2026 GUIDE

28TH EDITION

to the Measurement & Control Market

ISA Sarnia Section

Setting the Standard for Automation™

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2026 28TH EDITION GUIDE to the Measurement & Control Market

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Message from the Reference Guide Committee

Greetings Fellow ISA Members and Users of this Reference Guide:

On behalf of ISA Sarnia Section we would like to welcome you to the 28th edition of this Reference Guide. We are excited to share this comprehensive resource with you. This guide has been developed to support your work, empower your decision-making, and help you make the most of our tools and systems.

Sarnia Section Reference Guide Committee in partnership with Grafiks Marketing & Communications created this reference with clarity, accuracy, and your needs in mind. We hope it enhances your understanding, streamlines your technical procurement processes, and enriches your experience working in Instrumentation, Systems & Automation area.

Every year we strive to enhance this Guide in its participation and content. We are also increasing our electronic footprint and trying our best to make our on-line version as user-friendly as possible. You can also visit the on-line version of this Reference Guide at **www.isasarnia.com.**

We would like to thank all the technical contributors and all the advertisers for their continued support. We also would like to thank all the users of this Reference Guide. It is your valuable support that has kept this Guide strong for the last 25+ years. We would like to request all users, when you call or write to any of the advertisers, please mention that you have seen their advertisement in the ISA Sarnia Reference Guide.

The reference guide generates much needed revenue for ISA Sarnia section to function and offer valuable programs that it has been offering to the local Automation community for the past 76 years.

We would like to request all users to help us get more advertisers for this guide. When you are dealing with any suppliers/manufacturers that not in this guide, please mention to them how important it is to be part of this Reference Guide.

We continue to strive to make the technical information section in this guide more accurate & current. We are always looking for new technical information and volunteers. Please contact anyone of the committee members.

Thank you for your dedication and for being part of our mission. We welcome your feedback as we continue to improve and evolve this resource.

Enjoy your new 2026 Reference Guide.
Cheers everyone!

ATTENTION MEMBERS OF ISA

If you would like to ensure that you advertise in this publication on an annual basis contact:

ISA Reference Guide Committee

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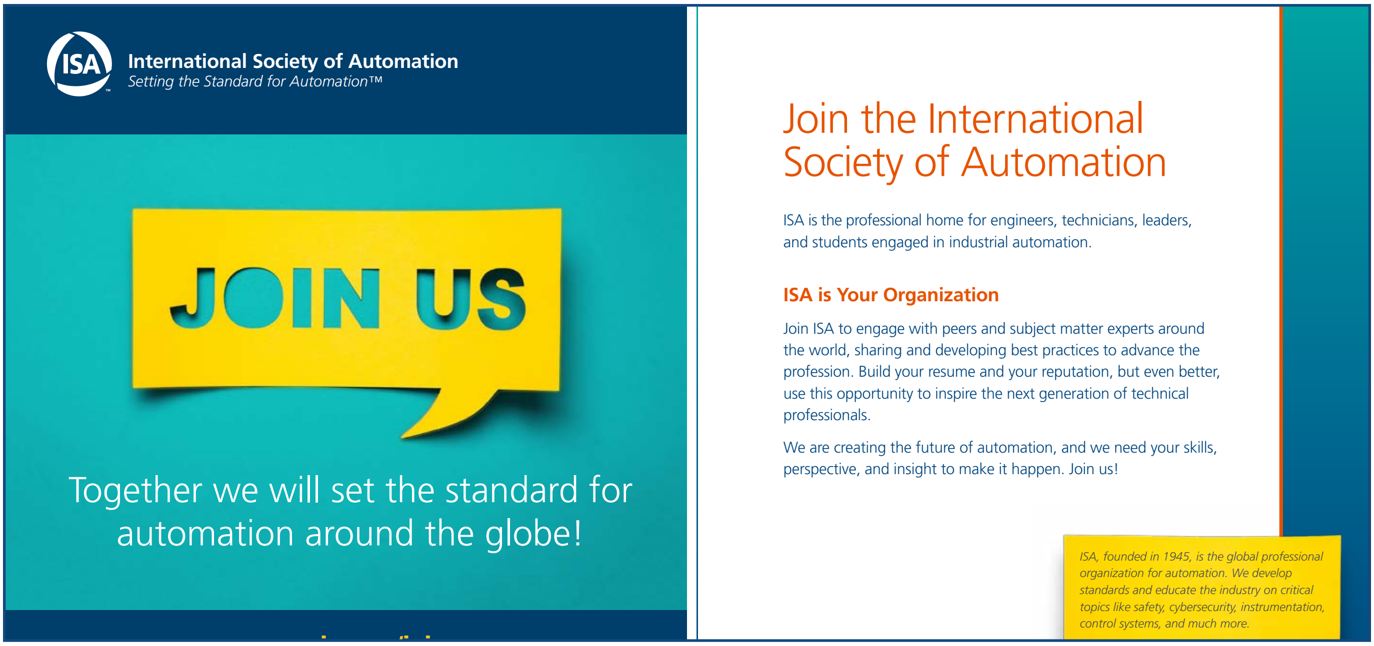

Quick Facts

1 ISA members can view all ISA standards, recommended practices, and technical reports online, free of charge.

2 ISA members receive a 20%* discount on all ISA training courses—both classroom and online. They can also access all pre-recorded ISA webinars for free.

3 ISA members receive a 20% discount when they apply to take ISA's Certified Control Systems Technician® (CCST®) and Certified Automation Professional® (CAP®) exams.

4 ISA members receive a discount on all ISA conference and symposia registrations. In some cases, joining ISA when you register for an event is like getting your membership for free!

5 ISA members get a 20% discount on ISA published books, plus a free subscription to InTech magazine and online access to ISA Transactions. They also receive regular editions of two e-newsletters: Automation Weekly and ISA Insights.

6 ISA members get unlimited technical division memberships.

7 Getting involved in an ISA section is one of the most convenient ways to network and get engaged with others in your profession.

2026 28TH EDITION GUIDE to the Measurement & Control Market

ISA Sarnia Section

"Dedicated to advancing the knowledge and practice related to the theory, design, manufacture and use of instruments and controls in science and industry."

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Contents

ISA Sarnia Section President's Message

As we reflect on the past year, I want to begin with a sincere thank you to every member of our Instrumentation, Systems & Automation community. Your participation, generosity in sharing knowledge, and commitment to helping one another are what make our section thrive.

This year, we continued to grow not just in numbers, but in impact. Through well attended diner meetings, bigger & better Automation Show & Technical Conference, educational seminar and member networking opportunities, we created spaces where professionals at all stages could learn, collaborate, and advance the effective use of automation for the betterment of the society.

Our section supports practical learning, open exchange, and inclusive participation. Whether solving complex automation challenges, mentoring new members, or contributing time as a volunteer or speaker, you helped strengthen our IS&A community.

I would like to extend special appreciation to our section volunteers, whose dedication behind the scenes makes everything possible. As a non-profit, we rely on your passion and generosity, and we are deeply grateful for your contribution.

To the user of this Reference Guide, thank you for your dedication and for being part of our mission. We welcome your feedback as we continue to improve and evolve this resource.

To the Advertisers of this Reference Guide, accept our sincere appreciation for your participation and unwavering support through out the years, without your participation this guide would have not been possible.

I encourage each of you to stay engaged — attend events, share your experiences, volunteer when you can, and invite others to join us.

Enjoy your new 2026 Reference Guide. Cheers everyone!

Kalpen Vachharajani

ISA Sarnia Section President

Things To Do Today

- ❏ Join ISA
- ❏ Attend Dinner Meeting
- ❏ Join a Techical Committee
- ❏ Attend Conference
- ❏ Bring in New Member
- ❏ Read IN-TECH

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ISA Sarnia Section

Sarnia Section General Member Meetings

Year 2026:
January 26, March 30, May 25 (AGM)
September 28, November 30

Year 2027:
January 25, March 29, May 31 (AGM)
September 27, November 29

Executive Meetings

Year 2026:
February 23, April 27, June 29, August 31, October 26, December 6

Year 2027:
February 22, April 26, June 28, August 30, October 25, December 6

Confirm place and times on our website at isasarnia.com

ISA Sarnia Section Executive Group

To find or contact any of your ISA Sarnia Executive, visit our website at **www.isasarnia.com** and look for the Executive Group, or scan the QR code.

Past Presidents

1945/46 - ISA officially was born as the Instrument Society of America on April 28 1945, in Pittsburgh, Pennsylvania, USA

1946/47 - Albert F. Sperry, chairman of Panelit Corporation, became ISA's first president in 1946. Sarnia Section not yet chartered.

1947/48 - C.G. Elder (Sarnia Section received charter September 1, 1947)

1948/49	W.J. Graeb
1949/50	Ken Goldring
1950/51	Amby Upfold
1951/52	Ken Goldring
1952/53	Amby Upfold
1953/54	Warren McKay
1954/55	Jack Heatley
1955/56	Larry Hall
1956/57	Harold Kohlmeier
1957/58	Ron Asselstine
1958/59	Mike Hicks
1959/60	Mike Hicks
1960/61	Mike Hicks
1961/62	George Mills
1962/63	Robert Brayne
1963/64	Robert Newman
1964/65	Robert Newman
1965/66	Ted Stock
1966/67	Ted Stock
1967/68	Bill Rion
1968/69	Bud Dodds
1969/70	Ray Wechselberger
1970/71	Bill Glendon
1971/72	Curt McDonald
1972/73	Everett Maness
1973/74	Stan Thrift
1974/75	Bernard West
1975/76	E.A. Comello
1976/77	Jim Henrikson
1977/78	Jim Johnson
1978/79	Ron Thurier
1979/80	Dave Braedley
1980/81	John Stassen
1981/82	Wayne Jamieson
1982/83	Frank Bandura
1983/84	John Tranter
1984/85	Robb Sharp
1985/86	Ron Kells
1986/87	Howie Whitton
1987/88	Joe Lobo
1988/89	Irvin Hawkes
1989/90	Rich Paterson
1990/91	Ken Blair
1991/92	Jim Lomax
1992/93	Bob Kelly
1993/94	Bill Arundell
1994/95	Larry Corbett
1995/96	Mike Murray
1996/97	Randy Dennie
1997/98	Andrew Tucker
1998/99	Mike Murray
1999/2000	Mike Murray
2000/2001	Randy Dennie
2001/2002	Randy Dennie
2002/2003	Kalpen Vachharajani
2003/2004	Don Murch
2004/2005	Brian Smith
2005/2006	Don Murch
2006/2007	R. Steven Webster
2007/2008	Brian Davidson
2008/2009	Brian Davidson
2009/2010	Jeff Talbot
2010/2011	Jeff Talbot
2011/2012	Rob Dickson
2012/2013	Rob Dickson
2013/2014	Mike Murray
2014/2015	Mike Murray
2015/2016	Kalpen Vachharajani
2016/2017	Kalpen Vachharajani
2017/2018	Mike Murray
2018/2019	Mike Murray
2019/2020	Mike Murray
2020/2021	Mike Murray
2021/2022	Kalpen Vachharajani
2022/2023	Dave Woodill
2023/2024	Dave Woodill
2024/2025	Ken Armitage

Why should you join ISA?

ISA is Your Organization

Join ISA to engage with peers and subject matter experts around the world, sharing and developing best practices to advance the profession.

We are creating the future of automation, and we need your skills, perspective, and insight to make it happen.

Standards

ISA develops consensus industry standards for automation technologies and applications in key areas such as security, safety, batch control, enterprise integration, wireless communications, traditional instrumentation, measurement, and control.

> ISA members have access to all ISA standards, recommended practices, and technical reports online.

Education and Training

ISA has leading-edge training available on topics that matter most: communications, control systems, cybersecurity, plant maintenance, and safety. Courses are offered online via self-instruction, online instructor-assisted, or at a regional classroom location.

> ISA offers unbiased, vendor-neutral training and education programs where you can develop your skills through in-depth, real-world material. ISA members are eligible for course discounts.

Geographic Sections

ISA Sections engage in the community to provide information, resources, and scholarships to advance the automation profession. By participating in your local section, you will have opportunities to access resources such as table top exhibits, subject matter experts, networking and leadership opportunities, and local employment opportunities.

> Network with professionals in your local area through geographic sections.

Technical Divisions

ISA Technical Divisions exchange information in newsletters with timely technical articles and news, and through exclusive division online communities.

> Divisions align members around specific technical areas of interest and expertise across a wide-range of automation disciplines.

- Analysis Division
- Automatic Controls and Robotics Division
- Automation Project Management and Delivery Division
- Building Automation Systems Division
- Chemical and Petroleum Division
- Communications Division
- Construction and Design Division
- Education Division
- Food and Pharmaceutical Division
- Mining and Metals Division
- Power Industry Division
- Process Measurement and Control Division
- Pulp and Paper Division
- Safety and Security Division
- Smart Manufacturing and IIoT Division
- Test Measurement Division
- Water and Wastewater Division

Conferences and Events

ISA organizes many events around the world. By attending an event, you will have the opportunity to exchange ideas, engage with ISA leaders in policy-setting and strategizing during the annual leadership conference, and discover new technologies alongside some of the brightest minds in the automation industry. Review ISA's calendar for worldwide events.

> ISA hosts topic-focused and industry-specific, face-to-face events in dozens of countries throughout the year. Members can hear expert speakers and panel discussions at a discounted rate.

Publishing

Written and reviewed by experts, ISA Publications help keep automation professionals fully informed about the latest technical developments, applications, trends, and standards. Technical topics include safety, cybersecurity, instrumentation, process control, wireless technology, and many others.

> Through ISA's publications, members have access to thousands of articles and technical papers at no charge.

Certification

ISA Certification provides an objective, third-party assessment and confirmation of a person's skills, and gives them the opportunity to stand out from the crowd and be recognized. ISA currently offers two certification programs: Certified Automation Professional® (CAP®) and Certified Control Systems Technician® (CCST®).

> ISA members can apply to take ISA's Certified Control Systems Technician® (CCST®) and Certified Automation Professional® (CAP®) exams at a discount.

ISA Connect

ISA Connect is an online community to engage in technical conversations and share best practices.

> The ISA Connect Technical Discussion Forum is exclusively for members.

Members will have the ability to network and communicate with other members around the world, contribute and subscribe to technical discussions, share and access resources in the technical library, and discover opportunities to get involved in ISA.

Membership benefits at-a-glance

Member Programs

- Local section
- Technical divisions
- Automation Career Center
- Leadership opportunities
- Member Directory
- Use of ISA member logo
- ISA Connect Technical Discussion Forum
- Expert Directory

Standards and Publications

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- *InTech* magazine
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Education and Certification

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PRODUCT CATEGORY/ SUPPLIER CROSS REFERENCE

IMPORTANT NOTICE

The ISA Sarnia Section Reference Guide has been carefully compiled. Every precaution was taken to prevent errors or omissions to ensure maximum accuracy. ISA cannot guarantee the correctness of the information provided to them, and therefore shall not be liable for damages resulting from errors or omissions in this directory. We apologize for any errors made. If the information provided on your company has changed please contact us so that the changes will be made for next years Reference Guide. Your assistance is greatly appreciated.

Publications Committee

PRODUCT CATEGORY/SUPPLIER

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Thank You!

Thank you from all of us at ISA Sarnia Section for your continued support over the last 28 years. We sincerely hope that you find your Reference Guide of benefit. Be sure to view the electronic version of this publication at **www.isasarnia.com.**

We encourage you to let the executive know what you think of our efforts or if there is anything that you wish to see done differently.

Best regards,
ISA Sarnia Section Executive

ISA Membership Benefits

Programs

Discover how members connect and share through technical forums, leadership opportunities and more.

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- Geographic Sections
- Technical Divisions
- Career Center

Standards

As an ISA member, access over 150 standards that reflect the expertise of industry leaders from around the world!

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- Join a committee

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Members get the latest information on technology development, applications, trends, and standards within the automation industry through ISA publications and technical resources.

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- Industry magazine subscription

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- ISA Mentor
- Event registration discount
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For more information or to join, visit www.isa.org/join

60-0724

TECHNICAL SECTION

This technical section has been prepared by the
ISA Sarnia Section for exclusive use by ISA Sarnia Section.

Temperature Sensor Comparisons

Thermocouples - Pros & Cons

Advantages
- Inexpensive
- Fast responding
- Rugged
- Tip sensitive
- Self-powered
- Range of -200 to 2300 °C
- Small diameters 0.010”(0.25 mm)
- Multi-point sensing

Disadvantages
- Non-linear
- Least stable
- Sensitivity is low
- Low voltage output
- Requires special extension wire
- Reference required
- Accuracy degrades over time

RTD – Pros & Cons

Advantages
- Linear output
- Long term stability
- Long term stability
- Special extension wire not required
- More accurate than a thermocouple
- Repeatable

Disadvantages
- Limited range of -200 to 850 °C
- Slow response
- Current source required
- Self-heating error
- More expensive than a thermocouple
- Less rugged than a thermocouple

RTD vs. Thermocouple

RTD Advantages
- Higher Accuracy
- Higher Stability
- Does not Require Cold Junction Compensation
- Better Linearity

T/C Advantages
- Rugged
- Small Size
- Fast Response
- Wide Range
- Self powered

Table of Contents

Sarnia Information

Latitude	Approximately 43.00 N
Longitude	Approximately 82.30 W
Elevation	Approximately 181m
Minimum Recorded Temperature	-28.7 C
Maximum Recorded Temperature	40 C
Jan 2.5% Design Temperature	-16.0 C
Jan 1% Design Temperature	-18.0 C
July 2.5% Design Dry Bulb Temperature	32.2 C
July 2.5% Design Wet Bulb Temperature	23.0 C
Annual Average Temperature	8.2 C
Annual Total Degree Days Below 18 C	3800
Atmospheric Pressure Average	99.44 Pa
Maximum 24 Hour Rainfall	98.0 mm
Annual Total Precipitation	890.0 mm
10 Year Storm 15 min	23.0 mm
10 Year Storm 1 hour	36.9 mm
100 Year Storm 15 min	41.8 mm
100 Year Storm 1 hour	52.3 mm
Ground Snow Load	1.0 Kpa
Hourly Wind Pressure - 1/10	0.35 Kpa
Hourly Wind Pressure - 1/30	0.43 Kpa
Hourly Wind Pressure - 1/100	0.52 Kpa
Prevailing Wind Direction	SW
Frost Penetration	1.2 m
Seismic Design Parameter Za	0
Seismic Design Parameter Zv	0
Seismic Design Parameter V	0

Properties of Selected Gases

Gas	Chemical Formula	Molecular Weight	Density ① lb/ft³	Specific ② Gravity	Individual Gas Constant R	Ratio of Specific Heat $K = C_p/C_v$
Acetylene	C_2H_2	26.0382	.06858	0.897	59.348	1.28
Air	—	28.9644	.07649	1.000	53.352	1.40
Ammonia	NH_3	17.0306	.04488	0.587	90.738	1.29
Argon	A	39.9480	.10553	1.379	38.683	1.67
Butane-N	C_4H_{10}	58.1243	.15873	2.075	26.586	1.09
Butane-ISO	C_4H_{10}	58.1243	.15814	2.067	26.586	1.10
Carbon Dioxide	CO_2	44.0100	.11684	1.528	35.113	1.28
Carbon Monoxide	CO	28.0106	.07397	0.967	55.169	1.41
Chlorine	CL_2	70.9060	.19046 0°C	2.490 0°C	21.794	1.36
Ethane	C_2H_6	30.0701	.08005	1.047	51.391	1.19
Ethylene	C_2H_4	28.0542	.07392	0.967	55.083	1.22
Helium	He	4.00260	.01056	0.138	386.07	1.66
Heptane, Average	C_7H_{16}	100.2060	.26451	3.458	15.421	—
Hextane, Average	C_6H_{14}	86.1785	.22748	2.974	17.932	1.08
Hydrochloric Acid	HCL	36.4610	.09606	1.256	42.383	1.40
Hydrogen	H_2	2.01594	.00532	0.070	766.55	1.40
Hydrogen Sulfide	H_2S	34.0799	.09024	1.177	45.344	1.32
Methane	CH_4	16.0430	.04243	0.555	96.324	1.31
Methyl Chloride	CH_3CL	50.4881	.13292	1.738	30.606	1.20
Neon	Ne	20.1830	.05155	0.674	76.565	1.64
Nitric Oxide	NO	30.0061	.07908	1.034	51.500	1.40
Nitrogen	N_2	28.0130	.07397	0.967	55.164	1.40
Nitrous Oxide	N_2O	44.0128	.11606	1.518	35.111	1.26
Octane, Average	C_8H_{18}	114.2330	.30153	3.942	13.528	—
Oxygen	O_2	31.9988	.08453	1.105	48.293	1.40
Pentane, ISO	C_5H_{12}	72.1514	.19045	2.490	21.418	1.06
Propane	C_3H_8	44.0972	.11854	1.550	35.044	1.33
Propylene	C_3H_6	42.081	.04842 −47°C	0.634 −47°C	36.722	1.14
Sulphur Dioxide	SO_2	64.0630	.16886	2.208	24.122	1.25

① Density is given for gas at 14.73 psia and 60°F unless noted.

② Specific gravity used air at 14.73 and 60°F as base conditions.

Air Density

Temperature		Air Density 1bm/FT³											
°F	°C	14.73 PSIA	100 PSIA	200 PSIA	300 PSIA	400 PSIA	500 PSIA	600 PSIA	700 PSIA	800 PSIA	900 PSIA	1000 PSIA	1100 PSIA
−40	−40	0.0949	0.6488	1.3087	1.9796	2.661	3.3525	4.0533	4.7628	5.4768	6.2031	6.9315	7.6632
−20	−29	0.0905	0.6182	1.245	1.8799	2.5227	3.1728	3.8295	4.492	5.1594	5.8308	6.5051	7.1811
0	−17.8	0.0866	0.5905	1.1875	1.7906	2.3995	3.0135	3.6321	4.2547	4.8805	5.5086	6.1382	6.7684
20	− 6.7	0.0830	0.5652	1.1353	1.71	2.2887	2.8711	3.4567	4.0447	4.6347	5.2258	5.8175	6.409
40	4.4	0.0797	0.5421	1.0878	1.6368	2.1886	2.7429	3.2992	3.857	4.4157	4.9748	5.5338	6.092
60	15.6	0.0765	0.5208	1.0442	1.5699	2.0974	2.6266	3.1569	3.6879	4.2191	4.7502	5.2805	5.8098
80	26.7	0.0737	0.5012	1.0041	1.5085	2.0141	2.5205	3.0275	3.5347	4.0416	4.5478	5.0529	5.5567
100	37.8	0.0711	0.4829	0.9670	1.4519	1.9375	2.4234	2.9093	3.3949	3.8798	4.3637	4.8464	5.3274
120	49	0.0687	0.4660	0.9327	1.3997	1.8668	2.3339	2.8006	3.2666	3.7316	4.1954	4.6577	5.1184
140	60	0.0664	0.4503	0.9007	1.3511	1.8013	2.2511	2.7001	3.1482	3.5951	4.0406	4.4845	4.9265
160	71	0.0641	0.4356	0.871	1.3061	1.7406	2.1744	2.6073	3.0391	3.4695	3.8985	4.3257	4.7509
180	82	0.0621	0.4218	0.8432	1.264	1.684	2.103	2.521	2.938	3.3529	3.7665	4.1783	4.5882
200	93	0.0602	0.4089	0.8171	1.2246	1.6311	2.0364	2.4405	2.8432	3.2444	3.6439	4.0417	4.4375
220	104	0.0585	0.3967	0.7927	1.1877	1.5815	1.9741	2.3654	2.7551	3.1432	3.5296	3.9144	4.2972
240	116	0.0568	0.3853	0.7697	1.1529	1.5349	1.9156	2.2948	2.6725	3.0485	3.4228	3.7953	4.1658
260	127	0.0552	0.3745	0.7480	1.1202	1.4911	1.8606	2.2288	2.5956	2.9608	3.3239	3.6846	4.0424
280	138	0.0537	0.3644	0.7275	1.0893	1.4497	1.8088	2.1666	2.5231	2.8779	3.2306	3.5803	3.9264
300	149	0.0523	0.3547	0.7081	1.0601	1.4107	1.7599	2.1078	2.4546	2.7997	3.1424	3.4819	3.8174
320	160	0.0510	0.3456	0.6898	1.0325	1.3737	1.7136	2.0523	2.3897	2.7256	3.059	3.389	3.7147
340	171	0.0497	0.3369	0.6724	1.0063	1.3388	1.6698	1.9997	2.3283	2.6553	2.98	3.3013	3.6184

Vapor Pressure of Water

VAPOR PRESSURE OF WATER (psia)					
°F	psia	°F	psia	°F	psia
32	.088	100	.950	160	4.741
40	.122	105	1.102	165	5.335
45	.148	110	1.275	170	5.992
50	.178	115	1.470	175	6.715
55	.214	120	1.693	180	7.510
60	.256	125	1.942	185	8.383
65	.306	130	2.223	190	9.339
70	.363	135	2.537	195	10.385
75	.430	140	2.889	200	11.526
80	.507	145	3.281	205	12.769
85	.596	150	3.718	210	14.123
90	.698	155	4.203	212	14.696
95	.815				

Critical Pressures of Some Common Liquids

Liquid	psia	Bar Absolute	Liquid	psia	Bar Absolute
Acetic Acid	840	58.0	Hexane	433	29.9
Acetic Anhydride	676	46.6	Hydrogen	188	13.0
Acetone	691	47.6	Hydrogen Sulphide	1308	90.1
Acetylene	911	62.9	Isopropyl Alcohol	779	53.8
Air	547	37.7	Methane	673	46.4
Ammonia	1638	113.0	Methyl Alcohol	1156	79.8
Benzene	701	48.3	Methyl Chloride	967	66.7
Bromine	1485	102.3	Nitrogen	492	33.9
Butadiene	627	43.3	Octane	362	25.0
Butane	529	36.5	Oxygen	730	50.4
Butyl Alcohol	711	49.0	Pentane	485	33.5
Carbon Dioxide	1072	74.0	Phenol	889	61.3
Carbon Tetrachloride	661	45.6	Propane	617	42.6
Dowtherm A	465	32.1	Propylene	661	45.6
Dowtherm E	465	32.1	Propyl Alcohol	735	50.7
Ethane	717	49.5	Propyl Chloride	664	45.8
Ethyl Alcohol	927	64.0	Pyridine	882	60.8
Ethyl Chloride	2750	190.0	Pyridine Pure	882	60.8
Ethylene	742	51.2	Toluene	611	42.1
Heptane	394	27.2	Water	3206	221.0

Physical Constants of Various Fluids

Fluid	Formula	Molecular Weight	Boiling Point at 14.696 psia °F	Specific Gravity	
				Liquid (Water=1.00)	Gas (Air=1.00)
Acetic Acid	$HC_2H_3O_2$	60.05	245	1.05	
Acetone	C_3H_6O	58.08	133	0.79	2.01
Acetylene	C_2H_2	26.03	-119	0.62	0.90
Air	N_2O_2	28.97	-317	0.86	1.00
Alcohol, Ethyl	C_2H_6O	46.07	173	0.789	1.59
Alcohol, Methyl	CH_4O	32.04	148	0.791	1.11
Ammonia	NH_3	17.03	-28	0.62	0.59
Ammonium Chloride*	NH_4Cl			1.07	
Ammonium Hydroxide*	NH_3OH			0.91	
Ammonium Sulfate*	$(NH_4)_2SO_4$			1.15	
Aniline	C_6H_7N	93.12	365	1.02	
Argon	A	39.94	-302	1.65	1.38
Benzene	C_6H_6	78.08	176	0.88	2.70
Bromine	Br_2	159.84	138	2.93	5.52
Butane	C_4H_{10}	58.10	31	0.58	2.07
Calcium Carbonate*	$CaCO_3$			1.48	
Calcium Chloride*	$CaCl_2$			1.23	
Calcium Hydroxide*	$Ca(OH)_2$			1.31	
Carbon Dioxide	CO_2	44.01	-109		1.52
Carbon Disulfide	CS_2	76.10	115	1.29	2.63
Carbon Monoxide	CO	28.01	-314	0.80	0.97
Carbon Tetrachloride	CCl_4	153.84	170	1.59	5.31
Chlorine	Cl_2	70.91	-30	1.42	2.45
Chromic Acid	H_2CrO_4	118.03		1.21	
Citric Acid	$C_6H_8O_7$	192.12		1.54	
Copper Sulfate*	$CuSO_4$			1.17	
Cyclohexane	C_6H_{12}	84.13	177	0.78	2.91
Cyclopentane	C_5H_{10}	70.10	121	0.75	2.42
Diethylamine	$(C_2H_5)_2NH$	73.12	133	0.71	
Ethane	C_2H_6	30.05	-128	0.57	1.05
Ethyl Chloride	C_2H_5Cl	64.50	55	0.90	2.22
Ethylene	C_2H_4	28.04	-155		0.97
Ferric Chloride*	$FeCl_3$			1.23	
Flourine	F_2	38.00	-305	1.11	1.31
Formaldehyde	H_2CO	30.03	-6	0.82	1.08
Formic Acid	HCO_2H	46.03	214	1.23	
Freon	CCl_2F_2	120.90	-18	1.35	4.17
Furfural	$C_5H_4O_2$	96.08	324	1.16	
Gasoline	C_6H_{14}	86.20	145		
Glycerine	$C_3H_8O_3$	92.09	554	1.26	
Glycol	$C_2H_6O_2$	62.07	387	1.11	
Helium	He	4.003	-454	0.18	0.14
Heptane	C_7H_{16}	100.20	209	0.69	3.46
Hexane	C_6H_{14}	86.14	156	0.66	2.98
Hydrochloric Acid	HCl	36.47	-115	1.64	
Hydrofluoric Acid	HF	20.01	66	0.92	
Hydrogen	H_2	2.016	-422	0.07	0.07
Hydrogen Chloride	HCl	36.47	-115		1.26
Hydrogen Peroxide	H_2O_2	34.016	185	1.44	
Hydrogen Sulfide	H_2S	34.07	-76	0.79	1.17

Physical Constants of Various Fluids (Continued)

