STANDARDS OF TUBULAR EXCHANGER MANUFACTURERS ASSOCIATION

Fifth Edition
1968

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TUBULAR EXCHANGER MANUFACTURERS ASSOCIATION, INC.
331 Madison Avenue, New York, N.Y. 10017
George P. Byrne, Jr., Secretary-Treasurer

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Revised

Third Printing — 1972

MEMBERSHIP LIST

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PREFACE

Fifth Edition—1968, Second Printing—1970, Third Printing—1972

The fifth edition of the Standards retains the useful data and features found in the previous edition, plus many clarifications and expansions. All sections have been rewritten to incorporate new data which were not previously available. This second printing includes additional updated material and certain editorial changes and corrections, including suggestions which have resulted from extensive use of the Standards by both manufacturers and users of shell and tube exchangers.

A Mechanical Standards Class "B", covering the requirements of heat exchangers for chemical process service, is included to supplement Classes "R" and "C".

The Fifth Edition of the TEMA Standards was compiled by the Editorial Committee of the Technical Committee

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The Tubular Exchanger Manufacturers Association, Inc.

acknowledges with appreciation

the cooperation of

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American Society of Mechanical Engineers

American National Standards Institute, Inc.

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NOTE TO USERS OF THE TEMA STANDARDS

Efficient use of the TEMA Standards requires specifying not only TEMA but also the Mechanical Standards Class "R", "C" or "B", to which the manufacturer must adhere. TEMA "R", TEMA "C", and TEMA "B" are meaningful specifications, TEMA alone is not.

Corresponding subject matter in the three Mechanical Standards is covered by paragraphs identically numbered except for the prefix letter. Reference must be made to the paragraphs under the Class specified since numerous variations exist among identically numbered paragraphs in subsections "R", "C", and "B".

It is the intention of the Tubular Exchanger Manufacturers Association that this edition of its Standards may be used beginning with the date of issuance, and that its requirements supersede those of the previous edition six months from such date of issuance, except for heat exchangers contracted for prior to the end of the six month period. For this purpose, the date of issuance is January 1, 1968. The date of issuance for the second printing is May 1, 1970. The date of issuance for the third printing is June 1, 1972.

Questions on interpretation of the TEMA Standards should be addressed to the Secretary. Inquiries will be handled promptly unless committee action is required. Inquiries requiring development of new technical information will only be transmitted through the next addendum or edition of the Standards.

Heat Exchanger Nomenclature

N-1 SIZE NUMBERING AND TYPE DESIGNATION—RECOMMENDED PRACTICE

It is recommended that heat exchanger size and type be designated by numbers and letters as described below.

N-1.1 SIZE

Sizes of shells (and tube bundles) shall be designated by numbers describing shell (and tube bundle) diameters and tube lengths, as follows:

N-1.11 NOMINAL DIAMETER

The nominal diameter shall be the inside diameter of the shell in inches, rounded off to the nearest integer. For kettle reboilers the nominal diameter shall be the port diameter followed by the shell diameter, each rounded off to the nearest integer.

N-1.12 NOMINAL LENGTH

The nominal length shall be the tube length in inches. Tube length for straight tubes shall be taken as the actual overall length. For U-tubes the length shall be taken as the straight length from end of tube to bend tangent.

N-1.2 TYPE

Type designation shall be by letters describing stationary head, shell (omitted for bundles only), and rear head, in that order, as indicated in Figure N-1.2.

N-1.3 TYPICAL EXAMPLES

N-1.31

Split-ring floating head exchanger with removable channel and cover, single pass shell, 23¼" inside diameter with tubes 16' long.
SIZE 23-192 TYPE AES.

N-1.32

U-tube exchanger with bonnet type stationary head, split flow shell, 19" inside diameter with tubes 7' straight length.
SIZE 19-84 TYPE BGU.

