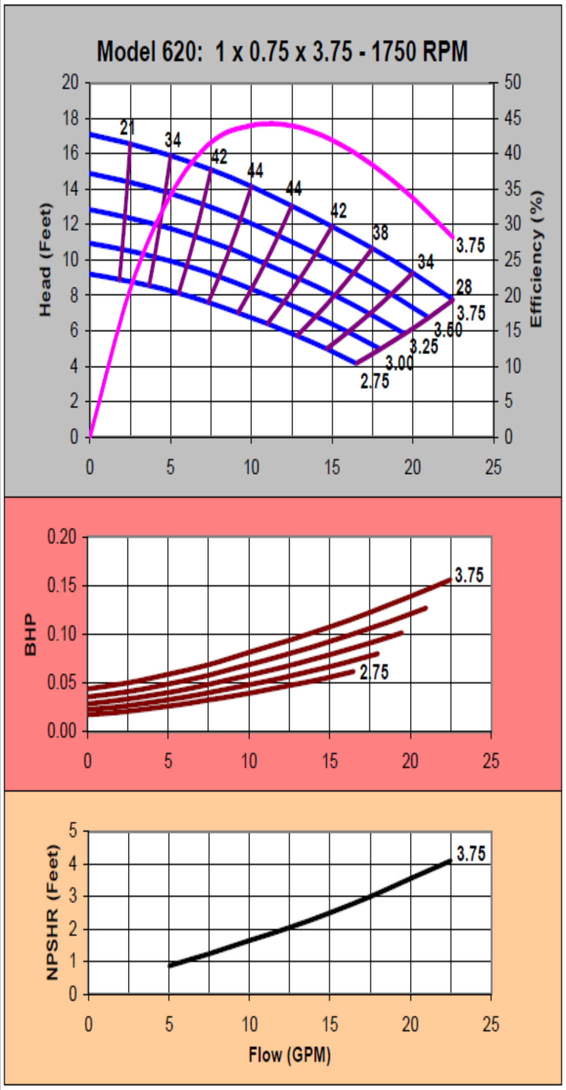
To convert inches to millimeters, multiply by 25.4; to convert square inches to square millimeters, multiply by 645; to convert feet to meters, multiply by 0.3048; to convert square feet to square meters, multiply by 0.0929; to convert pounds per foot to kilograms per meter, multiply by 1.49; to convert gallons to cubic meters, multiply by 3.7854×10^{-3}; and to convert pounds to kilograms, multiply by 0.4536.

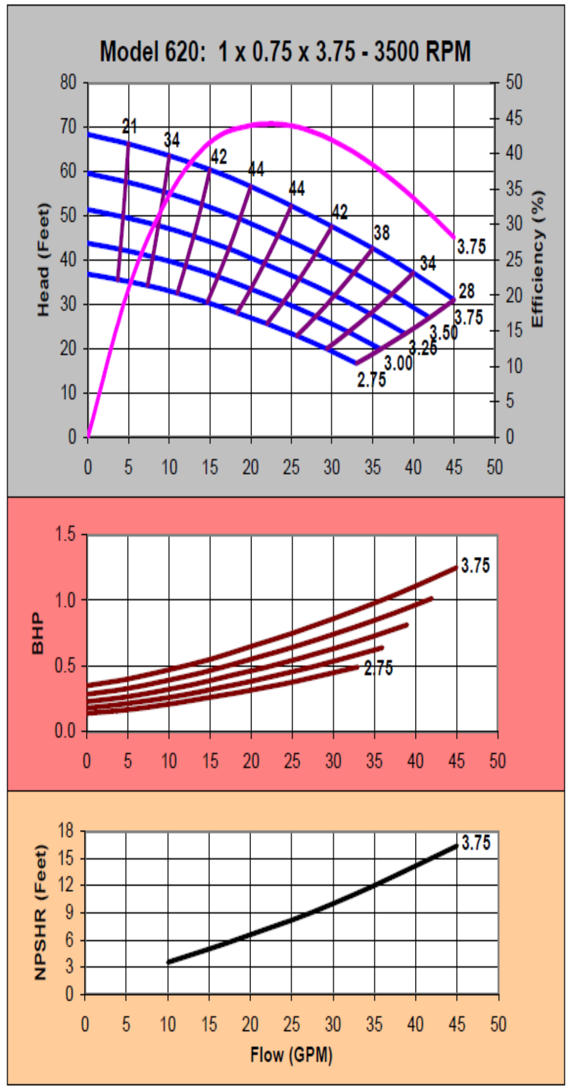
Clasificación de Bombas



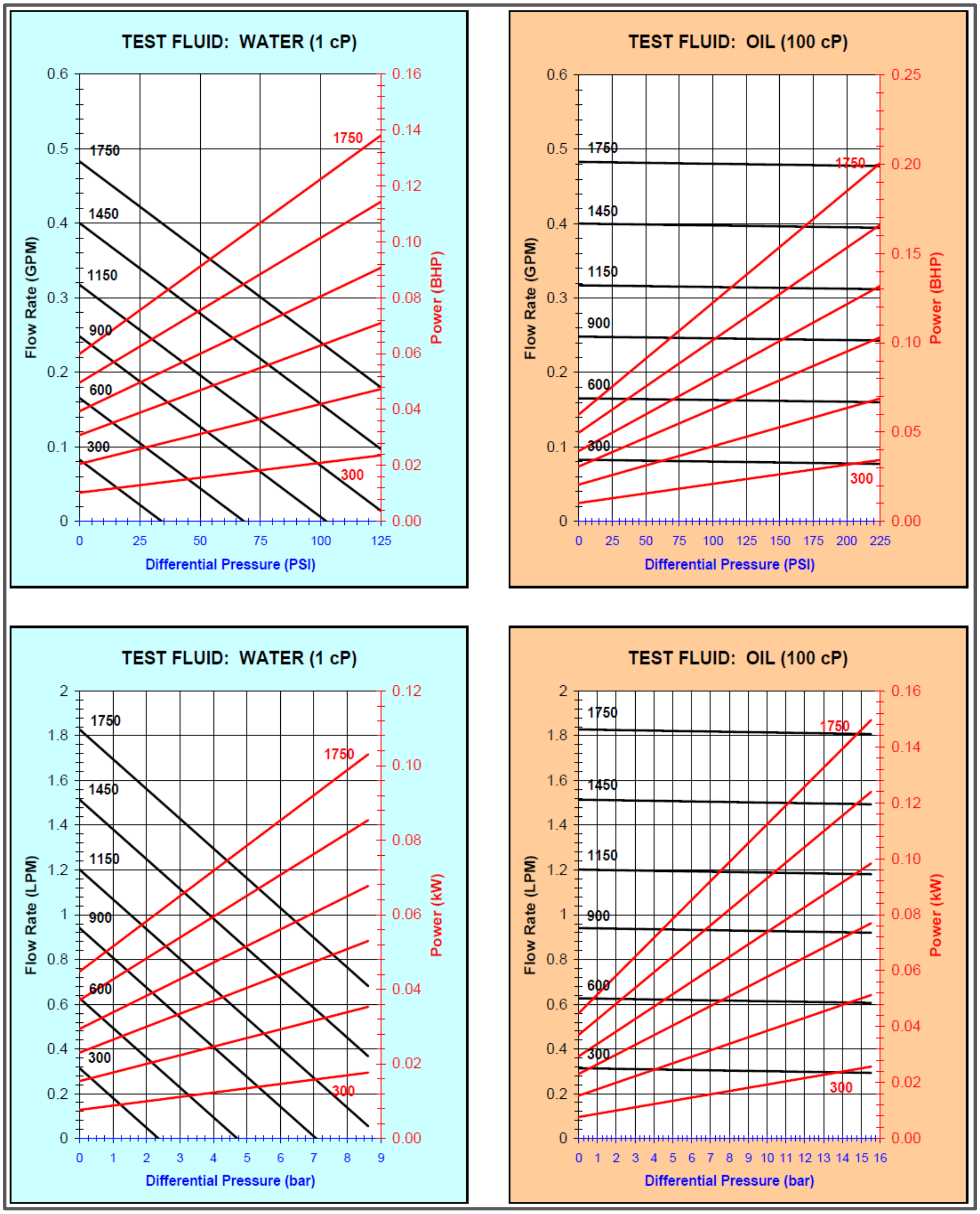
Curvas Típicas para Bombas Centrífugas




Model 620: 1 x 0.75 x 3.75 - 1750 RPM
Head (Feet)
Efficiency (%)
21
34
42
44
44
42
38
34
28
3.75
3.75
3.50
3.25
3.00
2.75
BHP
3.75
2.75
NPSHR (Feet)
3.75
Flow (GPM)

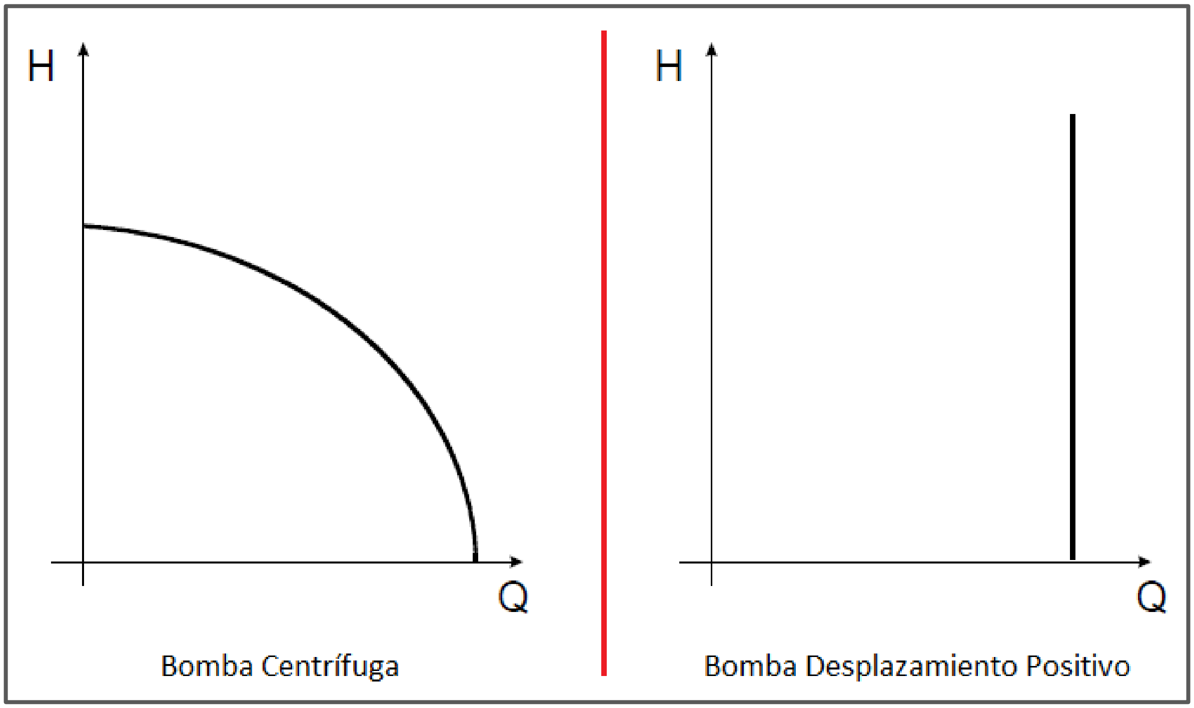

Model 620: 1 x 0.75 x 3.75 - 3500 RPM
Head (Feet)
Efficiency (%)
21
34
42
44
44
42
38
34
28
3.75
3.75
3.50
3.25
3.00
2.75
BHP
3.75
2.75
NPSHR (Feet)
3.75
Flow (GPM)

Curvas Típicas para Bombas de Desplazamiento Positivo



Comparación Bomba Centrífuga vs. Bomba Desplazamiento Positivo

Observando las gráficas de Altura desarrollada por cada bomba (*H*) en función del Caudal (*Q*), se puede apreciar la diferencia en el comportamiento dinámico de cada tipo de bomba.



Transferencia de Energía

Componentes de la Densidad de Flujo de Energía q (*Ley de Fourier*)

Expresión vectorial de la ecuación de razón de cambio de Fourier: $\bar{q} = -k\nabla T$

Coordenadas Rectangulares	Coordenadas Cilíndricas	Coordenadas Esféricas
$q_x = -k\dfrac{\partial T}{\partial x}$	$q_r = -k\dfrac{\partial T}{\partial r}$	$q_r = -k\dfrac{\partial T}{\partial r}$
$q_y = -k\dfrac{\partial T}{\partial y}$	$q_\theta = -k\dfrac{1}{r}\dfrac{\partial T}{\partial \theta}$	$q_\theta = -k\dfrac{1}{r}\dfrac{\partial T}{\partial \theta}$
$q_z = -k\dfrac{\partial T}{\partial z}$	$q_z = -k\dfrac{\partial T}{\partial z}$	$q_\phi = -k\dfrac{1}{r\,\mathrm{sen}\,\theta}\dfrac{\partial T}{\partial \phi}$

Ecuación de Energía en Función de las Densidades de Flujo de Energía y de Cantidad de Movimiento

Coordenadas Rectangulares[e]:

$$\rho \hat{C}_v\left(\frac{\partial T}{\partial t}+v_x\frac{\partial T}{\partial x}+v_y\frac{\partial T}{\partial y}+v_z\frac{\partial T}{\partial z}\right)=-\left[\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}\right]$$
$$-T\left(\frac{\partial p}{\partial T}\right)_\rho\left(\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}\right)-\left\{\tau_{xx}\frac{\partial v_x}{\partial x}+\tau_{yy}\frac{\partial v_y}{\partial y}+\tau_{zz}\frac{\partial v_z}{\partial z}\right\}$$
$$-\left\{\tau_{xy}\left(\frac{\partial v_x}{\partial y}+\frac{\partial v_y}{\partial x}\right)+\tau_{xz}\left(\frac{\partial v_x}{\partial z}+\frac{\partial v_z}{\partial x}\right)+\tau_{yz}\left(\frac{\partial v_y}{\partial z}+\frac{\partial v_z}{\partial y}\right)\right\}$$

Coordenadas Cilíndricas[e]:

$$\rho \hat{C}_v\left(\frac{\partial T}{\partial t}+v_r\frac{\partial T}{\partial r}+\frac{v_\theta}{r}\frac{\partial T}{\partial \theta}+v_z\frac{\partial T}{\partial z}\right)=-\left[\frac{1}{r}\frac{\partial}{\partial r}(rq_r)+\frac{1}{r}\frac{\partial q_\theta}{\partial \theta}+\frac{\partial q_z}{\partial z}\right]$$
$$-T\left(\frac{\partial p}{\partial T}\right)_\rho\left(\frac{1}{r}\frac{\partial}{\partial r}(rv_r)+\frac{1}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{\partial v_z}{\partial z}\right)-\left\{\tau_{rr}\frac{\partial v_r}{\partial r}+\tau_{\theta\theta}\frac{1}{r}\left(\frac{\partial v_\theta}{\partial \theta}+v_r\right)+\tau_{zz}\frac{\partial v_z}{\partial z}\right\}$$
$$-\left\{\tau_{r\theta}\left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right)+\frac{1}{r}\frac{\partial v_r}{\partial \theta}\right]+\tau_{rz}\left(\frac{\partial v_z}{\partial r}+\frac{\partial v_r}{\partial z}\right)+\tau_{\theta z}\left(\frac{1}{r}\frac{\partial v_z}{\partial \theta}+\frac{\partial v_\theta}{\partial z}\right)\right\}$$