Fluid	Formula	Molecular Weight	Boiling Point at 14.696 psia °F	Specific Gravity Liquid (Water=1.00)	Specific Gravity Gas (Air=1.00)
Isopropyl Alcohol	C_3H_8O	60.09	180	0.78	2.08
Kerosene	C_9H_20	128.30	278	0.75	
Magnesium Chloride*	$MgCl_2$			1.22	
Magnesium Hydroxide*	$Mg(OH)_2$			1.34	
Mercury	Hg	200.61	670	13.60	6.93
Methane	CH_4	16.04	-259	0.43	0.56
Methyl Bromide	CH_3Br	94.95	38	1.73	3.27
Methyl Chloride	CH_3Cl	50.49	-11	0.99	1.74
Methyl Ethyl Ketone	$CH_3CH_2COCH_3$	72.10	176	0.81	
Naphthalene	$C_{10}H_8$	128.16	424	1.14	4.43
Nitric Acid	HNO_3	63.02	187	1.50	
Nitrobenzene	$C_6H_5NO_2$	123.08	410	1.20	
Nitrogen	N_2	28.02	-320	0.81	0.97
Nitrous Oxide	N_2O	44.10	-126	1.98	1.52
Octane	C_8H_{18}	114.20	258	0.71	3.94
Oxygen	O_2	32.00	-297	1.14	1.105
Pentane	C_5H_{12}	72.12	97	0.63	2.49
Phenol	C_6H_5OH	94.10	358	1.07	
Phosphoric Acid	H_3PO_4	98.00	415	1.83	
Potassium Chloride*	KCl			1.16	
Potassium Hydroxide*	KOH			1.24	
Propane	C_3H_8	44.10	-44	0.59	1.55
Sodium Carbonate*	Na_2CO_3			1.38	
Sodium Chloride*	NaCl			1.19	
Sodium Hydroxide*	NaOH			1.27	
Sodium Sulfate*	Na_2SO_4			1.24	
Sodium Thiosulfate*	$Na_2S_2O_3$			1.23	
Starch	$(C_6H_{10}O_5)x$			1.50	
Styrene	C_8H_8	104.10	293	0.91	3.60
Sugar Solutions*	$C_{12}H_{22}O_{11}$			1.10	
Sulfur Dioxide	SO_2	64.60	14	1.39	2.21
Sulfuric Acid	H_2SO_4	98.08	626	1.83	
Tetraethyl Lead	$Pb(C_2H_5)_4$	323.40	195	1.66	
Toluene	C_7H_8	92.10	231	0.87	3.18
Trichloroethylene	$CHCl:CCl_2$	131.40	188	1.46	
Water	H_2O	18.016	212	1.00	0.62
Zinc Chloride*	$ZnCl_2$			1.24	
Zinc Sulfate	$ZnSO_4$			1.31	

* Aqueous solution - 25% by weight of compound

Properties of Saturated Water

Temperature °F	Temperature °C	Density lbm/FT³	Specific Gravity G_f	Viscosity Centipoise
32	0.0	62.4140	1.0007	1.75
33	0.6	62.4167	1.0007	1.72
34	1.1	62.4191	1.0008	1.69
35	1.7	62.4212	1.0008	1.66
36	2.2	62.4229	1.0008	1.63
37	2.8	62.4242	1.0009	1.61
38	3.3	62.4252	1.0009	1.58
39	3.9	62.4258	1.0009	1.55
40	4.4	62.4261	1.0009	1.53
41	5.0	62.4261	1.0009	1.50
42	5.6	62.4257	1.0009	1.48
43	6.1	62.4251	1.0009	1.45
44	6.7	62.4241	1.0009	1.43
45	7.2	62.4229	1.0008	1.41
46	7.8	62.4213	1.0008	1.38
47	8.3	62.4194	1.0008	1.36
48	8.9	62.4173	1.0007	1.34
49	9.4	62.4149	1.0007	1.32
50	10.0	62.4122	1.0007	1.30
51	10.6	62.4092	1.0006	1.28
52	11.1	62.4059	1.0006	1.26
53	11.7	62.4024	1.0005	1.24
54	12.2	62.3986	1.0004	1.22
55	12.8	62.3946	1.0004	1.20
56	13.3	62.3903	1.0003	1.19
57	13.9	62.3858	1.0002	1.17
58	14.4	62.3810	1.0002	1.15
59	15.0	62.3760	1.0001	1.14
60	15.6	62.3707	1.0000	1.12
61	16.1	62.3652	.9999	1.10
62	16.7	62.3595	.9998	1.09
63	17.2	62.3535	.9997	1.07
64	17.8	62.3474	.9996	1.06
65	18.3	62.3410	.9995	1.04
66	18.9	62.3344	.9994	1.03
67	19.4	62.3275	.9993	1.02
68	20.0	62.3205	.9992	1.00
69	20.6	62.3132	.9991	.988
70	21.1	62.3058	.9990	.975
71	21.7	62.2981	.9988	.962
72	22.2	62.2902	.9987	.950
73	22.8	62.2822	.9986	.937
74	23.3	62.2739	.9984	.925
75	23.9	62.2654	.9983	.913
76	24.4	62.2568	.9982	.902
77	25.0	62.2479	.9980	.890
78	25.6	62.2389	.9979	.879
79	26.1	62.2297	.9977	.868
80	26.7	62.2203	.9976	.857
81	27.2	62.2107	.9974	.847
82	27.8	62.2009	.9973	.837
83	28.3	62.1910	.9971	.826
84	28.9	62.1809	.9970	.816
85	29.4	62.1706	.9968	.807
90	32.2	62.1166	.9959	.761
95	35.0	62.0585	.9950	.718
100	37.8	61.9964	.9940	.680
105		61.9307	.9929	.645
110	43.0	61.8612	.9918	.612
115		61.7884	.9907	.582
120	49.0	61.7121	.9894	.555
125		61.6326	.9882	.529
130	54.0	61.5500	.9868	.505
135		61.4643	.9855	.483
140	60.0	61.3757	.9840	.463
145		61.2842	.9826	.444
150	66.0	61.1899	.9811	.426
155		61.0928	.9795	.410
160	71.0	60.9932	.9779	.394

Temperature °F	Temperature °C	Density lbm/FT³	Specific Gravity G_f	Viscosity Centipoise
165		60.8909	.9763	.380
170	77	60.7862	.9746	.366
175		60.6789	.9729	.353
180	82	60.5693	.9717	.341
185		60.4573	.9693	.330
190	88	60.3430	.9675	.319
195		60.2265	.9656	.309
200	93	60.1076	.9637	.300
205		59.9866	.9618	.291
210	99	59.8635	.9598	.282
215		59.7382	.9578	.274
220	104	59.6108	.9558	.267
225		59.4813	.9537	.259
230	110	59.3497	.9516	.252
235		59.2161	.9494	.246
240	116	59.0804	.9472	.239
245		58.9428	.9450	.233
250	121	58.8031	.9428	.228
255		58.6614	.9405	.222
260	127	58.5177	.9382	.217
265		58.3720	.9359	.212
270	132	58.2244	.9335	.207
275		58.0747	.9311	.203
280	138	57.9231	.9287	.198
285		57.7695	.9262	.194
290	143	57.6139	.9237	.190
295		57.4563	.9212	.186
300	149	57.2966	.9186	.183
305		57.1350	.9161	.179
310	154	56.9713	.9134	.176
315		56.8056	.9108	.172
320	160	56.6378	.9081	.169
325		56.4680	.9054	.166
330	166	56.2960	.9026	.163
335		56.1220	.8998	.160
340	171	55.9458	.8970	.157
345		55.7674	.8941	.155
350	177	55.5859	.8912	.152
355		55.4042	.8883	.150
360	182	55.2192	.8853	.147
365		55.0320	.8823	.145
370	188	54.8424	.8793	.143
375		54.6506	.8762	.141
380	193	54.4563	.8731	.139
385		54.2597	.8700	.137
390	199	54.0606	.8668	.135
395		53.8590	.8635	.133
400	204	53.6548	.8603	.131
405		53.4481	.8569	.129
410	210	53.2387	.8536	.127
415		53.0267	.8502	.126
420	216	52.8119	.8467	.124
425		52.5942	.8433	.122
430	221	52.3737	.8397	.121
435		52.1503	.8361	.119
440	227	51.9238	.8325	.118
445		51.6942	.8288	.116
450	232	51.4615	.8251	.115
455		51.2255	.8213	.114
460	238	50.9862	.8175	.112
465		50.7434	.8136	.111
470	243	50.4971	.8096	.110
475		50.2472	.8056	.109
480	249	49.9935	.8016	.108
485		49.7359	.7974	.106
490	254	49.4744	.7932	.105
495		49.2087	.7890	.104

Viscosity of Gases (mPa.s) From 0 to 400°C

Substance	Temperature, °C								
	0	50	100	150	200	250	300	350	400
Air	0.0171	0.0195	0.0217	0.0238	0.0258	0.0278	0.0297	0.0317	0.0337
Oxygen	0.0189	0.0216	0.0242	0.0266	0.0289	0.0310	0.0330	0.0349	0.0369
Nitrogen	0.0166	0.0188	0.0208	0.0227	0.0245	0.0263	0.0280	0.0296	0.0309
Hydrogen	0.0084	0.0094	0.0103	0.0112	0.0121	0.0130	0.0138	0.0146	0.0153
Methane	0.0103	0.0118	0.0133	0.0147	0.0160	0.0172	0.0184	0.0195	0.0207
Ethane	0.0085	0.0100	0.0114	0.0128	0.0141	0.0154	0.0167	0.0180	0.0193
Propane	0.0074	0.0088	0.0101	0.0113	0.0125	0.0137	0.0149	0.0161	0.0173
Carbon Monoxide	0.0166	0.0189	0.0208	0.0226	0.0245	0.0265	0.0286	0.0306	0.0321
Carbon Dioxide	0.0139	0.0164	0.0187	0.0209	0.0229	0.0248	0.0267	0.0285	0.0302
Chlorine	0.0123	0.0147	0.0168	0.0189	0.0209	0.0230	0.0251	0.0272	0.0293
Hydrogen Sulphide	0.0117	0.0138	0.0159	0.0179	0.0200	0.0221	0.0243	0.0265	0.0287
Sulphur Dioxide	0.0116	0.0139	0.0161	0.0182	0.0204	0.0226	0.0248	0.0268	0.0285
Ammonia	0.0092	0.0109	0.0128	0.0146	0.0165	0.0181	0.0199	0.0216	0.0233

Viscosity of Water and Steam

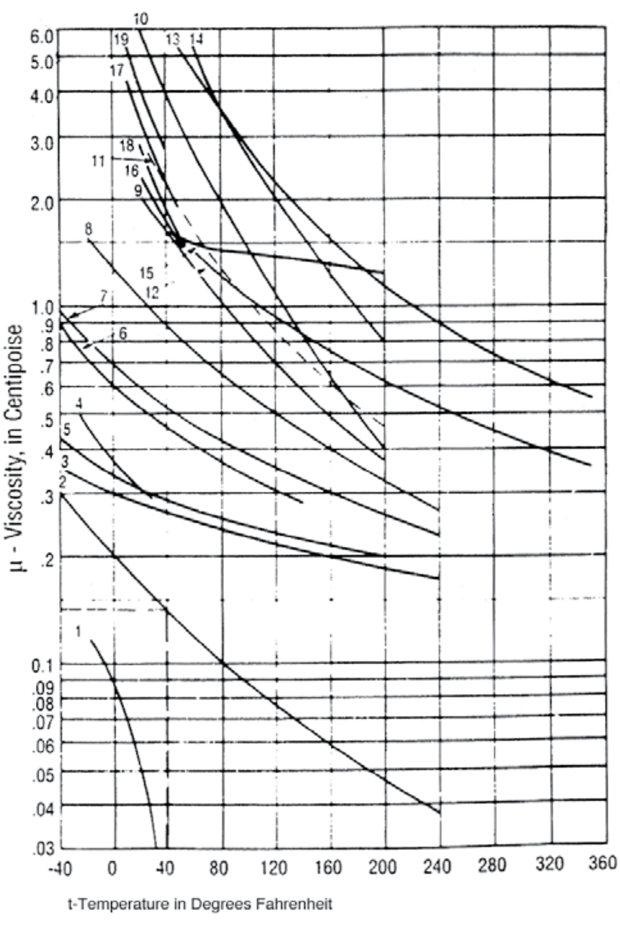
Temperature °F (°C)	Viscosity of Water and Steam—In Centipoise (μ) 1 psia	2 psia	5 psia	10 psia	20 psia	50 psia	100 psia	200 psia	500 psia	1000 psia
Saturated Water	.667	.524	.388	.313	.255	.197	.164	.138	.111	.094
Saturated Steam	.010	.010	.011	.012	.012	.013	.014	.015	.017	.019
1000 (538)	.030	.030	.030	.030	.030	.030	.030	.030	.030	.031
950 (510)	.029	.029	.029	.029	.029	.029	.029	.029	.029	.030
900 (482)	.028	.028	.028	.028	.028	.028	.028	.028	.028	.028
850 (454)	.026	.026	.026	.026	.026	.026	.027	.027	.027	.027
800 (427)	.025	.025	.025	.025	.025	.025	.025	.025	.026	.026
750 (399)	.024	.024	.024	.024	.024	.024	.024	.024	.025	.025
700 (371)	.023	.023	.023	.023	.023	.023	.023	.023	.023	.024
650 (343)	.022	.022	.022	.022	.022	.022	.022	.022	.023	.023
600 (316)	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021
550 (288)	.020	.020	.020	.020	.020	.020	.020	.020	.020	.019
500 (260)	.019	.019	.019	.019	.019	.019	.019	.018	.018	.103
450 (232)	.018	.018	.018	.018	.017	.017	.017	.017	.115	.116
400 (204)	.016	.016	.016	.016	.016	.016	.016	.016	.131	.132
350 (177)	.015	.015	.015	.015	.015	.015	.015	.152	.153	.154
300 (149)	.014	.014	.014	.014	.014	.014	.182	.183	.183	.184
250 (121)	.013	.013	.013	.013	.013	.228	.228	.228	.228	.229
200 (93)	.012	.012	.012	.012	.300	.300	.300	.300	.300	.301
150 (66)	.011	.011	.427	.427	.427	.427	.427	.427	.427	.428
100 (37.8)	.680	.680	.680	.680	.680	.680	.680	.680	.680	.680
50 (10)	1.299	1.299	1.299	1.299	1.299	1.299	1.299	1.299	1.299	1.298
32 (0)	1.753	1.753	1.753	1.753	1.753	1.753	1.753	1.752	1.751	1.749

Values below the line are for water.

Viscosity of Various Liquids

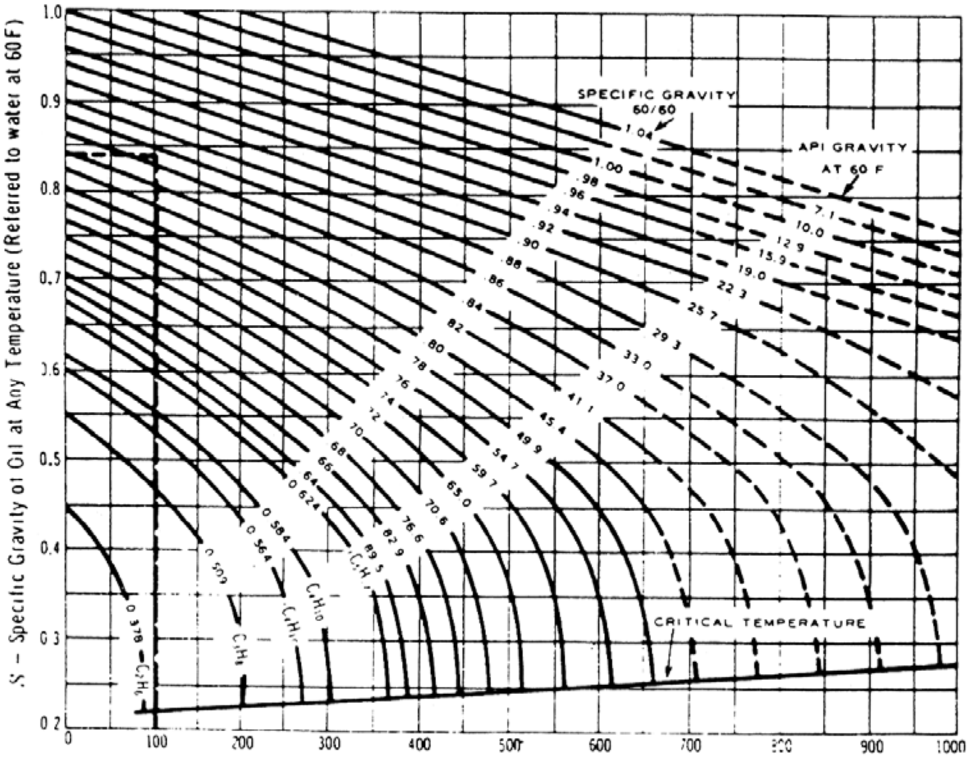
1. Carbon Dioxide .... CO_2
2. Ammonia .... NH_3
3. Methyl Chloride .... CH_3Cl
4. Sulphur Dioxide .... SO_2
5. Freon 12 .... F-12
6. Freon 114 .... F-114
7. Freon 11 .... F-11
8. Freon 113 .... F-113
9. Ethyl Alcohol
10. Isopropyl Alcohol
11. 20% Sulphuric Acid .... 20% H_2SO_4
12. Dowtherm E
13. Dowtherm A
14. 20% Sodium Hydroxide .... 20% NaOH
15. Mercury
16. 10% Sodium Chloride Brine .... 10% NaCl
17. 20% Sodium Chloride Brine .... 20% NaCl
18. 10% Calcium Chloride Brine .... 10% $CaCl_2$
19. 20% Calcium Chloride Brine .... 20% $CaCl_2$

Example: The viscosity of ammonia at 40°F is 0.14 centipoise.



Specific Gravity—
Temperature Relationship for Petroleum Oils

(Reproduced by permission from the Oil and Gas Journal)



C_2H_6 = Ethane
C_3H_8°Propane
C_4H_{10} = Butane
iC_4H_{10} = Isobutane
iC_5H_{12} = Isopentane

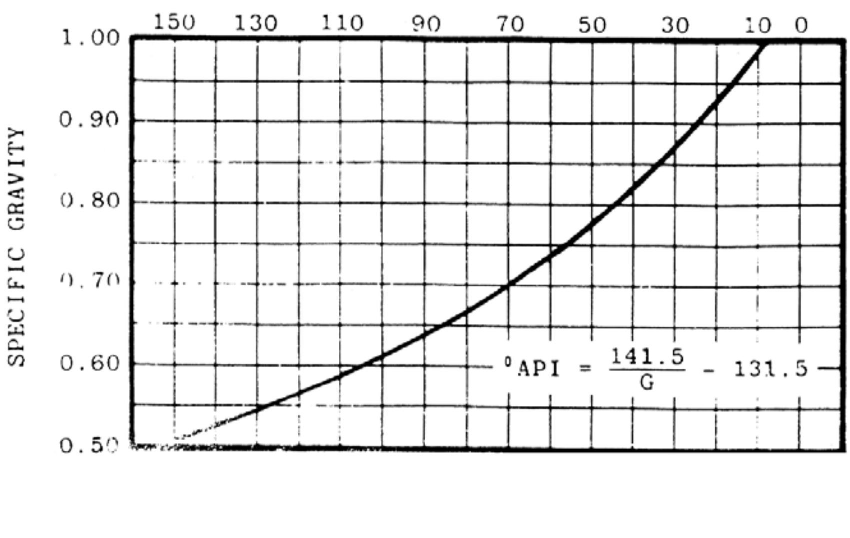
Example: The specific gravity of an oil at 60°F is 0.85. The specific gravity at 100°F = 0.83.

To find the weight density of a petroleum oil at its flowing temperature when the specific gravity at 60°F is known, multiply the specific gravity of the oil at flowing temperature (see chart above) by 62.4, the density of water at 60°F.

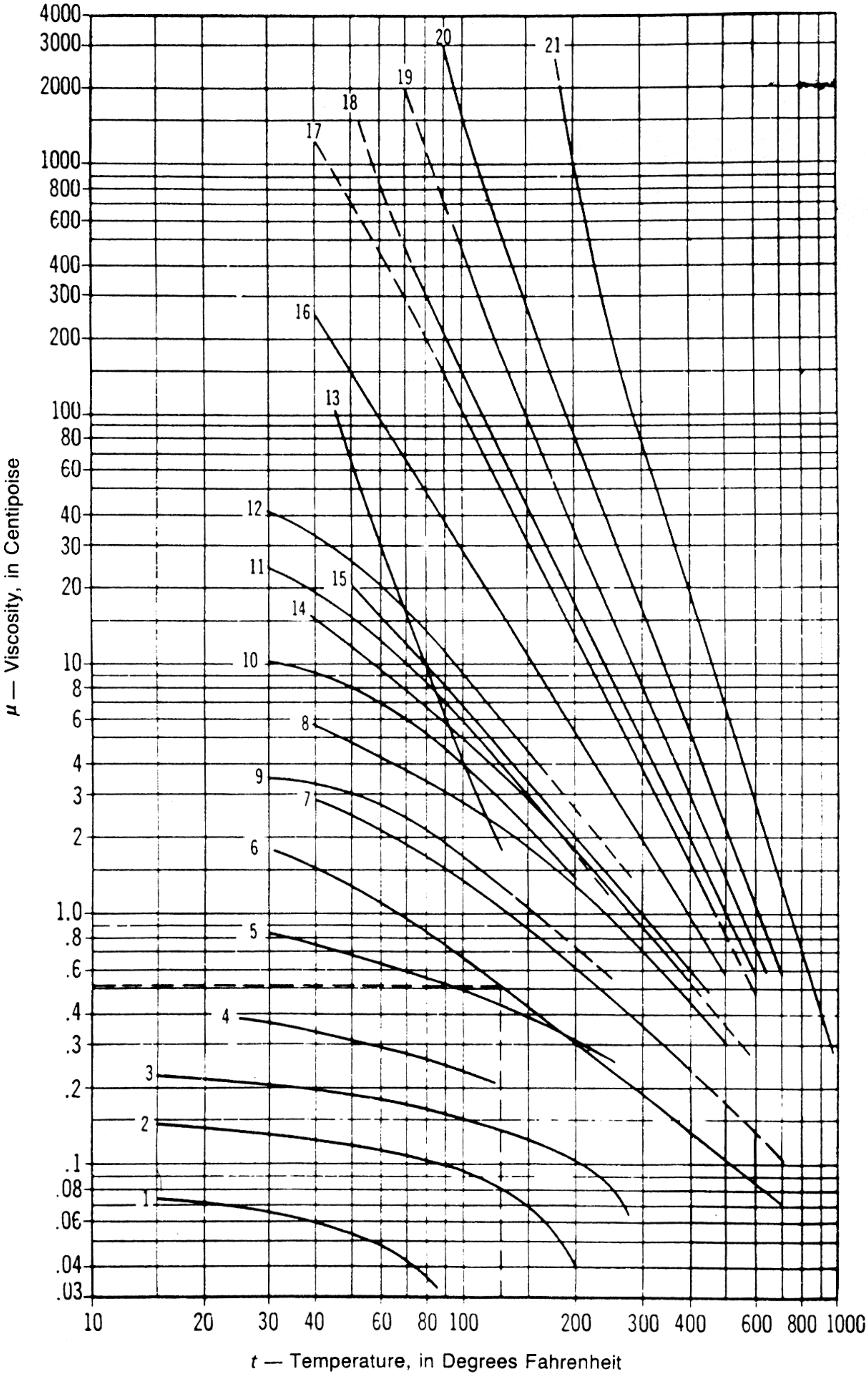
*Reprinted from Crane Company's Technical Paper 410.

Chart for Specific Gravity versus API Gravity

for hydrocarbon based products and water gravity ° A.P.I.



Viscosity of Water and Liquid Petroleum Products



1. Ethane (C_2H_6)
2. Propane (C_3H_8)
3. Butane (C_4H_{10})
4. Natural Gasoline
5. Gasoline
6. Water
7. Kerosene
8. Distillate
9. 48 Deg. API Crude
10. 40 Deg. API Crude
11. 35.6 Deg. API Crude
12. 32.6 Deg. API Crude
13. Salt Creek Crude
14. Fuel 3 (Max.)
15. Fuel 5 (Min.)
16. SAE 10 Lube (100 V.I.
17. SAE 30 Lube (100 V.I.
18. Fuel 5 (Max.) or Fuel 6 (Min.)
19. SAE 70 Lube (100 V.I.
20. Bunker C Fuel (Max.) and M.C. Residuum
21. Asphalt

Example: The viscosity of water at 125°F is 0.52 centipoise (Curve No 6).

Flammable Properties of Common Gases and Vapors

	CSA Class 1 Group	Flash Point C	Auto Ignition Temp C	LEL % by Volume	HEL % by Volume	Vapor Density Air = 1
Acetone	C	-18	465	2.6	12.8	2
Acetylene	A	Gas	305	2.5	100	0.9
Benzene	D	-11	560	1.3	7.1	2.8
Butadiene	B	Gas	420	2	12	1.9
Butane	D	Gas	405	1.9	8.5	2
1-Butene	D	-80	385			2
cis-2-Butene	D	-62	324	1.7	9.7	2
trans-2-Butene	D	-73	324	1.7	9.7	2
iso-Butyl alcohol (2-methyl 1-propropanol)	D	28	427	1.2	10.9	2.6
tert-Butyl alcohol	D	11	480	2.4	8	2.6
Carbon Monoxide	C	Gas	609	12.5	74	0.96
Cresols	D	94	558	1.1		
Cumene	D	44	425	0.9	6.5	4.1
Cyclohexane	D	-20	245	1.3	8	2.9
Ethane	D	Gas	515	3	12.5	1
Ethyl Alcohol (ethanol)	D	13	365	3.3	19	1.6
Ethyl Chloride	D	-50	519	3.8	15.4	2.2
Ethylene	C	Gas	490	2.7	36	1
Ethylene Oxide	B	-20	429	3.6	100	1.5
Gasoline	D	-43	280-471	1.4	7.6	3 - 4
n-Hexane	D	-22	222	1.1	7.5	3
Hydrogen	B	Gas	500	4	75	0.1
Hydrogen Sulphide	C	Gas	260	4	49	1.2
Isoprene	D	-54	220	2	9	2.4
Jet Fuel (JP4)	C	-23	240	1.3	8	
Kerosene (#1 Oil)	D	38	210	0.7	5	
Methane (Natural Gas)	D	Gas	540	5	15	0.6
Methyl Alcohol (methanol)	D	11	385	6.7	36	1.1
Methylamine	D	Gas	430	4.9	27	1
Methylene Chloride	D		615	15.5	66	2.9
Methyl Mercaptan	C			3.9	21.8	1.7
Nonene	D					
Octene	D	21		0.8	6.7	3.9
n-Pentane	D	-40	260	1.5	7.8	2.5
Petroleum Naptha	D	-2	278	0.9	6.7	4.1
Phenol	D	80	715			3.2
Propane	D	Gas	450	2.2	9.5	1.6
Propylene	D	Gas	460	2	11.1	1.5
Styrene	D	32	490	1.1	6.1	3.6
Toluene	D	4	480	1.2	7.1	3.1
Vinyl Chloride	D	Gas	472	3.6	33	2.2
Xylene (mixed)	D	27	465	1	7	3.7

Compressibility Factor Z

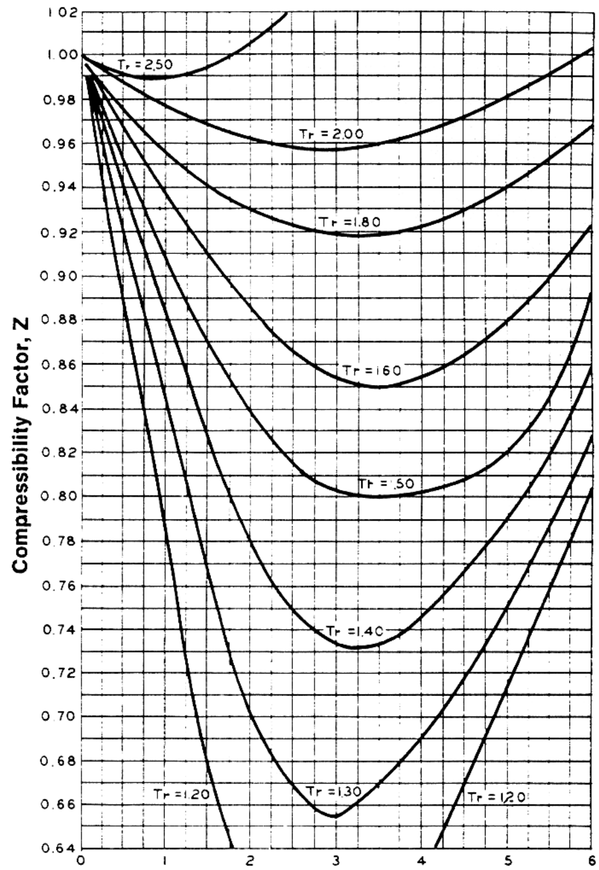
For many real gases subjected to commonly encountered temperatures and pressures, the perfect gas laws are not satisfactory for flow measurement accuracy and therefore correction factors must be used.

Following conventional flow measurement practice, the compressibility factor Z, in the equation $p_v = ZRT$, will be used. Z can usually be ignored below 100 psi for common gases.

The value of Z does not differ materially for different gases when correlated as a function of the reduced temperature, T_r, and reduced pressure, p_r, found from Figures 2 and 3.

Figure 2 is an enlargement of a portion of Figure 3. Values taken from these figures are accurate to approximately plus or minus two percent.

To obtain the value of Z for a pure substance, the reduced pressure and reduced temperature are calculated as the ratio of the actual absolute gas pressure and its corresponding critical absolute pressure and absolute temperature and its absolute critical temperature.