N-1.33

Pull-through floating head kettle type reboiler having stationary head integral with tube-sheet, 23" port diameter and 37" inside shell diameter with tubes 16' long.
SIZE 23/37-192 TYPE CKT.

N-1.34

Fixed tubesheet exchanger with removable channel and cover, bonnet type rear head, two pass shell, 33⅛" inside diameter with tubes 8' long.
SIZE 33-96 TYPE AFM.

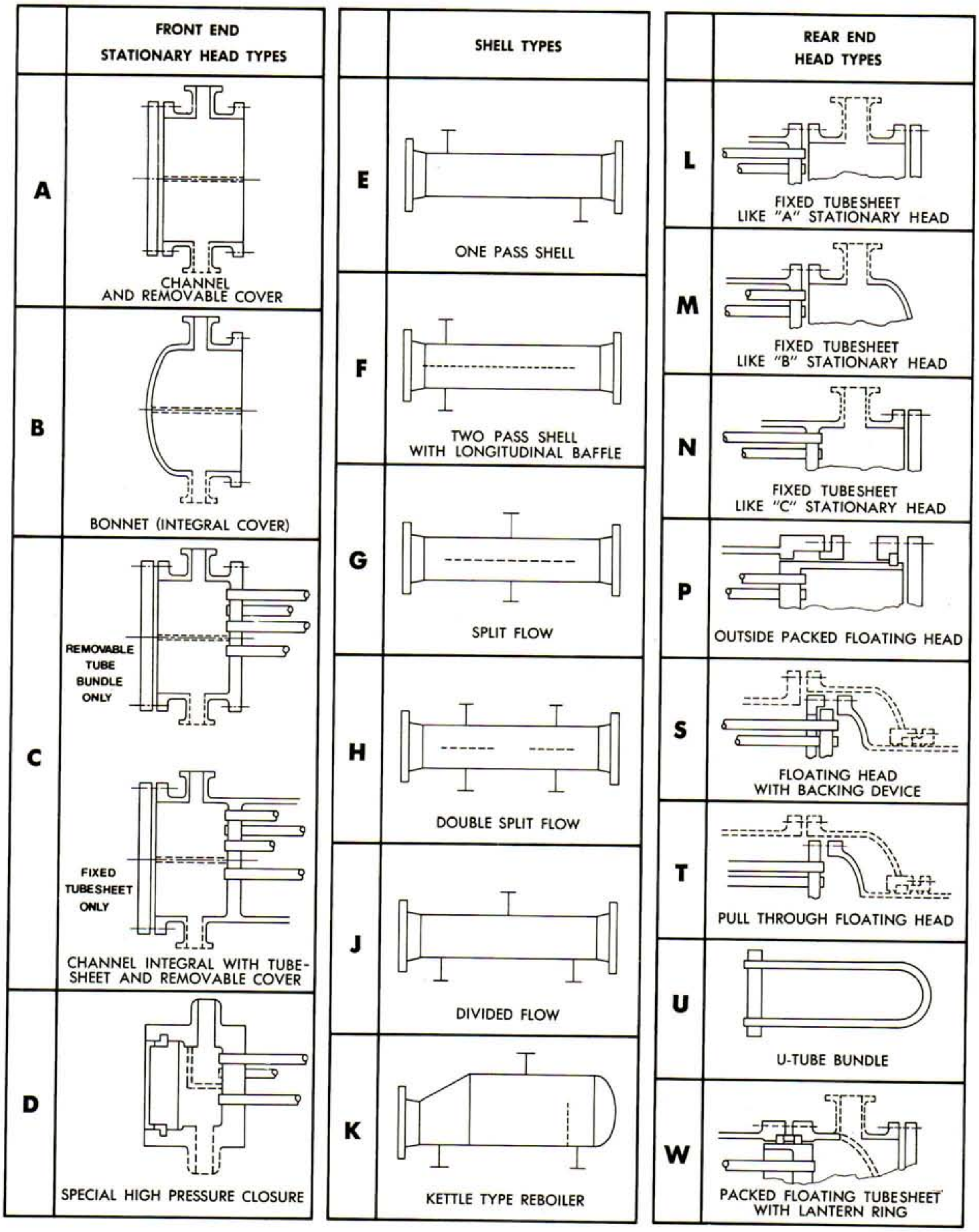
N-1.35

Fixed tubesheet exchanger having stationary and rear heads integral with tubesheets, single pass shell, 17" inside diameter with tubes 16' long.
SIZE 17-192 TYPE CEN.