Coordenadas Esféricas[e]:

$$\rho \hat{C}_v\left(\frac{\partial T}{\partial t}+v_r\frac{\partial T}{\partial r}+\frac{v_\theta}{r}\frac{\partial T}{\partial \theta}+\frac{v_\phi}{r\,\mathrm{sen}\,\theta}\frac{\partial T}{\partial \phi}\right)=-\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 q_r\right)+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial}{\partial \theta}(q_\theta\,\mathrm{sen}\,\theta)\right.$$
$$\left.+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial q_\phi}{\partial \phi}\right]-T\left(\frac{\partial p}{\partial T}\right)_\rho\left(\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 v_r\right)+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial}{\partial \theta}(v_\theta\,\mathrm{sen}\,\theta)+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\phi}{\partial \phi}\right)$$
$$-\left\{\tau_{rr}\frac{\partial v_r}{\partial r}+\tau_{\theta\theta}\frac{1}{r}\left(\frac{\partial v_\theta}{\partial \theta}+v_r\right)+\tau_{\phi\phi}\left(\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\phi}{\partial \phi}+\frac{v_r}{r}+\frac{v_\theta\cot\theta}{r}\right)\right\}$$
$$-\left\{\tau_{r\theta}\left(\frac{\partial v_\theta}{\partial r}+\frac{1}{r}\frac{\partial v_r}{\partial \theta}-\frac{v_\theta}{r}\right)+\tau_{r\phi}\left(\frac{\partial v_\phi}{\partial r}+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_r}{\partial \phi}-\frac{v_\phi}{r}\right)\right.$$
$$\left.+\tau_{\theta\phi}\left(\frac{1}{r}\frac{\partial v_\phi}{\partial \theta}+\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial v_\theta}{\partial \phi}-\frac{\cot\theta}{r}v_\phi\right)\right\}$$

[e] Los términos entre corchetes { } corresponden a la disipación viscosa y generalmente pueden despreciarse, excepto para sistemas que poseen elevados gradientes de velocidad.

Ecuación de Energía en Función de las Propiedades de Transporte

Para fluidos newtonianos de ρ, μ y k constantes: obsérvese que la constancia de ρ implica que $\hat{C}_v = \hat{C}_p$

Coordenadas Rectangulares[f]:

$$\rho\hat{C}_v\left(\frac{\partial T}{\partial t}+v_x\frac{\partial T}{\partial x}+v_y\frac{\partial T}{\partial y}+v_z\frac{\partial T}{\partial z}\right)=k\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right]$$
$$+2\mu\left\{\left(\frac{\partial v_x}{\partial x}\right)^2+\left(\frac{\partial v_y}{\partial y}\right)^2+\left(\frac{\partial v_z}{\partial z}\right)^2\right\}+\mu\left\{\left(\frac{\partial v_x}{\partial y}+\frac{\partial v_y}{\partial x}\right)^2\right.$$
$$\left.+\left(\frac{\partial v_x}{\partial z}+\frac{\partial v_z}{\partial x}\right)^2+\left(\frac{\partial v_y}{\partial z}+\frac{\partial v_z}{\partial y}\right)^2\right\}$$

Coordenadas Cilíndricas[f]:

$$\rho\hat{C}_v\left(\frac{\partial T}{\partial t}+v_r\frac{\partial T}{\partial r}+\frac{v_\theta}{r}\frac{\partial T}{\partial \theta}+v_z\frac{\partial T}{\partial z}\right)=k\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2}+\frac{\partial^2 T}{\partial z^2}\right]$$
$$+2\mu\left\{\left(\frac{\partial v_r}{\partial r}\right)^2+\left[\frac{1}{r}\left(\frac{\partial v_\theta}{\partial \theta}+v_r\right)\right]^2+\left(\frac{\partial v_z}{\partial z}\right)^2\right\}+\mu\left\{\left(\frac{\partial v_\theta}{\partial z}+\frac{1}{r}\frac{\partial v_z}{\partial \theta}\right)^2\right.$$
$$\left.+\left(\frac{\partial v_z}{\partial r}+\frac{\partial v_r}{\partial z}\right)^2+\left[\frac{1}{r}\frac{\partial v_r}{\partial \theta}+r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right)\right]^2\right\}$$

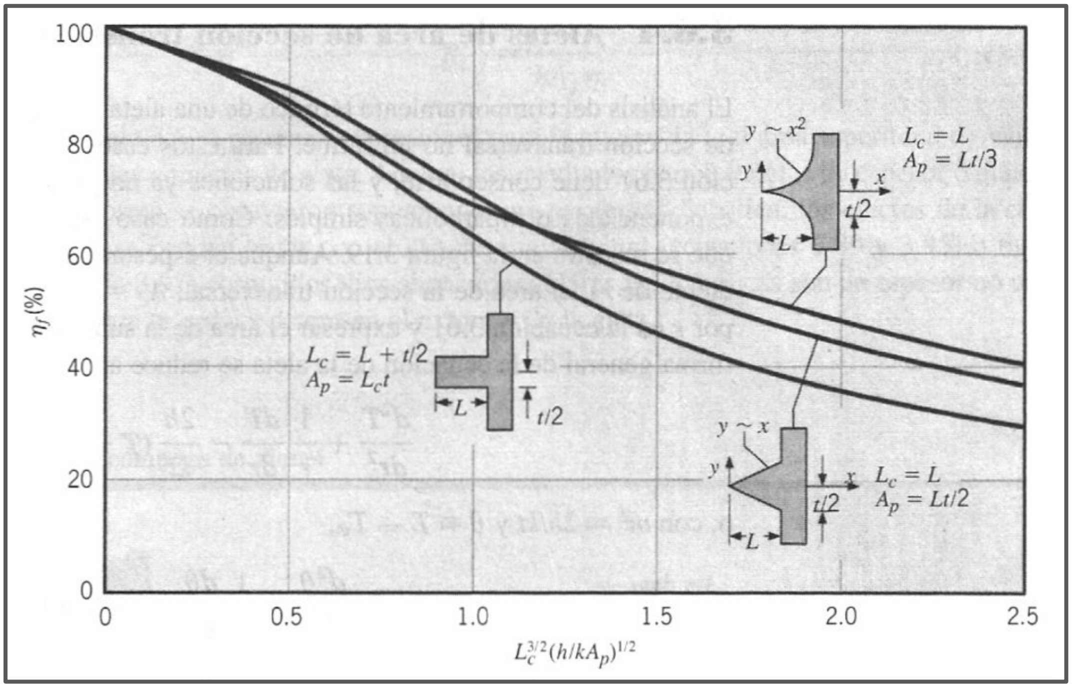
Coordenadas Esféricas[f]:

$$\rho\hat{C}_v\left(\frac{\partial T}{\partial t}+v_r\frac{\partial T}{\partial r}+\frac{v_\theta}{r}\frac{\partial T}{\partial \theta}+\frac{v_\phi}{r\operatorname{sen}\theta}\frac{\partial T}{\partial \phi}\right)=k\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right)+\frac{1}{r^2\operatorname{sen}\theta}\frac{\partial}{\partial \theta}\left(\operatorname{sen}\theta\frac{\partial T}{\partial \theta}\right)\right.$$
$$\left.+\frac{1}{r^2\operatorname{sen}^2\theta}\frac{\partial^2 T}{\partial \phi^2}\right]+2\mu\left\{\left(\frac{\partial v_r}{\partial r}\right)^2+\left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_r}{r}\right)^2+\left(\frac{1}{r\operatorname{sen}\theta}\frac{\partial v_\phi}{\partial \phi}+\frac{v_r}{r}+\frac{v_\theta\cot\theta}{r}\right)^2\right\}$$
$$+\mu\left\{\left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right)+\frac{1}{r}\frac{\partial v_r}{\partial \theta}\right]^2+\left[\frac{1}{r\operatorname{sen}\theta}\frac{\partial v_r}{\partial \phi}+r\frac{\partial v_\phi}{\partial r}\left(\frac{v_\phi}{r}\right)\right]^2+\left[\frac{\operatorname{sen}\theta}{r}\frac{\partial}{\partial \theta}\left(\frac{v_\phi}{\operatorname{sen}\theta}\right)+\frac{1}{r\operatorname{sen}\theta}\frac{\partial v_\theta}{\partial \phi}\right]^2\right\}$$

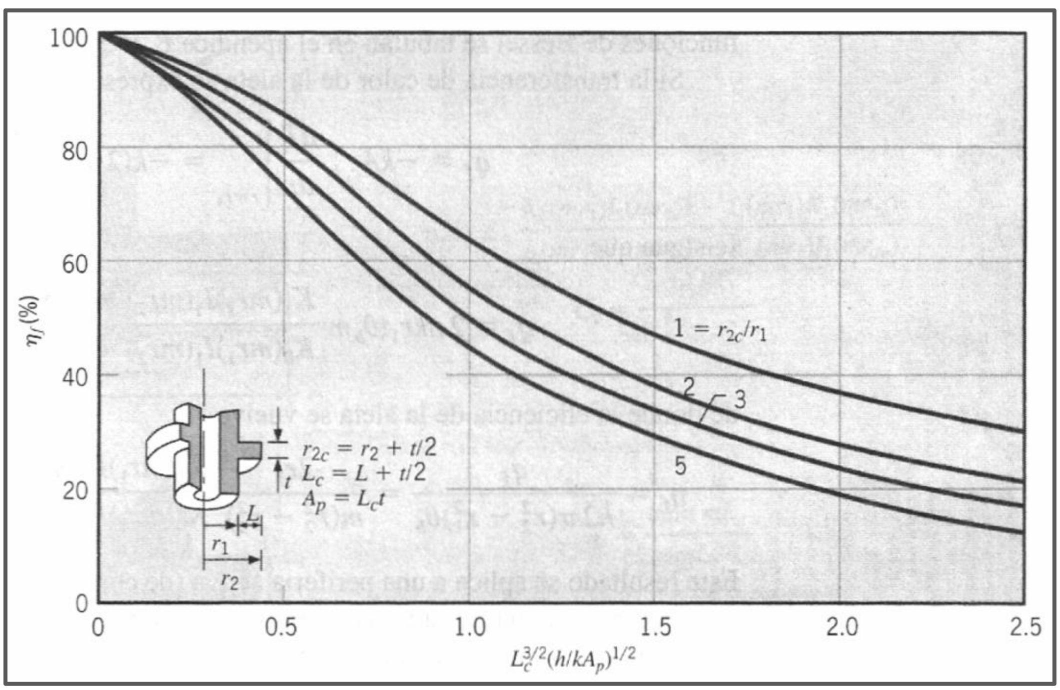
[f] Los términos entre corchetes { } corresponden a la disipación viscosa y generalmente pueden despreciarse, excepto para sistemas que poseen elevados gradientes de velocidad.

Eficiencia de Superficies Extendidas

Aletas Rectas con Perfiles Rectangulares, Triangulares y Parabólicos



Aletas Anulares de Perfil Rectangular



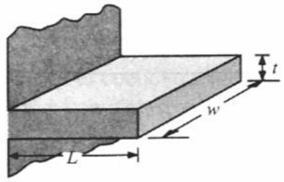
Expresiones para la Eficiencia de Aleta en las Formas Más Comunes

Aletas rectas

Rectangular[a]

$A_f = 2wL_c$

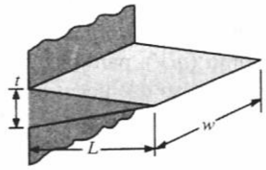
$L_c = L + (t/2)$



$$\eta_f = \frac{\tanh mL_c}{mL_c}$$

Triangular[a]

$A_f = 2w[L^2 + (t/2)^2]^{1/2}$

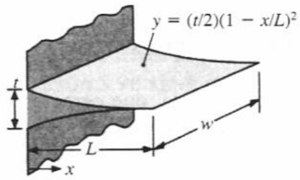


$$\eta_f = \frac{1}{mL}\frac{I_1(2mL)}{I_0(2mL)}$$

Parabólica[a]

$A_f = w[C_1L^2 + (L^2/t)\ln(t/L + C_1)]$

$C_1 = [1 + (t/L)^2]^{1/2}$



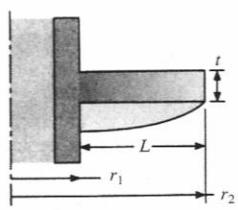
$$\eta_f = \frac{2}{[4(mL)^2 + 1]^{1/2} + 1}$$

Aleta circular

Rectangular[a]

$A_f = 2\pi(r_{2c}^2 - r_1^2)$

$r_{2c} = r_2 + (t/2)$



$$\eta_f = C_2 \frac{K_1(mr_1)I_1(mr_{2c}) - I_1(mr_1)K_1(mr_{2c})}{I_0(mr_1)K_1(mr_{2c}) + K_0(mr_1)I_1(mr_{2c})}$$

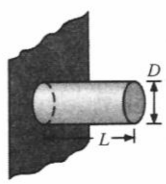
$$C_2 = \frac{(2r_1/m)}{(r_{2c}^2 - r_1^2)}$$

Aletas de punta

Rectangular[b]

$A_f = \pi D L_c$

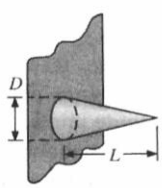
$L_c = L + (D/4)$



$$\eta_f = \frac{\tanh mL_c}{mL_c}$$

Triangular[a]

$A_f = \frac{\pi D}{2}[L^2 + (D/2)^2]^{1/2}$



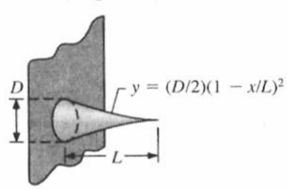
$$\eta_f = \frac{2}{mL}\frac{I_2(2mL)}{I_1(2mL)}$$

Parabólica[a]

$A_f = \frac{\pi L^3}{8D}\left\{C_3C_4 - \frac{L}{2D}\ln[(2DC_4/L) + C_3]\right\}$

$C_3 = 1 + 2(D/L)^2$

$C_4 = [1 + (D/L)^2]^{1/2}$



$$\eta_f = \frac{2}{[4/9(mL)^2 + 1]^{1/2} + 1}$$

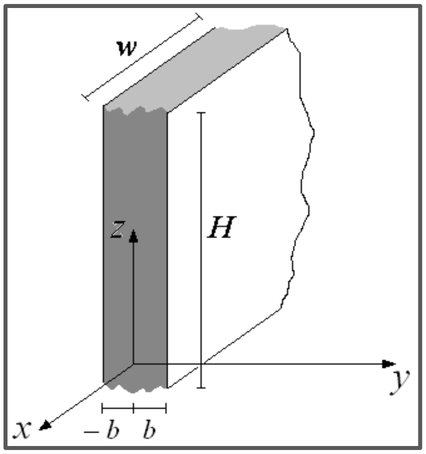
[a] $m = (2h/kt)^{1/2}$.