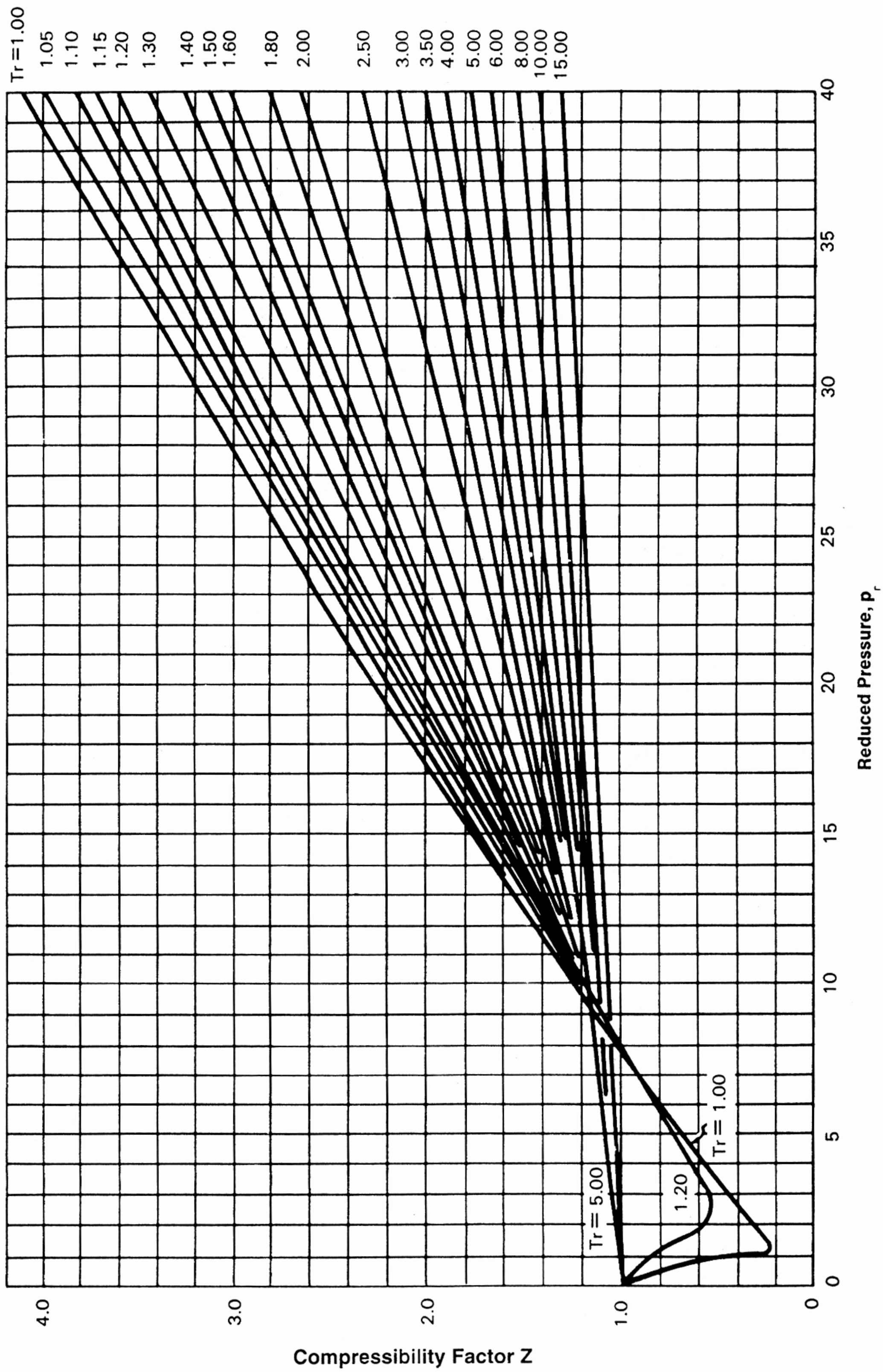


Reduced Pressure, p_r
Figure 2
Compressibility Factors for Gases with Reduced Pressures from 0 to 6

(Data from the charts of L. C. Nelson and E. F. Obert, Northwestern Technological Institute)

The compressibility factor Z obtained from the Nelson-Obert charts is generally accurate within 3 to 5 percent. For hydrogen, helium, neon and argon, certain restrictions apply. Please refer to specialized literature.

Compressibility



$$p_r = \frac{\text{inlet pressure (absolute)}}{\text{critical pressure (absolute)}} \qquad T_r = \frac{\text{inlet temperatuare(absolute)}}{\text{critical temperature (absolute)}}$$

Figure 3
Compressibility Factors for Gases with Reduced Pressures from 0 - 40

(Reproduced from the charts of L. C. Nelson and E. F. Obert, Northwestern Technological Institute)

Thermodynamic Critical Constants and Density of Elements, Inorganic and Organic Compounds

Element or Compound	Density - lb/ft³ 14.7 psia & 60°F		Density - kg/m³ 1013 mbar & 15.6°C		Mol Wt
	Liquid	Gas	Liquid	Gas	
Acetic Acid, CH_3-CO-OH	65.7		1052.4		66.1
Acetone, CH_3-CO-CH_3	49.4		791.3		58.1
Acetylene, C_2H_2		0.069		1.11	26.0
Air, O_2+N_2		0.0764		1.223	29.0
Ammonia, NH_3		0.045		0.72	17.0
Argon, A		0.105		1.68	39.9
Benzene, C_6H_6	54.6		874.6		78.1
Butane, C_4H_{10}		0.154		2.47	58.1
Carbon Dioxide, CO_2		0.117		1.87	44.0
Carbon Monoxide, CO		0.074		1.19	28.0
Carbon Tetrachloride, CCl_4	99.5		1593.9		153.8
Chlorine, Cl_2		0.190		3.04	70.9
Ethane, C_2H_6		0.080		1.28	30.1
Ethyl Alcohol, C_2H_5OH	49.52		793.3		46.1
Ethylene, CH_2=CH_2		0.074		1.19	28.1
Ethyl Ether, C_2H_5-O-C_2H_5	44.9		719.3		74.1
Fluorine, F_2		0.097		1.55	38.0
Helium, He		0.011		0.18	4.00
Heptane, C_7H_{16}	42.6		682.4		100.2
Hydrogen, H_2		0.005		0.08	2.02
Hydrogen Chloride, HCl		0.097		1.55	36.5
Isobutane, $(CH_3)_2$ CH-CH_3		0.154		2.47	58.1
Isopropyl Alcohol, CH_3-CHOH-CH_3	49.23		788.6		60.1
Methane, CH_4		0.042		0.67	16.0
Methyl Alcohol, H-CH_2OH	49.66		795.5		32.0
Nitrogen, N_2		0.074		1.19	28.0
Nitrous Oxide, N_2O		0.117		1.87	44.0
Octane, CH_3-$(CH_2)_6$-CH_3	43.8		701.6		114.2
Oxygen, O_2		0.084		1.35	32.0
Pentane, C_5H_{12}	38.9		623.1		72.2
Phenol, C_6H_5OH	66.5		1065.3		94.1
Phosgene, $COCl_2$		0.108		1.73	98.9
Propane, C_3H_8		0.117		1.87	44.1
Propylene, CH_2=CH-CH_3		0.111		1.78	42.1
Refrigerant 12, CCl_2F_2		0.320		5.13	120.9
Refrigerant 22, $CHClF_2$		0.228		3.65	86.5
Sulfur Dioxide, SO_2		0.173		2.77	64.1
Water, H_2O	62.34		998.6		18.0

Thermodynamic Critical Constants and Density of Elements, Inorganic and Organic Compounds

Element or Compound	Critical Pressure - p_c		Critical Temperature - T_c		k *
	psia	bar (abs)	°F	°C	C_p / C_v
Acetic Acid, CH_3-CO-OH	841	58.0	612	322	1.15
Acetone, CH_3-CO-CH_3	691	47.6	455	235	-
Acetylene, C_2H_2	911	62.9	97	36	1.26
Air. O_2+N_2	547	37.8	-222	-141	1.40
Ammonia, NH_3	1638	113.0	270	132	1.33
Argon, A	705	48.6	-188	-122	1.67
Benzene, C_6H_6	701	48.4	552	289	1.12
Butane, C_4H_{10}	529	36.5	307	153	1.09
Carbon Dioxide, CO_2	1072	74.0	88	31	1.30
Carbon Monoxide, CO	514	35.5	-218	-139	1.40
Carbon Tetrachloride, CCl_4	661	45.6	541	283	-
Chlorine, Cl_2	1118	77.0	291	144	1.36
Ethane, C_2H_6	717	49.5	90	32	1.22
Ethyl Alcohol, C_2H_5OH	927	64.0	469	243	1.13
Ethylene, CH_2=CH_2	742	51.2	50	10	1.26
Ethyl Ether, C_2H_5-O-C_2H_5	522	36.0	383	195	-
Fluorine, F_2	367	25.3	-247	-155	1.36
Helium, He	33.2	2.29	-450	-268	1.66
Heptane, C_7H_{16}	394	27.2	513	267	-
Hydrogen, H_2	188	13.0	-400	-240	1.41
Hydrogen Chloride, HCl	1199	82.6	124	51	1.41
Isobutane, (CH_3) CH-CH_3	544	37.5	273	134	1.10
Isopropyl Alcohol, CH_3-CHOH-CH_3	779	53.7	455	235	-
Methane, CH_4	673	46.4	-117	-83	1.31
Methyl Alcohol, H-CH_2OH	1156	79.6	464	240	1.20
Nitrogen, N_2	492	34.0	-233	-147	1.40
Nitrous Oxide, N_2O	1054	72.7	99	37	1.30
Octane, CH_3-$(CH_2)_6$-CH_3	362	25.0	565	296	1.05
Oxygen, O_2	730	50.4	-182	-119	1.40
Pentane, C_5H_{12}	485	33.5	387	197	1.07
Phenol, C_6H_5OH	889	61.3	786	419	-
Phosgene, $COCl_2$	823	56.7	360	182	-
Propane, C_3H_8	617	42.6	207	97	1.13
Propylene, CH_2=CH-CH_3	661	45.6	198	92	1.15
Refrigerant 12, CCl_2F_2	582	40.1	234	112	1.14
Refrigerant 22, $CHClF_2$	713	49.2	207	97	1.18
Sulfur Dioxide, SO_2	1142	78.8	315	157	1.29
Water, H_2O	3206	221.0	705	374	1.32

* Standard Conditions

Properties of Steam

US Customary Units

Saturated					Superheated: Total Temperature - °F									
Abs. P'	Gauge P	Sat. Temp.	*	Sat	360	400	440	480	500	600	700	800	900	1000
14.696	0.0	212.00	V	26.80	33.03	34.68	36.32	37.96	38.78	42.86	46.94	51.00	55.07	59.13
			hg	1150.4	1221.1	1239.9	1258.8	1277.6	1287.1	1334.8	1383.2	1432.3	1482.3	1533.1
20.0	5.3	227.96	V	20.08	24.21	25.43	26.65	27.86	28.46	31.47	34.47	37.46	40.45	43.44
			hg	1156.3	1220.3	1239.2	1258.2	1277.1	1286.6	1334.4	1382.9	1432.1	1482.1	1533.0
30.0	15.3	250.33	V	13.746	16.072	16.897	17.714	18.528	18.933	20.95	22.96	24.96	26.95	28.95
			hg	1164.1	1218.6	1237.9	1257.0	1276.2	1285.7	1333.8	1382.4	1431.7	1481.8	1532.7
40.0	25.3	267.25	V	10.498	12.001	12.628	13.247	13.862	14.168	15.688	17.198	18.702	20.20	21.70
			hg	1169.7	1216.9	1236.5	1255.9	1275.2	1284.8	1333.1	1381.9	1431.3	1481.4	1532.4
50.0	35.3	281.01	V	8.515	9.557	10.065	10.567	11.062	11.309	12.532	13.744	14.950	16.152	17.352
			hg	1174.1	1215.2	1235.1	1254.7	1274.2	1283.9	1332.5	1381.4	1430.9	1481.1	1532.1
60.0	45.3	292.71	V	7.175	7.927	8.357	8.779	9.196	9.403	10.427	11.441	12.449	13.452	14.454
			hg	1177.6	1213.4	1233.6	1253.5	1273.2	1283.0	1331.8	1380.9	1430.5	1480.8	1531.9
70.0	55.3	302.92	V	6.206	6.762	7.136	7.502	7.863	8.041	8.924	9.796	10.662	11.524	12.383
			hg	1180.6	1211.5	1232.1	1252.3	1272.2	1282.0	1331.1	1380.4	1430.1	1480.5	1531.6
80.0	65.3	312.03	V	5.472	5.888	6.220	6.544	6.862	7.020	7.797	8.562	9.322	10.077	10.830
			hg	1183.1	1209.7	1230.7	1251.1	1271.1	1281.1	1330.5	1379.9	1429.7	1480.1	1531.3
90.0	75.3	320.27	V	4.896	5.208	5.508	5.799	6.084	6.225	6.920	7.603	8.279	8.952	9.623
			hg	1185.3	1207.7	1229.1	1249.8	1270.1	1280.1	1329.8	1379.4	1429.3	1479.8	1531.0
100.0	85.3	327.81	V	4.432	4.663	4.937	5.202	5.462	5.589	6.218	6.835	7.446	8.052	8.656
			hg	1187.2	1205.7	1227.6	1248.6	1269.0	1279.1	1329.1	1378.9	1428.9	1479.5	1530.8
120.0	105.3	341.25	V	3.728	3.844	4.081	4.307	4.527	4.636	5.165	5.683	6.195	6.702	7.207
			hg	1190.4	1201.6	1224.4	1246.0	1266.9	1277.2	1327.7	1377.8	1428.1	1478.8	1530.2
140.0	125.3	353.02	V	3.220	3.258	3.468	3.667	3.860	3.954	4.413	4.861	5.301	5.738	6.172
			hg	1193.0	1197.3	1221.1	1243.3	1264.7	1275.2	1326.4	1376.8	1427.3	1478.2	1529.7
160.0	145.3	363.53	V	2.834	---------	3.008	3.187	3.359	3.443	3.849	4.244	4.631	5.015	5.396
			hg	1195.1	---------	1217.6	1240.6	1262.4	1273.1	1325.0	1375.7	1426.4	1477.5	1529.1
180.0	165.3	373.06	V	2.532	---------	2.649	2.813	2.969	3.044	3.411	3.764	4.110	4.452	4.792
			hg	1196.9	---------	1214.0	1237.8	1260.2	1271.0	1323.5	1374.7	1425.6	1476.8	1528.6
200.0	185.3	381.79	V	2.288	---------	2.631	2.513	2.656	2.726	3.060	3.380	3.693	4.002	4.309
			hg	1198.4	---------	1210.3	1234.9	1257.8	1268.9	1322.1	1373.6	1424.8	1476.2	1528.0
220.0	205.3	389.86	V	2.087	---------	2.125	2.267	2.400	2.465	2.772	3.066	3.352	3.634	3.913
			hg	1199.6	---------	1206.5	1231.9	1255.4	1266.7	1320.7	1372.6	1424.0	1475.5	1527.5
240.0	225.3	397.37	V	1.918	---------	1.9276	2.062	2.187	2.247	2.533	2.804	3.068	3.327	3.584
			hg	1200.6	---------	1202.5	1228.8	1253.0	1264.5	1319.2	1371.5	1423.2	1474.8	1526.9
260.0	245.3	404.42	V	1.774	---------	---------	1.8882	2.006	2.063	2.330	2.582	2.827	3.067	3.305
			hg	1201.5	---------	---------	1225.7	1250 5	1262.3	1317.7	1370.4	1422.3	1474.2	1526.3
280.0	265.3	411.05	V	1.651	---------	---------	1.7388	1.8512	1.9047	2.156	2.392	2.621	2.845	3.066
			hg	1202.3	---------	---------	1222.4	1247.9	1260.0	1316.2	1369.4	1421.5	1473.5	1525.8
300.0	285.3	417.33	V	1.543	---------	---------	1.6090	1.7165	1.7675	2.005	2.227	2.442	2.652	2.859
			hg	1202.8	---------	---------	1219.1	1245.3	1257.6	1314.7	1368.3	1420.6	1472.8	1525.2
320.0	305.3	423.29	V	1.448	---------	---------	1.4950	1.5985	1.6472	1.8734	2.083	2.285	2.483	2.678
			hg	1203.4	---------	---------	1215.6	1242.6	1255.2	1313.2	1367.2	1419.8	1472.1	1524.7
340.0	325.3	428.97	V	1.364	---------	---------	1.3941	1.4941	1.5410	1.7569	1.9562	2.147	2.334	2.518
			hg	1203.7	---------	---------	1212.1	1239.9	1252.8	1311.6	1366.1	1419.0	1471.5	1524.1
360.0	345.3	434.40	V	1.289	---------	---------	1.3041	1.4012	1.4464	1.6533	1.8431	2.025	2.202	2.376
			hg	1204.1	---------	---------	1208.4	1237.1	1250.3	1310.1	1365.0	1418.1	1470.8	1523.5

* V = Specific volume, cubic feet per pound
hg = total heat of steam, Btu per pound

Properties of Steam (continued)

US Customary Units

Saturated					Superheated: Total Temperature - °F									
Abs. P'	Gauge P	Sat. Temp.	*	Sat	500	540	600	640	660	700	740	800	900	1000
380.0	365.3	439.60	V	1.222	1.3616	1.4444	1.5605	1.6345	1.6707	1.7419	1.8118	1.9149	2.083	2.249
			hg	1204.3	1247.7	1273.1	1308.5	1331.0	1342.0	1363.8	1385.3	1417.3	1470.1	1523.0
400.0	385.3	444.59	V	1.161	1.2851	1.3652	1.4770	1.5480	1.5827	1.6508	1.7177	1.8161	1.9767	2.134
			hg	1204.5	1245.1	1271.0	1306.9	1329.6	1340.8	1362.7	1384.3	1416.4	1469.4	1522.4
420.0	405.3	449.39	V	1.106	1.2158	1.2935	1.4014	1.4697	1.5030	1.5684	1.6324	1.7267	1.8802	2.031
			hg	1204.6	1242.5	1268.9	1305.3	1328.3	1339.5	1361.6	1383.3	1415.5	1468.7	1521.9
440.0	425.3	454.02	V	1.055	1.1526	1.2282	1.3327	1.3984	1.4306	1.4934	1.5549	1.6454	1.7925	1.9368
			hg	1204.6	1239.8	1266.7	1303.6	1326.9	1338.2	1360.4	1382.3	1414.7	1468.1	1521.3
460.0	445.3	458.50	V	1.009	1.0948	1.1685	1.2698	1.3334	1.3644	1.4250	1.4842	1.5711	1.7124	1.8508
			hg	1204.6	1237.0	1264.5	1302.0	1325.4	1336.9	1359.3	1381.3	1413.8	1467.4	1520.7
480.0	465.3	462.82	V	0.967	1.0417	1.1138	1.2122	1.2737	1.3038	1.3622	1.4193	1.5031	1.6390	1.7720
			hg	1204.5	1234.2	1262.3	1300.3	1324.0	1335.6	1358.2	1380.3	1412.9	1466.7	1520.2
500.0	485.3	467.01	V	0.927	0.9927	1.0633	1.1591	1.2188	1.2478	1.3044	1.3596	1.4405	1.5715	1.6996
			hg	1204.4	1231.3	1260.0	1298.6	1322.6	1334.2	1357.0	1379.3	1412.1	1466.0	1519.6
520.0	505.3	471.07	V	0.891	0.9473	1.0166	1.1101	1.1681	1.1962	1.2511	1.3045	1.3826	1.5091	1.6326
			hg	1204.2	1228.3	1257.7	1296.9	1321.1	1332.9	1355.8	1378.2	1411.2	1465.3	1519.0
540.0	525.3	475.01	V	0.857	0.9052	0.9733	1.0646	1.1211	1.1485	1.2017	1.2535	1.3291	1.4514	1.5707
			hg	1204.0	1225.3	1255.4	1295.2	1319.7	1331.5	1354.6	1377.2	1410.3	1464.6	1518.5
560.0	545.3	478.85	V	0.826	0.8659	0.9330	1.0224	1.0775	1.1041	1.1558	1.2060	1.2794	1.3978	1.5132
			hg	1203.8	1222.2	1253.0	1293.4	1318.2	1330.2	1353.5	1376.1	1409.4	1463.9	1517.9
580.0	565.3	482.58	V	0.797	0.8291	0.8954	0.9830	1.0368	1.0627	1.1131	1.1619	1.2331	1.3479	1.4596
			hg	1203.5	1219.0	1250.5	1291.7	1316.7	1328.8	1352.3	1375.1	1408.6	1463.2	1517.3
600.0	585.3	486.21	V	0.769	0.7947	0.8602	0.9463	0.9986	1.0241	1.0732	1.1207	1.1899	1.3013	1.4096
			hg	1203.2	1215.7	1248.1	1289.9	1315.2	1327.4	1351.1	1374.0	1407.7	1462.5	1516.7
620.0	605.3	489.75	V	0.744	0.7624	0.8272	0.9118	0.9633	0.9880	1.0358	1.0821	1.1494	1.2577	1.3628
			hg	1202.9	1212.4	1245.5	1288.1	1313.7	1326.0	1349.9	1373.0	1406.8	1461.8	1516.2
640.0	625.3	493.21	V	0.719	0.7319	0.7962	0.8795	0.9299	0.9541	1.0008	1.0459	1.1115	1.2168	1.3190
			hg	1202.5	1209.0	1243.0	1286.2	1312.2	1324.6	1348.6	1371.9	1405.9	1461.1	1515.6
660.0	645.3	496.58	V	0.697	0.7032	0.7670	0.8491	0.8985	0.9222	0.9679	1.0119	1.0759	1.1784	1.2778
			hg	1202.1	1205.4	1240.4	1284.4	1310.6	1323.2	1347.4	1370.8	1405.0	1460.4	1515.0
680.0	665.3	499.88	V	0.675	0.6759	0.7395	0.8205	0.8690	0.8922	0.9369	0.9800	1.0424	1.1423	1.2390
			hg	1201.7	1201.8	1237.7	1282.5	1309.1	1321.7	1346.2	1369.8	1404.1	1459.7	1514.5
700.0	685.3	503.10	V	0.655	---------	0.7134	0.7934	0.8411	0.8639	0.9077	0.9498	1.0108	1.1082	1.2024
			hg	1201.2	---------	1235.0	1280.6	1307.5	1320.3	1345.0	1368.7	1403.2	1459.0	1513.9
750.0	735.3	510.86	V	0.609	---------	0.6540	0.7319	0.7778	0.7996	0.8414	0.8813	0.9391	1.0310	1.1196
			hg	1200.0	---------	1227.9	1275.7	1303.5	1316.6	1341.8	1366.0	1400.9	1457.2	1512.4
800.0	785.3	518.23	V	0.568	---------	0.6015	0.6779	0.7223	0.7433	0.7833	0.8215	0.8763	0.9633	1.0470
			hg	1198.6	---------	1220.5	1270.7	1299.4	1312.9	1338.6	1363.2	1398.6	1455.4	1511.0
850.0	835.3	525.26	V	0.532	---------	0.5546	0.6301	0.6732	0.6934	0.7320	0.7685	0.8209	0.9037	0.9830
			hg	1197.1	---------	1212.7	1265.5	1295.2	1309.0	1335.4	1360.4	1396.3	1453.6	1509.5
900.0	885.3	531.98	V	0.500	---------	0.5124	0.5873	0.6294	0.6491	0.6863	0.7215	0.7716	0.8506	0.9262
			hg	1195.4	---------	1204.4	1260.1	1290.9	1305.1	1332.1	1357.5	1393.9	1451.8	1508.1
950.0	935.3	538.42	V	0.471	---------	0.4740	0.5489	0.5901	0.6092	0.6453	0.6793	0.7275	0.8031	0.8753
			hg	1193.7	---------	1195.5	1254.6	1286.4	1301.1	1328.7	1354.7	1391.6	1450.0	1506.6
1000.0	985.3	544.61	V	0.445	---------	---------	0.5140	0.5546	0.5733	0.6084	0.6413	0.6878	0.7604	0.8294
			hg	1191.8	---------	---------	1248.8	1281.9	1297.0	1325.3	1351.7	1389.2	1448.2	1505.1

* V = Specific volume, cubic feet per pound
hg = total heat of steam, Btu per pound

Properties of Steam (continued)

US Customary Units

Saturated					Superheated: Total Temperature - °F										
Abs. P'	Gauge P	Sat. Temp.	*	Sat	660	700	740	760	780	800	860	900	1000	1100	1200
1100.0	1085.3	556.31	V	0.4001	0.5110	0.5445	0.5755	0.5904	0.6049	0.6191	0.6601	0.6866	0.7503	0.8117	0.8716
			hg	1187.8	1288.5	1318.3	1345.8	1358.9	1371.7	1384.3	1420.8	1444.5	1502.2	1558.8	1615.2
1200.0	1185.3	567.22	V	0.3619	0.4586	0.4909	0.5206	0.5347	0.5484	0.5617	0.6003	0.6250	0.6843	0.7412	0.7967
			hg	1183.4	1279.6	1311.0	1339.6	1353.2	1366.4	1379.3	1416.7	1440.7	1499.2	1556.4	1613.1
1300.0	1285.3	577.46	V	0.3293	0.4139	0.4454	0.4739	0.4874	0.5004	0.5131	0.5496	0.5728	0.6284	0.6816	0.7333
			hg	1178.6	1270.2	1303.4	1333.3	1347.3	1361.0	1374.3	1412.5	1437.0	1496.2	1553.9	1611.0
1400.0	1385.3	587.10	V	0.3012	0.3753	0.4062	0.4338	0.4468	0.4593	0.4714	0.5061	0.5281	0.5805	0.6305	0.6789
			hg	1173.4	1260.3	1295.5	1326.7	1341.3	1355.4	1369.1	1408.2	1433.1	1493.2	1551.4	1608.9
1500.0	1485.3	596.23	V	0.2765	0.3413	0.3719	0.3989	0.4114	0.4235	0.4352	0.4684	0.4893	0.5390	0.5862	0.6318
			hg	1167.9	1249.8	1287.2	1320.0	1335.2	1349.7	1363.8	1403.9	1429.3	1490.1	1548.9	1606.8
1600.0	1585.3	604.90	V	0.2548	0.3112	0.3417	0.3682	0.3804	0.3921	0.4034	0.4353	0.4553	0.5027	0.5474	0.5906
			hg	1162.1	1238.7	1278.7	1313.0	1328.8	1343.9	1358.4	1399.5	1425.3	1487.0	1546.4	1604.6
1700.0	1685.3	613.15	V	0.2354	0.2842	0.3148	0.3410	0.3529	0.3643	0.3753	0.4061	0.4253	0.4706	0.5132	0.5542
			hg	1155.9	1226.8	1269.7	1305.8	1322.3	1337.9	1352.9	1395.0	1421.4	1484.0	1543.8	1602.5
1800.0	1785.3	621.03	V	0.2179	0.2597	0.2907	0.3166	0.3284	0.3395	0.3502	0.3801	0.3986	0.4421	0.4828	0.5218
			hg	1149.4	1214.0	1260.3	1298.4	1315.5	1331.8	1347.2	1390.4	1417.4	1480.8	1541.3	1600.4
1900.0	1885.3	628.58	V	0.2021	0.2371	0.2688	0.2947	0.3063	0.3173	0.3277	0.3568	0.3747	0.4165	0.4556	0.4929
			hg	1142.4	1200.2	1250.4	1290.6	1308.6	1325.4	1341.5	1385.8	1413.3	1477.7	1538.8	1598.2
2000.0	1985.3	635.82	V	0.1878	0.2161	0.2489	0.2748	0.2863	0.2972	0.3074	0.3358	0.3532	0.3985	0.4311	0.4668
			hg	1135.1	1184.9	1240.0	1282.6	1301.4	1319.0	1335.5	1381.2	1409.2	1474.5	1536.2	1596.1
2100.0	2085.3	642.77	V	0.1746	0.1962	0.2306	0.2567	0.2682	0.2789	0.2890	0.3167	0.3337	0.3727	0.4089	0.4433
			hg	1127.4	1167.7	1229.0	1274.3	1294.0	1312.3	1329.5	1376.4	1405.0	1471.4	1533.6	1593.9
2200.0	2185.3	649.46	V	0.1625	0.1768	0.2135	0.2400	0.2514	0.2621	0.2721	0.2994	0.3159	0.3538	0.3887	0.4218
			hg	1119.2	1147.8	1217.4	1265.7	1286.3	1305.4	1323.3	1371.5	1400.8	1468.2	1531.1	1591.8
2300.0	2285.3	655.91	V	0.1513	0.1575	0.1978	0.2247	0.2362	0.2468	0.2567	0.2835	0.2997	0.3365	0.3703	0.4023
			hg	1110.4	1123.8	1204.9	1256.7	1278.4	1298.4	1316.9	1366.6	1396.5	1464.9	1528.5	1589.6
2400.0	2385.3	662.12	V	0.1407	----------	0.1828	0.2105	0.2221	0.2327	0.2425	0.2689	0.2848	0.3207	0.3534	0.3843
			hg	1101.1	----------	1191.5	1247.3	1270.2	1291.1	1310.3	1361.6	1392.2	1461.7	1525.9	1587.4
2500.0	2485.3	668.13	V	0.1307	----------	0.1686	0.1973	0.2090	0.2196	0.2294	0.2555	0.2710	0.3061	0.3379	0.3678
			hg	1091.1	----------	1176.8	1237.6	1261.8	1283.6	1303.6	1356.5	1387.8	1458.4	1523.2	1585.3
2600.0	2585.3	673.94	V	0.1213	----------	0.1549	0.1849	0.1967	0.2074	0.2172	0.2431	0.2584	0.2926	0.3236	0.3526
			hg	1080.2	----------	1160.6	1227.3	1252.9	1275.8	1296.8	1351.4	1383.4	1455.1	1520.6	1583.1
2700.0	2685.3	679.55	V	0.1123	----------	0.1415	0.1732	0.1853	0.1960	0.2059	0.2315	0.2466	0.2801	0.3103	0.3385
			hg	1068.3	----------	1142.5	1216.5	1243.8	1267.9	1289.7	1346.1	1378.9	1451.8	1518.0	1580.9
2800.0	2785.3	684.99	V	0.1035	----------	0.1281	0.1622	0.1745	0.1854	0.1953	0.2208	0.2356	0.2685	0.2979	0.3254
			hg	1054.8	----------	1121.4	1205.1	1234.2	1259.6	1282.4	1340.8	1374.3	1448.5	1515.4	1578.7
2900.0	2885.3	690.26	V	0.0947	----------	0.1143	0.1517	0.1644	0.1754	0.1853	0.2108	0.2254	0.2577	0.2864	0.3132
			hg	1039.0	----------	1095.9	1193.0	1224.3	1251.1	1274.9	1335.3	1369.7	1445.1	1512.7	1576.5
3000.0	2985.3	695.36	V	0.0858	----------	0.0984	0.1416	0.1548	0.1660	0.1760	0.2014	0.2159	0.2476	0.2757	0.3018
			hg	1020.8	----------	1060.7	1180.1	1213.8	1242.2	1267.2	1329.7	1365.0	1441.8	1510.0	1574.3
3100.0	3085.3	700.31	V	0.0753	----------	----------	0.1320	0.1456	0.1571	0.1672	0.1926	0.2070	0.2382	0.2657	0.2911
			hg	993.1	----------	----------	1166.2	1202.9	1233.0	1259.3	1324.1	1360.3	1438.4	1507.4	1572.1
3200.0	3185.3	705.11	V	0.0580	----------	----------	0.1226	0.1369	0.1486	0.1589	0.1843	0.1986	0.2293	0.2563	0.2811
			hg	934.4	----------	----------	1151.1	1191.4	1223.5	1251.1	1318.3	1355.5	1434.9	1504.7	1569.9
3206.0	3191.2	705.40	V	0.0503	----------	----------	0.1220	0.1363	0.1480	0.1583	0.1838	0.1981	0.2288	0.2557	0.2806
			hg	902.7	----------	----------	1150.2	1190.6	1222.9	1250.5	1317.9	1355.2	1434.7	1504.5	1569.8

* V = Specific volume, cubic feet per pound
hg = total heat of steam, Btu per pound