N-1.4 SPECIAL DESIGNS

Special designs are not covered and may be described as best suits the manufacturer.

FIGURE N-1.2


FRONT END
STATIONARY HEAD TYPES
A
CHANNEL
AND REMOVABLE COVER
B
BONNET (INTEGRAL COVER)
C
REMOVABLE
TUBE
BUNDLE
ONLY
FIXED
TUBESHEET
ONLY
CHANNEL INTEGRAL WITH TUBE-
SHEET AND REMOVABLE COVER
D
SPECIAL HIGH PRESSURE CLOSURE
SHELL TYPES
E
ONE PASS SHELL
F
TWO PASS SHELL
WITH LONGITUDINAL BAFFLE
G
SPLIT FLOW
H
DOUBLE SPLIT FLOW
J
DIVIDED FLOW
K
KETTLE TYPE REBOILER
REAR END
HEAD TYPES
L
FIXED TUBESHEET
LIKE "A" STATIONARY HEAD
M
FIXED TUBESHEET
LIKE "B" STATIONARY HEAD
N
FIXED TUBESHEET
LIKE "C" STATIONARY HEAD
P
OUTSIDE PACKED FLOATING HEAD
S
FLOATING HEAD
WITH BACKING DEVICE
T
PULL THROUGH FLOATING HEAD
U
U-TUBE BUNDLE
W
PACKED FLOATING TUBESHEET
WITH LANTERN RING

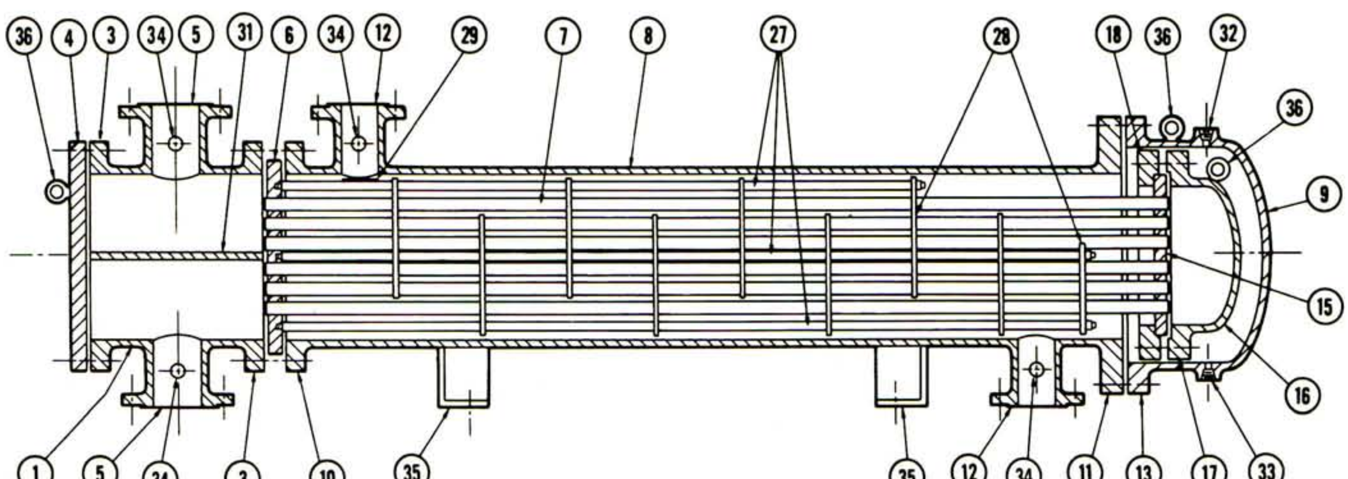
N-2 NOMENCLATURE OF HEAT EXCHANGER COMPONENTS

For the purpose of establishing standard terminology, Figure N-2 illustrates various types of heat exchangers. Typical parts and connections, for illustrative purposes only, are numbered for identification in Table N-2.