[b] $m = (4h/kD)^{1/2}$.

Conducción de Calor en Estado No Permanente

Soluciones Analíticas para el Perfil de Temperatura Adimensional

- **Placa Plana**



Solución Exacta:

$$T^*(y^*, Fo) = \sum_{n=1}^{\infty} C_n \cdot \exp\left(-\zeta_n^{\,2} Fo\right) \cdot \cos\left(\zeta_n \cdot x^*\right)$$

Con:

$$\begin{cases} Bi = \zeta_n \cdot \tan(\zeta_n) \\ C_n = \dfrac{4 \cdot sen(\zeta_n)}{2 \cdot \zeta_n + sen(2 \cdot \zeta_n)} \end{cases}$$

Válida para la siguiente ecuación y condiciones de borde adimensionales:

$$\frac{\partial T^*}{\partial Fo} = \nabla^{*2} T^*$$

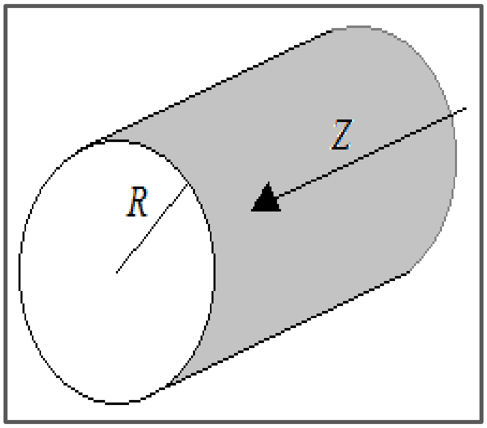
- Cond. Inicial: $Fo = 0 \qquad \forall y^* \quad \rightarrow \quad T^*(y^*, 0) = 1$

- Cond. Contorno: $Fo > 0$

$$\begin{cases} y^* = \pm 1 \quad \rightarrow \quad \left.\dfrac{\partial T^*}{\partial y^*}\right|_{y^* = \pm 1} = \pm Bi \cdot T^*(\pm 1, Fo) \\ y^* = 0 \quad \rightarrow \quad \left.\dfrac{\partial T^*}{\partial y^*}\right|_{y^* = 0} = 0 \end{cases}$$

Para valores de $Fo > 0{,}2$, la solución en serie infinita se puede aproximar con el primer término de la serie.

- **Cilindro Infinito**



Solución Exacta:

$$T^*(r^*,Fo) = \sum_{n=1}^{\infty} C_n \cdot \exp\left(-\zeta_n^{\,2} Fo\right) \cdot J_0\left(\zeta_n \cdot r^*\right)$$

Con:

$$\begin{cases} Bi = \zeta_n \cdot \dfrac{J_1(\zeta_n)}{J_0(\zeta_n)} \\ C_n = \dfrac{2}{\zeta_n} \cdot \dfrac{J_1(\zeta_n)}{J_0^{\,2}(\zeta_n) + J_1^{\,2}(\zeta_n)} \end{cases}$$

Válida para la siguiente ecuación y condiciones de borde adimensionales:

$$\frac{\partial T^*}{\partial Fo} = \frac{1}{r^*} \frac{\partial}{\partial r^*}\left(r^* \frac{\partial T^*}{\partial r^*}\right)$$

- Cond. Inicial: $Fo = 0 \qquad \forall r^* \quad \rightarrow \quad T^*(r^*,0) = 1$

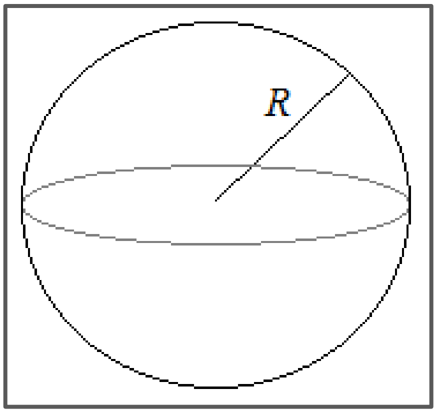
- Cond. Contorno: $Fo > 0$

$$\begin{cases} r^* = 1 \quad \rightarrow \quad \left.\dfrac{\partial T^*}{\partial r^*}\right|_{r^*=1} = \pm Bi \cdot T^*(1,Fo) \\ r^* = 0 \quad \rightarrow \quad \left.\dfrac{\partial T^*}{\partial r^*}\right|_{r^*=0} = 0 \end{cases}$$

J_0 y J_1 son las funciones de Bessel de primera clase.

Para valores de $Fo > 0{,}2$, la solución en serie infinita se puede aproximar con el primer término de la serie.

- **Esfera**



Solución Exacta:

$$T^*(r^*,Fo) = \sum_{n=1}^{\infty} C_n \cdot \exp\left(-\zeta_n^{\,2} Fo\right) \cdot \frac{1}{\zeta_n \cdot r^*} \cdot \operatorname{sen}\left(\zeta_n \cdot r^*\right)$$

Con:

$$\begin{cases} Bi = 1 - \zeta_n \cdot \cot(\zeta_n) \\ C_n = \dfrac{4 \cdot \left[\operatorname{sen}(\zeta_n) - \zeta_n \cdot \cos(\zeta_n)\right]}{2 \cdot \zeta_n - \operatorname{sen}(2 \cdot \zeta_n)} \end{cases}$$

Válida para la siguiente ecuación y condiciones de borde adimensionales:

$$\frac{\partial T^*}{\partial Fo} = \frac{1}{r^{*2}} \frac{\partial}{\partial r^*}\left(r^{*2} \frac{\partial T^*}{\partial r^*}\right)$$

- Cond. Inicial: $Fo = 0 \qquad \forall r^* \rightarrow T^*(r^*,0) = 1$

- Cond. Contorno: $Fo > 0$

$$\begin{cases} r^* = 1 \rightarrow \left.\dfrac{\partial T^*}{\partial r^*}\right|_{r^*=1} = \pm Bi \cdot T^*(1,Fo) \\ r^* = 0 \rightarrow \left.\dfrac{\partial T^*}{\partial r^*}\right|_{r^*=0} = 0 \end{cases}$$

Para valores de $Fo > 0{,}2$, la solución en serie infinita se puede aproximar con el primer término de la serie.

Coeficientes Empleados para la Aproximación de un Término en las Soluciones de Serie de la Conducción Transitoria Unidimensional

	Pared Plana		Cilindro Infinito		Esfera	
Bi	ξ_1 (rad)	C_1	ξ_1 (rad)	C_1	ξ_1 (rad)	C_1
0,01	0,0998	1,0017	0,1412	1,0025	0,1730	1,0030
0,02	0,1410	1,0033	0,1995	1,0050	0,2445	1,0060
0,03	0,1732	1,0049	0,2439	1,0075	0,2989	1,0090
0,04	0,1987	1,0066	0,2814	1,0099	0,3450	1,0120
0,05	0,2217	1,0082	0,3142	1,0124	0,3852	1,0149
0,06	0,2425	1,0098	0,3438	1,0148	0,4217	1,0179
0,07	0,2615	1,0114	0,3708	1,0173	0,4550	1,0209
0,08	0,2791	1,0130	0,3960	1,0197	0,4860	1,0239
0,09	0,2956	1,0145	0,4195	1,0222	0,5150	1,0268
0,10	0,3111	1,0160	0,4417	1,0246	0,5423	1,0298
0,15	0,3779	1,0237	0,5376	1,0365	0,6608	1,0445
0,20	0,4328	1,0311	0,6170	1,0483	0,7593	1,0592
0,25	0,4801	1,0382	0,6856	1,0598	0,8448	1,0737
0,30	0,5218	1,0450	0,7465	1,0712	0,9208	1,0880
0,40	0,5932	1,0580	0,8516	1,0932	1,0528	1,0164
0,50	0,6533	1,0701	0,9408	1,1143	1,1656	1,1441
0,60	0,7051	1,0814	1,0185	1,1346	1,2644	1,1713
0,70	0,7506	1,0919	1,0873	1,1539	1,3225	1,1978
0,80	0,7910	1,1016	1,1490	1,1725	1,4320	1,2236
0,90	0,8274	1,1107	1,2048	1,1902	1,5044	1,2488
1,0	0,8630	1,1191	1,2558	1,2071	1,5708	1,2732
2,0	1,0769	1,1795	1,5995	1,3384	2,0288	1,4793
3,0	1,1925	1,2102	1,7887	1,4191	2,2889	1,6227
4,0	1,2646	1,2287	1,9081	1,4698	2,4556	1,7201
5,0	1,3138	1,2402	1,9898	1,5029	2,5704	1,7870
6,0	1,3496	1,2479	2,0490	1,5253	2,6537	1,8338
7,0	1,3766	1,2532	2,0937	1,5411	2,7165	1,8674
8,0	1,3978	1,2570	2,1286	1,5526	2,7654	1,8921
9,0	1,4149	1,2598	2,1566	1,5611	2,8044	1,9106
10,0	1,4289	1,2620	2,1795	1,5677	2,8363	1,9249
20,0	1,4961	1,2699	2,2881	1,5919	2,9857	1,9781
30,0	1,5202	1,2717	2,3261	1,5973	3,0372	1,9898
40,0	1,5325	1,2723	2,3455	1,5993	3,0632	1,9942
50,0	1,5400	1,2727	2,3572	1,6002	3,0788	1,9962
100,0	1,5552	1,2731	2,3809	1,6015	3,1102	1,9990
∞	1,5707	1,2733	2,4050	1,6018	3,1415	2,0000

Gráficas de Gurney-Lurie

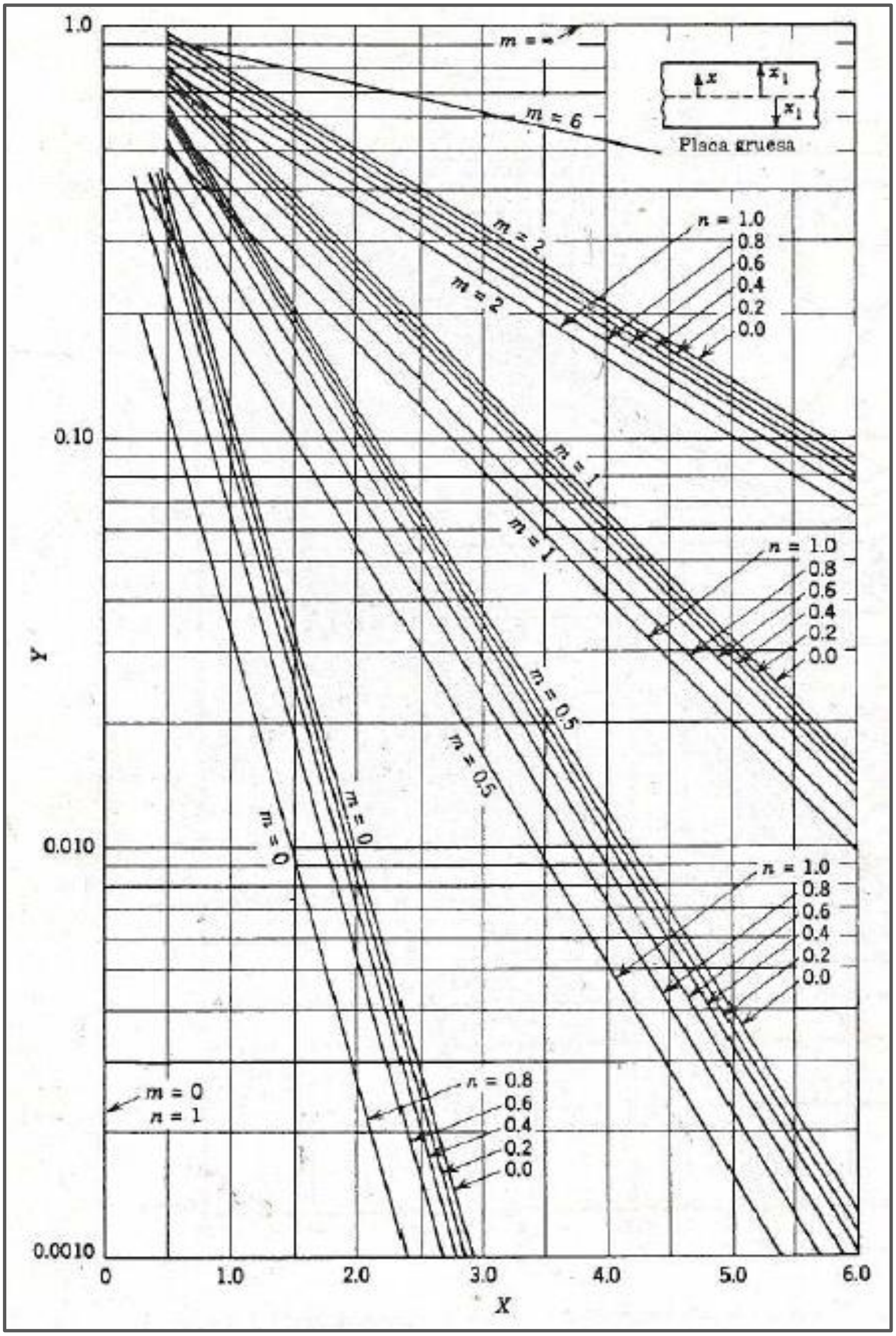
- Definición de Variables:

	Símbolo del parámetro	Transferencia de masa molecular	Conducción de calor
Cambio incompleto, razón adimensional	Y	$\frac{c_{A_1} - c_A}{c_{A_1} - c_{A_0}}$	$\frac{T_\infty - T}{T_\infty - T_0}$
Tiempo relativo	X	$\frac{D_{AB}t}{x_1^2}$	$\frac{\alpha t}{x_1^2}$
Posición relativa	n	$\frac{x}{x_1}$	$\frac{x}{x_1}$
Resistencia relativa	m	$\frac{D_{AB}}{k_c x_1}$	$\frac{k}{h x_1}$