Saturated Steam Table

Pressure Inches Hg at 32 °F	Absolute Pressure Lbs./Sq. In.	Temperature °F	Cu. Ft./Lb. Sat. Vapor	TOTAL HEAT IN B.T.U. PER LB.		
				Sat. Liquid	Evap.	Sat. Vapor
1.02	0.5	80	642	47.60	1047.5	1095.1
2.03	1	101	334	69.69	1035.3	1105.0
4.06	2	126	174	93.97	1021.6	1115.6
6.09	3	142	119	109.33	1012.7	1120.0
10.15	5	162	74.0	130.10	1000.4	1130.6
15.3	7.5	180	50.3	147.81	989.9	1137.7
20.3	10	193	38.4	161.13	981.8	1143.0
28.5	14	209	28.0	177.55	971.8	1149.3
29.92	14.696	212	26.8	180.0	970.2	1150.2
Gauge Pressure Lbs./Sq. In.						
0.0	14.696	212	26.8	180.0	970.2	1150.2
1.3	16	216	24.8	184.35	967.4	1151.8
2.3	17	219	23.4	187.48	965.4	1152.9
3.3	18	222	22.2	190.48	963.5	1154.0
4.3	19	225	21.1	193.34	961.7	1155.0
5.3	20	228	20.1	196.09	959.9	1156.0
7.3	22	233	18.4	201.25	956.6	1157.8
10.3	25	240	16.3	208.33	951.9	1160.2
15.3	30	250	13.7	218.73	945.0	1163.7
20.3	35	259	11.9	227.82	938.9	1166.7
25.3	40	267	10.5	235.93	933.3	1169.2
30.3	45	274	9.40	243.28	928.2	1171.5
35.3	50	281	8.51	249.98	923.5	1173.5
40.3	55	287	7.78	256.19	919.1	1175.3
45.3	60	293	7.17	261.98	915.0	1177.0
50.3	65	298	6.65	267.39	911.1	1178.5
55.3	70	303	6.20	272.49	907.4	1179.9
60.3	75	307	5.81	277.32	903.9	1181.2
65.3	80	312	5.47	281.90	900.5	1182.4
70.3	85	316	5.16	286.90	897.3	1183.6
75.3	90	320	4.89	290.45	894.2	1184.6
80.3	95	324	4.65	294.47	891.2	1185.6
85.3	100	328	4.42	298.33	888.2	1186.6
90.3	105	331	4.22	302.03	885.4	1187.5
95.3	110	335	4.04	305.61	882.7	1188.3
100.3	115	338	3.88	309.04	880.0	1189.1
105.3	120	341	3.72	312.37	877.4	1189.8
110.3	125	344	3.60	315.60	874.9	1190.5
115.3	130	347	3.45	318.73	872.4	1191.2
120.3	135	350	3.33	321.77	870.0	1191.8
125.3	140	353	3.22	324.74	867.7	1192.4
130.3	145	356	3.20	327.63	865.3	1193.0
135.3	150	358	3.01	330.44	863.1	1193.5
140.3	155	361	2.92	333.18	860.8	1194.0
145.3	160	363	2.83	335.86	858.7	1194.5
150.3	165	366	2.75	338.47	856.5	1195.0
155.3	170	368	2.67	341.03	854.5	1195.4
160.3	175	370	2.60	343.54	852.3	1195.9
165.3	180	373	2.53	345.99	850.3	1196.3
170.3	185	375	2.46	348.42	848.2	1196.7
175.3	190	377	2.40	350.77	846.3	1197.0
180.3	195	380	2.34	353.07	844.3	1197.4
185.3	200	382	2.28	355.33	842.4	1197.8
210.3	225	392	2.039	366.10	833.2	1199.3
235.3	250	401	1.841	376.02	824.5	1200.5
260.3	275	409	1.678	385.24	816.3	1201.6
285.3	300	417	1.541	393.90	808.5	1202.4
335.3	350	432	1.324	409.81	793.7	1203.6
385.3	400	444	1.160	424.2	779.8	1204.1
435.3	450	456	1.030	437.4	766.7	1204.1
485.3	500	467	0.926	449.7	754.0	1203.7
585.3	600	486	0.767	472.3	729.8	1202.1
685.3	700	503	0.653	492.9	706.8	1199.7
785.3	800	518	0.565	511.8	684.9	1196.7
885.3	900	532	0.496	529.5	663.8	1193.3
985.3	1000	544	0.442	546.0	643.5	1189.6
1235.3	1250	572	0.341	583.6	595.6	1179.2
1485.3	1500	596	0.274	617.5	550.2	1167.6
1985.3	2000	635	0.187	679.0	460.0	1139.0
2485.3	2500	668	0.130	742.8	352.8	1095.6
2985.3	3000	695	0.084	823.1	202.5	1025.6
3211.3	3226	706	0.0522	925.0	0	925.0

Preface – Units and Conversion Factors

Rapidly becoming the most commonly used units system in the world, the International System of Units (SI, for Systeme International d'Unites) derives nearly all quantities needed in all technologies from only seven base units: the meter (m), for length; the kilogram (kg), for mass (what is usually called weight); the second (s), for time; the ampere (A), for electric current; the Kelvin (K), for thermodynamic temperature; the mole (mol), for amount of substance; and the candela (cd), for luminous intensity. There are also two supplementary units, the radian (rad), for plane angle, and the steradian (sr), for solid angle. More information on the properties of these units and their conversion factors can be found in documents published by the International Standards Organization.

To take maximum advantage of the SI system, only base, supplementary, or derived SI units should be used. The appropriate units for quantities commonly used in process control are listed in Table 1, along with the base or supplementary units from which they are derived.

SI units are terms and symbols to abbreviate numbers and show relationships between any number and its unit. For example, 1 000 000 (one million) meters is expressed as one megameter or one Mm. The most common terms and symbols are listed in the Multiplication Factors Table on page 93.

To assist in preserving the advantage of SI as a coherent system, it is advisable to minimize the use of units from other systems. It is also desirable not to mix unit symbols with unit names or abbreviations (including the name "per" and its symbol, "/"). Some examples of proper and improper usage are listed below.

PROPER USAGE	IMPROPER USAGE
joules per kilogram	joules/kilogram
J/kg	joules/kg
kilometers per second	kilometers/second
km/s	km/second
liters per minute	liters/minute
L/min	L/m (because "m" alone means "meter")

All units in the following table are listed in alphabetical order and are cross-referenced to commonly used units in both the U.S. customary and metric systems.

In some units, the preferred form may pose too great a magnitude for all applications. For example, while kilogram is the proper term for mass, a very small amount is more easily expressed in terms of grams. Similarly, kilowatts are usually used instead of watts and kilopascals instead of pascals. The expression of speed (which in an aspect of velocity) takes this concept a little further; the proper term is meter per second, but common usage expresses traffic speeds as kilometers per hour in SI countries.

Pressure and mass are two particularly appropriate examples, since each is affected (at least very slightly) by gravity. For example, many pressure and differential pressure instruments use forms of springs as measuring elements, which measure force directly; these are called "gravity-independent". However, the pressure standards used to calibrate the springs, such as dead-weight testers which measure the force of gravity on a column of mercury or other substance of fixed mass, are often "gravity-dependent". Pneumatic systems cancel the effect of gravity when the same type of pressure standard is used for both input and output (current or voltage). They must have either a gravity-independent input or be calibrated in a way that accommodates the local gravitational force (either by incorporating a correction factor or by calibrating the pressure instrument at the location where it will be used).

Complicating the problem is the fact that force units (which more closely reflect weight) often incorporate mass terminology (for example, pounds-force or kilograms-force). Even pressure units sometimes use mass terminology (e.g., pounds per square inch). The SI system provides the means to incorporate the effect of gravity, establish a common terminology, and distinguish pure mass from force (mass accelerated over a distance), pressure (force per unit area), density (mass per unit volume), and flow (mass per unit time). Even energy, power, and torque units are partially derived from mass, but mass is not a significant enough factor for the mass vs. force issue to be of concern. Refer to the table of proper SI units to see how they all relate.

Notes about Units

The following is general information about the unit categories and helpful hints for working with individual units.

ABSOLUTE VISCOSITY:
Also called "dynamic viscosity" or just "viscosity".

ACCELERATION:

1. "Meter per second squared" (the term preferred in SI guidelines) is also called "meters per second per second".
2. The acceleration of gravity is about 10 m/s^2.

ANGULAR VELOCITY:

1. The SI unit for this is defined in terms of a supplemental unit, the radian; rad/s.
2. The terms "revolutions per minute" and "revolutions per second" are properly abbreviated "r/min" and "r/s", respectively, rather than "rpm" and "rps".
3. This category is also called rotational frequency, primarily in specifications on rotating machinery, when the revolution per second and revolution per minute are widely used as units.

AREA:

1. The term "hectare" (abbreviated "ha") is used as an alternative name for square hectometer and is restricted to the measurement of large land areas. Agricultural engineers use the term to relate machines to field sizes.
2. The square meter is also called "centare."
3. Although the centimeter (cm) is rarely used to indicate length (meter or millimeter is preferred), the square centimeter (cm^2) is often used to indicate area because the interval between the square meter (m^2) and square millimeter (mm^2) is so great (1 000 000 to 1).

ENERGY:

1. This unit category includes "quantity of heat" and "work".
2. The use of the calorie was discontinued by SI.
3. The kilowatt-hour and variations thereon (e.g., MW-h, GW-h), although not proper SI units (the joule is the proper one), are in widespread use for measurement of electric energy.

4. The units based on the electronovolt (eV, keV, MeV, and GeV) are also improperly but widely used in atomic and nuclear physics and in accelerator technology (the joule should be used).
5. The joule is equivalent to one watt-second.

FORCE:
1. The use of the kilogram-force (once widely used in Europe) was discontinued by SI.
2. The kilogram-force is also called "kilopond".

KINEMATIC VISCOSITY:
The SI unit, the square meter per second (m^2/s) is equivalent to the English unit Stoke (St) and the SI unit square millimeter per second (mm^2/s) is equivalent to the English unit centiStoke (cSt).

LENGTH:
1. The smaller units in this category (like the meter and millimeter) are easy to learn because they can be related to items contacted every day. For example, a U.S. dime is about one millimeter thick, a U.S. quarter is about 25 millimeters wide, and the height of most home doorways is about two meters. However, the kilometer is harder to visualize and is therefore easier to learn by memorization. Following is a list of common values.

miles or mph	km or km/h
10	16
25	40
50	80
55	90
62	100
75	120
100	160

2. The millimeter is used all over the world on industrial engineering drawings.
3. The use of centimeter is generally restricted to body measurements, clothing sizes, and textile weights.
4. The micrometer (sometimes called "micron") is the preferred unit to express surface finish.

MASS:
1. The kilogram and gram will generally replace the use of the pound and ounce, respectively.
2. Two aspirin, an American dollar bill, and one paper clip each weigh about one gram.
3. A kilogram is the weight of one liter of water.
4. The alternate name of "tonne" is "metric ton". A tonne is equal to one megagram.
5. A load-supporting rating (e.g., floor load) should be expressed in kilograms.
6. This unit category is also called "weight".

MASS PER UNIT TIME:
This unit category is also called "flow" and "mass flow".

MASS PER UNIT VOLUME:
1. This unit category is also called "density", "mass density", and "mass capacity".
2. One part per million is equal to one milligram per liter or one gram per cubic meter, referenced as "by weight in water" at a specified temperature.

PLANE ANGLES:
1. The radian, a supplementary SI unit, is the proper unit for this category. The decimalized degree (defined as [pi ÷ 180] rad) is not proper but is widely used. Although the minute and the second are still widely accepted, their use is discouraged because they require an extra conversion step.
2. The plane angle is also called just "angle".

POWER:
1. There are several types of horsepower. The one usually assumed is electric horsepower (unless otherwise stated).
2. Boiler horsepower is primarily used to rate the size of small industrial boilers.
3. The use of the calorie was discontinued by SI on January 1, 1978.
4. Power is also called "heat flow rate" and "radiant flux".

PRESSURE:
1. Although the pascal is the proper SI unit for pressure, the kilopascal (kPa) is recognized for use in all fields except high vacuum measurement of absolute pressure, for which the pascal may be more convenient.
2. The kPa is used for measurement of both gauge and absolute pressure (gauge pressure is absolute pressure minus ambient pressure [ambient pressure is usually atmospheric pressure]). However, when absolute pressure is intended, the unit kPa should be followed by the word "absolute".
3. The bar is a convenient multiple of the pascal, the proper SI term for pressure (1 bar = 10^5 Pa), but its use is discouraged. The millibar is and will continue to be widely used in meteorology; however, the kilopascal should be used in most cases.
4. The mmHg is also called "torr". (The torr was once widely used in Europe but its use, as well as use of the kilogram-force per square centimeter, was discontinued by SI).
5. This unit category is also called "stress" and "force per unit area".

SOLID ANGLE:
The steradian is a supplementary SI unit.

TEMPERATURE:
1. Technically, this unit is called "thermodynamic temperature".
2. The proper SI unit for this category is the Kelvin, *not* the degree Kelvin. For example, a temperature would be correctly expressed as 283K or, less properly but more commonly, as 10°C (though not 10C). But be careful not to confuse the abbreviation for Kelvin with the designation for 1000, as in a 10K ohm resistor.
3. Degrees Celsius was called Degrees Centigrade and it is the most commonly encountered form of temperature measurement.
4. One degree Celsius as a temperature interval is equal to one Kelvin unit.
5. Kelvin is the absolute temperature scale in the metric (Celsius) system.
6. Degrees Rankine is the absolute temperature scale in the English (Fahrenheit) system.

TIME:

1. The second is the proper SI unit of time. However, a coherent system of time measurement is not practical (e.g., a solar day cannot be conveniently divided into kilo-seconds). Therefore, the noncoherent system now in use with minutes, hours, days, and years will continue to be used indefinitely.
2. Time units can be defined as mean or sidereal: mean time closely approximates actual star movement but is modified slightly to provide regularity of measurement; sidereal units are based on actual movement of stars but do not break down into neat units (e.g., a sidereal day is 23 hours, 56 minutes, and 4.09 seconds long - expressed in mean time).
3. Note that the SI symbol for "year" is "a".

TORQUE:

1. The units in this category are mathematically the same as those in the category "bending movement", although the application of the units is different.
2. Torque is also called "moment of force".
3. The preferred unit for this category, the N·m, is the same as the definition for the energy unit joule (J = N·m), but the two should not be used interchangeably since they have different applications.
4. The use of the unit kilogram-force times meter was discontinued by SI.

VELOCITY:

1. The best way to learn the commonly used velocity measurement, kilometers per hour (although meters per second is the proper unit), is by memorizing comparable values. (Refer to the kilometers-to-miles list under "LENGTH".
2. This unit category includes "speed". (Velocity, a vector, is magnitude plus direction while speed, a scalar, is magnitude only.)

VOLUME:

1. Although liters are frequently used as a substitute for quarts, at least in the U.S., it is not technically correct to do so. According to SI guidelines, the cubic meter should be used instead. However, the liter will probably continue to be used for measurement of displacement of an internal combustion engine and for the volume of space in a refrigerator or the trunk of a car.
2. A liter is equivalent to a cube 10 cm on each side (a cubic decimeter).
3. A milliliter is equivalent to a cubic centimeter.
4. The symbol for liter has been a lower case l, but is changing to upper case L to avoid confusion with the number one (1).
5. Water and gas supplies for homes and factories - in fact, almost anything now measured in cubic feet - will be measured in cubic meters, the proper SI unit.
6. Automotive fuel consumption is expressed in countries using the metric system as liters per 100 kilometers or kilometers per liter rather than miles per gallon. A conversion estimate from mpg to L/100 km is achieved by dividing 235 by the mpg (e.g., if you normally get 20 mpg, you will get approximately 12 L/100 km); to go from mpg to km/L, divide the mpg by 2.35 (e.g., 20 mpg = 8.5 km/L).
7. This unit category is also called "capacity".

VOLUME PER UNIT TIME:

This unit category is also called "instantaneous volume velocity" or just "volume velocity". The unit category "mass per unit time" also includes flow.

NOTE: In some cases, a prefix symbol is the same as a unit symbol, so it is important to look at the position of each symbol in the term to determine its meaning. For example, in ms the "m" means "milli" (millisecond), but in km the "m" means "meter" (kilometer). Also to avoid confusion, it is important that no more than one prefix be used when forming the decimal multiple or submultiple of a derived unit. For example, mμm should be expressed as nm. Refer to Table I - Proper SI Units for appropriate abbreviations.

Another general rule is to use SI prefixes to indicate order of magnitude and eliminate nonsignificant digits and leading zeroes. This also provides a convenient conversational alternative to the powers-of-ten notation preferred in computation. For example,

12300 mm	becomes 12.3m
12.3×10^3m	becomes 12.3km
0.001230 μA	becomes 1.23nA

Another point illustrated by the numbers in Table 1 is the placeholding value of the comma. Outside the United States the comma is sometimes used instead of the decimal point (e.g., the American 0.00123 would be written 0,00123). To avoid confusion, recommended international practice uses a space instead of a comma when dividing numbers into groups of three digits (a decimal point is still used to indicate a break between numbers greater than one and numbers less than one). This applies to groupings of numbers on either side of zero. For example, 12,300.001230 could be written as 12 300.001 230.

TABLE I – Proper SI Units

Quantity	Name of Unit	Symbol of Derived Unit	Unit Expressed as Base or Supplementary Units
Absolute Viscosity	Pascal Second	Pa·s	Pa x s
Acceleration	Meter per Second Squared		m/s^2
Angular Velocity	Radian per Second		rad/s
Area	Square Meter		m^2
Energy	Joule	J	N·m (kg x m^2 x s^{-2})
Force	Newton	N	kg x m x s^{-2}
Kinematic Viscosity	Square Meters per Second		m^2/s
Length	Meter		m
Mass	Kilogram		kg
Mass per Unit Time	Kilogram per Second		kg/s
Mass per Unit Volume	Kilograms per Cubic Meter		kg/m^3
Plane Angle	Radians	rad	m x m^{-1}
Power	Watt	W	J/s (kg x m^{-2} x s^{-3})
Pressure	Pascal	Pa	N/m^2 (kg x m^{-1} x s^{-2})
Solid Angle	Steradian	sr	m^2 x m^{-2}
Temperature	Kelvin		K
	Celsius	°C	K-273.15
Time	Second		s
Torque	Newton-Meter	N·m	kg/s^2 x m
Velocity	Meters per Second		m/s
Volume	Cubic Meters		m^3
Volume per Unit Time	Cubic Meters per Second		m^3/s

Formulas, Conversions and Definitions

Pressures and Densities

Pressure = $\frac{\text{force}}{\text{area}}$

1 column of water 1 foot deep = 62.4 pounds per square foot, or 0.433 pounds per square inch. 1 column of water 1 centimeter deep = 1 gram per square centimeter.

Specific Gravity = number of times a substance is as heavy as an equal body of water, or Specific gravity (liquid)= $\frac{\text{weight of liquid}}{\text{weight of equal volume of water}}$

Density = $\frac{\text{weight}}{\text{volume}}$

Pressure = depth x density, or force per unit area. An increase in pressure is transmitted equally through the liquid.

Specific Gravity (solid) = $\frac{\text{weight of body}}{\text{weight of equal volume of water}}$

or Specific gravity (solid)= $\frac{\text{weight of body}}{\text{loss of weight in water}}$

One cubic yard of air weighs about 2 pounds. Atmospheric pressure at sea level = about 15 pounds per square inch.

Velocities and Energies

Velocity = $\frac{\text{distance}}{\text{time}}$

Acceleration= $\frac{\text{change of velocity}}{\text{time}}$

Acceleration of gravity= $\frac{\text{32 feet per second}}{\text{seconds}}$

Centripetal force = $\frac{\text{weight}}{\text{acceleration of gravity}}$ x $\frac{(\text{velocity})^2}{\text{radius}}$

Potential Energy = weight of body x elevation

Kinetic Energy: $\frac{1}{2}$ $\frac{\text{weight}}{\text{acceleration of gravity}}$ x $(\text{velocity})^2$ac

Momentum = mass of body x its velocity

Mass = $\frac{\text{weight}}{\text{acceleration of gravity}}$ $\sqrt{\frac{L}{G}}$

Period of pendulum: T = 2π

Wave velocity = wave frequency x wave length, or v=nx1

Speed of Sound: 1090 feet per second in air at 0 degrees Centigrade. Velocity of sound increases 2 feet per second for each degree Centigrade rise in temperature above zero degrees Centigrade.

Electricity

1 ampere = 1 coulomb per second
1 volt = 1 joule per coulomb

Ohm's Law: Current = $\frac{\text{potential difference}}{\text{resistance}}$

or **Amperes** = $\frac{\text{volts or 1}}{\text{ohms}}$ $\frac{V}{R}$

Ampere = electric current
Volt = potential difference
Ohm = electrical resistance
One volt potential difference will drive 1 ampere through a resistance of 1 ohm.

The resistance of conductor can be calculated by the formula:

$R = \frac{k1}{d^2}$ (Where 1 is length, d is diameter, and k is constant)

The combined resistance of conductors connected in parallel is

$$\frac{1}{Rc} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

1 Watt is the power of a current on 1 ampere when the potentail difference is 1 volt.

To compute electric power: P (power in watts) = V (voltage in volts) x1 (current in amperes) or P=VxI.
To compute the heat (H), produced by a current (I) through a resistance (R), in a time (t), use the equation: $H=I_2xRxtx0.24$ cal/watt-sec.

Lights and Lenses

1 foot-candle: the illumination of any point on a surface 1 foot from a standard candle.

Illumination (ft-c) = $\frac{\text{intensity (candles)}}{\text{distance in feet}^2}$

Velocity of Light = 186,000 miles per sec.

Index of refraction = $\frac{\text{velocity of light in air}}{\text{velocity of light in the substance}}$

Lens image equation: $\frac{1}{D_0}$ x $\frac{1}{D_1 f}$ = 1

Magnification = $\frac{\text{image length}}{\text{object length}}$ or $\frac{\text{image distance}}{\text{object distance}}$

Formulas, Conversions and Definitions

Heat

To convert Fahrenheit to Centigrade: subtract 32 from F, then multiply by 5/9 written C=5/9 (F-32). NOTE: Centigrade is now referred to as Celsius. (NOTE: 212F=100). To convert Centigrade to Fahrenheit: multiply C by 9/5, then add 32, written F = (9/5C) +32.

To convert Centigrade to Absolute or Kelvin scale: add 273 to C.

To convert Fahrenheit to Absolute or Kelvin scale: first convert F to C, then add 273.

Boyle's Law: $p_1 \times v_1 = p_2 \times v_2$ at constant temperature. Zero degrees Kelvin is the lowest possible temperature.

In Kelvin Absolute temperature scale: water boils at 373K, freezes at 273K.

Charles' Law: $\frac{V_1}{V_2} = \frac{T_1}{T_2}$ at constant pressure

Combination of Charles' and Boyle's Laws:

$$\frac{V_1P_1}{T_1} = \frac{V_2P_2}{T_2}$$

When heated through one degree Centigrade, any gas expands $\frac{1}{273}$ of its volume at 0 degrees Centigrade if the pressure remains constant. One BTU is the heat required to raise the temperature of 1 pound of water through 1 degree Fahrenheit.

One calorie: the heat required to raise the temperature of 1 gram of water through 1 degree Centigrade.

Specific Heat: heat required to raise the temperature of a unit mass of that substance through 1 degree. If H is total heat and M is mass, $H=M \times sx\ (t_2-t_1)$

Heat of melting or heat of fusion, L, is the quantity of heat needed to melt one unit weight of substance without changing its temperature, or H=MxL.

0 calories of heat required to melt 1 gram of ice without raising its temperature,

Boiling point of liquid: that temperature at which the vapor pressure is equal to the pressure above the liquid.

0.427 kilogram-meter (kg-m) = 1 calorie

$$\frac{\text{work}}{\text{mechanical equivalent of heat}}$$

Horsepower

1 horsepower = 550 ft-lb sec

Horsepower = $\frac{\text{force(lb)} \times \text{distance (ft)}}{\text{550 ft-lb sec} \times \text{time (sec)}}$

Friction Constant = $\frac{\text{friction force}}{\text{weight}}$

Work = force x distance moved

Power = $\frac{\text{work}}{\text{time}}$

1 watt - 10,200 gram-centimeters per sec.

1 kilowatt is 1000 watts

1 kilowatt is approximately 1-1/3 horsepower

Dyne is absolute metric unit of force. **Erg** is its unit of work.

1 Erg = force of 1 dyne acting through 1 centimeter

1 Joule = 10,000,000 ergs or about 3/4 foot pounds

The law of work when friction is neglected: effort force x effort distance = resistance force x resistance distance
Mechanical advantage of a machine =

$$\frac{\text{resistance force}}{\text{effort force}}$$

When friction is zero, mechanical advantage of a machine:

$$\frac{\text{effort distance}}{\text{resistance distance}}$$

Mechanical advantage of a lever: = $\frac{\text{effort arm}}{\text{resistance arm}}$

Moment of force = force x lever arm
Frictionless mechanical advantage of an inclined **plane** = $\frac{\text{length}}{\text{height}}$

Frictionless mechanical advantage of a wheel and axle:

$$\frac{\text{circumference of wheel}}{\text{circumference of axle}}$$

Units and Conversion Factors

Millimeters to Decimals

mm	*Decimal*	*mm*	*Decimal*	*mm*	*Decimal*	*mm*	*Decimal*	*mm*	*Decimal*
0.01	.00039	0.41	.01614	0.81	.03189	21	.82677	61	2.40157
0.02	.00079	0.42	.01654	0.82	.03228	22	.86614	62	2.44094
0.03	.00118	0.43	.01693	0.83	.03268	23	.90551	63	2.48031
0.04	.00157	0.44	.01732	0.84	.03307	24	.94488	64	2.51969
0.05	.00197	0.45	.01772	0.85	.03346	25	.98425	65	2.55906
0.06	.00236	0.46	.01811	0.86	.03386	26	1.02362	66	2.59843
0.07	.00276	0.47	.01850	0.87	.03425	27	1.06299	67	2.63780
0.08	.00315	0.48	.01890	0.88	.03465	28	1.10236	68	2.67717
0.09	.00354	0.49	.01929	0.89	.03504	29	1.14173	69	2.71654
0.10	.00394	0.50	.01969	0.90	.03543	30	1.18110	70	2.75591
0.11	.00433	0.51	.02008	0.91	.03583	31	1.22047	71	2.79528
0.12	.00472	0.52	.02047	0.92	.03622	32	1.25984	72	2.83465
0.13	.00512	.053	.02087	0.93	.03661	33	1.29921	73	2.87402
0.14	.00551	0.54	.02126	0.94	.03701	34	1.33858	74	2.91339
0.15	.00591	0.55	.02165	0.95	.03740	35	1.37795	75	2.95276
0.16	.00630	0.56	.02205	0.96	.03780	36	1.41732	76	2.99213
0.17	.00669	0.57	.02244	0.97	0.3819	37	1.45669	77	3.03150
0.18	.00709	0.58	.02283	0.98	.03858	38	1.49606	78	3.07087
0.19	.00748	0.59	.02323	0.99	.03898	39	1.53543	79	3.11024
0.20	.00787	0.60	.02362	1.00	.03937	40	1.57480	80	3.14961
0.21	.00827	0.61	.02402	1	.03937	41	1.61417	81	3.18898
0.22	.00866	0.62	.02441	2	.07874	42	1.65354	82	3.22835
0.23	.00906	0.63	.02480	3	.11811	43	1.69291	83	3.26772
0.24	.00945	0.64	.02520	4	.15748	44	1.73228	84	3.30709
0.25	.00984	0.65	.02559	5	.19685	45	1.77165	85	3.34646
0.26	.01024	0.66	.02598	6	.23622	46	1.81102	86	3.38583
0.27	.01063	0.67	.02638	7	.27559	47	1.85039	87	3.42520
0.28	.01102	0.68	.02677	8	.31496	48	1.88976	88	3.46457
0.29	.01142	0.69	.02717	9	.35433	49	1.92913	89	3.50394
0.30	.01181	0.70	.02756	10	.39370	50	1.96850	90	3.54331
0.31	.01220	0.71	.02795	11	.43307	51	2.00787	91	3.58268
0.32	.01260	0.72	.02835	12	.47244	52	2.04724	92	3.62205
0.33	.01299	0.73	.02874	13	.51181	53	2.08661	93	3.66142
0.34	.01339	0.74	.02913	14	.55118	54	2.12598	94	3.70079
0.35	.01378	0.75	.02953	15	.59055	55	2.16535	95	3.74016
0.36	.01417	0.76	.02992	16	.62992	56	2.20472	96	3.77953
0.37	.01457	0.77	.03031	17	.66929	57	2.24409	97	3.81890
0.38	.01496	0.78	.03071	18	.70866	58	2.28346	98	3.85827
0.39	.01535	0.79	.03110	19	.74803	59	2.32283	99	3.89764
0.40	.01575	0.80	.03150	20	.78740	60	2.36220	100	3.93701

Conversion Tables

Fractions to Decimals to Millimeters

Fraction	Decimal	mm	Fraction	Decimal	mm
1/64	0.0156	0.3969	33/64	0.5156	13.0969
1/32	0.0312	0.7938	17/32	0.5312	13.4938
3/64	0.0469	1.1906	35/64	0.5469	13.8906
1/16	0.0625	1.5875	9/16	0.5625	14.2875
5/64	0.0781	1.9844	37/64	0.5781	14.6844
3/32	0.0938	2.3812	19/32	0.5938	15.0812
7/64	0.1094	2.7781	39/64	0.6094	15.4781
1/8	0.1250	3.1750	5/8	0.6250	15.8750
9/64	0.1406	3.5719	41/64	0.6406	16.2719
5/32	0.1562	3.9688	21/32	0.6562	16.6688
11/64	0.1719	4.3656	43/64	0.6719	17.0656
3/16	0.1875	4.7625	11/16	0.6875	17.4625
13/64	0.2031	5.1594	45/64	0.7031	17.8594
7/32	0.2188	5.5562	23/32	0.7188	18.2562
15/64	0.2344	5.9531	47/64	0.7344	18.6531
1/4	0.2500	6.3500	3/4	0.7500	19.0500
17/64	0.2656	6.7469	49/64	0.7656	19.4469
9/32	0.2812	7.1438	25/32	0.7812	19.8438
19/64	0.2969	7.5406	51/64	0.7969	20.2406
5/16	0.3125	7.9375	13/16	0.8125	20.6375
21/64	0.3281	8.3344	53/64	0.8281	21.0344
11/32	0.3438	8.7312	27/32	0.8438	21.4312
23/64	0.3594	9.1281	55/64	0.8594	21.8281
3/8	0.3750	9.5250	7/8	0.8750	22.2250
25/64	0.3906	9.9219	57/64	0.8906	22.6219
13/32	0.4062	10.3188	29/32	0.9062	23.0188
27/64	0.4219	10.7156	59/64	0.9219	23.4156
7/16	0.4375	11.1125	15/16	0.9375	23.8125
29/64	0.4531	11.5094	15/16	0.9531	24.2094
15/32	0.4688	11.9062	31/32	0.9688	24.6062
31/64	0.4844	12.3031	63/64	0.9844	25.0031
1/2	0.5000	12.7000	1	1.0000	25.4000