TABLE N-2

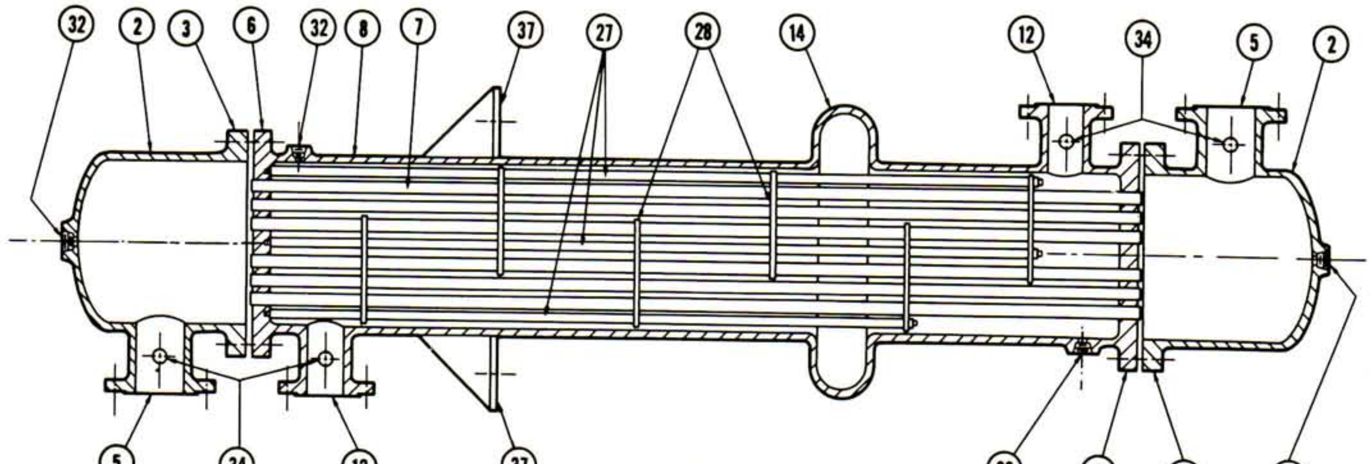
1. Stationary Head—Channel
2. Stationary Head—Bonnet
3. Stationary Head Flange—Channel or Bonnet
4. Channel Cover
5. Stationary Head Nozzle
6. Stationary Tubesheet
7. Tubes
8. Shell
9. Shell Cover
10. Shell Flange—Stationary Head End
11. Shell Flange—Rear Head End
12. Shell Nozzle
13. Shell Cover Flange
14. Expansion Joint
15. Floating Tubesheet
16. Floating Head Cover
17. Floating Head Flange
18. Floating Head Backing Device
19. Split Shear Ring
20. Slip-on Backing Flange
21. Floating Head Cover—External
22. Floating Tubesheet Skirt
23. Packing Box Flange
24. Packing
25. Packing Follower Ring
26. Lantern Ring
27. Tie Rods and Spacers
28. Transverse Baffles or Support Plates
29. Impingement Baffle
30. Longitudinal Baffle
31. Pass Partition
32. Vent Connection
33. Drain Connection
34. Instrument Connection
35. Support Saddle
36. Lifting Lug
37. Support Bracket
38. Weir
39. Liquid Level Connection