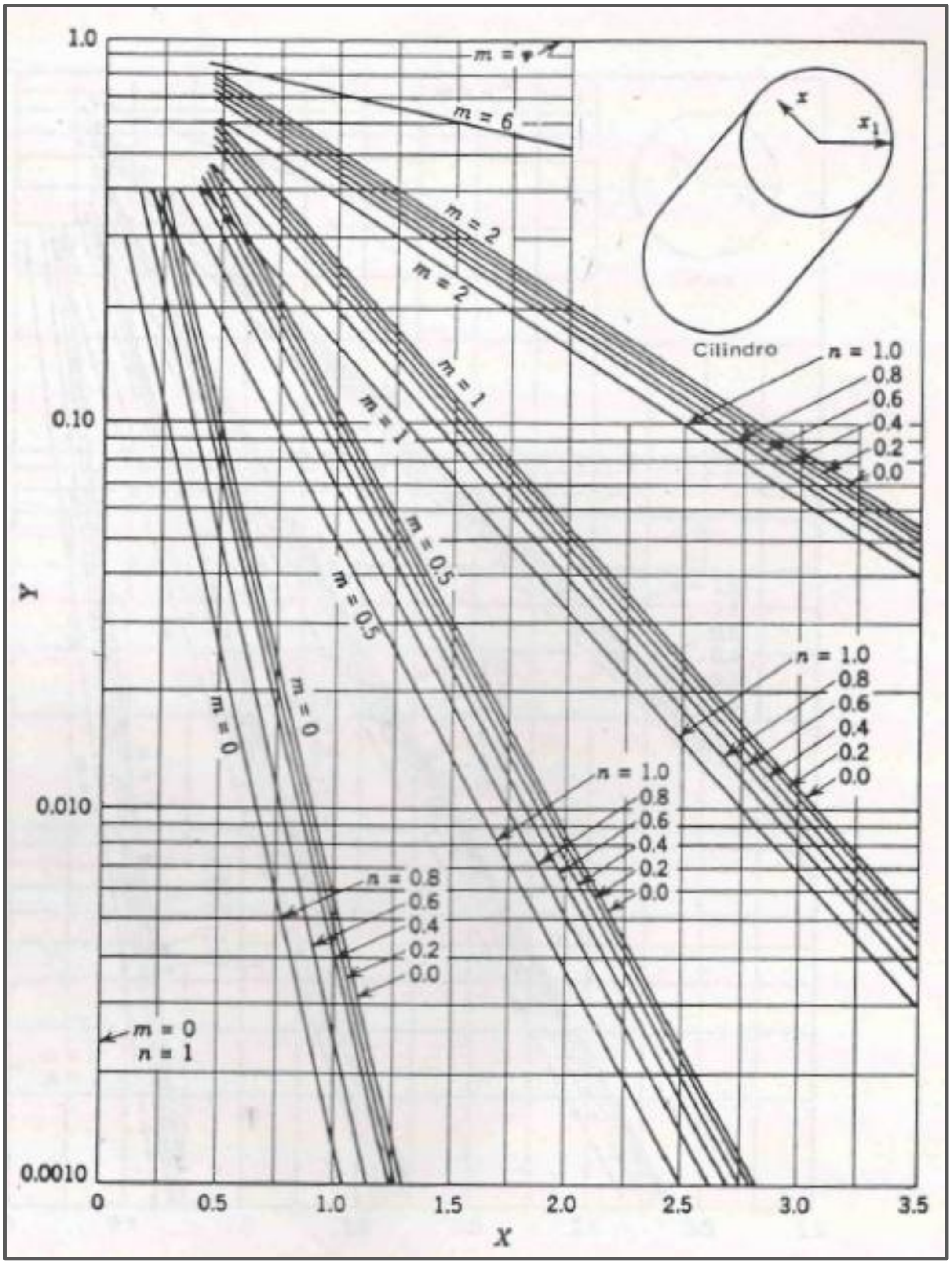
T = temperatura
c_A = concentración de la componente A
x = distancia del centro a cualquier punto
t = tiempo
k = conductividad térmica
h, k_c = coeficientes de transferencia convectiva
α = difusividad térmica
D_{AB} = difusividad de la masa

subíndices
0 = condición inicial en el tiempo $t = 0$
1 = frontera
A = componente A
∞ = condición de referencia correspondiente a la temperatura

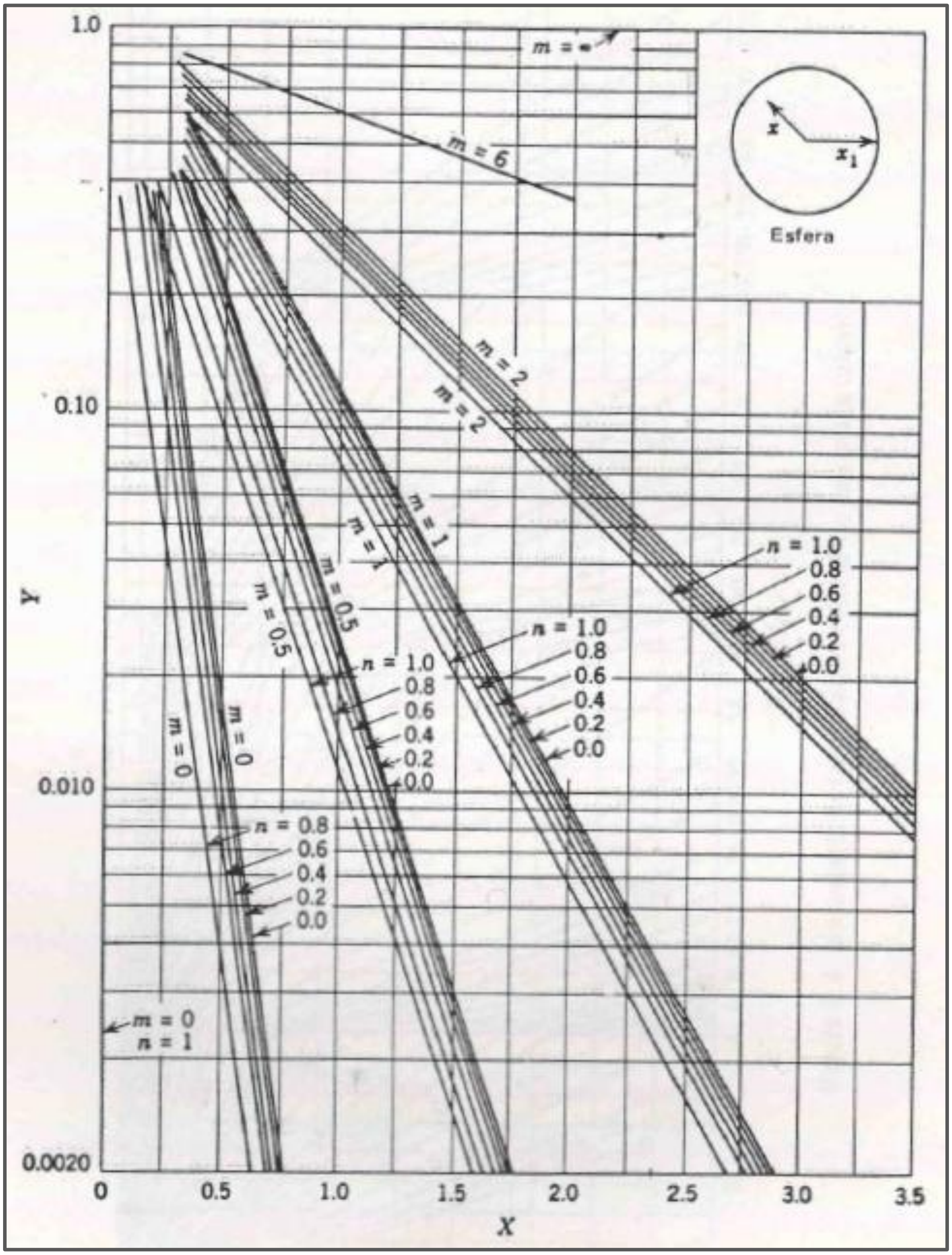
- **Simetría Plana:**



- **Simetría Cilíndrica:**

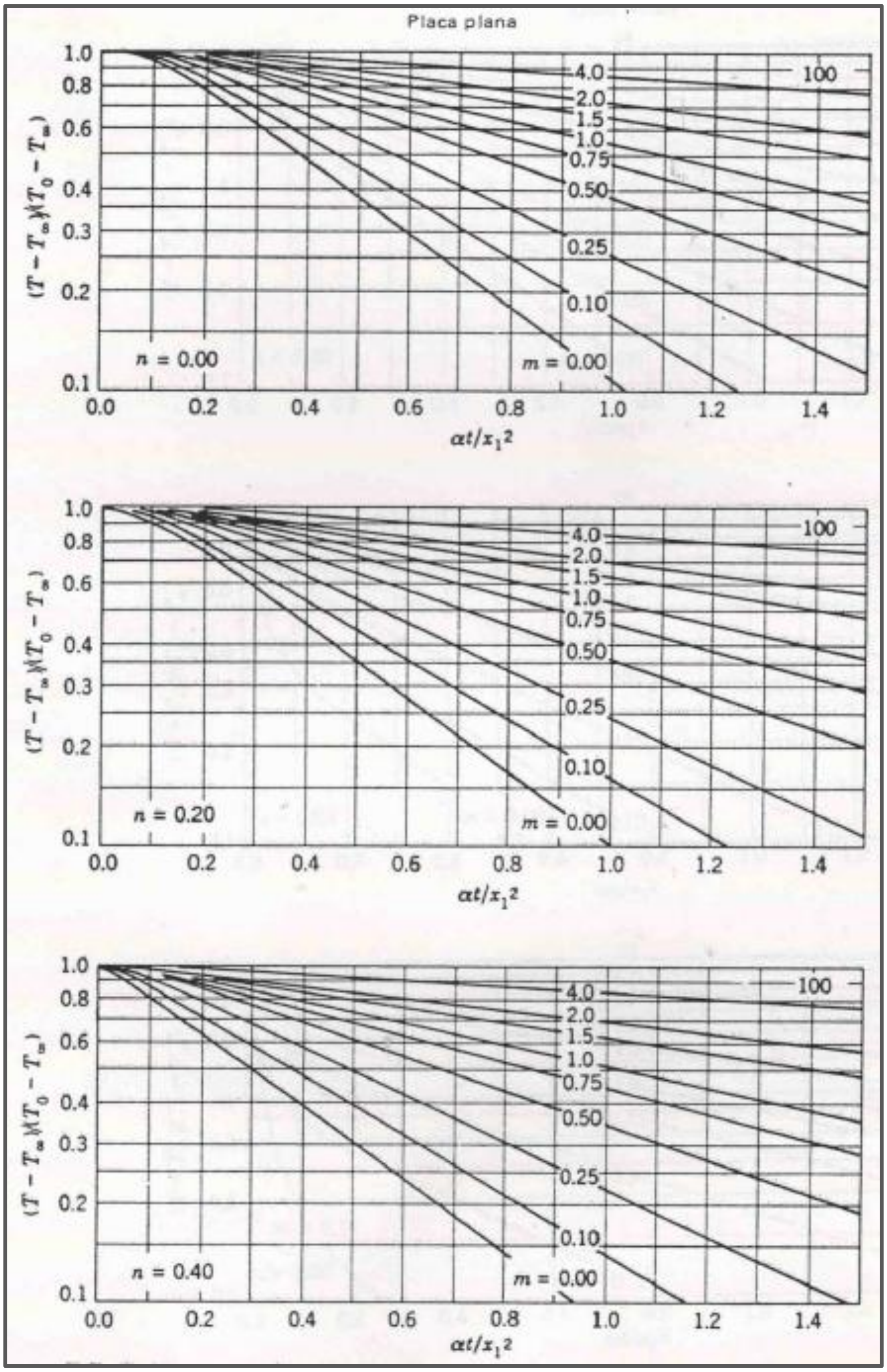


- **Simetría Esférica:**

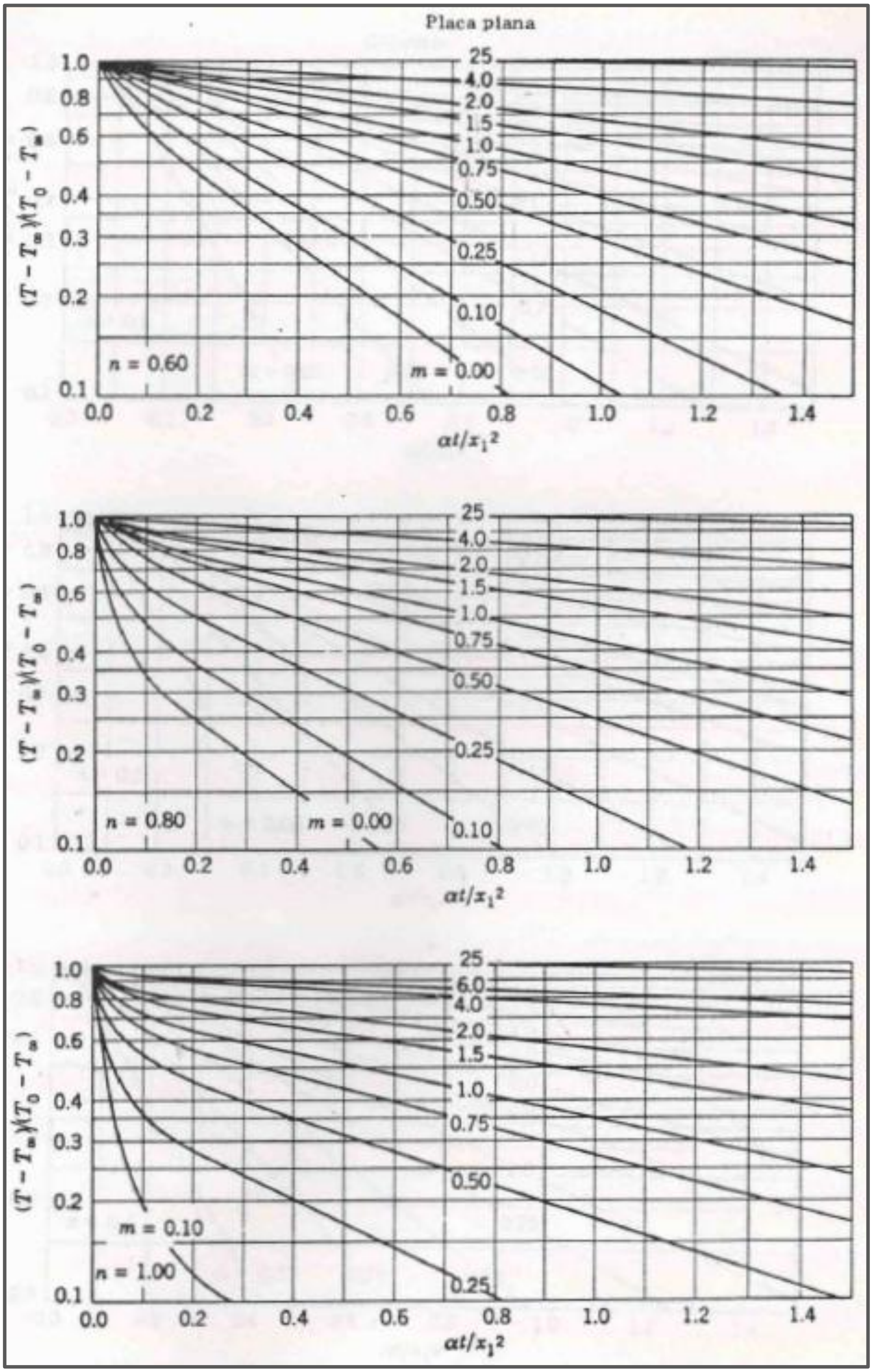


Gráficas para la Solución de Problemas de Transferencia en Estado No Permanente[g]