Decimals to Millimeters

Decimal	mm	Decimal	mm
0.001	0.0254	0.500	12.700
0.002	0.0508	0.510	12.9540
0.003	0.0762	0.520	13.2080
0.004	0.1016	0.530	13.4620
0.005	0.1270	0.540	13.7160
0.006	0.1524	0.550	13.9700
0.007	0.1778	0.560	14.2240
0.008	0.2032	0.570	14.4780
0.009	0.2286	0.580	14.7320
0.010	0.2540	0.590	14.9860
0.020	0.5080		
0.030	0.7620		
0.040	1.0160	0.600	15.2400
0.050	1.2700	0.610	15.4940
0.060	1.5240	0.620	15.7480
0.070	1.7780	0.630	16.0020
0.080	2.0320	0.640	16.2560
0.090	2.2860	0.650	16.5100
		0.660	16.7640
0.100	2.5400	0.670	17.0180
0.110	2.7940	0.680	17.2720
0.120	3.0480	0.690	17.5260
0.130	3.3020		
0.140	3.5560		
0.150	3.8100		
0.160	4.0640	0.700	17.7800
0.170	4.3180	0.710	18.0340
0.180	4.5720	0.720	18.2880
0.190	4.8260	0.730	18.5420
		0.740	18.7960
0.200	5.0800	0.750	19.0500
0.210	5.3340	0.760	19.3040
0.220	5.5880	0.770	19.5580
0.230	5.8420	0.780	19.8120
0.240	6.0960	0.790	20.0660
0.250	6.3500		
0.260	6.6040		
0.270	6.8580		
0.280	7.1120	0.800	20.3200
0.290	7.3660	0.810	20.5740
		0.820	20.8280
0.300	7.6200	0.830	21.0820
0.310	7.8740	0.840	21.3360
0.320	8.1280	0.850	21.5900
0.330	8.3820	0.860	21.8440
0.340	8.6360	0.870	22.0980
0.350	8.8900	0.880	22.3520
0.360	9.1440	0.890	22.6060
0.370	9.3980		
0.380	9.6520		
0.390	9.9060	0.900	22.8600
0.400	10.1600	0.910	23.1140
0.410	10.4140	0.920	23.3680
0.420	10.6680	0.930	23.6220
0.430	10.9220	0.940	23.8760
0.440	11.1760	0.950	24.1300
0.450	11.4300	0.960	24.3840
0.460	11.6840	0.970	24.6380
0.470	11.9380	0.980	24.8920
0.480	12.1920	0.990	25.1460
0.490	12.4460	1.000	25.4000

Weights

Symbol	Grain Units	Grams Per Unit	Troy Ounces Per Unit	Avoirdupois Ounces Per Unit	Troy Pounds Per Unit	Avoirdupois Pounds Per Unit	Kilograms Per Unit	Metric Tons Per Unit	Avoirdupois Tons Per Unit	Per Unit
gr	Grain	1	.0648	.002083	.002286	.0001736	.0001429	–	–	–
g	Gram	15.4324	1	.032151	.035274	.002679	.002205	.001	–	–
oz. t.	Ounce Troy	480	31.1035	1	1.09715	.083333	0.68571	.031103	–	–
oz. av.	Ounce Av.	437.5	28.3495	.911458	1	.075955	.0625	.028350	–	–
lb. t.	Pound Troy	5760	373.242	12	13.1657	1	.822857	.37324	.000373	.000411
lb. av.	Pound Av.	7000	453.59	14.5833	16	1.215278	1	.45359	.000454	.00050
kg	Kilograms	–	1000	32.1507	35.274	2.67923	2.20462	1	.001	.001102
–	Ton Metric	–	–	32150.7	35274	2679.23	2204.62	1000	1	1.10231
–	Ton Av.	–	–	29166.7	32000	2430.56	2000	907.185	.907185	1

e.g. 1 gram = .032151 troy ounces
so 40 grams would be (40 g)
(.032151 oz.t/g) = 1.28604 oz.t

Conversion Tables

Units and Conversion Factors

Linear Measure								
Symbol	Unit	Inches per Unit	Feet per Unit	Yards per Unit	Miles per Unit	Centimeters per Unit	Meters per Unit	Kilometers per Unit
in	Linear Inch	1	0.0833	0.027778	–	2.54	0.0254	–
ft	Linear Foot	12	1	0.3333	–	30.480	0.3048	–
yd	Linear Yard	36	3	1	–	91.44	0.9144	–
mi	Linear Mile	63360	5280	1760	1	–	1609.34	1.609
cm	Centimeter	0.3937	0.0328	0.010936	–	1	0.01	–
m	Meter	39.37	3.2808	1.093613	–	100	1	.001
km	Kilometer	39370	3280.8	1093.613	.6214	–	1000	1

Eg. 1 meter = 3.2808 ft so 300 meters would be (300m) (3.2808 ft/m) = 984.24 ft.

Square Measure								
Symbol	Unit	Square Inches per Unit	Square Feet per Unit	Square Yards per Unit	Acres per Unit	Square Centimeters per Unit	Square Meters per Unit	Hectares per Unit
in^2	Square Inch	1	0.006944	0.0007716	–	6.4516	0.000645	–
ft^2	Square Foot	144	1	0.111111	–	929.034	0.0929	–
yd^2	Square Yard	1296	9	1	–	8361.274	0.836127	–
–	[1]Acre	–	43560	4840	1	–	4047	0.4047
cm^2	Sq. Centimeter	.15500	0.0010764	0.00011960	–	1	0.0001	
m^2	Square Meter	1550.0031	10.76391	1.195990	–	10000	1	0.0001
–	Hectares	–	–	11954.8	2.47	–	1000	1

1) 640 Acres = 1 square mile. Eg. 1 square meter = 1.195990 square yards so 30 square meters would be ($30m^2$) (1.195990 yd^2/m^2) = 35.88 yd2

Cubic Measure						
Symbol	Unit	Cubic Inches per Unit	Cubic Feet per Unit	Cubic Yards per Unit	Cubic Centimeters per Unit	Cubic Meters per Unit
cu in	Cubic Inch	1	.0005787	.00002143	16.387064	.000016387
cu ft	Cubic Foot	1728	1	.037037	28316.847	.018317
cu yard	Cubic Yard	46656	27	1	764554.9	.7646
cu cm or cm^3	Cu Centimeter	0.0610237	.0000353	.000001308	1	.000001
cu m or m^3	Cubic Meter	61023.74	35.31467	1.307951	1,000,000	1

Eg. $1m^3$ = 1.307951cu yds so 3 cubic meters would be ($3m^3$) (1.307942 cu yd/m^3) = 3.923853 cu yd

Liquid Measure						
Symbol	Unit	Fluid Ounces per Unit	Pints per Unit	Quarts per Unit	Gallons per Unit	Litres per Unit
fl. oz.	Fluid Ounces	1	.0625	.03125	.0078125	.02957
–	Pint	16	1	.5	.125	.4732
1 qt.	Quart	32	2	1	.25	.9464
gal	Gallons	128	8	4	1	3.7854
1	Litre	33.814	2.1134	1.0567	.26417	1

Eg. 1 Litre = .26418 gallons so 4 Litres would be (4l) (.26418 gal/l) = 1.05672 gal

Weights										
Symbol	Grain Units	Grams per Unit	Troy Ounces per Unit	Avoirdupois Ounces per Unit	Troy Pounds per Unit	Avoirdupois Pounds per Unit	Kilograms per Unit	Metric Tons per Unit	Avoirdupois Tons per Unit	Per Unit
gr	Grain	1	.0648	.002083	.002286	.0001736	.0001429	–	–	–
g	Gram	15.4324	1	.032151	.035274	.002679	.002205	.001	–	–
oz. t.	Ounce Troy	480	31.1035	1	1.09715	.083333	.068571	.031103	–	–
oz. av.	Ounce Av.	437.5	28.3495	.911458	1	.075955	.0625	.028350	–	–
lb. t.	Pound Troy	5760	373.242	12	13.1657	1	.822857	.37324	.000373	.000411
lb. av.	Pound Av.	7000	453.59	14.5833	16	1.215278	1	.45359	.000454	.00050
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–	Ton Metric	–	–	32150.7	35274	2679.23	2204.62	1000	1	1.10231
–	Ton Av.	–	–	29166.7	32000	2430.56	2000	907.185	.907185	1

Eg. 1 gram = .032151 troy ounces so 40 grams would be (40g) (.032151 oz.t./g) = 1.28604 oz. t.

Pressure Conversion

from \ to	PSI	KPA	Inches* H_2O	mmH_2O	Inches** Hg	mm Hg	Bars	m Bars	Kg/cm^2	gm/cm^2
PSI	1	6.8948	27.7620	705.1500	2.0360	51.7149	0.0689	68.9470	0.0703	70.3070
KPA	0.1450	1	4.0266	102.2742	0.2953	7.5006	0.0100	10.0000	0.0102	10.197
Inches* H_2O	0.0361	0.2483	1	25.4210	0.0734	1.8650	0.0025	2.4864	0.0025	2.5355
mm H_2O	0.0014	0.0098	0.0394	1	0.0028	0.0734	0.0001	0.0979	0.00001	0.0982
Inches** Hg	0.4912	3.3867	13.6195	345.936	1	25.4000	0.0339	33.8639	0.0345	34.532
mm Hg	0.0193	0.1331	0.5362	13.6195	0.0394	1	0.0013	1.3332	0.0014	1.3595
Bars	14.5040	100.000	402.180	10215.0	29.5300	750.060	1	1000	1.0197	1019.72
m Bars	0.0145	0.1000	0.4022	10.2150	0.0295	0.7501	0.001	1	0.0010	1.0197
Kg/cm^2	14.2233	97.9047	394.408	10018.0	28.9590	735.559	0.9000	980.700	1	1000
gm/cm^2	0.0142	0.0979	0.3944	10.0180	0.0290	0.7356	0.0009	0.9807	0.001	1

EXAMPLE 1 mm Hg = 0.5362 inches H_2O = 1.3332 mBars
97 mm Hg = 97(0.5362) = 52.0114 inches H_2O
97 mm Hg = 97(1.3332) = 129.3204 mBars

* at 60 °F
** at 32 °F

Volume Conversion

from \ to	cm^3	liter	m^3	in^3	ft^3	yd^3	fl oz	fl pt	fl qt	gal	gal (Imp.)	bbl (oil)	bbl (liq)
cm^3	1	0.001	1×10^{-6}	0.06102	3.53×10^{-5}	1.31×10^{-4}	0.03381	0.00211	0.00106	2.64×10^{-4}	2.20×10^{-4}	6.29×10^{-6}	8.39×10^{-6}
liter	1000	1	0.001	61.02	0.03532	0.00131	33.81	2.113	1.057	0.2642	0.2200	0.00629	0.00839
m^3	1×10^{6}	1000	1	6.10×10^{4}	35.31	1.308	3.38×10^{4}	2113	1057	264.2	220.0	6.290	8.386
in^3	16.39	0.01639	1.64×10^{-5}	1	5.79×10^{-4}	2.14×10^{-5}	0.5541	0.03463	0.01732	0.00433	0.00360	1.03×10^{-4}	1.37×10^{-4}
ft^3	2.83×10^{4}	28.32	0.02832	1728	1	0.03704	957.5	59.84	29.92	7.481	6.229	0.1781	0.2375
yd^3	7.65×10^{5}	764.5	0.7646	4.67×10^{4}	27	1	2.59×10^{4}	1616	807.9	202.0	168.2	4.809	6.412
fl oz	29.57	0.02957	2.96×10^{-6}	1.805	0.00104	3.87×10^{-5}	1	0.06250	0.03125	0.00781	0.00651	1.86×10^{-4}	2.48×10^{-4}
fl pt	473.2	0.4732	4.73×10^{-4}	28.88	0.01671	6.19×10^{-4}	16	1	0.5000	0.1250	0.1041	0.00298	0.00397
fl qt	946.4	0.0463	9.46×10^{-4}	57.75	0.03342	0.00124	32	2	1	0.2500	0.2082	0.00595	0.00794
gal	3785	3.785	0.00379	231.0	0.1337	0.00495	128	8	4	1	0.8327	0.02381	0.03175
gal (Imp.)	4546	4.546	0.00455	277.4	0.1605	0.00595	153.7	9.608	4.804	1.201	1	0.02859	0.03813
bbl (oil)	1.59×10^{5}	159.0	0.1590	9702	5.615	0.2079	5376	336	168	42	34.97	1	1.333

1 cord = 128 ft^3 = 3.625 m^3

Flow Rate Conversion

from \ to	lit/sec	gal/min	ft^3/sec	ft^3/min	bbl/hr	bbl/day
lit/sec	1	15.85	0.03532	2.119	22.66	543.8
gal/min	0.06309	1	0.00223	0.1337	1.429	34.30
ft^3/sec	28.32	448.8	1	60	641.1	1.54×10^{4}
ft^3/min	0.4719	7.481	0.01667	1	10.69	256.5
bbl/hr	0.04415	0.6997	0.00156	0.09359	1	24
bbl/day	0.00184	0.02917	6.50×10^{-5}	0.00390	0.04167	1

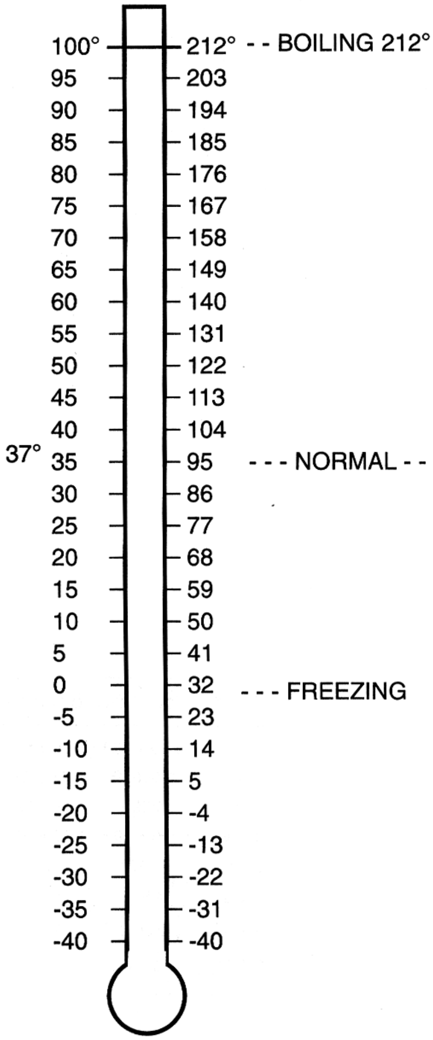
bbl refers to bbl oil = 42 gallons

Temperature Conversions

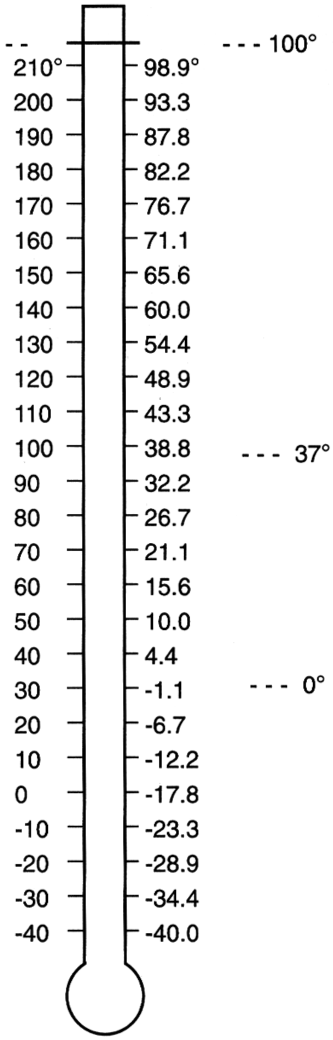
Temperature Conversions

Fahrenheit thermometers are in common use in the United States, but scientists and all others who use the metric system use the scale called Celsius. This scale is the same as Centigrade, but the National Insistute of Standards and Technology has recommended the use of the term Celsius since 1948. See the conversions below:

Celcius to Fahrenheit



Fahrenheit to Celcius



Centigrade-Fahrenheit Dimension Conversion Ratios

C	F	C	F	C	F
0	32.0	35	95.0	70	158.0
1	33.8	36	96.8	71	159.8
2	35.6	37	98.6	72	161.6
3	37.4	38	100.4	73	163.4
4	39.2	39	102.2	74	165.2
5	41.0	40	104.0	75	167.0
6	42.8	41	105.8	76	168.8
7	44.6	42	107.6	77	170.6
8	46.4	43	109.4	78	172.4
9	48.2	44	111.2	79	174.2
10	50.0	45	113.0	80	176.0
11	51.8	46	114.8	81	177.8
12	53.6	47	116.0	82	179.6
13	55.4	48	118.4	83	181.4
14	57.2	49	120.2	84	183.2
15	59.0	50	122.0	85	185.0
16	60.8	51	123.8	86	186.8
17	62.6	52	125.6	87	188.6
18	64.4	53	127.4	88	190.1
19	66.2	54	129.2	89	192.2
20	68.0	55	131.0	90	194.0
21	69.8	56	132.8	91	195.8
22	71.6	57	134.6	92	197.6
23	73.4	58	136.4	93	199.4
24	75.2	59	138.2	94	201.2
25	77.0	60	140.0	95	203.0
26	78.8	61	141.8	96	204.0
27	80.6	62	143.6	97	206.6
28	82.4	63	145.4	98	208.4
29	84.2	64	147.2	99	210.2
30	86.0	65	149.0	100	212.0
31	87.8	66	150.8		
32	89.6	67	152.6		
33	91.4	68	154.4		
34	93.2	69	156.2		

Centigrade-Fahrenheit Conversion

F=(Cx $^9/_5$) + 32C=(F-32) x$^5/_8$

To convert Celsius degrees into Fahrenheit: multiply by 9, divide by 5 and add 32.
To convert Fahrenheit into Celsius: subtract 32 from Fahrenheit, multiply by 5, divide by 9

Centigrade-Fahrenheit Conversion

F=(Cx $^9/_5$) + 32C=(F-32) x$^5/_8$

Metric Conversions

Conversion Ratios

Multiply	By	To Obtain
Diameter circle	3.141	Circumference circle
Diameter circle	0.8862	Side of equal square
Diameter circle squared	0.7854	Area of circle
Circular mils	0.7854	Square mils
Diameter sphere squared	3.1416	Area of sphere
Diameter sphere cubed	0.5236	Volume of sphere
U.S. gallons	0.8327	Imperial gallons (British)
U.S. gallons	0.1337	Cubic feet
U.S. gallons	8.330	Pounds of water (20C)
Cubic feet	62.427	Pounds of water (4C)
Feet of water (4C)	0.4335	Pounds per square inch
Inches of mercury (0C)	0.4912	Pounds per square inch
Seconds squared	16.08	Feet fallen from rest
Knots	1.1516	Miles per hour
To obtain the above	Divide by	Starting with the above

Metric Conversions

	Metric	U.S.
Length		
	1 millimeter	=0.03937 inches
	1 centimeter	=0.3937 inches
	1 decimeter	=3.937 inches
	1 meter	=39.37 inches
	1 meter	=3.280 feet
	1 meter	=1.094 yards
	1 dekameter	=32.808 feet
	1 kilometer	=3280.8 feet
	1 kilometer	=0.621 miles
Area		
	1 square millimeter	=0.002 square inches
	1 square centimeter	=0.155 square inches
	1 square decimeter	=15.500 square inches
	1 square meter	=10.764 square feet
	1 square meter	=1.196 square yards
	1 acre	=119.599 square yards
	1 hectare	=2.471 acres
	1 square kilometer	=0.386 square miles
Volume		
	1 millimeter	=0.271 fluid drams
	1 liter	=1.057 liquid quarts
	1 dekaliter	=2.642 gallons
	1 hectoliter	=26.418 gallons
Weight		
	1 milligram	=0.015 grains
	1 gram	=15.432 grains
	1 gram	=0.035 ounces
	1 kilogram	=25.274 ounces
	1 kilogram	=2.205 pounds
	1 metric ton	=1.102 short (U.S.) tons
	1 metric ton	=2,204.623 pounds

	U.S.	Metric
Length		
	1 inch	=2.54 centimeters
	1 foot	=0.3048 meters
	1 yard	=0.9144 meters
	1 mile	=1,609.3 meters
	1 mile	=1,609 kilometers
Area		
	1 square inch	=6.4516 square centimeters
	1 square foot	=9.2903 square decimeters
	1 square yard	=0.836 square meters
	1 acre	=0.405 hectares
	1 square mile	=2.5899 square kilometers
Volume		
	1 pint	=0.473 liter
	1 quart	=0.946 liter
	1 gallon	=3.785 liters
Weight		
	1 grain	=64.799 milligrams
	1 ounce	=28.350 grams
	1 pound	=453.592 grams
	1 short ton	=.907 metric ton

Temperature Sensor Technology

Table 3
Sheaths Max. Operating Temp.

Material	Max. Temperature (F°)
Carbon Steel	1000°F
304/316 SS	1800°F
**Monel TM	2000°F
***Hastelloy TM C	2000°F
446 Stainless Steel	2000°F
Nickel	2000°F
****Inconel TM 600	2100°F
*****Kanthal TM	2200°F
Quartz	2300°F
Cobalt Tungsten	2400°F
Titanium	2700°F
Zirconium	3000°F
Silicon Carbide	3000°F
Platinum Rhodium	3050°F
Silicon Nitride	3150°F
Mullite (Porcelain)	3200°F
99% Alumia (Al203)	3400°F
Moly (molybdenum)	4000°F
Tantium	4500°F
Tungsten	5000°F

Table 4
Interior Insulations
Max. Operating Temp.

Material	Max. Temperature (F°)
(1) Al203	2400°F
(2) Mg 0	2500°F
(3) Th O2°	4000°F
(4) Be 0 (toxic)	4200°F

Table 6
Temperature Span vs.
Thermistor Resistance

Temperature	Resistance (Ohms)
+300 to 600°F	100K-500K @ 25°C
+150 to 300°F	2K-75K @ 25°C
+32 to 212°F	2K-5K @ 25°C
-100 to +150°F	100-1K @ 25°C

* *Trademark of Hoskins Mfg. Co.*
** *Trademark of International Nickel Co.*
*** *Trademark of Union Carbide Co.*
**** *Trademark of International Nickel Co.*
***** *Trademark of Kanthal Corp.*

Table 5
Lead Insulations
Max. Operating Temp.

Material	Max. Temperature (F°)
Teflon	500°F
Kapton	55/750°F
Glass	1200°F
Asbestos	1200°F
Cefir (R)	2500°F
Ceramic	3000 to 4000°F

RTDs (Resistance Temperature Detectors)

RTDs are made of copper, nickel, balco (nickel-iron) and platinum, with platinum now becoming the industry standard. These are resistance temperature detectors made of a single high purity wire, usually 0.001″ in diameter, space wound onto a ceramic mandrel. Lead wires of nickel plated or ni-clad copper are fusion or resistance welded onto the sensor, usually in a three-wire or four-wire configuration. The sensor itself is then inserted into a thermowell of appropriate material and pressure rated for the intended environment. Most sheathed sensors (RTD or T/C) in industial applications are brazed or welded onto appropriate fittings and attached through a pipe extension to a connection head.

These intermediate leads are normally glass insulated and are brought out to the end of the sheath through powdered aluminum oxide insulation or a suitable high temperature epoxy. The external lead wires are attached (welded, brazed, soldered, etc.) and potted with a moisture sealing compound (epoxy or ceramic cement). If operation is above 700°F, preoxidized inconel tubing may replace the stainless steel sheath to avoid outgassing contamination.

Standard RTD resistance (at ice point) are 100 and 200 ohms for platinum, 120 or 500 ohm for nickel and 604 or 2000 ohm for balco. Copper RTDs (and thermistors) are specified at 25°C (77°F) instead of ice point (32°F). Thus a 10 or 100 ohm copper RTD is actually 9.038 or 90.38 ohms @ 32°F.

RTD's used the most instrumentation and the only standard to date, DIN, is 100 ohm platinum with a coefficient of 0.00385Ω/Ω°C (or 3850 ppm), indicating a resistance of 138.50 ohms at boiling point (100°C, 212°F). Tables for the Calendar-Van Dusen Equation have been calculated for both DIN 3850 alphas and higher U.S. Reference Grade (higher purity (99.999%) platinum), alphas, such as 3915 and 3923 ppm.

Theoretically, it is possible to build an RTD above 1200°F. Unfortunately, platinum is easy to contaminate or strain, which shifts the "alpha" or temperature coefficient, rendering the sensor unstable.

Thermistors

As resistance temperature devices (RTD), thermistors provide a direct indication of absolute temperature. They do not need cold junction compensation. They are excellent for low temperature measurements (-450°F) and to a high temperature of about 600°F, above which they decrease in stability. Their sensing area is small and their low mass (unless sheathed) allows a fairly fast response time of measurement.

Thermistors exhibit very high sensitivity and may change resistance 10 million to one over the span of -100 to +400°C where a platinum RTD would only change resistance by a 4:1 ratio over the same span. A thermocouple's output over its entire temperature range will change only 10 or 15 to 1. Compared with thermocouple accuracies of a few degrees and RTD accuracy of possibly a tenth of a degree, thermistor offer accuracies of ±.01°C over narrow temperature spans.

Efforts have been made recently to overcome their extreme nonlinearity by increasing the number of elements in the measuring network. With three thermistor networks, the linearity has been improved and the temperature span widened.

With curve matched and selected units, thermistor interchangeably has yielded accuracies of ±0.2°C over wider temperature ranges. Their low cost makes them attractive in volume applications such as the automotive industry and for refrigeration controls. Their upper temperature limit (600°F) effectively precludes them from use in the power, chemical and metal process industries. They are widely used in temperature controllers for copiers, air conditioning, photography, and other limited applications.

Temperature Sensor Technology

Types of Sensors

There are three basic types of temperature sensors commonly used today: Thermistors, Thermocouples and Platinum RTDs. Listed below in tabular format are the important features of each of these devices.

In general, thermocouples provide the most economical means of measurement over the widest temperature detectors which include both thermistors and platinum RTDs will, in general, provide a more accurate means of absolute temperature measurement. This is true, however, over narrow temperature ranges.

Thermocouples

Thermocouples (T/C) are practically the only option available today to measure temperatures in the range from +1200°F to +5000°F.

When using and selecting thermocouples, it is very important to consider the atmosphere, environment, (how corrosive, how much pressure or vacuum, reducing or oxidizing atmosphere), as well as the temperature being measured. These and other factors not only affect the choice of material used for insulation, wire size, wire insulation and sheaths, but also may determine the construction of the sensor.

Most thermocouples are physically mounted in stainless steel (type 304 or 316) sheaths, approximately 0.25 inch diameter. They are mineral insulated inside and bendable to different shapes. External lead wire insulation includes teflon, micatemp and ceramic beads or cloth. Wire sizes used depend on the sheath diameter and other factors. Larger diameters (from 12-16 gauge) are often used in open or exposed junction configurations. Larger diameter wires are also required to operate at higher temperatures.

The following tables show the maximum operating temperatures for thermocouples and their related components.

Comparison of Temperature Sensors

Specification	*Platinum RTD***	*Thermocouple*	*Thermistor*
Typical Operating Temperature Range	-320°F to +1200°F	-320°F to +2300°F	-150°F to +300°F
Accuracy Interchangeability	-40 to 212°F:±0.5°F 212 to 932°F:±3°F 932 to 1200°F:±3.75°F	32 to 530°F:±1 ½°F to ±4°F 530 to 2300°F:± ½ to ± ¾%*	-40 to 2121°F:±0.5°F degrades rapidly over 212°F
Typical Sensitivity at 32°F	0.21 mV/°F with bridge	0.02 mV/°F	2 mV/°F with bridge
Stability	±0.01% for 5 Years	1 to 2°F per year	±0.2 to 0.5°F per year
Repeatability	0.05°F	2 to 4°F	0.2 to 1°F
Linearity	GOOD	AVERAGE	POOR
Size (Min.) Diameter	0.125″ diameter	0.015″ diameter	0.100″
Time Response	2-5/secs.	2-5/secs.	1-2/secs.
Remarks	Best for accuracy & stability over wide temp. range	Low signal-level Not best accuracy	Wide range, economical, limited on temp., poor linearity	High sensitivity

** % of measuring reading.*
*** Industrial grade, 100 ohms, at 0°C, at 0°C, with 1.0 milliampere excitation.*
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In addition, thermocouples require a reference junction. The output voltage of a T/C is approximately proportional to the temperature difference between the measuring (hot) junction and the reference (cold) junction. This constant of proportionality is known as the Seebeck Coefficient and ranges from 5 to 50V/°C for commonly used thermocouples. The best way to know the temperature at the reference junction is to keep this junction in an ice bath resulting in zero output voltage of 0°C (32°F), A more convenient approach used in electronic instruments is known as cold junction compensation. This technique adds a compensating voltage to the thermocouple's output so that the reference junction appears to be at 0°, independent of the actual temperature. If this compensating voltage is proportionality as the thermocouple, changes in ambient temperature will have no effect on output voltage.

Table 1
Sheath and Wire Sizes

Sheath Diameter		*Wire Diameter*		
Fractions	*Inches*	*Inches*	*mm*	*Gauge*
1/16	0.062	0.01 to 0.013	0.2 to 0.32	28-32
1/18	0.125	0.016 to 0.02	0.4 to 0.8	24-36
3/16	0.188	0.032	0.8	20
1/4	0.250	0.032 to 0.040	0.8 to 1.0	18-20

Table 2
Thermocouples Max. Operating Temp.