FIGURE N-2

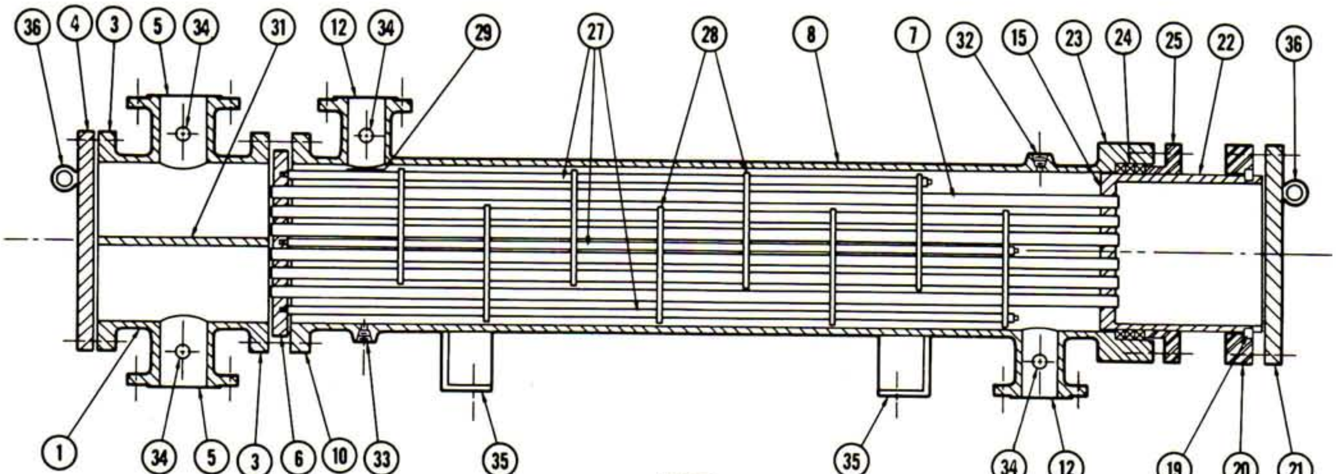


AES

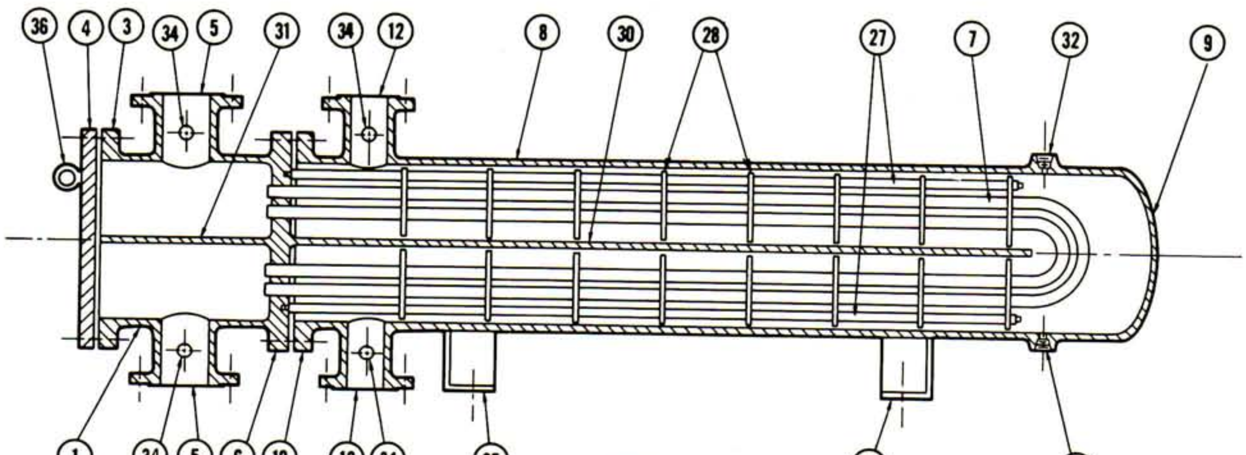
FIGURE N-2 (CONTINUED)