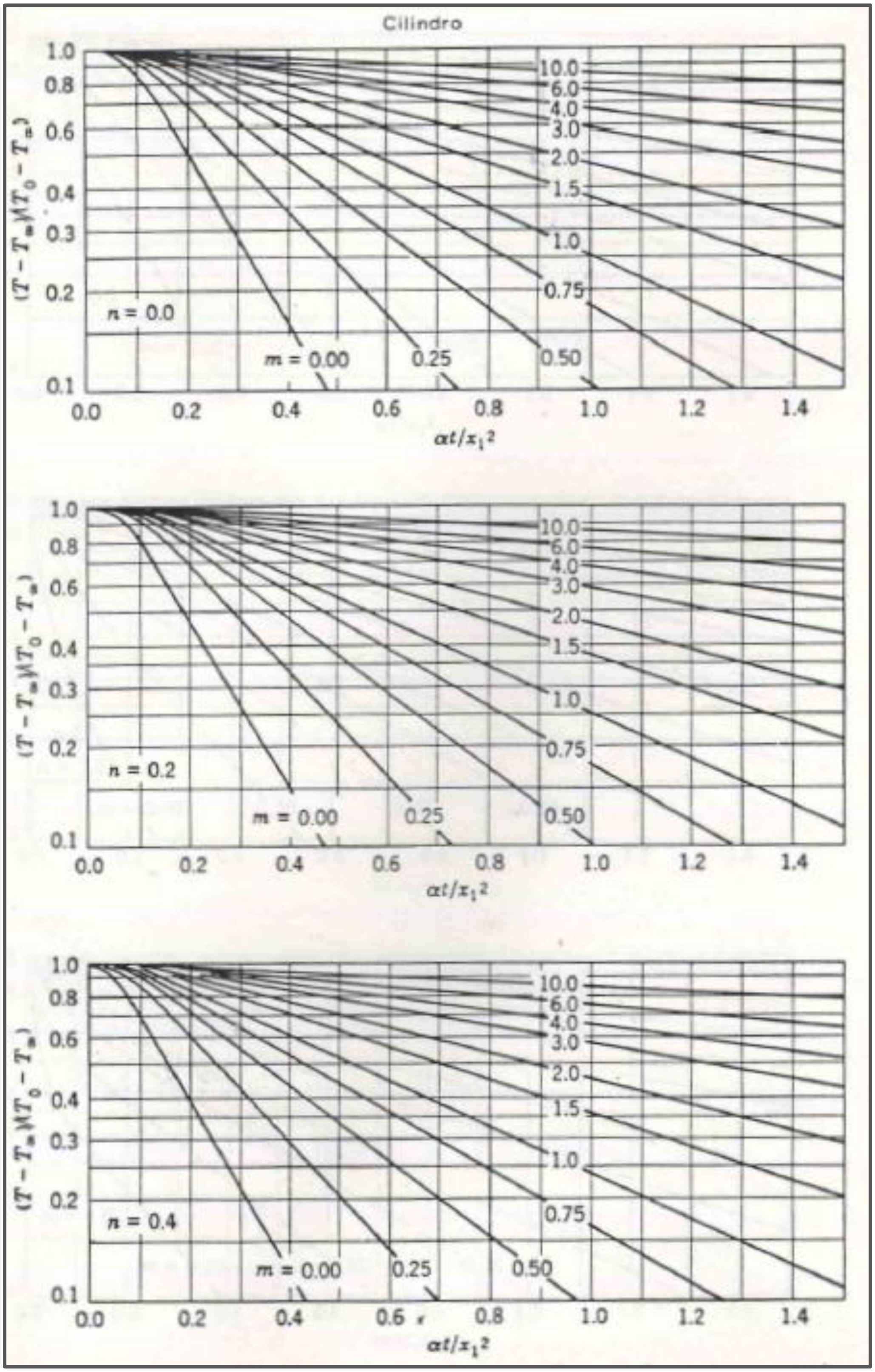
- **Placa Plana:**

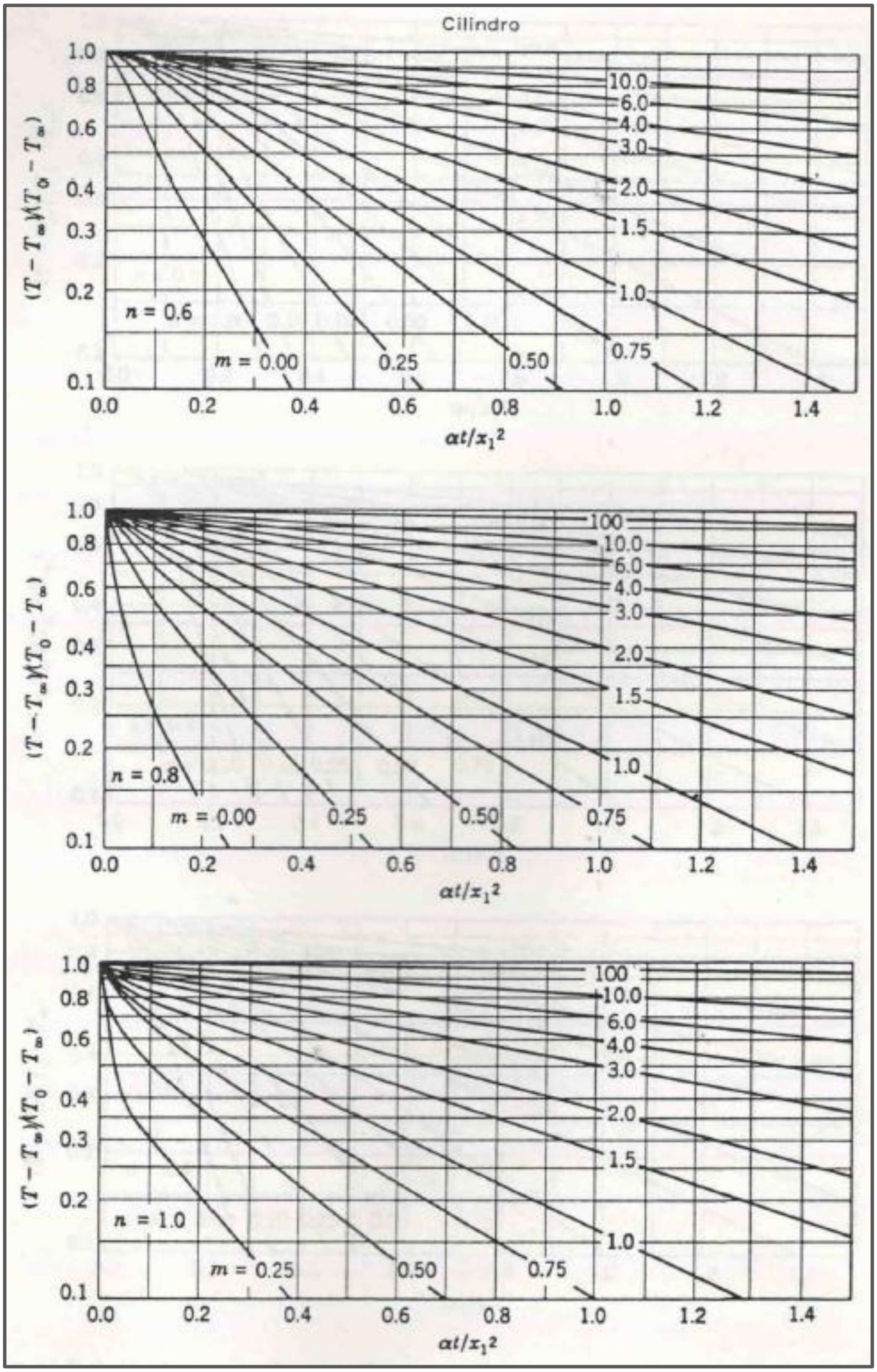


[g] Las variables n y m se definen como: $n = x/L_C$ y $m = 1/Bi$

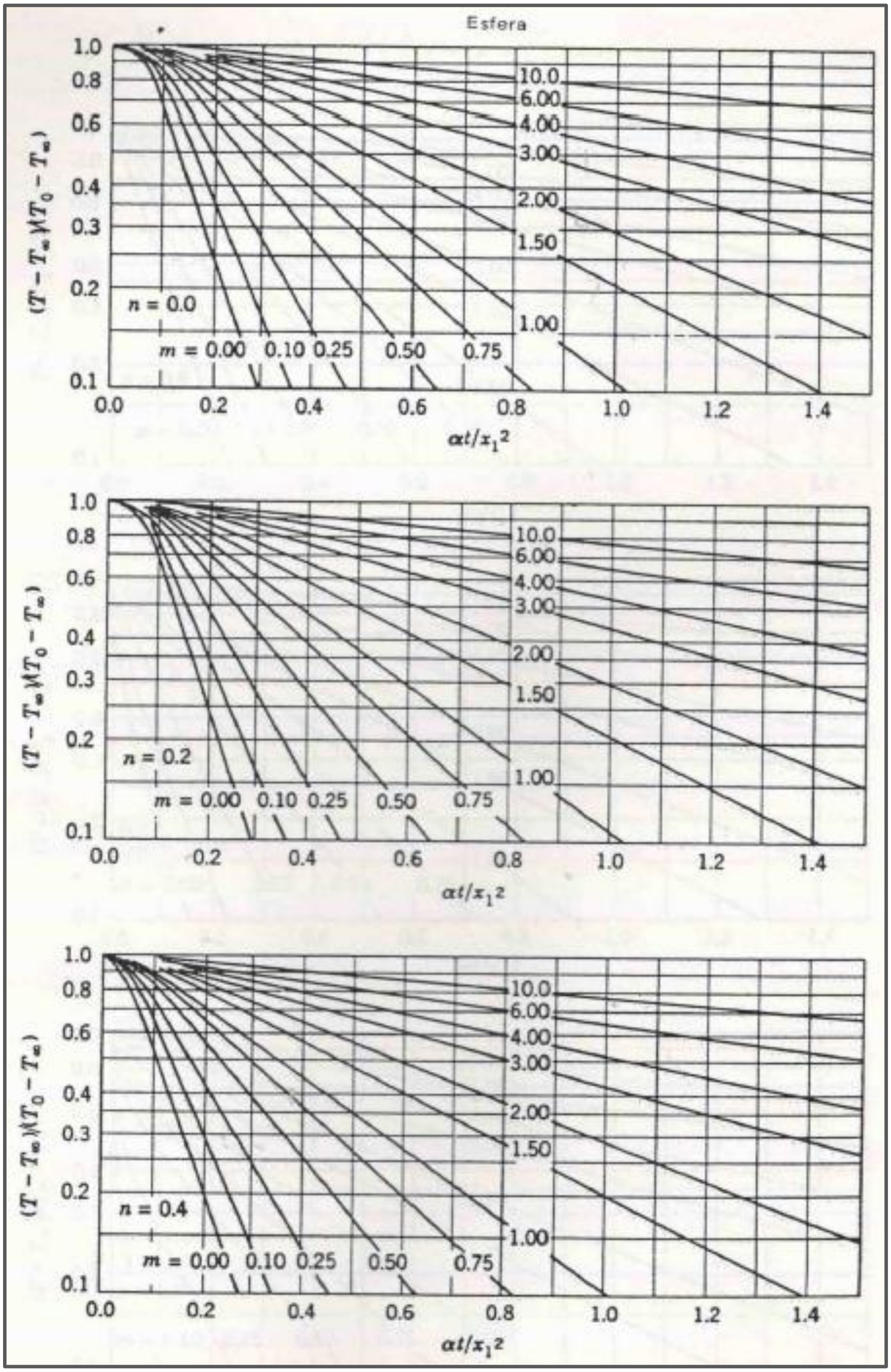

Placa plana
$(T - T_s)/(T_0 - T_s)$
1.0
0.8
0.6
0.4
0.3
0.2
0.1
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
$\alpha t/x_1^2$
25
4.0
2.0
1.5
1.0
0.75
0.50
0.25
0.10
$n = 0.60$
$m = 0.00$
$n = 0.80$
$m = 0.00$
6.0
$m = 0.10$
$n = 1.00$

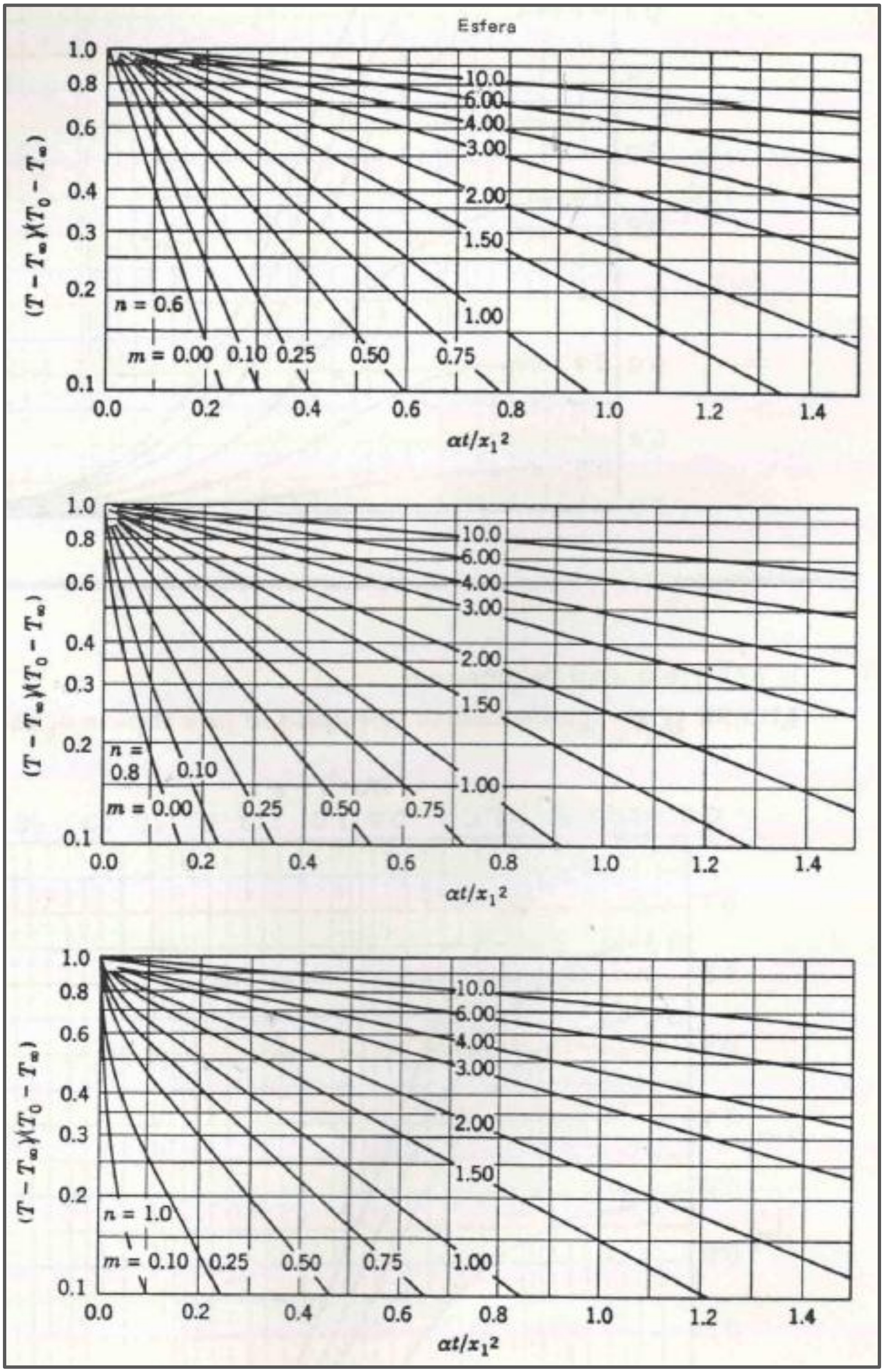
- **Cilindro:**


Cilindro
$(T - T_\infty)/(T_0 - T_\infty)$
1.0
0.8
0.6
0.4
0.3
0.2
0.1
n = 0.0
n = 0.2
n = 0.4
m = 0.00
0.25
0.50
0.75
1.0
1.5
2.0
3.0
4.0
6.0
10.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
$\alpha t/x_1^2$