Thermocouples	*Max. Temperature (F°)*
J Iron Constantan	2192°F
*K Chromel Alumel TM	2501°F
T Copper Constantan	752°F
E Chromel Constantan	1832°F
R/S Platinum Rhodium	3214°F
B Platinum Rhodium	3308°F
C Tungsten Rhenium	5000°F

Thermocouple Wire Specifications

ANSI Color Code for Thermocouple and Thermocouple Extension Wire						
ANSI Type	Wire Alloys	*Thermocouple Wire Color*		*T/C extension Wire Color*		
		Polarity	*Individual*	*Overall*	*Individual*	*Overall*
T	Copper Constantan	+TP -TN	Blue Red	Brown	Blue Red	Blue
J	Iron Constantan	+JP -Jn	White Red	Brown	White Red	Black
E	Chromel Constantan	+EP -EN	Purple Red	Brown	Purple Red	Purple
K	Chromel Alumel	+KP -KN	Yellow Red	Brown	Yellow Red	Yellow
R	Platinum 13% Rhodium Platinum	+RP -RN			Black Red	Green
S	Platinum 10% Rhodium Platinum	+SP -SN			Black Red	Green
B	Platinum 30% Rhodium Platinum 6% Rhodium	+BP -BN			Grey Red	Grey

Bare Thermocouple Wire Approximately Weight feet/lb.									
Wire Ga B&S	*Wire Size Dia.*	*Type J*		*Type K*		*Type T*		*Type E*	
		Iron+ JP	*Constantan- JN*	*Chromel+ KP*	*Alumel- KN*	*Copper+ TP*	*Constantan- TN*	*Chromel+ EP*	*Constantan- EN*
6	.162	14.2	12.6	13	13	12.6	12.6	13	12.6
7	.144	18.0							
8	.128	22.8	20.2	21	21	19.8	20.2	21	20.2
14	.064	91.2	80.9	83	83	80.5	80.9	83	80.9
16	.050	144	127	130	130	128	127	130	127
18	.040	233	207	212	212	203	207	212	207
20	.032	365	324	331	331	324	324	331	324
24	.020	925	821	838	838	820	821	838	821
26	.015	1478	1312	1340	1340	1299	1312	1340	1312
28	.012	2353	2089	2130	2130	2062	2089	2130	2089
30	.010	3736	3316	3370	3370	3294	3316	3370	3316
36	.005	14940	13260	13500	13500	13250	13260	13500	13260

Nominal Thermocouple Resistance Ohms per Double Foot @ 68°F (20°C)								
Wire Ga B&S	*Wire Size Dia.*	*ANSI Types*						
		J	K	T	E	S	R	B
6	.162	.014	.023	.012	.027	.007	.007	.008
*7	.144	.021						
8	.128	.022	.036	.019	.044	.010	.010	.013
14	.064	.089	.147	.074	.176	.044	.044	.054
16	.050	.141	.232	.117	.277	.069	.069	.086
18	.040	.229	.377	.190	.450	.112	.113	.139
20	.032	.357	.588	.297	.702	.175	.178	.218
24	.020	.905	1.488	.754	1.778	.449	.453	.550
26	.015	1.441	2.450	1.200	2.840	.701	.708	.875
28	.012	2.297	3.590	1.920	4.330	1.062	1.073	1.392
30	.010	3.650	6.020	2.940	7.190	1.794	1.813	2.213
36	.005	14.660	24.080	12.220	28.800	7.150	7.226	8.897

American Wire Gauge (AWG)	Size Dia. Inches
7/0	—
6/0	0.5800
5/0	0.5165
4/0	0.4600
3/0	0.4096
2/0	0.3648
1/0	0.3249
1	0.2893
2	0.2576
3	0.2294
4	0.2043
5	0.1819
6	0.1620
7	0.1443
8	0.1285
9	0.1144
10	0.1019
11	0.0907
12	0.0808
13	0.0720
14	0.0641
15	0.0571
16	0.0508
17	0.0453
18	0.0403
19	0.0359
20	0.0320
21	0.0285
22	0.0253
23	0.0226
24	0.0201
25	0.0179
26	0.0159
27	0.0142
28	0.0126
29	0.0113
30	0.0100
31	0.00893
32	0.00795
33	0.00708
34	0.00630
35	0.00561
36	0.00500
37	0.00445
38	0.00396
39	0.00353
40	0.00314
41	0.00280
42	0.00249
43	0.00222
44	0.00198
45	0.00176
46	0.00157
47	0.00140
48	0.00124
49	0.00111
50	0.00099

Thermocouple Wire Specifications

Selection and Use of Thermocouple and Thermocouple Extension Wire

Thermocouple wire can be fabricated into accurate and dependable thermocouples by joining the thermoelements together at the sensing end. Thermocouple wire or thermocouple extension wire must be used to extend thermocouples to indication or control instrumentation. The conditions of measurement determine the type of thermocouple wire and insulation to be used. Temperature range, environment, protection, insulation requirements, response and service life should be considered. The following parameters serve as a guide to the selection of wire. For basic application study refer to Maelin literature "Applying the Systems Concept to Thermocouple Installations" an ISA reprint.

Temperature Limits for Thermocouple Wire

Temperature limits for standard thermocouples that are protected with a closed end protecting tube are shown. These limits are suggested for continuous temperature sensing where insulation is not a factor. For unprotected thermocouples where fast response is required, these limits should be reduced for equivalent service life.

Upper Temperature Limits for Thermocouples

Thermocouple Type	*ANSI TYPE SYMBOL*	*WIRE GAUGE (AWG)*				
		8 GAL	*14 GAL*	*20 GAL*	*24 GAL*	*30 GAL*
Copper-Constantan	T		370°C (700°F)	260°C (500°F)	200°C (400°F)	150°C (300°F)
*Iron-Constantan	J	760°C (1400°F)	600°C (1100°F)	500°C (900°F)	370°C (700°F)	320°C (600°F)
Chromel™-Constantan	E	870°C (1600°F)	650°C (1200°F)	550°C (1000°F)	430°C (800°F)	430°C (800°F)
Chromel™-Alumel™	K	1260°C (2300°F)	1100°C (2000°F)	1000°C (1800°F)	870°C (1600°F)	760°C (1400°F)
Nicrosil-Nisil	N	1260°C (2300°F)	1100°C (2000°F)	1000°C (1800°F)	870°C (1600°F)	760°C (1400°F)
Platinum-10% Rhodium	S				1480°C (2700°F)	
Platinum-13% Rhodium	R				1480°C (2700°F)	
Platinum-30% vs. 6% Rhodium	B				1700°C (3100°F)	
Tungsten-26% Rhenium	WR=				2300°F (4200°F)	
Tungsten-3% vs. 25% Rhenium	W3=				2300°F (4200°F)	
Tungsten-5% vs. 26% Rhenium	W5=				2300°F (4200°F)	

* Magnetic ™ Trade Mark Hoskins Mfg. Co. = Not ANSI Symbol

Insulation Characteristics

Insu. Code	*Insulation Description Individual/Overall*	*Continuous Use Temperature Limits*	*Single Exposure Temperature Limit*	*Moisture Resistance*	Abrasion Resistance
601 603	PVC/PVC PVC Rip Cord	-20 to +221°F -29 to +105°C	221°F 105°C	Excellent "	Good "
605	Polyvinyl/Polyvinyl Twisted & Shielded	-20 to +176°F -29 to 80°C	176°F 80°C	Excellent Excellent	Good Good
606	Nylon/Nylon	350°F	–	Fair	Excellent
607 608	Teflon on Singles (FEP) Teflon/Teflon (FEP ext.)	400°F 204°F	600°F 316°C	Excellent "	Excellent "
609	Teflon/Teflon TFE Tape	-90 to 500°F -68 to 260°C	600°F 316°C	Excellent "	Very Good "
610	Teflon/Teflon FEP Twisted & Shielded	400°F 204°C	600°F 316°C	Excellent "	Excellent "
611	TFE, Synthetic Fiber/ Synthetic Fiber	500°F 260°C	700°F 371°C	Good "	Good "
612	FEP, Fiberglass/ Fiberglass	400°F 204°C	600°F 316°C	Good "	Good "
618	Ceramic Fiber/ Ceramic Fiber	2600°F 1430°C	2600°F 1430°C	Fair "	Fair "
620	Vitreous Silica Fiber/ Vitreous Silica Fiber	1600°F 871°C	2000°F 1093°C	Fair "	Fair "
622	High Temp. Glass/ High Temp. Glass	1300°F 704°C	1600°F 871°C	Fair "	Fair "
623	High Temp. Fiberglass Twisted	1300°F 482°C	1300°F 538°C	Fair "	Fair "
628	Fiberglass/Fiberglass	900°F 482°C	1000°F 528°C	Good to 400°F (204°C)	Fair "
S	SS Overbraid	–	–	–	Excellent

Dimensions of Steel Tubing

Outside Diameter		Wall Thickness		Inside Diameter	Flow Area
(in)	(mm)	(in)	(mm)	(mm)	(m^2)
1/8	3.18	0.028	0.71	1.75	2.413×10^{-6}
		0.032	0.81	1.55	1.885×10^{-6}
		0.035	0.89	1.40	1.533×10^{-6}
3/16	4.76	0.032	0.81	3.14	7.729×10^{-6}
		0.035	0.89	2.98	6.996×10^{-6}
1/4	6.35	0.035	0.89	4.57	1.642×10^{-5}
		0.049	1.24	3.86	1.171×10^{-5}
		0.065	1.65	3.05	7.297×10^{-6}
3/16	7.94	0.035	0.89	6.16	2.979×10^{-5}
		0.049	1.24	5.45	2.331×10^{-5}
		0.065	1.65	4.64	1.688×10^{-5}
3/8	9.53	0.035	0.89	7.75	4.714×10^{-5}
		0.049	1.24	7.04	3.888×10^{-5}
		0.065	1.65	6.22	3.042×10^{-5}
1/2	12.70	0.035	0.89	10.92	9.365×10^{-5}
		0.049	1.24	10.21	8.189×10^{-5}
		0.065	1.65	9.40	6.937×10^{-5}
		0.083	2.11	8.48	5.652×10^{-5}
5/8	15.88	0.035	0.89	14.10	1.561×10^{-4}
		0.049	1.24	13.39	1.408×10^{-4}
		0.065	1.65	12.57	1.241×10^{-4}
		0.083	2.11	11.66	1.068×10^{-4}
3/4	19.05	0.049	1.24	16.56	2.154×10^{-4}
		0.065	1.65	15.75	1.948×10^{-4}
		0.083	2.11	14.83	1.728×10^{-4}
		0.109	2.77	13.51	1.434×10^{-4}
7/8	22.23	0.049	1.24	19.74	3.059×10^{-4}
		0.065	1.65	18.92	2.812×10^{-4}
		0.083	2.11	18.01	2.547×10^{-4}
		0.109	2.77	16.69	2.187×10^{-4}

Commercial Wrought Steel Pipe Data (ANSI B36.10)

	Nominal Pipe Size		O.D.	Wall Thickness		I.D.	Flow Area	
	mm	inches	inches	mm	inches	inches	mm^2	sq in
Schedule 10	350	14	14	6.35	0.250	13.5	92200	143
	400	16	16	6.35	0.250	15.5	121900	189
	450	18	18	6.35	0.250	17.5	155500	241
	500	20	20	6.35	0.250	19.5	192900	299
	600	24	24	6.35	0.250	23.5	280000	434
	750	30	30	7.92	0.312	29.4	437400	678
Schedule 20	200	8	8.63	6.35	0.250	8.13	33500	51.9
	250	10	10.8	6.35	0.250	10.3	53200	82.5
	300	12	12.8	6.35	0.250	12.3	76000	117.9
	350	14	14.0	7.92	0.312	13.4	90900	141
	400	16	16.0	7.92	0.312	15.4	120000	186
	450	18	18.0	7.92	0.312	17.4	152900	237
	500	20	20.0	9.53	0.375	19.3	187700	291
	600	24	24.0	9.53	0.375	23.3	274200	425
	750	30	30.0	12.70	0.500	29.0	426400	661
Schedule 30	200	8	8.63	7.04	0.277	8.07	33000	51.2
	250	10	10.8	7.80	0.307	10.1	52000	80.7
	300	12	12.8	8.38	0.330	12.1	74200	115
	350	14	14.0	9.53	0.375	13.3	89000	138
	400	16	16.0	9.53	0.375	15.3	118000	183
	450	18	18.0	11.13	0.438	17.1	148400	230
	500	20	20.0	12.70	0.500	19.0	183200	284
	600	24	24.0	14.27	0.562	22.9	265100	411
	750	30	30.0	15.88	0.625	28.8	418700	649
Schedule 40*	15	1/2	0.84	2.77	0.109	0.622	190	0.304
	20	3/4	1.05	2.87	0.113	0.824	340	0.533
	25	1	1.32	3.38	0.133	1.05	550	0.864
	32	1 1/4	1.66	3.56	0.140	1.38	970	1.50
	40	1 1/2	1.90	3.68	0.145	1.61	1300	2.04
	50	2	2.38	3.91	0.154	2.07	2150	3.34
	65	2 1/2	2.88	5.16	0.203	2.47	3100	4.79
	80	3	3.50	5.49	0.216	3.07	4700	7.39
	100	4	4.50	6.02	0.237	4.03	8200	12.7
	150	6	6.63	7.11	0.280	6.07	18600	28.9
	200	8	8.63	8.18	0.322	7.98	32200	50.0
	250	10	10.8	9.27	0.365	10.02	50900	78.9
	300	12	12.8	10.31	0.406	11.9	72200	112
	350	14	14.0	11.13	0.438	13.1	87100	135
	400	16	16.0	12.70	0.500	15.0	114200	177
	450	18	18.0	14.27	0.562	16.9	144500	224
	500	20	20.0	15.06	0.593	18.8	179300	278
	600	24	24.0	17.45	0.687	22.6	259300	402

***Standard wall pipe same as Schedule 40 through 10" size. 12" size data follows.**

300	12	12.8	9.53	0.375	12.00	72900	113

Commercial Wrought Steel Pipe Data (ANSI B36.10) (continued)

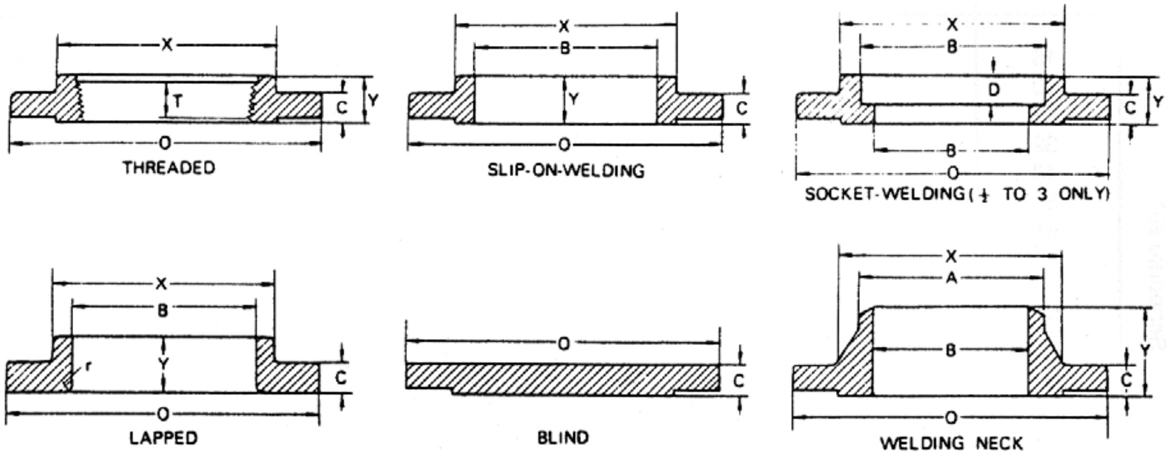
	Nominal Pipe Size		O.D.	Wall Thickness		I.D.	Flow Area	
	mm	inches	inches	mm	inches	inches	mm²	sq in
Schedule 80*	15	1/2	0.84	3.73	0.147	0.546	150	0.234
	20	3/4	1.05	3.91	0.154	0.742	280	0.433
	25	1	1.32	4.55	0.179	0.957	460	0.719
	32	1 1/4	1.66	4.85	0.191	1.28	820	1.28
	40	1 1/2	1.90	5.08	0.200	1.50	1140	1.77
	50	2	2.38	5.54	0.218	1.94	1900	2.95
	65	2 1/2	2.88	7.01	0.276	2.32	2700	4.24
	80	3	3.50	7.62	0.300	2.90	4200	6.61
	100	4	4.50	8.56	0.337	3.83	7400	11.5
	150	6	6.63	10.97	0.432	5.76	16800	26.1
	200	8	8.63	12.70	0.500	7.63	29500	45.7
	250	10	10.8	15.06	0.593	9.56	46300	71.8
	300	12	12.8	17.45	0.687	11.4	65800	102
	350	14	14.0	19.05	0.750	12.5	79300	123
	400	16	16.0	21.41	0.843	14.3	103800	161
	450	18	18.0	23.80	0.937	16.1	131600	204
	500	20	20.0	26.16	1.03	17.9	163200	253
	600	24	24.0	30.99	1.22	21.6	235400	365
Schedule 160	15	1/2	0.84	4.75	0.187	0.466	110	0.171
	20	3/4	1.05	5.54	0.218	0.614	190	0.296
	25	1	1.32	6.35	0.250	0.815	340	0.522
	32	1 1/4	1.66	6.35	0.250	1.16	680	1.06
	40	1 1/2	1.90	7.14	0.281	1.34	900	1.41
	50	2	2.38	8.71	0.343	1.69	1450	2.24
	65	2 1/2	2.88	9.53	0.375	2.13	2300	3.55
	80	3	3.50	11.13	0.438	2.62	3500	5.41
	100	4	4.50	13.49	0.531	3.44	6000	9.28
	150	6	6.63	18.24	0.718	5.19	13600	21.1
	200	8	8.63	23.01	0.906	6.81	23500	36.5
	250	10	10.8	28.70	1.13	8.50	36600	56.8
	300	12	12.8	33.27	1.31	10.1	51900	80.5
	350	14	14.0	35.81	1.41	11.2	63400	98.3
	400	16	16.0	40.39	1.59	12.8	83200	129
	450	18	18.0	45.21	1.78	14.4	105800	164
	500	20	20.0	50.04	1.97	16.1	130900	203
	600	24	24.0	59.44	2.34	19.3	189000	293
Double Extra Strong	15	1/2	0.84	7.47	0.294	0.252	30	0.050
	20	3/4	1.05	7.82	0.308	0.434	90	0.148
	25	1	1.32	9.09	0.358	0.599	180	0.282
	32	1 1/4	1.66	9.70	0.382	0.896	400	0.630
	40	1 1/2	1.90	10.16	0.400	1.10	610	0.950
	50	2	2.38	11.07	0.436	1.50	1140	1.77
	65	2 1/2	2.89	14.02	0.552	1.77	1600	2.46
	80	3	3.50	15.24	0.600	2.30	2700	4.16
	100	4	4.50	17.12	0.674	3.15	5000	7.80
	150	6	6.63	21.94	0.864	4.90	12100	18.8
	200	8	8.63	22.22	0.875	6.88	23900	37.1

***Extra strong pipe same as Schedule 80 through 8" size. 10" & 12" size data follows.**

250	10	10.8	12.70	0.500	9.75	48200	74.7
300	12	12.8	12.70	0.500	11.8	69700	108

Size Table

1. ANSI Type Flange (150 lb)



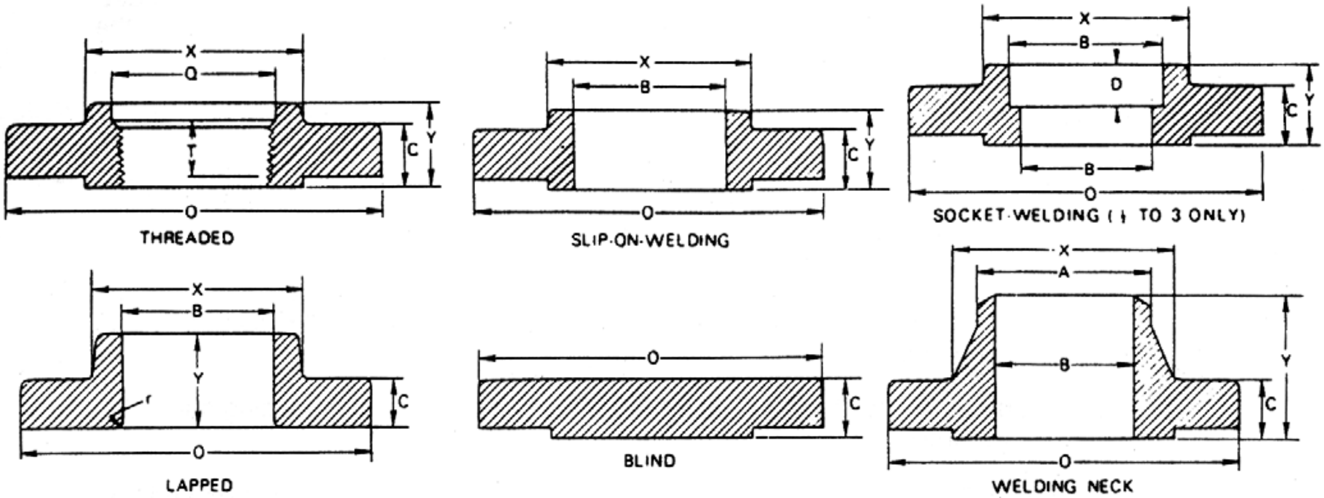
Dimensions of class 150 steel flanges

1	2	3	4	5	6	7	8	9	10	11	12	13	14
					Length Through Hub				Bore				
Nominal Pipe Size	Outside Diameter of Flange	Thickness of Flange Min.	Diameter of Hub	Hub Diameter Beginning of Chamfer Welding Neck	Threaded Slip-On Socket Welding	Lapped	Welding Neck	Thread Length Threaded Min.	Slip-On Socket Welding Min.	Lapped Min.	Welding Neck Socket Welding	Corner Radius of Bore of Lapped Flange and Pipe	Depth of Socket
	O	C	X	A	Y	Y	Y	T	B	B	B	r	D
½	3.50	0.44	1.19	0.84	0.62	0.62	1.88	0.62	0.88	0.90	0.62	0.12	0.38
¾	3.88	0.50	1.50	1.05	0.62	0.62	2.06	0.62	1.09	1.11	0.82	0.12	0.44
1	4.25	0.56	1.94	1.32	0.69	0.69	2.19	0.69	1.36	1.38	1.05	0.12	0.50
1¼	4.62	0.62	2.31	1.66	0.81	0.81	2.25	0.81	1.70	1.72	1.38	0.19	0.56
1½	5.00	0.69	2.56	1.90	0.88	0.88	2.44	0.88	1.95	1.97	1.61	0.25	0.62
2	6.00	0.75	3.06	2.38	1.00	1.00	2.50	1.00	2.44	2.46	2.07	0.31	0.69
2½	7.00	0.88	3.56	2.88	1.12	1.12	2.75	1.12	2.94	2.97	2.47	0.31	0.75
3	7.50	0.94	4.25	3.50	1.19	1.19	2.75	1.19	3.57	3.60	3.07	0.38	0.81
3½	8.50	0.94	4.81	4.00	1.25	1.25	2.81	1.25	4.07	4.10	3.55	0.38	–
4	9.00	0.94	5.31	4.50	1.31	1.31	3.00	1.31	4.57	4.60	4.03	0.44	–
5	10.00	0.94	6.44	5.56	1.44	1.44	3.50	1.44	5.66	5.69	5.05	0.44	–
6	11.00	1.00	7.56	6.63	1.56	1.56	3.50	1.56	6.72	6.75	6.07	0.50	–
8	13.50	1.12	9.69	8.63	1.75	1.75	4.00	1.75	8.72	8.75	7.98	0.50	–
10	16.00	1.19	12.00	10.75	1.94	1.94	4.00	1.94	10.88	10.92	10.02	0.50	–
12	19.00	1.25	14.38	12.75	2.19	2.19	4.50	2.19	12.88	12.92	12.00	0.50	–
14	21.00	1.38	15.75	14.00	2.25	3.12	5.00	2.25	14.14	14.18	To be	0.50	–
16	23.50	1.44	18.00	16.00	2.50	3.44	5.00	2.50	16.16	16.19	Specified	0.50	–
18	25.00	1.56	19.88	18.00	2.69	3.81	5.50	2.69	18.18	18.20	by	0.50	–
20	27.50	1.69	22.00	20.00	2.88	4.06	5.69	2.88	20.20	20.25	pur-	0.50	–
24	32.00	1.88	26.12	24.00	3.25	4.38	6.00	3.25	24.25	24.25	chaser	0.50	–

Notes: (1) All dimensions are given in inches.
(2) For machining tolerances see ANSI Standard B 16.5 - Latest Addition

Size Table

2. ANSI Type Flange (300 lb)



Dimensions of class 300 steel flanges

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
					Length Through Hub				Bore					
Nominal Pipe Size	Outside Diam. eter of Flange	Thick- ness of Flange Min.	Diam- eter of Hub	Hub Diameter Beginning of Chamfer Welding Neck	Threaded Slip-On Socket Welding	Lapped	Welding Neck	Thread Length Thread- ed Min.	Slip-On Socket Welding Min.	Lapped Min.	Welding Neck Socket Welding	Corner Radius of Bore of Lapped Flange and Pipe	Counter Bore Threaded Flange Min.	Depth of Socket
	O	C	X	A	Y	Y	Y	T	B	B	B	r	Q	D
1/2	3.75	0.56	1.50	0.84	0.88	0.88	2.06	0.62	0.88	0.90	0.62	0.12	0.93	0.38
3/4	4.62	0.62	1.88	1.05	1.00	1.00	2.25	0.62	1.09	1.11	0.82	0.12	1.14	0.44
1	4.88	0.69	2.12	1.32	1.06	1.06	2.44	0.69	1.36	1.38	1.05	0.12	1.41	0.50
1 1/4	5.25	0.75	2.50	1.66	1.06	1.06	2.56	0.81	1.70	1.72	1.38	0.19	1.75	0.56
1 1/2	6.12	0.81	2.75	1.90	1.19	1.19	2.69	0.88	1.95	1.97	1.61	0.25	1.99	0.62
2	6.50	0.88	3.31	2.38	1.31	1.31	2.75	1.12	2.44	2.46	2.07	0.31	2.50	0.69
2 1/2	7.50	1.00	3.94	2.88	1.50	1.50	3.00	1.25	2.94	2.97	2.47	0.31	3.00	0.75
3	8.25	1.12	4.62	3.50	1.69	1.69	3.12	1.25	3.57	3.60	3.07	0.38	3.63	0.81
3 1/2	9.00	1.19	5.25	4.00	1.75	1.75	3.19	1.44	4.07	4.10	3.55	0.38	4.13	–
4	10.00	1.25	5.75	4.50	1.88	1.88	3.38	1.44	4.57	4.60	4.03	.044	4.63	–
5	11.00	1.38	7.00	5.56	2.00	2.00	3.88	1.69	5.66	5.69	5.05	0.44	5.69	–
6	12.50	1.44	8.12	6.63	2.06	2.06	3.88	1.81	6.72	6.75	6.07	0.50	6.75	–
8	15.00	1.62	10.25	8.63	2.44	2.44	4.38	2.00	8.72	8.75	7.98	0.50	8.75	–
10	17.50	1.88	12.62	10.75	2.62	3.75	4.62	2.19	10.88	10.92	10.02	0.50	10.88	–
12	20.50	2.00	14.75	12.75	2.88	4.00	5.12	2.38	12.88	12.92	12.00	0.50	12.94	–
14	23.00	2.12	16.75	14.00	3.00	4.38	5.62	2.50	14.14	14.18		0.50	14.19	–
16	25.50	2.25	19.00	16.00	3.25	4.75	5.75	2.69	16.16	16.19	To be	0.50	16.19	–
18	28.00	2.38	21.00	18.00	3.50	5.12	6.25	2.75	18.18	18.20	specified	0.50	18.19	–
20	30.50	2.50	23.12	20.00	3.75	5.50	6.38	2.88	20.20	20.25	by pur-	0.50	20.19	–
24	36.00	2.75	27.62	24.00	4.19	6.00	6.62	3.25	24.25	24.25	chaser	0.50	24.19	–

Notes: (1) All dimensions are given in inches.
(2) For machining tolerances see ANSI Standard B 16.5 - Latest Addition

Glossary[1]

Globe Valve Nomenclature

Bonnet: A valve pressure retaining boundary which may guide the stem and contain the packing box and seal. The major part of the bonnet assembly, excluding the sealing means. (This term is often used in referring to the bonnet and its included packing parts. More properly, this group of component parts should be called the Bonnet Assembly.)

Bonnet Assembly: (Commonly Bonnet, more properly Bonnet Assembly): An assembly including the part through which a valve plug stem moves and a means for sealing against leakage along the stem. It usually provides a means for mounting the actuator.

Cage: A hollow cylindrical trim element that is a guide to align the movement of a valve plug with a seat ring. The cage may also retain the seat ring in the valve body. (The walls of the cage have openings which usually determine the flow characteristic of the control valve.)

Cage Guided Valve: A type of valve which uses a cage for plug guiding and alignment. See *Cage.*

Extension Bonnet: A bonnet with an extension between the packing box and bonnet flange for hot or cold service.

Globe Valve: A valve construction style with a linear motion flow controlling member with one or more ports, normally distinguished by a globular-shaped cavity around the port region. Two categories are commonly recognized depending on the method of plug guiding; cage guided and stem or plug guided.

Guide Bushing: A bushing in a bonnet, bottom flange, or body to align the movement of a valve plug with a seat ring.

Isolating Valve: A hand-operated valve between the packing lubricator and the packing box to shut off the fluid pressure from the lubricator.

Packing Box (Assembly): The part of the bonnet assembly used to seal against leakage around the valve plug stem. Included in the complete packing box assembly are various combinations of some or all of the following component parts: Packing, Packing Follower, Packing Nut, Lantern Ring, Packing Spring, Packing Flange, Packing Flange Studs or Bolts, Packing Flange Nuts, Packing Ring, Packing Wiper Ring, Felt Wiper Ring.

Packing Lubricator: An optional part of the bonnet assembly used to inject lubricant into the packing box.

Port: A fixed opening, normally the inside diameter of a seat ring, through which fluid passes.

Retaining Ring: A split ring that is used to retain a separable flange on a valve body.

Seat: That portion of the seat ring or valve body which a valve plug contacts for closure.

Seat Ring: A separate piece inserted in a valve body to form a valve body port. It generally provides a seating surface for the closure member.

1. Many of the definitions contained herein are either direct quotations of or derived from the Instrument Society of America's ANSI Approved Standard *S75.05 - Control Valve Terminology.* Copyright © ISA 1986. Reproduced herein by permission.

Separable Flange: A flange which fits over a valve body flow connection. It is generally held in place by means of a retaining ring.

Stem: See *Valve Plug Stem.*

Stem Connector: A two piece clamp which connects the actuator stem to the valve plug stem.

Stem or Plug-Guided Valve: A valve whose plug is guided by a bushing surrounding the plug or the stem (as opposed to cage guiding).

Trim: The internal parts of a valve which are in flowing contact with the controlled fluid. (In a globe valve body, trim would typically include valve plug, seat ring, cage, stem, and stem pin.)

Trim, Anti-Cavitation: Trim which is specifically designed to eliminate or reduce cavitation and cavitation damage in a control valve. A common approach uses a specially designed cage to maintain high pressures within the valve to prevent the liquid from cavitating.

Trim, Balanced: Trim which uses some design technique to equalize the forces of the flowing media on the bottom and the top of the plug. This technique reduces the actuator force necessary to throttle and seat the plug.