BEM

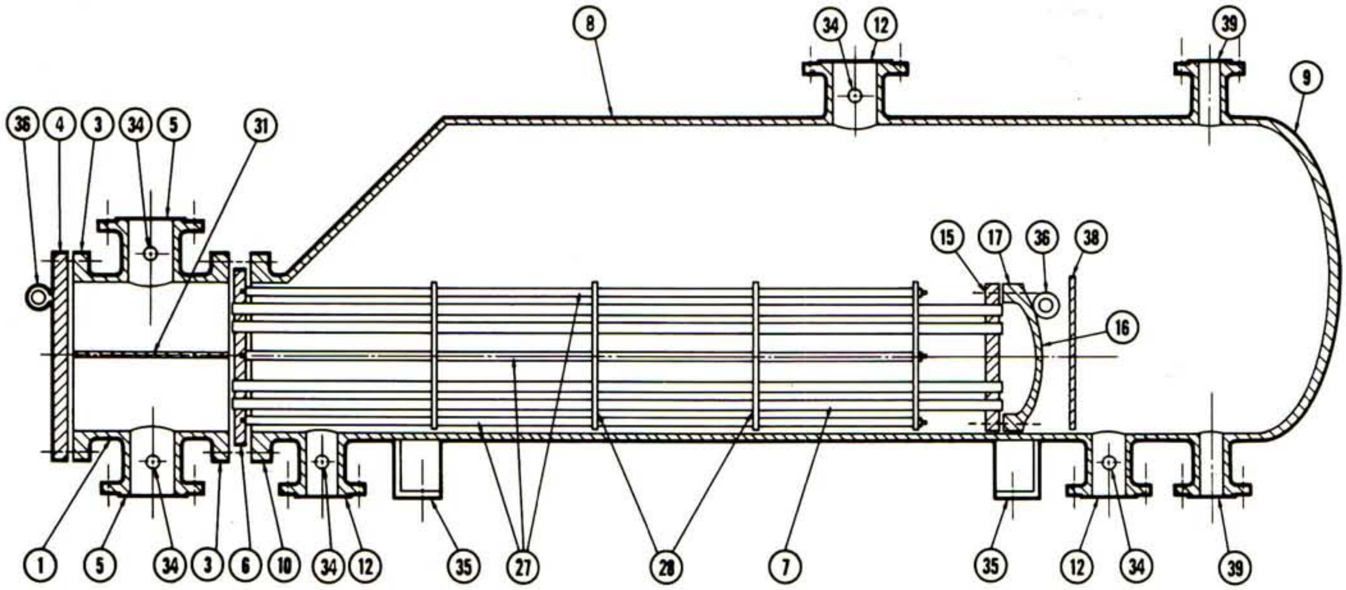


AEP

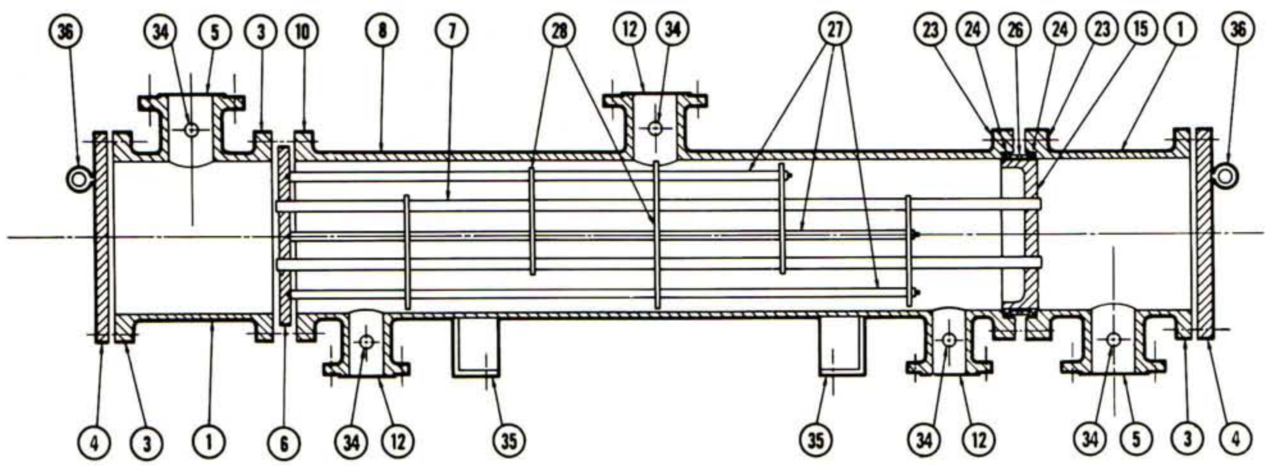