Cilindro
$(T - T_\infty)/(T_0 - T_\infty)$
$n = 0.6$
$m = 0.00$
0.25
0.50
0.75
1.0
1.5
2.0
3.0
4.0
6.0
10.0
$\alpha t/x_1^2$
$n = 0.8$
$m = 0.00$
100
$n = 1.0$
$m = 0.25$

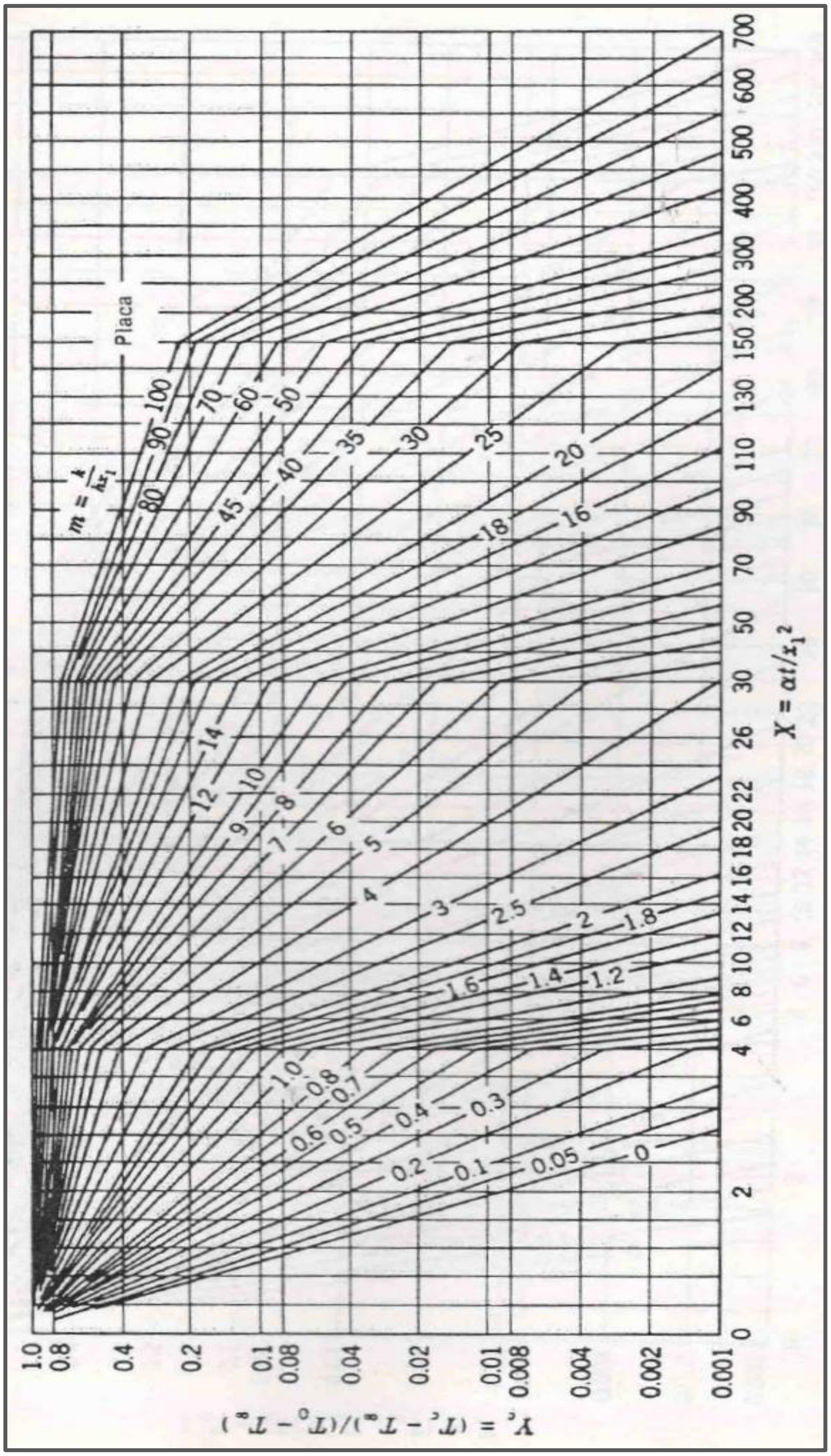
- **Esfera:**


Esfera
n = 0.0
m = 0.00 0.10 0.25 0.50 0.75
10.0
6.00
4.00
3.00
2.00
1.50
1.00
(T − T∞)/(T0 − T∞)
αt/x1²
n = 0.2
n = 0.4

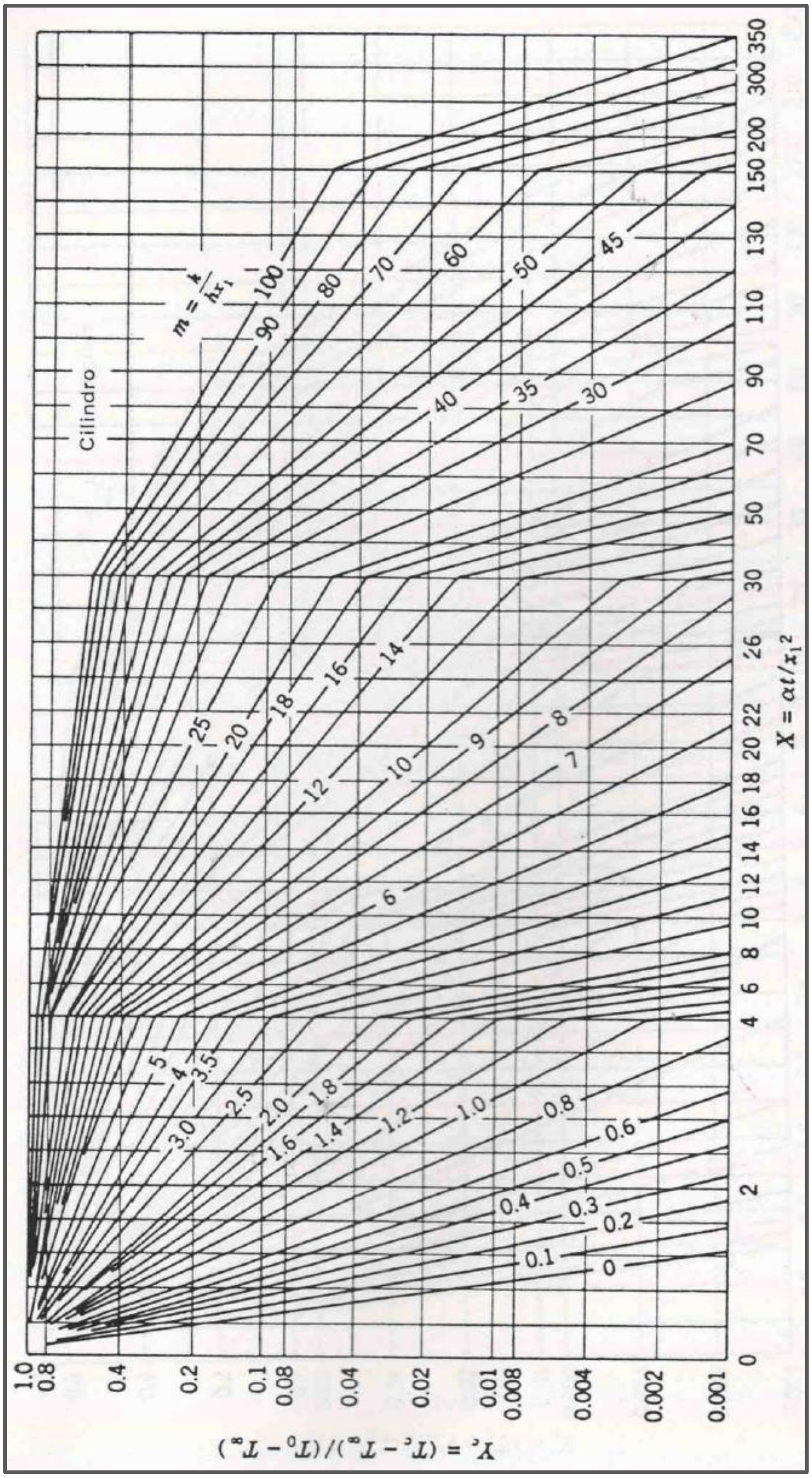

Esfera
$(T - T_\infty)/(T_0 - T_\infty)$
$\alpha t / x_1^2$
n = 0.6
m = 0.00 0.10 0.25 0.50 0.75
1.00 1.50 2.00 3.00 4.00 6.00 10.0
n = 0.8
m = 0.00 0.10 0.25 0.50 0.75
1.00 1.50 2.00 3.00 4.00 6.00 10.0
n = 1.0
m = 0.10 0.25 0.50 0.75 1.00
1.50 2.00 3.00 4.00 6.00 10.0

Gráficas de la Temperatura Central para Distintas Geometrías

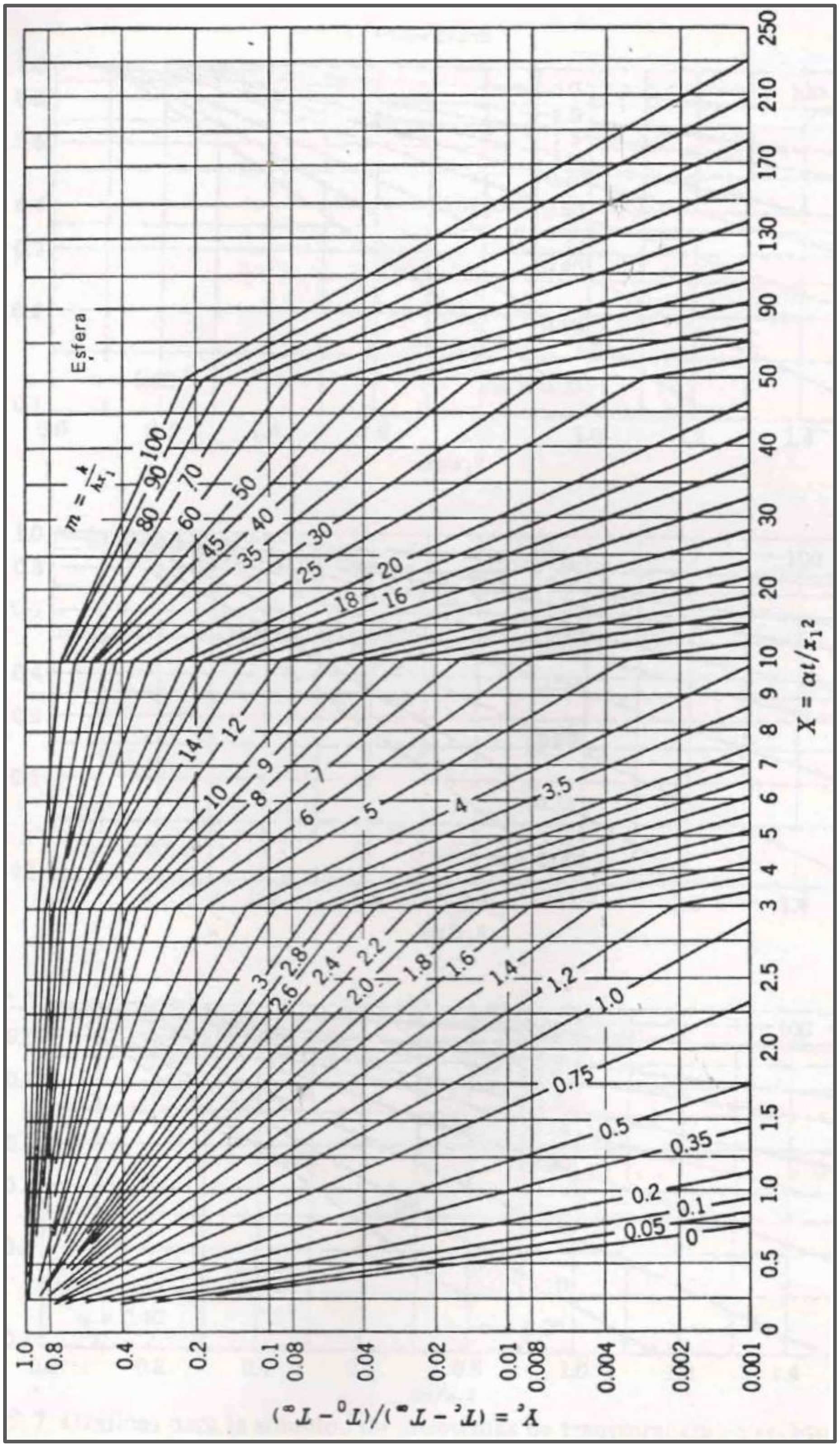
- Historia de la Temperatura Central de una Placa Infinita:



- Historia de la temperatura Central de un Cilindro Infinito:

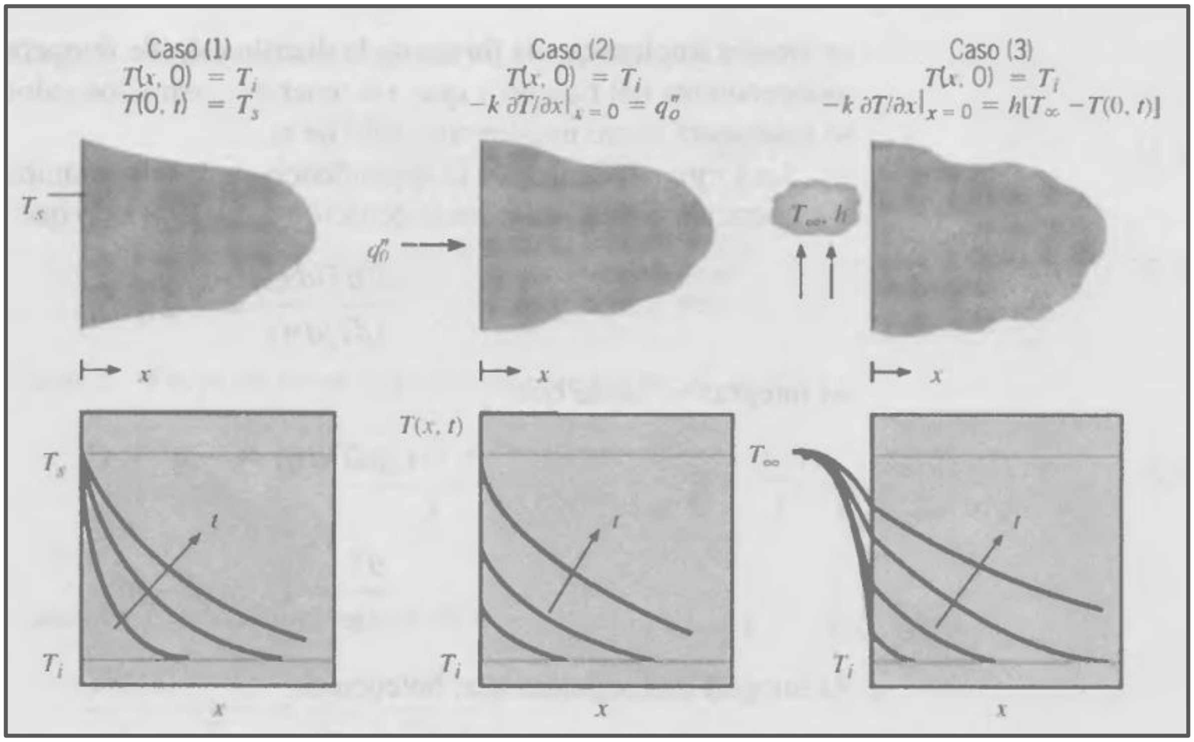


- Historia de la Temperatura Central de una Esfera:

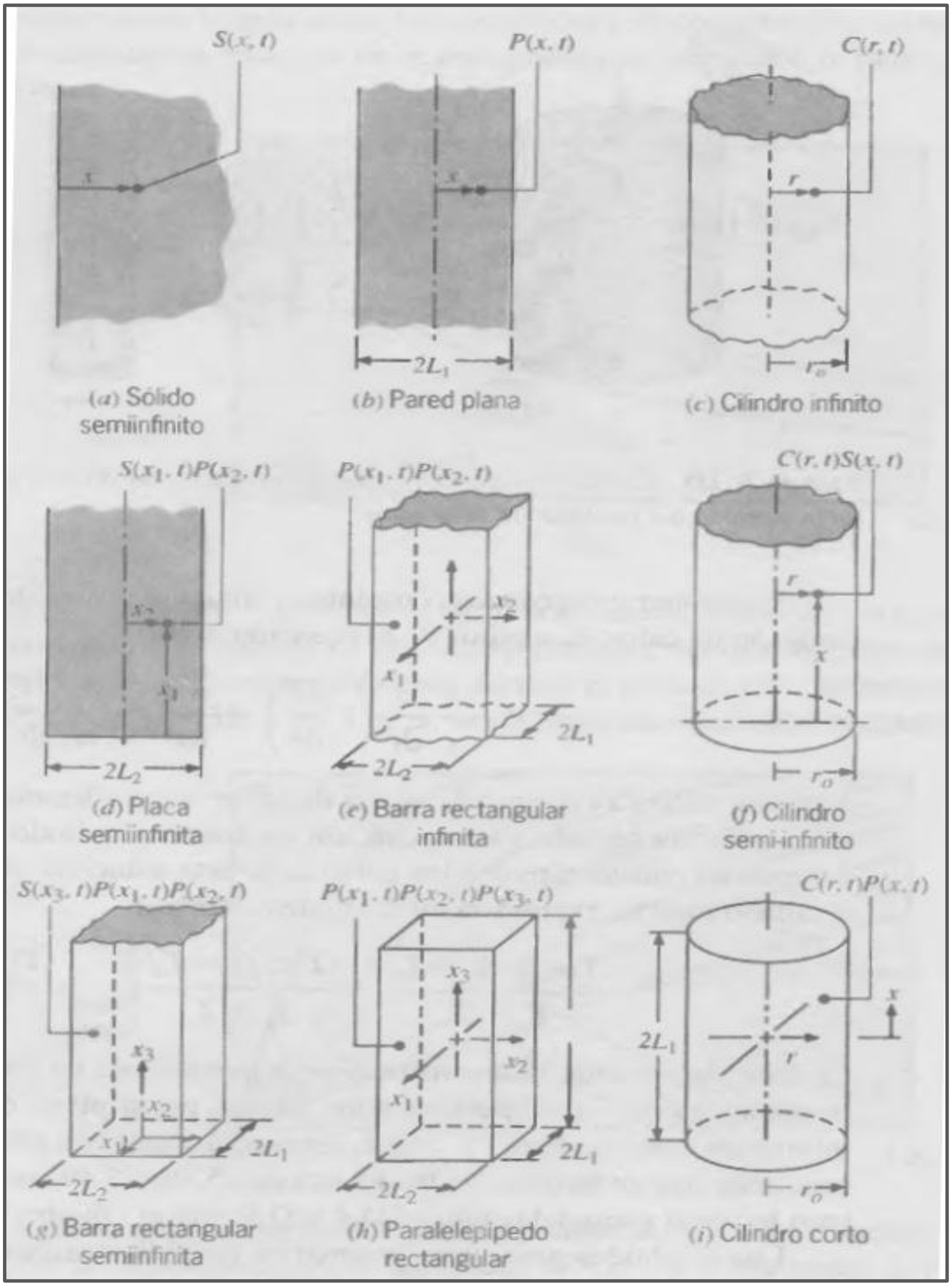


Distribuciones de Temperatura en un Sólido Semi-Infinito para Distintas Condiciones de Superficie

a) Temperatura superficial constante
b) Flujo de calor superficial constante
c) Convección superficial



Soluciones para Sistemas Multidimensionales Expresadas como Productos de Resultados Unidimensionales



En cada caso la solución multidimensional se establece como el producto de las siguientes soluciones unidimensionales:

$$S_{(x,t)} = \left.\frac{T_{(x,t)} - T_\infty}{T_i - T_\infty}\right|_{\substack{\text{Solido}\\\text{Semiinfinito}}}$$

$$P_{(x,t)} = \left.\frac{T_{(x,t)} - T_\infty}{T_i - T_\infty}\right|_{\substack{\text{Pared}\\\text{plana}}}$$

$$C_{(r,t)} = \left.\frac{T_{(r,t)} - T_\infty}{T_i - T_\infty}\right|_{\substack{\text{Cilindro}\\\text{Infinito}}}$$

Transferencia de Materia

La ecuación de Continuidad de *A* en Diversos Sistemas Coordenados en Base Molar

Coordenadas Rectangulares:

$$\frac{\partial C_A}{\partial t}+\left(\frac{\partial N_{Ax}}{\partial x}+\frac{\partial N_{Ay}}{\partial y}+\frac{\partial N_{Az}}{\partial z}\right)=R_A$$

Coordenadas Cilíndricas:

$$\frac{\partial C_A}{\partial t}+\left(\frac{1}{r}\frac{\partial}{\partial x}\left(rN_{Ar}\right)+\frac{1}{r}\frac{\partial N_{A\theta}}{\partial \theta}+\frac{\partial N_{Az}}{\partial z}\right)=R_A$$

Coordenadas Esféricas:

$$\frac{\partial C_A}{\partial t}+\left(\frac{1}{r^2}\frac{\partial}{\partial x}\left(r^2N_{Ar}\right)+\frac{1}{r\operatorname{sen}\theta}\frac{\partial}{\partial \theta}\left(N_{A\theta}\operatorname{sen}\theta\right)+\frac{1}{r\operatorname{sen}\theta}\frac{\partial N_{A\phi}}{\partial \phi}\right)=R_A$$

La Ecuación de Continuidad de *A* para *ρ* y D_{AB} Constantes en Base Molar

Coordenadas Rectangulares:

$$\frac{\partial C_A}{\partial t}+\left(v_x\frac{\partial C_A}{\partial x}+v_y\frac{\partial C_A}{\partial y}+v_z\frac{\partial C_A}{\partial z}\right)=D_{AB}\left(\frac{\partial^2 C_A}{\partial x^2}+\frac{\partial^2 C_A}{\partial y^2}+\frac{\partial^2 C_A}{\partial z^2}\right)+R_A$$

Coordenadas Cilíndricas:

$$\frac{\partial C_A}{\partial t}+\left(v_r\frac{\partial C_A}{\partial r}+v_\theta\frac{1}{r}\frac{\partial C_A}{\partial \theta}+v_z\frac{\partial C_A}{\partial z}\right)$$
$$=D_{AB}\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial C_A}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 C_A}{\partial \theta^2}+\frac{\partial^2 C_A}{\partial z^2}\right)+R_A$$

Coordenadas Esféricas:

$$\frac{\partial C_A}{\partial t}+\left(v_r\frac{\partial C_A}{\partial r}+v_\theta\frac{1}{r}\frac{\partial C_A}{\partial \theta}+v_\phi\frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial C_A}{\partial \phi}\right)$$
$$=D_{AB}\left(\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial C_A}{\partial r}\right)+\frac{1}{r^2\,\mathrm{sen}\,\theta}\frac{\partial}{\partial \theta}\left(\mathrm{sen}\,\theta\frac{\partial C_A}{\partial \theta}\right)+\frac{1}{r^2\,\mathrm{sen}^2\,\theta}\frac{\partial^2 C_A}{\partial \phi^2}\right)+R_A$$

La ecuación de Continuidad de *A* en Diversos Sistemas Coordenados en Base Másica

Coordenadas Rectangulares:

$$\frac{\partial \omega_A}{\partial t} + \left(\frac{\partial n_{Ax}}{\partial x} + \frac{\partial n_{Ay}}{\partial y} + \frac{\partial n_{Az}}{\partial z} \right) = r_A$$

Coordenadas Cilíndricas:

$$\frac{\partial \omega_A}{\partial t} + \left(\frac{1}{r} \frac{\partial}{\partial x} \left(r n_{Ar} \right) + \frac{1}{r} \frac{\partial n_{A\theta}}{\partial \theta} + \frac{\partial n_{Az}}{\partial z} \right) = r_A$$

Coordenadas Esféricas:

$$\frac{\partial \omega_A}{\partial t} + \left(\frac{1}{r^2} \frac{\partial}{\partial x} \left(r^2 n_{Ar} \right) + \frac{1}{r \operatorname{sen} \theta} \frac{\partial}{\partial \theta} \left(n_{A\theta} \operatorname{sen} \theta \right) + \frac{1}{r \operatorname{sen} \theta} \frac{\partial n_{A\phi}}{\partial \phi} \right) = r_A$$

La Ecuación de Continuidad de *A* para *ρ* y *D_{AB}* Constantes en Base Másica

Coordenadas Rectangulares:

$$\frac{\partial \omega_A}{\partial t} + \left(v_x \frac{\partial \omega_A}{\partial x} + v_y \frac{\partial \omega_A}{\partial y} + v_z \frac{\partial \omega_A}{\partial z} \right) = D_{AB} \left(\frac{\partial^2 \omega_A}{\partial x^2} + \frac{\partial^2 \omega_A}{\partial y^2} + \frac{\partial^2 \omega_A}{\partial z^2} \right) + r_A$$

Coordenadas Cilíndricas:

$$\frac{\partial \omega_A}{\partial t} + \left(v_r \frac{\partial \omega_A}{\partial r} + v_\theta \frac{1}{r} \frac{\partial \omega_A}{\partial \theta} + v_z \frac{\partial \omega_A}{\partial z} \right)$$
$$= D_{AB} \left(\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial \omega_A}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 \omega_A}{\partial \theta^2} + \frac{\partial^2 \omega_A}{\partial z^2} \right) + r_A$$

Coordenadas Esféricas:

$$\frac{\partial \omega_A}{\partial t} + \left(v_r \frac{\partial \omega_A}{\partial r} + v_\theta \frac{1}{r} \frac{\partial \omega_A}{\partial \theta} + v_\phi \frac{1}{r \operatorname{sen} \theta} \frac{\partial \omega_A}{\partial \phi} \right)$$
$$= D_{AB} \left(\frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial \omega_A}{\partial r} \right) + \frac{1}{r^2 \operatorname{sen} \theta} \frac{\partial}{\partial \theta} \left(\operatorname{sen} \theta \frac{\partial \omega_A}{\partial \theta} \right) + \frac{1}{r^2 \operatorname{sen}^2 \theta} \frac{\partial^2 \omega_A}{\partial \phi^2} \right) + r_A$$

Analogías entre Transferencia de Calor y Masa a Bajas Velocidades de Transferencia

	Heat transfer quantities (pure fluids)	Binary mass transfer quantities (isothermal fluids, molar units)
Profiles	T	x_A
Diffusivity	$\alpha = k/\rho\hat{C}_p$	$\mathfrak{D}_{AB}$
Effect of profiles on density	$\beta = -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p$	$\xi = -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial x_A}\right)_{p,T}$
Flux	$\mathbf{q}$	$\mathbf{J}_A^* = \mathbf{N}_A + x_A(\mathbf{N}_A + \mathbf{N}_B)$
Transfer rate	Q	$W_{A0} - x_{A0}(W_{A0} + W_{B0})$
Transfer coefficient	$h = \frac{Q}{A\,\Delta T}$	$k_x = \frac{W_{A0} - x_{A0}(W_{A0} + W_{B0})}{A\,\Delta x_A}$
Dimensionless groups common to all three correlations	$\mathrm{Re} = l_0 v_0 \rho/\mu$ $\mathrm{Fr} = v_0^2/g l_0$	$\mathrm{Re} = l_0 v_0 \rho/\mu$ $\mathrm{Fr} = v_0^2/g l_0$
Dimensionless groups that are different	$\mathrm{Nu} = h l_0/k$ $\mathrm{Pr} = \hat{C}_p\mu/k$ $\mathrm{Gr} = l_0^3\rho^2 g\beta\Delta T/\mu^2$ $\mathrm{Pé} = \mathrm{RePr} = l_0 v_0 \hat{C}_p/k$	$\mathrm{Sh} = k_x l_0/c\mathfrak{D}_{AB}$ $\mathrm{Sc} = \mu/\rho\mathfrak{D}_{AB}$ $\mathrm{Gr}_x = l_0^3\rho^2 g\xi\Delta x_A/\mu^2$ $\mathrm{Pé} = \mathrm{ReSc} = l_0 v_0/\mathfrak{D}_{AB}$
Chilton–Colburn *j*-factors	$j_H = \mathrm{NuRe}^{-1}\mathrm{Pr}^{-1/3} = \frac{h}{\rho\hat{C}_p v_0}\left(\frac{\hat{C}_p\mu}{k}\right)^{2/3}$	$j_D = \mathrm{ShRe}^{-1}\mathrm{Sc}^{-1/3} = \frac{k_x}{c v_0}\left(\frac{\mu}{\rho\mathfrak{D}_{AB}}\right)^{2/3}$

Relaciones y Funciones Matemáticas

Gradiente, Laplaciano, Divergencia y Rotor en Distintos Sistemas Coordenados

Coordenadas Cartesianas:

$$\vec{\nabla} V = \frac{\partial V}{\partial x}\hat{x} + \frac{\partial V}{\partial y}\hat{y} + \frac{\partial V}{\partial z}\hat{z}$$

$$\nabla^2 V = \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2}$$

$$\vec{\nabla} \cdot \vec{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}$$

$$\vec{\nabla} \times \vec{A} = \left[\frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z}\right]\hat{x} + \left[\frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x}\right]\hat{y} + \left[\frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y}\right]\hat{z}$$