Trim, Noise Abatement: Trim which is specifically designed to eliminate or reduce control valve noise due to turbulence associated with high velocity flow. A common approach uses a slotted or drilled hole cage to reduce flowstream turbulence.

Trim, Reduced Capacity: A valve trim package which provides a smaller than standard port diameter to reduce capacity of the valve. Often used in startup situations when increased capacity at a later date is anticipated.

Trim, Soft-seated: Globe valve trim with an elastomer, plastic, or other readily deformable material used as an insert, either in the valve plug or seat ring, to provide very tight shutoff with minimal actuator force.

Valve Body: A housing for internal parts having inlet and outlet flow connections. Among the most common valve body constructions are: a) Single-ported valve bodies having one port and one valve plug, b) Double-ported valves bodies having two ports and one valve plug, c) Two-way valve bodies having two flow connections, one inlet and one outlet, d) Three-way valve bodies having three flow connections, two of which may be inlets with one outlet (for converging or mixing flows), or one inlet and two outlets (for diverging or diverting flows). (The term Valve Body, or even just Body, frequently is used in referring to the valve body together with its bonnet assembly and included trim parts. More properly, this group of components should be called the Valve Body Assembly).

Valve Body Assembly: (Commonly Valve Body or Body, more properly Valve Body Assembly): An assembly of a body, bonnet assembly, bottom flange (if used), and trim elements. The trim includes the valve plug which opens, closes, or partially obstructs one or more ports.

Valve Plug: A movable part which provides a variable restriction in a port.

Valve Plug Stem: The rod or shaft which connects the actuator to the plug.

Rotary-Shaft Valve Nomenclature

Ball, Full: The flow-controlling member of rotary-shaft control valves utilizing a complete sphere with a flow passage through it.

Ball, V-notch: The flow-controlling member for a popular style of throttling ball valve. The V-notch ball includes a polished or plated partial-sphere surface that rotates against the seal ring throughout the travel range. The V-shaped notch in the ball permits wide rangeability and produces an equal percentage flow characteristic.

Ball Segment, Eccentric: The flow controlling member of the eccentric rotary plug valve. Because of its eccentric action, it clears its seat soon after opening. This results in longer life, especially in erosive services, and reduces the actuator force required to operate the valve.

Note

The balls mentioned above, and the disks which follow, perform a function comparable to the valve plug in a globe-style control valve. That is, as they rotate they vary the size and shape of the flowstream by opening more or less the seal area to the flowing fluid.

Disk, Conventional: The flow-controlling member used in the most common varieties of butterfly rotary valves. High dynamic torques normally limit conventional disks to 60 degrees maximum rotating in throttling service.

Disk, Dynamically Designed: A butterfly valve disk contoured to reduce dynamic torque at large increments of rotation, thereby making it suitable for throttling service with up to 90 degrees of disk rotation.

Disk, Eccentric: Common name for valve design in which the positioning of the valve shaft/disk connections causes the disk to take a slightly eccentric path on opening. (This allows the disk to be swung out of contact with the seal as soon as it is opened, thereby reducing friction and wear.) This design is also commonly referred to as a high performance butterfly valve (HPBV).

Flangeless Body: Body style common to rotary-shaft control valves. Flangeless bodies are held between ANSI-class flanges by long through-bolts. (Sometimes also called wafer-style valve bodies.)

Flow Ring: Heavy-duty ring used in place of ball seal ring for V-notch rotary valves in severe service applications where some leakage can be tolerated.

High Performance Butterfly Valve (HPBV): See *Disk, Eccentric*.

Plug, Eccentric: See *Ball, Eccentric Segment*

Reverse Flow: Flow of a fluid in the opposite direction from that normally considered the standard direction. (Some rotary-shaft control valves, such as conventional-disk butterfly valves, are capable of handling flow equally well in either direction. Other rotary designs may require modification of actuator linkage to handle reverse flow. Capacity and allowable working pressures are often lowered to maintain allowable leakage limits with flow in the reverse direction.)

Rotary-Shaft Control Valve: A valve style in which the flow closure member (full ball, partial ball, or disk) is rotated in the flowstream to modify the amount of fluid passing through the valve.

Seal Ring: The portion of a rotary-shaft control valve assembly corresponding to the seat ring of a globe valve. Positioning of the disk or ball relative to the seal ring determines the flow area and capacity of the unit at that particular increment of rotational travel. As indicated above, some seal ring designs permit bi-directional flow.

Shaft: The portion of a rotary-shaft control valve assembly corresponding to the valve stem of a globe valve. Rotation of the shaft positions the disk or ball in the flowstream and thereby controls the amount of fluid which can pass through the valve.

Shim Seals: Thin, flat, circular metal gaskets, usually 0.005-inch (0.125 mm) thick, used in varying numbers to adjust seal deflection in V-notch ball rotary control valves. (Adding more shim seals reduces the amount of seal deflection; reducing the number of shim seals used increases the amount of seal deflection obtained.)

Standard Flow: For those rotary-shaft control valves having a separate seal ring or flow ring, the flow direction in which fluid enters the valve body through the pipeline adjacent to the seal ring and exits from the side opposite the seal ring. (Sometimes called Forward Flow. See also *Reverse Flow.*)

Venturi-Ball: The spherically (ball) shaped closure member of a reduced port ball valve.

Wafer-Style Valve Body: A flangeless type of butterfly or gate, short face-to-face, valve body. Also called a flangeless valve body; it is clamped between pipeline flanges.

Control Valve Attributes, Specifications, and Applications Terminology

Actuator: A device which supplies force and motion to the valve closure member

Block Valve: An isolating valve, often a butterfly valve, used to create a bypass around the control valve. A bypass is frequently created so that service may be performed on the control valve without shutting down the process.

Cavitation: In liquid service, the noisy and potentially damaging phenomenon that accompanies vapor cavity bubble formation and collapse in the flowstream.

Capacity: Rate of flow through a valve under stated conditions.

Clearance Flow: That flow below the minimum controllable flow with the valve plug not seated.

Closure Member: A moveable part of the valve which is positioned in the flow path to modify the rate of flow through the valve.

Control Valve: A power operated device which modifies the fluid flow rate in a process control system. It consists of a valve connected to an actuator mechanism that is capable of changing the position of a flow controlling element in the valve in response to a signal from the controlling system.

Corrosion: The damaging effects of hostile media on control valve components resulting from material incompatibility.

Cv: Flow coefficient commonly used for liquids. See *Flow Coefficient*

Dynamic Unbalance: The net force produced on the valve plug in any stated open position by the fluid pressure acting upon it.

Equal Percentage Flow Characteristic: The inherent flow characteristic which for equal increments of rated travel will ideally give equal percentage changes of the flow coefficient C_v.

Erosion: The damaging effects of gritty or dirty media media on control valve components. Erosion is forestalled with valve designs which separate the flowstream from critical valve components and with hardened materials.

Fail-Closed: A condition wherein the valve port remains closed should the actuating power fail.

Fail-Open: A condition wherein the valve port remains open should the actuating power fail.

Flashing: A phenomenon observed in liquid service when the pressure of the media falls below its vapor pressure and does not recover to a higher pressure. Flashing commonly produces damage to control valve components which gives the appearance of erosion damage (smooth, polished cavities on the affected components).

Flow Characteristic: Relationship between flow through the valve and percent rated travel as the latter is varied from 0 to 100 percent. This is a special term. It should always be designated as either inherent flow characteristic or installed flow characteristic. Common flow characteristics are linear, equal percentage, and quick opening. See *Inherent Flow Characteristic* and *Installed Flow Characteristic.*

Flow Coefficient (C_V): The number of U.S. gallons per minute of 60 degree F water that will flow through a valve with a one pound per square inch pressure drop.

Hard Facing: The process of applying a material harder than the surface to which it is applied. This technique is used to resist fluid erosion and/or to reduce the chance of galling between moving parts, particularly at high temperature.

Hardness: Metallic material hardness is commonly expressed by either a Brinell number or a Rockwell number. (In either case, the higher the number, the harder the material. For example, a material with a Rockwell "C" hardness of 60 is file hard while a hardness of 20 is fairly soft. Elastomer hardness is determined by a Durometer test.)

Inherent Flow Characteristic: Flow characteristic when constant pressure drop is maintained across the valve.

Inlet: The body opening through which fluid enters the valve.

Installed Flow Characteristic: Flow characteristic when pressure drop across the valve varies as dictated by flow and related conditions in the system in which the valve is installed.

Leakage: Quantity of fluid passing through an assembled valve when the valve is in the fully closed position under stated closure forces, with pressure differential and pressure as specified. Leakage is is usually expressed as a percentage of the valve capacity at full rated travel.

Linear Flow Characteristic: An inherent flow characteristic which can be represented ideally by a straight line on a rectangular plot of flow versus percent rated travel. (Equal increments of travel yield equal increments of flow at a constant pressure drop.)

Noise, Control Valve: Generally refers to aerodynamic noise associated with flowstream turbulence in compressible fluids. Noise levels can be reduced to safe levels defined by OSHA and the EPA with noise-abatement trim (source treatment) and with silencers and diffusers (path treatment).

Normally Closed Control Valve: One which closes when the diaphragm pressure is reduced to atmospheric.

Normally Open Control Valve: One which closes when the diaphragm pressure is reduced to atmospheric.

Outlet: The body opening through which fluid exits the valve.

Pressure Drop: The difference between upstream pressure and downstream pressure using the control valve as a reference.

Pressure Drop, Maximum Allowable: The maximum flowing or shutoff pressure drop that a control valve can withstand. While maximum inlet pressure is commonly dictated by the valve body, maximum allowable pressure drop is generally limited by the internal controlling components (plug, stem, disk, shaft, bearings, seals). Maximum allowable pressure drop may apply to the pressure drop while flowing process fluids or at shutoff.

Push-Down-to-Close Construction: A globe-style valve construction in which the valve plug is located between the actuator and the seat ring, such that extension of the actuator stem moves the valve plug toward the seat ring, finally closing the valve. (Also called Direct Acting. The term may also be applied to rotary-shaft valve constructions where linear extension of the actuator stem moves the ball or disk toward the closed position.)

Push-Down-to-Open Construction: A globe-style valve construction in which the seat ring is located between the actuator and the valve plug, such that extension of the actuator stem moves the valve plug away from the seat ring, opening the valve. (Also called Reverse Acting. The term may also be applied to rotary-shaft valve constructions where linear extension of the actuator stem moves the ball or disk toward the open position.)

Quick Opening Flow Characteristic: An inherent flow characteristic in which there is maximum flow with minimum travel.

Rangeability: Ratio of maximum to minimum flow within which the deviation from the specified inherent flow characteristic does not exceed some stated limit. (A control valve that still does a good job of controlling when flow increases to 100 times the minimum controllable flow has a rangeability of 100 to 1. Rangeability might also be expressed as the ratio of the maximum to minimum controllable flow coefficients.)

Rated C_V: The value of C_V at the rated full-open position.

Recovery: A relative term used to describe how much flowstream pressure is reduced due to the design of the control valve; the ratio of maximum (valve fully open) downstream pressure to upstream pressure. For example:

High-Recovery Valve: A valve design that dissipates relatively little flow-stream energy due to streamlined internal contours and minimal flow turbulence. Therefore, pressure downstream of the valve vena contracta recovers to a high percentage of its inlet value. (Straight-through flow valves, such as rotary-shaft ball and butterfly valves, are typically high-recovery valves.)

Low-Recovery Valve: A valve design that dissipates a considerable amount of flowstream energy due to turbulence created by the contours of the flowpath. Consequently, pressure down-stream of the valve vena contracta recovers to a lesser percentage of its inlet value than is the case with a valve having a more streamlined flowpath. (Although individual designs vary, conventional globe-style valves generally have low pressure recovery capability.)

Seat Load: The contact force between the seat and the valve plug. (In practice, the selection of an actuator for a given control valve will be based on how much force is required to overcome static, stem, and dynamic unbalance with an allowance made for seat load.)

Shutoff: See *Leakage*.

Static Unbalance: The net force produced on the valve plug in its closed position by the fluid pressure acting upon it.

Stem Unbalance: The net force produced on the valve plug stem in any position by the fluid pressure acting upon it.

Stroke: See *travel.*

Travel, Rated: The amount of linear movement of the valve plug from the closed position to the rated full-open position. (The rated full-open position is the maximum opening recommended by the manufacturer.)

Throttling: The action of a control valve in motion as it regulates flow through a pipeline.

Vapor Pressure: The pressure at which a given liquid begins to vaporize.

Vena Contracta: The location where cross-sectional area of the flowstream is at its minimum size, where fluid velocity is at its highest level, and fluid pressure is at its lowest level. (The vena contracta normally occurs just downstream of the actual physical restriction in a control valve.)

Miscellaneous Abbreviations

ANSI: *American National Standards Institute.*

API: *American Petroleum Institute.*

ASME: *American Society of Mechanical Engineers.*

ASTM: *American Society for Testing and Materials.*

EPA: *Environmental Protection Agency*

ISA: *International Society of Automation.*

NACE: *National Association of Corrosion Engineers. (U.S.A.)*

OSHA: *Occupational Safety and Health Act. (U.S.A.)*

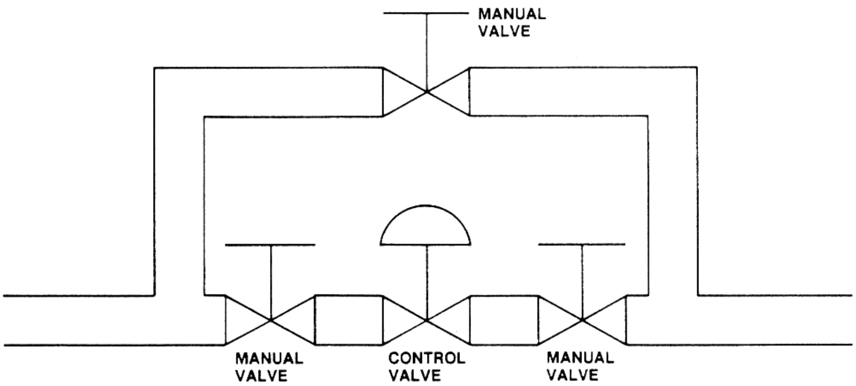
Shutoff

ANSI Class Seat Leakage

Shutoff is ordinarily stated in terms of classes of seat leakage defined in the *American National Standard for Control Valve Seat Leakage*. In actual service, shutoff leakage depends on many factors including pressure drop, temperature, the condition of the sealing surfaces, and the force load on the seat - which is a function of actuator force available. Since shutoff ratings are based on standard test conditions which may be very different from actual service conditions, service leakage cannot be absolutely predicted. However, the ANSI shutoff classes provide a good basis for comparison among valves of similar configuration.

ANSI Classes Compared

As we identify the different seat leakage standards, we can roughly calculate the seat leakage of a typical 3-inch globe body that would conform to each of the leak classes. First, because ANSI Class two, three, and four leakage is expressed as a percentage of rated capacity, we'll have to calculate the normal wide open flow of our three inch valve under test conditions. The basic formula for flow is C_V times the square-root of ΔP so we'll have to know the C_v of the valve and the pressure drop of our setup. The maximum rated C_v of 140 comes from the manufacturers literature and the pressure drop of 50 psi is one of the test conditions in the ANSI Standard. Solving the equation, we find that our 3-inch valve will produce a maximum flow of approximately 1,000 gallons per minute under test conditions.



Block and bypass piping arrangements are commonly used to isolate the control valve for maintenance or emergency situations. Such arrangements frequently eliminate the need for tight shutoff at the control valve.

ANSI Seat Leakage Classifications

Classes I-V

Leakage Class Designation	Maximum Leakage Allowable	Test Medium	Test Pressures	Testing Procedures Required for Establishing Rating
I	...	...	...	No test required provided user and supplier so agree.
II	0.5% of rated capacity	Air or water at 50-125°F (10-52°C)	45-60 psig or max. operating differential, whichever is lower	Pressure applied to valve inlet, with outlet open to atmosphere or connnected to a low head loss measuring device, full normal closing thrust provided by actuator.
III	0.1% of rated capacity	As above	As above	As above
IV	0.01% of rated capacity	As above	As above	As above
V	0.0005 ml per minute of water per inch of port diameter per psi differential.	Water at 50-125°F (10-52°C)	Max. service pressure drop across valve plug, not to exceed ANSI body rating. (100 psi pressure drop minimum)	Pressure applied to valve inlet after filling entire body cavity and connected piping with water and stroking valve plug closed. Use net specified max. actuator thrust, but no more, even if available during test. Allow time for leakage flow to stabilize.
VI	Not to exceed amounts shown in following table based on port diameter	Air or Nitrogen at 50-125°F (10-50°C)	50 psig or max. rated differential pressure across valve plug, whichever is lower.	Actuator should be adjusted to operating conditions specified with full normal closing thrust applied to valve plug seat. Allow time for leakage flow to stabilize and use suitable measuring device.

Class VI

NOMINAL PORT DIAMETER		LEAK RATE	
Inches	Millimeters	ml Per Minute	Bubbles Per Minute*
1	25	0.15	1
1-1/2	38	0.30	2
2	51	0.45	3
2-1/2	64	0.60	4
3	76	0.90	4
4	102	1.70	11
6	152	4.00	27
8	203	6.75	45

*Bubbles per minute as tabulated are an easily measured suggested alternative on a suitable calibrated measuring deivce such as a 1/4-inch O.D. x 0.032-inch wall tube submerged in water to a depth of 1/8-inch to 1/4-inch. The tube end shall be cut square and smooth with no chamfers or burrs and the tube axis shall be perpendicular to the surface of the water. Other apparatus may be constructed and the number of bubbles per minute may vary from these shown, as long as they correctly indicate the flow in ml per minute.

Class I

ANSI Class I shutoff does not require testing but is mutually defined by and agreed to by the user and supplier. It is a special classification that might apply to a valve with a higher leakage class rating which has been modified for some purpose. So, in our example, the amount of leakage would be negotiated between the customer and the manufacturer.

Class II

Class II shutoff allows leakage of up to one-half of one percent (0.5%) of the rated capacity of the valve using air or water as the test medium at a pressure drop of 50 psid. In our example, leakage of the specified valve is 5 gallons per minute.

Class III

Class III shutoff allows leakage of up to one-tenth of one percent (0.1%) of the rated capacity of the valve again using air or water as the test medium with a 50 psid pressure drop. This is one-fifth the leakage of Class II and, in the example, is one gallon per minute.

Class IV

Class IV shutoff allows leakage of one one-hundredth of one percent (.01%) of the rated capacity of the valve under the same test conditions as above. Leakage is slightly less than one pint per minute.

Class V

Class V standards become more stringent and allow only .0005 milliliters of water per minute per inch of port diameter at a minimum test pressure drop of 100 psid. In the example, wide open flow would be increased to about 1400 gallons per minute because of the increased test pressure. However, because of the more demanding requirements, an eyedropper could be used to measure leakage accumulated in one minute.

Class VI

Class VI standards are very demanding. Instead of water as a test medium, air or nitrogen is used with a pressure drop of 50 psid. The allowable leakage for different nominal port diameters is expressed in both milliliters per minute and bubbles per minute. Allowable leakage does not follow a linear scale but is identified for port diameters through 8-inches. Obviously, this leak class provides very tight shutoff.

Cost of Over-specifying Shutoff

In actual application, not all throttling valves need to provide tight shutoff. Block valves placed around the control valve provide the tight shutoff function. Over-specifiying control valve shutoff has been identified as one of the greatest unnecessary costs incurred during control valve selection. What typically happens is that every specifier in the chain - the designer, plant manager, engineer, and so on - adds a safety margin to the specifications; each person who reviews the plans and specifications increases the shutoff requirement. The result is good - though not always necessary - shutoff, at a progressive penalty in cost.

Special Cases

In some instances, tight shutoff should be specified even though it not a specific process requirement. For instance, when flowing toxic or flamable fluid, tight shutoff is often specified for safety reasons. In severe services involving erosive fluids, high pressure drops, or cavitation (discussed later), tight shutoff may be specified to reduce wear or erosion of closure members and seats.

ANSI Class Seat Leakage Comparison

Task: Calculate actual seat leakage of a typical 3-inch globe valve at all ANSI seat leakage classifications.

1. Seat leakage classes define maximum allowable leakage as a percent of the valve's rated capacity, so maximum flow under test conditions must be known.

2. Maximum flow (Q) = maximum $C_v \sqrt{\Delta P}$

   a. Maximum C_v = 140 (from manufacturers literature)

   b. ΔP = 50 psid (test condition for Classes II, III and IV)

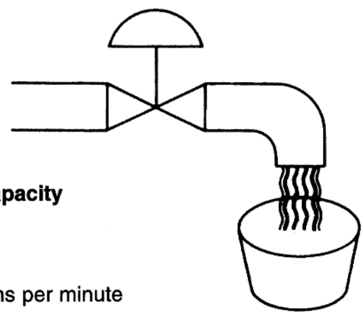
3. $Q = 140 \times \sqrt{50}$

   Q = 1,000 gallons per minute (approximate)

Class I

Not specified by ANSI. Leakage mutually agreed upon by user and supplier.

Class II

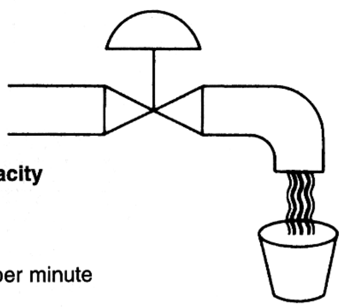


0.5% Rated Capacity

1,000
x 0.005
5 gallons per minute

5 GALLONS

Class III

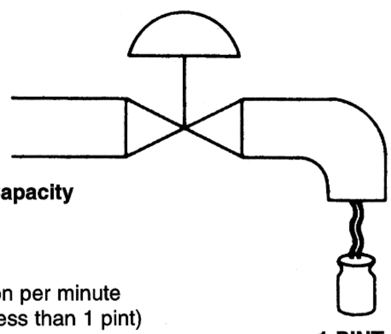


0.1% Rated Capacity

1,000
x 0.001
1 gallon per minute

1 GALLON
1 GALLON

Class IV

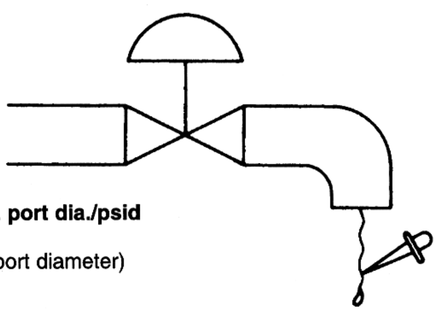


0.01% Rated Capacity

1,000
x 0.0001
0.1 gallon per minute
(less than 1 pint)

1 PINT

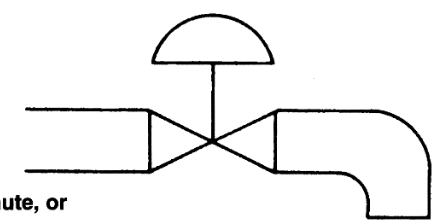
Class V



0.0005 mL/in. port dia./psid

3 (port diameter)
x 0.0005
0.0015
x 100[1] (minimum test psid)
0.15 mL per minute

Class VI



0.9 mL/minute, or

6 visible bubbles per minute

TIGHT!

1. Maximum flow under Class V test pressure of 100 psid minimum is approximately 1400 gallons per minute.

Cavitation and Flashing

Definition

Cavitation and flashing are phenomena which are often grouped together as they both can accompany high pressure drop applications. Cavitation is defined as the noisy and potentially damaging formation and collapsing of vapor cavities formed when the pressure of a liquid drops below its vapor pressure. The beginning stages of cavitation can often be detected by a hissing or roaring sound in the control valve or pipeline. Fully developed cavitation produces a sound giving the sensation that gravel is passing through the control valve.

Vena Contracta

When a control valve is applied to a system, there results in the flowstream a point of minimal cross-sectional area of flow. This point is referred to as the *vena contracta*. The vena contracta is generally slightly downstream of the point of maximum restriction in the control valve.

Vapor Pressure

When a fluid passes through the vena contracta, velocity increases and pressure decreases. When flowing liquids under certain conditions such as high pressure drop, pressure may decrease to a level which is below the vapor pressure of the liquid; that is, below the pressure at which the liquid begins to vaporize. If pressure at the vena contracta falls below this point, vapor cavities begin to form in the liquid.

Flashing

If the downstream pressure remains below the vapor pressure of the liquid, the vapor cavities remain in the flowstream and the process is *flashing*.

Cavitation

If downstream pressure recovers to a pressure above the vapor pressure of the liquid, the vapor cavities begin to collapse and the process is *cavitating*.

Damage

Both flashing and cavitation can result in damage to control valves and related equipment. The total damage which occurs depends on the intensity and location of the phenomenon, the materials of which the valve is made, and the total amount of time of exposure.

Flashing damage is produced by high velocity flowstreams impinging on valve parts. Damage from flashing resembles erosion and has a smooth, polished appearance. Control valves for flashing services generally use hard materials to resist the effects of high velocity flow.

Cavitation damage is produced when the vapor cavities collapse against valve parts or piping. The energy released during this change of state produces damage which is typically much more severe than flashing damage. Parts damaged by cavitation have a rough, pitted, cinder-like surface. Cavitation damage similar to the example may occur over years or, in extreme cases, in just a few minutes.

1 Control Valve Noise

1.1 Introduction

Noise pollution will soon become the third greatest menace to the human environment after air and water pollution. Since noise is a by-product of energy conversion, there will be increasing noise as the demand for energy for transportation, power, food, and chemicals increases.

In the field of control equipment, noise produced by valves has become a focal point of attention triggered in part by enforcement of the Occupational Safety and Health Act, which in most cases limits the duration of exposure to noise in industrial locations to the levels shown in Table 1.

Table 1

Duration of Exposure (Hours)	Sound Level (dBA)
8	90
4	95
2	100
1	105
1/2	110
1/4 or less	115

1.2 Acoustic Terminology

Noise
Noise is unwanted sound.

Sound
Sound is a form of vibration which propagates through elastic media such as air by alternately compressing and rarefying the media. Sound can be characterized by its frequency, spectral distribution, amplitude, and duration.

Sound Frequency
Sound frequency is the number of times that a particular sound is reproduced in one second, i.e., the number of times that the sound pressure varies through a complete cycle in one second. The human response analogous to frequency is pitch.

Spectral Distribution
The spectral distribution refers to the arrangement of energy in the frequency domain. Subjectively, the spectral distribution determines the quality of the sound.

Sound Amplitude
Sound amplitude is the displacement of a sound wave relative to its "at rest" position. This factor increases with loudness.

Sound Power
The sound power of a source is the total acoustic energy radiated by the source per unit of time.

Sound Power Level
The sound power level of a sound source, in decibels, is 10 times the logarithm to the base 10 of the ratio of the sound power radiated by the source to a reference power. The reference power is usually taken as 10^{-12} watt.

Sound Pressure Level: SPL
The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base of 10 of the ratio of the pressure of the sound to the reference pressure. The reference pressure is usually taken as 2×10^{-5} N/M^2.

Decibel: dB
The decibel is a unit which denotes the ratio between two numerical quantities on a logarithmic scale. In acoustic terms, the decibel is generally used to express either a sound power level or a sound pressure level relative to a chosen reference level.

Sound Level
A sound level, in decibels A-scale (dBA) is a sound pressure level which has been adjusted according to the frequency response of the A-weighting filter network. When referring to valve noise. the sound level can imply standard conditions such as a position 1 m downstream of the valve and 1 m from the pipe surface.

NEMA Enclosures for Control Equipment

Enclosure Purge Types

Purge Types

Type Z Reduces classification within an enclosure from Division 2 to non hazardous

Type Y Reduces classification within an enclosure from Division 1 to Division 2

Type X Reduces classification within an enclosure from Division 1 to non hazardous

Other Equipment for Hazardous Areas

Nonincendive Equipment Equipment that will not ignite a specific hazardous atmosphere under it's normal operating conditions. Note that exposed surface temperatures must be less than 80% of the auto-ignition temperature of the specific gas.

Intrinsically Equipment that is incapable of releasing sufficient energy to ignite a specific hazardous atmosphere under normal or abnormal conditions.

Safe Equipment

Enclosure Temperature codes for Hazardous Locations

Temperature code	Maximum External Temperature C
T1	450
T2	300
T2A	280
T2B	260
T2C	230
T2D	215
T3	200
T3A	180
T3B	165
T3C	160
T4	135
T4A	120
T5	100
T6	85

If Enclosure is not marked, rating is as follows

Group A	280 C	Group B	280 C
Group C	160 C	Group D	215 C

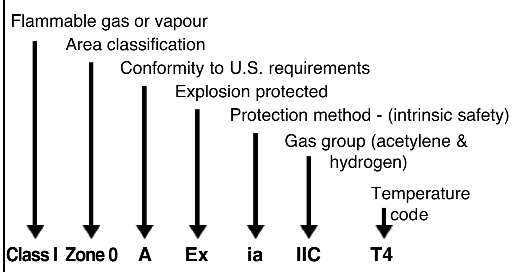
Enclosures NEMA Ratings

Enclosures	Classification	Description
Type 1	Nonhazardous	indoor use protecting against contact with the enclosed environment
Type 2	Nonhazardous	indoor use protecting against limited amounts of falling water & dirt.
Type 3	Nonhazardous	outdoor use protecting against windblown dust, rain, sleet, & external ice formation.
Type 3R	Nonhazardous	outdoor use protecting against rain, sleet, & external ice formation.
Type 3S	Nonhazardous	outdoor use protecting against windblown dust, rain, sleet, & provide for operation of external mechanisms if ice laden.
Type 4	Nonhazardous	indoor/outdoor use protecting against windblown dust and rain, splashing water, & hose directed water.
Type 4X	Nonhazardous	indoor/outdoor use protecting against corrosion, windblown dust, rain, splashing water & hose directed water.
Type 5	Nonhazardous	indoor use protecting against dust & falling dirt.
Type 6	Nonhazardous	indoor/outdoor use protecting against entry of water during occasional temporary submersion at a limited depth.
Type 6P	Nonhazardous	indoor/outdoor use protecting against entry of water during prolonged submersion at a limited depth.
Type 7	*Hazardous*	enclosures are for use indoors in locations classified as Class 1, Groups A, B, C, or D, as defined in the National Electric Code.
Type 8	*Hazardous*	enclosures are for use indoor or outdoor locations classified as Class 1, Groups A, B, C, or D, as defined in the National Electric Code.
Type 9	*Hazardous*	enclosures are for use indoors in locations classified as Class II, Groups E, F, or G, as defined in the National Electric Code.
Type 10	*Hazardous*	enclosures are constructed to meet the applicable requirements of the Mine Safety and Health Administration.
Type 11	Nonhazardous	indoor use protecting, by oil immersion, enclosed equipment against the corrosive effects of liquids and gases.
Type 12	Nonhazardous	indoor use protecting against dust,dirt & noncorrosive liquids
Type 12K	Nonhazardous	enclosures with knockouts are intended for indoor use protecting against dust, dirt & dripping noncorrosive liquids.
Type 13	Nonhazardous	indoor use protecting against dust, spray water, oil & noncorrosive coolants.

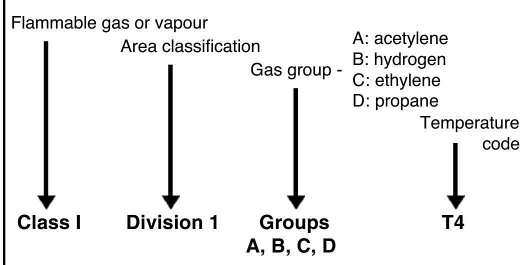
Hazardous Locations Equipment Marking

Markings for North America

Option A: (Zone System)
Ex ia IIC T4 (Canada)
Class I Zone 0 AEx ia IIC T4 (U.S.)

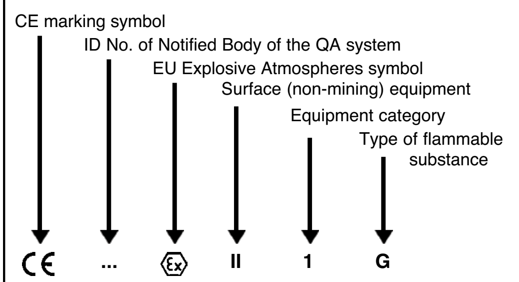


Option B: (DivisionSystem)

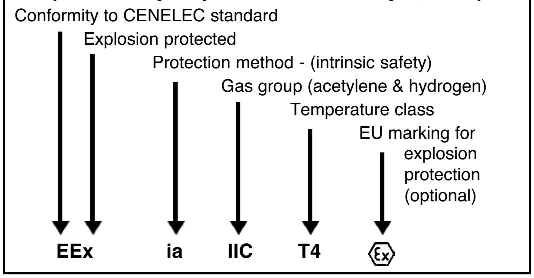


Markings for Europe

ATEX Directive (94/9/EC) on Potentially Explosive Atmospheres
(mandatory by July 1, 2003)



CENELEC (European) Directive (76/117/EEC)
(mandatory requirement until July 1, 2003)



Protection Methods for Combustible/Ignitable Dust Atmospheres

Protection Method	Division	North America Class II, III Standard		Europe (CENELEC), International (IEC) Zone	Standard	
		Canada CSA	US		Europe CENELEC	International IEC
Intrinsic Safety - ia	1	C22.2 No. 157	FM3610/UL913	—	—	—
Dust ignition protection	1	C22.2 No. 25 or E61241-1-1	UL 1203	20 / 21 / 22	EN50281-1-1	61241-1-1
Purged	1/2	—	NFPA 496	—	—	61241-4
Dust tight	2	C22.2 No. 25 or E61241-1-1	FM3611/UL1604	—	—	—
Non-incendive	2	—	FM3611/UL1604	—	—	—

Ingress Protection (IP) Codes

First NUMERAL Protection Against Solid Bodies	
0	No Protection
1	Objects Greater Than 50 mm
2	Objects Greater Than 12.5 mm
3	Objects Greater Than 2.5 mm
4	Objects Greater Than 1.0 mm
5	Dust-Protected
6	Dust-Tight

SECOND NUMERAL Protection Against Water	
0	No Protection
1	Vertically Dripping
2	Angled Dripping (15° tilted)
3	Spraying
4	Splashing
5	Jetting
6	Powerful Jetting
7	Temporary Immersion
8	Continuous Immersion

ATEX Directive 94/9/EC

Equipment Group	Equipment Category and Level of Protection	Presence of Explosive Atmosphere	Flammable Substances	Correlation with Hazardous Areas
I - Mines	M1 - very high level of protection	Presence	Methane, Dust	—
	M2 - high level of protection	Risk of Presence		—
II - Surface	1 - very high level of protection	Continuous Presence	G-Gas, Vapours Mist; D-Dust	Zone 0 (Gas etc.) Zone 20 (Dust)
	2 - high level of protection	Likely to Occur		Zone 1 (Gas etc.) Zone 21 (Dust)
	3 - normal level of protection	Unlikely to Occur		Zone 2 (Gas etc.) Zone 22 (Dust)

Protection Methods for Potentially Explosive Gas/Vapour Atmospheres

Protection Method	North America Class I						Europe (CENELEC), International (IEC)		
	Div.	Standard		Zone	Standard		Zone	Standard	
		Canada CSA	US		Canada CSA	US		European Norm (EN)	International IEC
Intrinsic Safety - ia (2 faults)	1	C22.2 No. 157	FM3610/ UL913	0	E60079-11	ISA 12.02.01/ UL2279	0	50020	60079-11
Intrinsic Safety - ib (1fault)	—	—	—	1	E60079-11	ISA 12.02.01/ UL2279	1	50020	60079-11
Explosionproof Flameproof - d	1	C22.2 No. 30	FM3615/ UL1203	1	E60079-1	ISA S12.22.01/ UL2279	1	50018	60079-1
Purged Pressurized - p	1/2	CSA TIL 13A/ NFPA 496	NFPA 496	1/2	E60079-2	—	1	50016	60079-2
Increased Safety - e	—	—	—	1	E79-7	ANSI/ISA S12.16.01/ UL2279	1	50019	60079-7
Encapsulation - m	—	—	—	1	E79-18	ISA S12.23.01/ UL2279	1	50028	60079-18
Oil immersion - o	—	—	—	1	E79-6	ANSI/ISA S12.26.01/ UL2279	1	50015	60079-6
Powder filled - q	—	—	—	1	E60079-5	ANSI/ISA S12.25.01/ UL2279	1	50017	60079-5
Non-incendive/ non-sparking	2	C22.2 No. 213	FM3611/ UL1604	—	—	—	—	—	—
Protection - n	—	—	—	2	E60079-15	UL2279	2	50021	60079-15
Special requirements (2 protection methods)	—	—	—	—	—	—	0	50284	—

Apparatus Grouping

Typical Gas/Dust/ Fibres/Flyings	US (NEC) Canada (CEC)	US (NEC) Canada (CEC) IEC, CENELEC
Acetylene	Class I, Group A	Group IIC
Hydrogen	Class I, Group B	
Ethylene	Class I, Group C	Group IIB
Propane	Class I, Group D	Group IIA
Methane	Gaseous Mines*	Group I*
Magnesium	Class II, Group E	IEC, CENELEC do not subdivide by material types
Coal	Class II, Group F	
Grain	Class II, Group G	
Cotton	Class III	

*not within scope of NEC or CEC

Class I - gas/vapour/mist, Class II - dust, Class III - fibres, flyings

Area Classification - Division versus Zone

Type of Area	NEC and CEC (North America)	CENELEC and IEC
Continuous Hazard	Division 1 or Zone 0	Zone 0
Intermittent Hazard	Division 1 or Zone 1	Zone 1
Hazard Under Abnormal Conditions	Division 2 or Zone 2	Zone 2

Electrical Safety Authority

Certification Marks Acceptable under the Electrical Safety Code

ESA Bulletin 2-7-20

Recognized Certification Markings

- BACL (Bay Area Compliance Laboratories)
- Canadian Standards Association
- Curtis Strauss
- DEKRA Certification BV
- Electrical Safety Authority – Field Evaluation (ESAFE)
- FM Approvals LLC
- IAPMO Research and Testing, Inc.
- ICC NTA, LLC
- IAPMO Ventures, LLC dba IAPMO EGS
- Internatinal Testing Laboratory Inc.
- Intertek Testing Services
- LabTest Certification Inc.
- Met Laboratories (MET)
- Nemko North America, Inc.
- NSF International
- OMNI Environmental Services Inc.
- QPS Evaluation Services, Inc.
- Quality Auditing Institute (QAI)
- SGS
- TR Arnold and Associates, Inc.
- TÜV Rheinland of North America, Inc.
- TÜV Süd America Inc.
- Underwriters' Laboratories of Canada (ULC)
- Underwriters' Laboratories Inc.

Recognized SPE-1000 Field Evaluation Marks

AC&E North America Inc.

Attesta International Safety Certification Inc.

Canadian Group for Approval Inc. (CGA)

Canadian Standards Association (CSA)

Electrical Safety Authority (operating as ESAFE)

International Testing Laboratory Inc.

Intertek Testing Services

LabTest Certification Inc.

MET Laboratories

Nemko Canada Inc.

QPS Evaluation Services, Inc.

Quality Auditing Institute

Q Test Inspection Ltd.

SEAC Engineering Inc.

TÜV Süd America Inc.

TÜV Rheinland of North America Inc.

Underwriters Laboratories of Canada (ULC)

Vision Integrity Engineering Ltd.

Recognized Panel-Only* Field Evaluation Agency Markings

AC&E North America Inc.

Attesta International Safety Certification Inc.

Canadian Standards Association (CSA)

Electrical Safety Authority (operating as ESAFE)

Intertek Testing Services

QPS Evaluation Services, Inc.

*PANEL-ONLY label identifies that the panel has been evaluated to the SPE-1000. It does not cover equipment that is added or connected to the panel.

Recognized SPE-3000 Field Evaluation Marks

Attesta International Safety Certification Inc.

Canadian Standards Association (CSA)

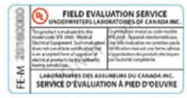
Electrical Safety Authority (operating as ESAFE)

Intertek Testing Services

LabTest Certification Inc.

QPS Evaluation Services, Inc.

Underwriters' Laboratories Inc.



Component Certification Markings that are not Recognized on Complete End-Use Products

Canadian Standards Association (CSA)

Underwriters' Laboratories Inc. (UL)

Note: Electrical components bearing these marks may have restrictions on their performance or may be incomplete in construction, and are intended to be used as part of a larger approved product or system. The Component Recognition marking is found on a wide range of products, including some switches, power supplies, printed wiring boards, some kinds of industrial control equipment and thousands of other product.

Withdrawn Field Evaluation Agency Markings**

LabTest Certification Inc.
Date Withdrawn: June 29, 2020

Electrical Safety Authority
(operating as ESAFE)
Date Withdrawn: Nov. 11, 2018

Quality Auditing Institute
Date Withdrawn: June 1, 2020

**These Field Evaluation marks are only acceptable on products labeled before the withdrawal date. Any product bearing these marks after the indicated withdrawal date are considered unapproved and cannot be used or sold in Ontario.

Area Classifications

Zone 0 – a location in which explosive gas atmospheres are present continuously or are present for long periods.

Zone 1 – a location in which:

a. explosive gas atmospheres are likely to occur in normal operation; or
b. the location is adjacent to a Zone 0 location, from which explosive gas atmospheres could be communicated.

Zone 2 – a location in which

a. explosive gas atmospheres are not likely to occur in normal operations and, if they do occur, they will exist for a short time only; or
b. the location is adjacent to a Zone 1 location, from which explosive gas atmospheres could be communicated, unless such communication is prevented by adequate positive-pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided

Zone 20 – a location in which an explosive dust atmosphere, in the form of a cloud of dust in air, is present continuously, or for long periods, or frequently.

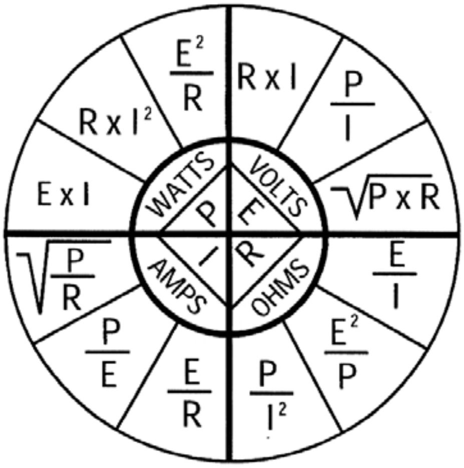
Zone 21 – a location in which an explosive dust atmosphere, in the form of a cloud of dust in air, is likely to occur in normal operation occasionally.

Zone 22 – a location in which an explosive dust atmosphere, in the form of a cloud of dust in air, is not likely to occur in normal operation but, if it does occur, will persisit for a short period only.

Ohm's Law

Ohm's Law

Volts (E)	Ohms (R)	Amperes (I)	Watts (W)
$E = IR$ $E = WR$ $E = W/I$	$E = E/I$ $R = E^2/W$ $R = W/I^2$	$I = E/R$ $I = W/E$ $I = W/R$	$W = EI$ $W = I^2R$ $W = E^2/R$



Amperage Conversion

Watts	Volts Single Phase 120	Volts Single Phase 240	Volts Single Phase 480	Volts 3 Phase Balanced Load 240	Volts 3 Phase Balanced Load 480	Watts
100	.83	.42	.21	.24	.13	100
150	1.25	.63	.31	.36	.18	150
200	1.67	.83	.42	.49	.25	200
250	2.08	1.04	.52	.61	.30	250
300	2.50	1.25	.63	.73	.37	300
350	2.92	1.46	.73	.85	.43	350
400	3.33	1.67	.84	.97	.49	400
450	3.75	1.88	.93	1.10	.55	450
500	4.17	2.08	1.04	1.20	.60	500
600	5.00	2.50	1.25	1.45	.73	600
700	5.83	2.92	1.46	1.70	.85	700
750	6.25	3.13	1.56	1.81	.91	750
800	6.67	3.33	1.67	1.93	.97	800
900	7.50	3.75	1.87	2.17	1.09	900
1000	8.33	4.17	2.10	2.41	1.21	1000
1100	9.17	4.58	2.30	2.65	1.33	1100
1200	10.0	5.00	2.51	2.90	1.45	1200
1250	10.4	5.21	2.61	3.10	1.55	1250
1300	10.8	5.42	2.71	3.13	1.57	1300
1400	11.7	5.83	2.91	3.38	1.69	1400
1500	12.5	6.25	3.12	3.62	1.82	1500
1600	13.3	6.67	3.34	3.86	1.93	1600
1700	14.2	7.08	3.54	4.10	2.05	1700
1750	14.6	7.29	3.65	4.22	2.10	1750
1800	15.0	7.50	3.75	4.34	2.17	1800
1900	15.8	7.92	3.96	4.58	2.29	1900
2000	16.7	8.33	4.17	4.82	2.41	2000
2200	18.3	9.17	4.59	5.30	2.65	2200
2500	20.8	10.4	5.21	6.10	3.05	2500
2750	23.0	11.5	5.73	6.63	3.32	2750
3000	25.0	12.5	6.25	7.23	3.62	3000
3500	29.2	14.6	7.30	8.45	4.23	3500
4000	33.3	16.7	8.33	9.64	4.82	4000
4500	37.5	18.8	9.38	10.84	5.42	4500
5000	41.7	20.8	10.42	12.1	6.1	5000
6000	50.0	25.0	12.50	14.50	7.25	6000
7000	58.3	29.2	14.59	16.9	8.5	7000
8000	66.7	33.3	16.67	19.3	9.65	8000
9000	75.0	37.5	18.75	21.7	10.85	9000
10000	83.3	41.7	20.85	24.1	12.1	10000

Electrical Formulas for Obtaining kW, kVA, HP and Amperes

Wanted	Single Phase	Two & Four-Phase	Three-Phase	Direct Current
Kilowatts	$\frac{I \times E \times PF}{1000}$	$\frac{I \times E \times 2 \times PF}{1000}$	$\frac{I \times E \times 1.73 \times PF}{1000}$	$\frac{I \times E}{1000}$
kVA	$\frac{I \times E}{1000}$	$\frac{I \times E \times 2}{1000}$	$\frac{I \times E \times 1.73}{1000}$	$\frac{I \times E}{1000}$
Horsepower	$\frac{I \times E \times \%Eff. \times PF}{746}$	$\frac{I \times E \times 2 \times \%Eff. \times PF}{746}$	$\frac{I \times E \times 1.73 \times \%Eff. \times PF}{746}$	$\frac{I \times E \times \%Eff.}{746}$
Amperes from kVA	$\frac{kVA \times 1000}{E}$	$\frac{kVA \times 1000}{2 \times E}$	$\frac{kVA \times 1000}{1.73 \times E}$	$\frac{kVA \times 1000}{E}$
Amperes from kW	$\frac{kW \times 1000}{E \times PF}$	$\frac{kW \times 1000}{2 \times E \times PF}$	$\frac{kW \times 1000}{1.73 \times E \times PF}$	$\frac{kW \times 1000}{E}$
Amperes from Hp	$\frac{Hp \times 746}{E \times \%Eff. \times PF}$	$\frac{Hp \times 746}{2 \times E \times \%Eff. \times PF}$	$\frac{Hp \times 746}{1.73 \times E \times \%Eff. \times PF}$	$\frac{Hp \times 746}{E \times \%Eff.}$

E = Volts I = Amperes %Eff. = Percent Efficiency PF = Power Factor

PID Loop Tuning Tips

DESCRIPTION OF PID UNITS

Proportional Term: is the amount added to the control output based on the current error.

Proportional Gain: is the multiplier Example: If the error is 10 and the Gain is 0.8 then the output will change 8%

Proportional Band: is the divider as a percentage Example: If the error is 10 and the Band is 125%, then the output is (10*(100/125)) = 8%

Conversion between P-GAIN and P-BAND

P-Band = 100 / P-GAIN

Integral Term: is the amount added to the output based on the sum of the error.

Time Constant: is the time for one full repeat of P-Term Example: If the P-Term is 10% and the time constant is 10 seconds, then the output will ramp up 10% every 10 seconds.

Reset Rate: is the amount the output will move in one second.

Example: If the P-Term is 8% and the reset rate is 0.1 repeats/sec, then the output will move 0.1 * 8 every second and take 10 seconds for the full repeat of the P-Term of 8%.

Integral Gain: is the same as the reset rate multiplied by the P-Gain.

Conversion between Time Constant and Reset Rate

Reset rate = 1 / time constant

I-Gain = (1 / Time Constant) * P-Gain

Derivative Term: is the amount subtracted from the output based on the rate of change of the error.

Time Constant: is the amount of time the controller will look forward

Derivative Gain: is the amount of time the controller looks forward multiplied by the P-Gain

DESCRIPTION OF PROCESSES

Fast Loops (flow, pressure)

P – Little (too much will cause cycling)

I – More

D- Not needed

Slow Loops (temperature)

P – More

I – Some (too much will cause cycling)

D- Some

Integrating (level, insulated temp)

P – More

I – Little (will cause cycling)

D – Must (If D is not used, the loop will cycle)

Noisy Loops (any PID loop where measurement is constantly changing)

P – Low

I – Most (Accumulated error)

D – Off (will cause cycling)

Closed Loop Step 1: KNOW THE PROCESS

Identify the loop you intend to tune and determine the speed of the loop. A rough categorization is as follows:

Fast Loop has response time from less than one second to about ten seconds, such as a flow loop. Use of a PI controller is sufficient.

Medium Loop has a response time of several seconds up to about 30 seconds. Such as a flow, temperature and pressure loop. Use either a PI or PID controller.

Slow loop has response time of more than 30 seconds, such as temperature or level loops. Use of a PID controller is recommended.

Closed Loop Step 2: KNOW THE CONTROLLER

Identify the units of your PID controller:

P – Proportional Term, can be also called the Proportional Gain (P-GAIN), or Proportional Band (P-BAND).

I – Integral can also be known as a time constant (in minutes or seconds), reset rate (1/sec or 1/min), or gain (reset rate multiplied by the proportional gain)

D – Derivative can be the time constant (in minutes or seconds), or derivative gain (derivative gain multiplied by the proportional gain).

For this guide assume the following terms: Proportional Gain, Integral reset rate, and derivative gain.

You will have to convert back to you controller units if necessary.

Closed Loop Step 3: WATCH THE RESPONSE

Make a small setpoint change (5%) or wait for a disturbance in the process if no setpoint change can be made. Then watch for process variable (PV) and control output (CO) responses.

- If no visible instantaneous change of control output upon the change of setpoint or no apparent overshoot (over damped), increase your proportional gain by 50%.
- If the Process Variable is unstable or has sustained oscillation, with overshoot greater than 25%, reduce proportional gain by 50% and reduce Integral Gain by 50%.
- If Process Variable oscillation persists with tolerable overshoot, reduce Proportional Gain by 20% and reduce the Integral Gain by 50%
- If 3 or more consecutive peaks occur upon the change of setpoint, reduce Integral Gain by 30% and increase Derivative Gain by 50%.
- If Process Variable stays fairly flat and below (or above) the setpoint for a long time, after change of setpoint or beginning of disturbance (long tail scenario), increase Integral Gain by 100%.

Repeat Step 3 until the closed loop response is satisfactory to you.

CODES AND STANDARDS OVERVIEW

The design, manufacture and use of control valves in power plants is governed by a variety of codes and standards. These documents provide for safe design and operation as well as consistency of product to facilitate plant construction and procurement.

This section summarizes the position regarding conformance to the most common codes and standards used to specify control valves for fossil power plant applications. The comments are divided into six groups: design standards, dimensional standards, performance testing, non-destructive examination, welding, and painting/cleaning. These comments apply to guide preparation of purchase specifications, as well as provide an awareness of situations where pricing adjustments are required. In many cases a minor change in specification can have significant commercial ramifications and only minor technical benefit.

Design standards. The boiler proper includes superheaters, economizers, reheaters, steam drums, water drums and other pressure parts connected directly to the boiler without intervening valves. The ASME Boiler and Pressure Vessel Code (BPVC) has administrative jurisdiction and technical responsibility for the boiler proper.

Boiler external piping is that piping which begins where the boiler proper terminates. This termination is considered to be:

- The first circumferential joint for welding end connections;

or

- the face of the first flange in bolted flanged connections;

or

- the first threaded joint in a threaded connection.

Boiler external piping extends up to and including the valves required by the ASME BPVC. This may include water drum, superheater, reheater, and economizer header drain and vent valves, steam drum vent valves, and steam drum level indicators. The ASME BPVC has administrative jurisdiction, while the ASME Section Committee B31.1 has technical responsibility. This means that design and construction rules are contained in ANSI/ASME B31.1, but that ASME code certification, data forms, code symbol stamping and/or inspections by authorized inspectors are per ASME BPVC Section I when required.

The remainder of the power plant piping (non-boiler external piping) and is covered by ANSI/ASME B31.1, Power Plant Piping.

ASME Boiler and Pressure Vessel Code - Section I. While control valves are not included in the boiler proper the boiler external piping may include control equipment. A common example is a steam drum level controller. Design and construction of these devices must comply with the requirements of ANSI/ASME B31.1 and also comply with the quality assurance requirements of ASME BPVC Section 1. This implies that vendors must provide inspection, data reports and stamping, which many are not authorized to provide. However, the ASME BPVC Section I waives these requirements for certain parts that already comply with an ANSI product standard or manufacturer's standard and which comply with certain other requirements for materials, welding and radiography and heat treatment documentation. Under these conditions, manufacturer may comply with ASME BPVC Section I without providing code stamping. The Comments to ANSI/ASME B31.1 later contain more information.

ANSI/ASME B31.1, Power Piping Code. Control valves and other equipment may be supplied per ANSI/ASME B31.1 to meet requirements for either boiler external piping or non-boiler external piping. In most cases, this code will be applied to both valves and level controls.

Valves:
This code references ANSI B16.34 as an applicable design standard for valves. To comply with ANSI/ASME B31.1, manufacturers builds valves per ANSI B16.34 and provides some additional marking requirements, per ANSI B16.34 and ANSI B16.5. The code prohibits the use of ungasketed, screwed bonnets (such as used in the Design GS) on source valves in steam service over 250 psig.

Level Controls:
Standard cage style level controls often require modifications before complying with ANSI/ASME B31.1. All branch welds (such as the side connection saddle welds) must have a fillet weld added. Torque tube retainer flanges must be brought up to code dimensions.

On both valves and level controls, fabrication welds (including valve body to reducer welds) may require radiographic or liquid penetrant/magnetic particle examination. This requirement depends on nominal pipe size, wall thickness at the weld, design pressure and design temperature.

ANSI B16.34. This standard covers pressure-temperature ratings, dimensions, materials, nondestructive examination requirements, testing and marketing of cast, forged, and fabricated flanged and buttweld end, and wafer or flangeless valves.

Pressure-temperature ratings provided in the code are divided into four groups as follows:

1. Standard Class
   These are the normal ANSI Classes 150 through 4500P-T ratings. Most standard products fall in these standard classes. Pressure temperature ratings are published for a variety of materials.

2. Intermediate Standard Class
   These ratings fall between standard class ratings and are

achieved by designing the valve body and bonnet with extra wall thickness and by designing the body-to-bonnet bolting to handle higher loads. NDE is not required. Only BWE valves may carry intermediate ratings. They many times allow use of less expensive products in high duty applications.

3. Special Class
These ratings are typically higher than standard class ratings and are obtained by ultrasonic or radiographic testing of the body and bonnet castings. Any BWE globe or angle valve may be given a special class rating. See ANSI B16.34 for these ratings.

4. Intermediate Special Class
These ratings require both the nondestructive examination of the body and bonnet (as in special class) and the extra wall thickness/bolt strength (as an intermediate class). These ratings fall between the special class ratings, and may be applied only to BWE valves which have intermediate ratings. Intermediate special class ratings for applicable products are published in vendor literature.

Special Class, Intermediate Standard Class and Intermediate Special Class ratings all require pricing considerations.

Valves built to comply with B16.34 must also meet marking requirements. To meet these requirements, manufacturer uses two nameplates, one with valve body information, one with actuator information. The full nameplate requirements are met only when ANSI B16.34 compliance is specified in writing by the customer.

ANSI B16.5. This standard covers the design of flanges and flanged fittings and also establishes flanged fitting ratings. Although the current edition of this standard is not a valve design standard, earlier issues (before 1973) were applied to valve design. Design responsibility was transferred to ANSI B16.34 in 1973 for buttweld end valves and in 1977 for flanged end valves.

ANSI B16.5 may be applied to valves several ways:

1. As a dimensional/design standard for the flanged ends of valves. Literature will commonly say "Mates with ANSI XXX flanges."
2. To designate the pressure-temperature rating of the valve. The bulletin will commonly say "Pressures consistent with the applicable ANSI flange rating."
3. As a valve design standard. This is not common now that ANSI B16.34 covers valve design, but many older valves or older specifications may reference ANSI B16.5 as the design specification.

MSS SP-66. This standard was published as a valve design standard prior to ANSI B16.34. Conformance to ANSI B16.34. Conformance to ANSI B16.34 should generally be specified in lieu of MSS SP-66. "Special inspections" per MSS SP-66 to increase the pressure-temperature ratings are now replaced by ANSI B16.34 special class ratings.

MSS SP-67. This standard covers design and test performance requirements for butterfly valves and divides them into three leak classes. In most situations, these leak classes have been superseded for control valve usage by the ANSI/ISA B16.104 Standards.

Type I: Tight shutoff valve. No leakage allowed.

Type II: Low leakage valve. Leakage within tolerances is allowed in the closed position. Type II valves are not subjected to a seat test unless required by the purchaser. When a test is required, the valve is to be subjected to a hydrostatic or air seat test at the rated shutoff pressure, and the leakage must not exceed the leak rate specified by the purchaser.

Type III: Nominal leakage valve. No seat leak test required.

MSS SP-67 also defines face-to-face dimensions for certain butterfly valves.

ASME Boiler and Pressure Vessel Code - Section VIII. This code covers requirements for pressure vessels. It is not used for valve design, although some design calculations for diffusers and actuators are based on Section VIII.

ANSI B16.10. This standard defines face-to-face dimensions for gate, plug, check, ball and control valves. Control valves covered include Class 125 and 250 cast iron through 8 inch size, and Class 150, 300, 400 and 600 steel flanged valves through 8 inch size. Face-to-face dimensions for large valves and high pressure valves will vary by manufacturer as necessary to suit the constraints of each design. Socket weld valves are covered by ANSI B16.11.

ANSI B16.37. This standard covers hydrostatic testing of control valves. Test pressures are 1.5 times the cold working pressure given in ANSI B16.34. The manufacturer complies with ANSI B16.37 on those products whose pressure shell is rated per ANSI Class B16.34 (i.e., with ANSI 150,300...etc. ratings). Testing is completed, when specified in full compliance with methods prescribed. As standard, manufacturer product is hydro tested by component using ANSI B16.37 pressures and procedures. This component hydrotest is followed by an aerostatic test after assembly to confirm gasket joint integrity. This procedure allows us to ensure the integrity of valve parts and joints and contributes more efficient manufacture.

ANSI/FCI 70-2 (formerly ANSI B16.104). This standard defines seat leak classes and testing procedures. Manufacturer complies with this standard on those valves which are given ANSI leak rates (i.e., ANSI Class III, IV, V...etc.). The standard prescribes test procedures for each leak class as well as allowable leak rates. For more information see Control Valve Selection in Chapter 1.

MSS SP-61. This standard covers pressure testing of steel valves. It includes testing of stem seals, shell hydro-test, and seat leakage. Specification of MSS SP-61 will lead to problems. The standard requires testing with packing which can lead to significant corrosion problems (see Packing Materials & Systems Chapter 12). Also, the seat leak test procedure is not adequate to recognize leak rates of different trim styles and sizes. This may lead to over or under-specification of leak rate. ANSI B16.37 and ANSI/FCI 70-2 should be requested instead.

SNT-TC-1A. This standard defines qualification requirements for personnel who perform non-destructive examination. All personnel doing NDE should be qualified per SNT-TC-1A.

ANSI B16.34. This standard allows increased pressure-temperature ratings for valves which are non-destructively examined (special class). Radiography or, with customer acceptance, ultrasonic testing, is performed on certain areas of the body and bonnet. Consequently, this standard includes test procedures and acceptance criteria for diographic, ultrasonic, magnetic particle and liquid penetrant examinations. Use of B16.34 is recommended in lieu of comparable MSS standards due to broader acceptance.

MSS SP-55. This standard covers visual examination of castings.

MSS SP-54. This standard covers radiographic examination of castings. Radiographic examination per ANSI B16.34 or ASTM E94 should be proposed, however, due to broader acceptance of the standard.

MSS SP-53. This standard covers magnetic particle examination. Again, magnetic particle examination per ANSI B16.34 should be proposed.

ASME Boiler and Pressure Vessel Code - Section V. Section V ccntains requirements and methods for non-destructive testing and describes procedures for various types of testing. This section is applicable only when it is specifically referenced and required by other ASME BPVC sections or other design specifications.

ASME Boiler and Pressure Vessel Code - Section IX. This standard defines requirements for qualification of welders and welding procedures. Welders and welding procedures should all comply with ASME Section IX. Non-compliance will violate other code and standard requirements.

SSPC-SP5, SSPC-SP6, SPPC-SP10. These standards define requirements for blast cleaning metal surfaces. Most vendor procedures will comply with either SSPC-SP6 or SSPC-SP10. Requirements for special blast cleaning will often be coupled with special painting requirements.