Coordenadas Cilíndricas:

$$\vec{\nabla} V = \frac{\partial V}{\partial r}\hat{r} + \frac{1}{r}\frac{\partial V}{\partial \theta}\hat{\theta} + \frac{\partial V}{\partial z}\hat{z}$$

$$\nabla^2 V = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial V}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 V}{\partial \theta^2} + \frac{\partial^2 V}{\partial z^2}$$

$$\vec{\nabla} \cdot \vec{A} = \frac{1}{r}\frac{\partial}{\partial r}(rA_r) + \frac{1}{r}\frac{\partial A_\theta}{\partial \theta} + \frac{\partial A_z}{\partial z}$$

$$\vec{\nabla} \times \vec{A} = \left[\frac{1}{r}\frac{\partial A_z}{\partial \theta} - \frac{\partial A_\theta}{\partial z}\right]\hat{r} + \left[\frac{\partial A_r}{\partial z} - \frac{\partial A_z}{\partial r}\right]\hat{\theta} + \left[\frac{1}{r}\frac{\partial}{\partial r}(rA_\theta) - \frac{1}{r}\frac{\partial A_r}{\partial \theta}\right]\hat{z}$$

Coordenadas Esféricas:

$$\vec{\nabla} V = \frac{\partial V}{\partial r}\hat{r} + \frac{1}{r}\frac{\partial V}{\partial \theta}\hat{\theta} + \frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial V}{\partial \phi}\hat{\phi}$$

$$\nabla^2 V = \frac{1}{r}\frac{\partial^2}{\partial r^2}(rV) + \frac{1}{r^2\,\mathrm{sen}\,\theta}\frac{\partial}{\partial \theta}\left(\mathrm{sen}\,\theta\frac{\partial V}{\partial \theta}\right) + \frac{1}{r^2\,\mathrm{sen}^2\,\theta}\frac{\partial^2 V}{\partial \phi^2}$$

$$\vec{\nabla} \cdot \vec{A} = \frac{1}{r^2}\frac{\partial}{\partial r}(r^2 A_r) + \frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial}{\partial \theta}(A_\theta\,\mathrm{sen}\,\theta) + \frac{1}{r\,\mathrm{sen}\,\theta}\frac{\partial A_\phi}{\partial \phi}$$

$$\vec{\nabla} \times \vec{A} = \left[\frac{1}{r\,\mathrm{sen}\,\theta}\left(\frac{\partial}{\partial \theta}(A_\phi\,\mathrm{sen}\,\theta) - \frac{\partial A_\theta}{\partial \phi}\right)\right]\hat{r} + \left[\frac{1}{r}\left(\frac{1}{\mathrm{sen}\,\theta}\frac{\partial A_r}{\partial \phi} - \frac{\partial}{\partial r}(rA_\phi)\right)\right]\hat{\theta}$$
$$+ \left[\frac{1}{r}\left(\frac{\partial}{\partial r}(rA_\theta) - \frac{\partial A_r}{\partial \theta}\right)\right]\hat{\phi}$$

Funciones Hiperbólicas

$$\begin{bmatrix} \cosh(x) = \dfrac{e^x + e^{-x}}{2} = \cosh(-x) \\ \tanh(x) = \dfrac{\text{senh}(x)}{\cosh(x)} \\ \cosh(x) + \text{senh}(x) = e^x \end{bmatrix}$$

$$\begin{bmatrix} \text{senh}(x) = \dfrac{e^x - e^{-x}}{2} = -\text{senh}(-x) \\ \text{cotanh}(x) = \dfrac{\cosh(x)}{\text{senh}(x)} \\ \cosh(x) - \text{senh}(x) = e^{-x} \end{bmatrix}$$

$$\begin{bmatrix} \cosh^2(x) - \text{senh}^2(x) = 1 \\ \text{senh}(x \pm y) = \text{senh}(x) \cdot \cosh(y) \pm \text{senh}(y) \cdot \cosh(x) \\ \cosh(x \pm y) = \cosh(x) \cdot \cosh(y) \pm \text{senh}(y) \cdot \text{senh}(x) \\ \tanh(x \pm y) = \dfrac{\tanh(x) \pm \tanh(y)}{1 \pm \tanh(x) \cdot \tanh(y)} \end{bmatrix}$$

$$\begin{bmatrix} \text{senh}(x) \cdot \text{senh}(y) = \tfrac{1}{2}\left[\cosh(x+y) - \cosh(x-y)\right] \\ \cosh(x) \cdot \cosh(y) = \tfrac{1}{2}\left[\cosh(x+y) + \cosh(x-y)\right] \\ \text{senh}(x) \cdot \cosh(y) = \tfrac{1}{2}\left[\text{senh}(x+y) + \text{senh}(x-y)\right] \end{bmatrix}$$

Función Gaussiana de Error

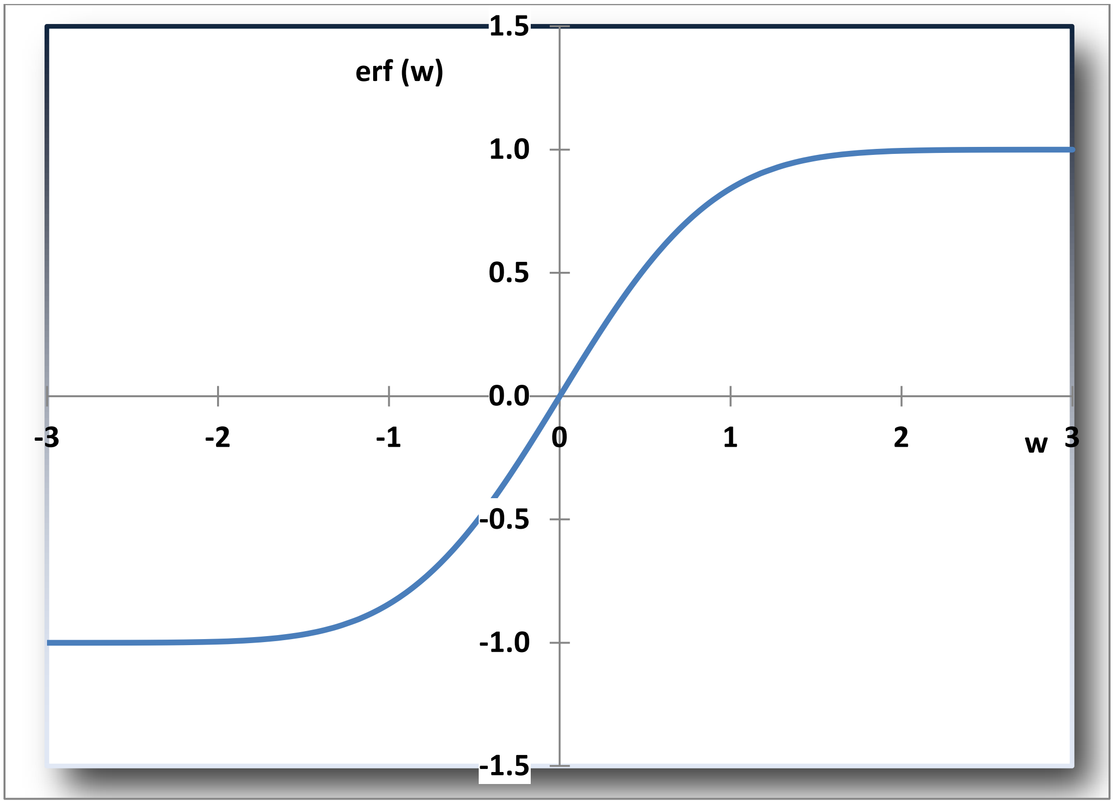
La función Gaussiana de error se define como:

$$\operatorname{erf}(w) = \frac{2}{\sqrt{\pi}} \int_0^w e^{-\upsilon^2} d\upsilon$$

- La función Gaussiena de error tabulada:

w	erf *w*	*w*	erf *w*	*w*	erf *w*
0.00	0.00000	0.36	0.38933	1.04	0.85865
0.02	0.02256	0.38	0.40901	1.08	0.87333
0.04	0.04511	0.40	0.42839	1.12	0.88679
0.06	0.06762	0.44	0.46622	1.16	0.89910
0.08	0.09008	0.48	0.50275	1.20	0.91031
0.10	0.11246	0.52	0.53790	1.30	0.93401
0.12	0.13476	0.56	0.57162	1.40	0.95228
0.14	0.15695	0.60	0.60386	1.50	0.96611
0.16	0.17901	0.64	0.63459	1.60	0.97635
0.18	0.20094	0.68	0.66378	1.70	0.98379
0.20	0.22270	0.72	0.69143	1.80	0.98909
0.22	0.24430	0.76	0.71754	1.90	0.99279
0.24	0.26570	0.80	0.74210	2.00	0.99532
0.26	0.28690	0.84	0.76514	2.20	0.99814
0.28	0.30788	0.88	0.78669	2.40	0.99931
0.30	0.32863	0.92	0.80677	2.60	0.99976
0.32	0.34913	0.96	0.82542	2.80	0.99992
0.34	0.36936	1.00	0.84270	3.00	0.99998

- Gráfico de la función error:



También, se define la función de error complementaria:

$$\mathrm{erf}\left(w\right) \equiv 1 - \mathrm{erf}\left(w\right)$$

Primeras Cuatro Raíces de la Ecuación Trascendental, $\xi_n \tan\xi_n = Bi$, para Conducción Transitoria en una Pared Plana

$Bi = \frac{hL}{k}$	ξ_1	ξ_1	ξ_1	ξ_1
0	0	3.1416	6.2832	9.4248
0.001	0.0316	3.1419	6.2833	9.4249
0.002	0.0447	3.1422	6.2835	9.4250
0.004	0.0632	3.1429	6.2838	9.4252
0.006	0.0774	3.1435	6.2841	9.4254
0.008	0.0893	3.1441	6.2845	9.4256
0.01	0.0998	3.1448	6.2848	9.4258
0.02	0.1410	3.1479	6.2864	9.4269
0.04	0.1987	3.1543	6.2895	9.4290
0.06	0.2425	3.1606	6.2927	9.4311
0.08	0.2791	3.1668	6.2959	9.4333
0.1	0.3111	3.1731	6.2991	9.4354
0.2	0.4328	3.2039	6.3148	9.4459
0.3	0.5218	3.2341	6.3305	9.4565
0.4	0.5932	3.2636	6.3461	9.4670
0.5	0.6533	3.2923	6.3616	9.4775
0.6	0.7051	3.3204	6.3770	9.4879
0.7	0.7506	3.3477	6.3923	9.4983
0.8	0.7910	3.3744	6.4074	9.5087
0.9	0.8274	3.4003	6.4224	9.5190
1.0	0.8603	3.4256	6.4373	9.5293
1.5	0.9882	3.5422	6.5097	9.5801
2.0	1.0769	3.6436	6.5783	9.6296
3.0	1.1925	3.8088	6.7040	9.7240
4.0	1.2646	3.9352	6.8140	9.8119
5.0	1.3138	4.0336	6.9096	9.8928
6.0	1.3496	4.1116	6.9924	9.9667
7.0	1.3766	4.1746	7.0640	10.0339
8.0	1.3978	4.2264	7.1263	10.0949
9.0	1.4149	4.2694	7.1806	10.1502
10.0	1.4289	4.3058	7.2281	10.2003
15.0	1.4729	4.4255	7.3959	10.3898
20.0	1.4961	4.4915	7.4954	10.5117
30.0	1.5202	4.5615	7.6057	10.6543
40.0	1.5325	4.5979	7.6647	10.7334
50.0	1.5400	4.6202	7.7012	10.7832
60.0	1.5451	4.6353	7.7259	10.8172
80.0	1.5514	4.6543	7.7573	10.8606
100.0	1.5552	4.6658	7.7764	10.8871
∞	1.5708	4.7124	7.8540	10.9956

Funciones de Bessel de Primera Clase

x	$J_0(x)$	$J_1(x)$
0.0	1.0000	0.0000
0.1	0.9975	0.0499
0.2	0.9900	0.0995
0.3	0.9776	0.1483
0.4	0.9604	0.1960
0.5	0.9385	0.2423
0.6	0.9120	0.2867
0.7	0.8812	0.3290
0.8	0.8463	0.3688
0.9	0.8075	0.4059
1.0	0.7652	0.4400
1.1	0.7196	0.4709
1.2	0.6711	0.4983
1.3	0.6201	0.5220
1.4	0.5669	0.5419
1.5	0.5118	0.5579
1.6	0.4554	0.5699
1.7	0.3980	0.5778
1.8	0.3400	0.5815
1.9	0.2818	0.5812
2.0	0.2239	0.5767
2.1	0.1666	0.5683
2.2	0.1104	0.5560
2.3	0.0555	0.5399
2.4	0.0025	0.5202

Funcines de Bessel[h] modificadas de Primera y Segunda Clase

x	$e^{-x}I_0(x)$	$e^{-x}I_1(x)$	$e^{x}K_0(x)$	$e^{x}K_1(x)$
0.0	1.0000	0.0000	∞	∞
0.2	0.8269	0.0823	2.1407	5.8334
0.4	0.6974	0.1368	1.6627	3.2587
0.6	0.5993	0.1722	1.4167	2.3739
0.8	0.5241	0.1945	1.2582	1.9179
1.0	0.4657	0.2079	1.1445	1.6361
1.2	0.4198	0.2152	1.0575	1.4429
1.4	0.3831	0.2185	0.9881	1.3010
1.6	0.3533	0.2190	0.9309	1.1919
1.8	0.3289	0.2177	0.8828	1.1048
2.0	0.3085	0.2153	0.8416	1.0335
2.2	0.2913	0.2121	0.8056	0.9738
2.4	0.2766	0.2085	0.7740	0.9229
2.6	0.2639	0.2046	0.7459	0.8790
2.8	0.2528	0.2007	0.7206	0.8405
3.0	0.2430	0.1968	0.6978	0.8066
3.2	0.2343	0.1930	0.6770	0.7763
3.4	0.2264	0.1892	0.6579	0.7491
3.6	0.2193	0.1856	0.6404	0.7245
3.8	0.2129	0.1821	0.6243	0.7021
4.0	0.2070	0.1787	0.6093	0.6816
4.2	0.2016	0.1755	0.5953	0.6627
4.4	0.1966	0.1724	0.5823	0.6453
4.6	0.1919	0.1695	0.5701	0.6292
4.8	0.1876	0.1667	0.5586	0.6142
5.0	0.1835	0.1640	0.5478	0.6003
5.2	0.1797	0.1614	0.5376	0.5872
5.4	0.1762	0.1589	0.5279	0.5749
5.6	0.1728	0.1565	0.5188	0.5633
5.8	0.1696	0.1542	0.5101	0.5525
6.0	0.1666	0.1520	0.5019	0.5422
6.4	0.1611	0.1479	0.4865	0.5232
6.8	0.1561	0.1441	0.4724	0.5060
7.2	0.1515	0.1405	0.4595	0.4905
7.6	0.1473	0.1372	0.4476	0.4762
8.0	0.1434	0.1341	0.4366	0.4631
8.4	0.1398	0.1312	0.4264	0.4511
8.8	0.1365	0.1285	0.4168	0.4399
9.2	0.1334	0.1260	0.4079	0.4295
9.6	0.1305	0.1235	0.3995	0.4198
10.0	0.1278	0.1213	0.3916	0.4108

[h] $I_{n+1(x)} = I_{n-1(x)} - (2n/x)I_{n(x)}$