CFU

FIGURE N-2 (CONTINUED)



AKT

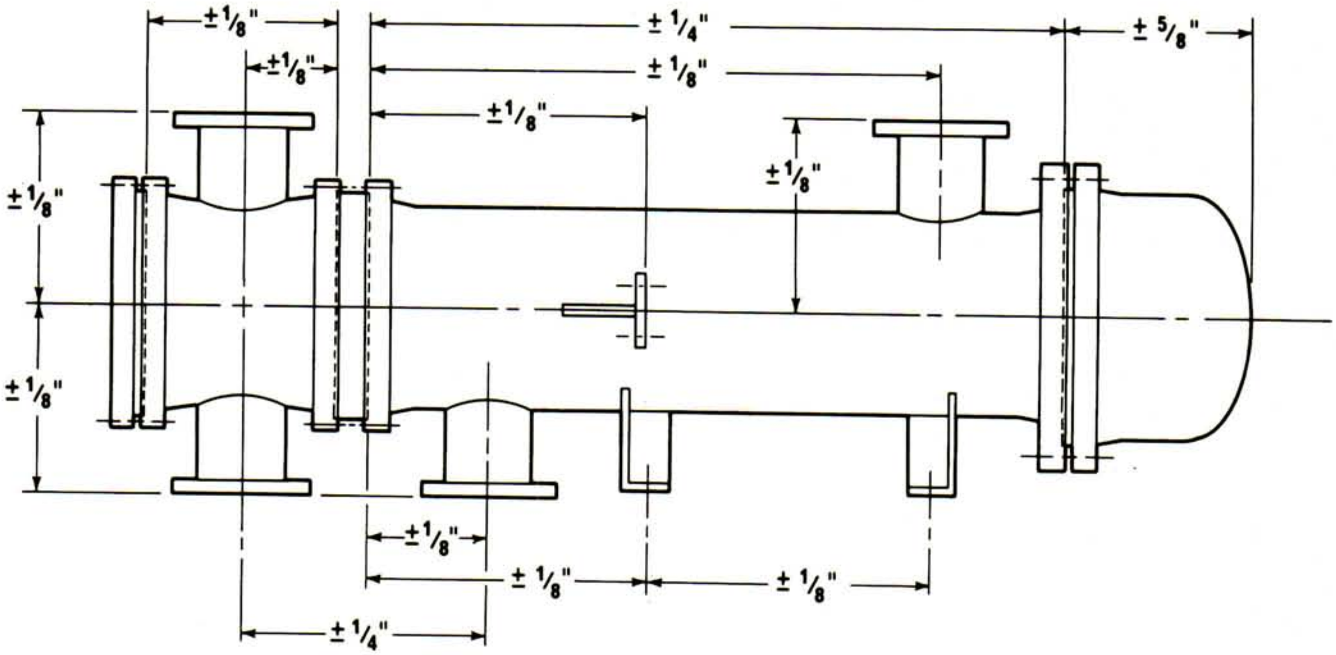


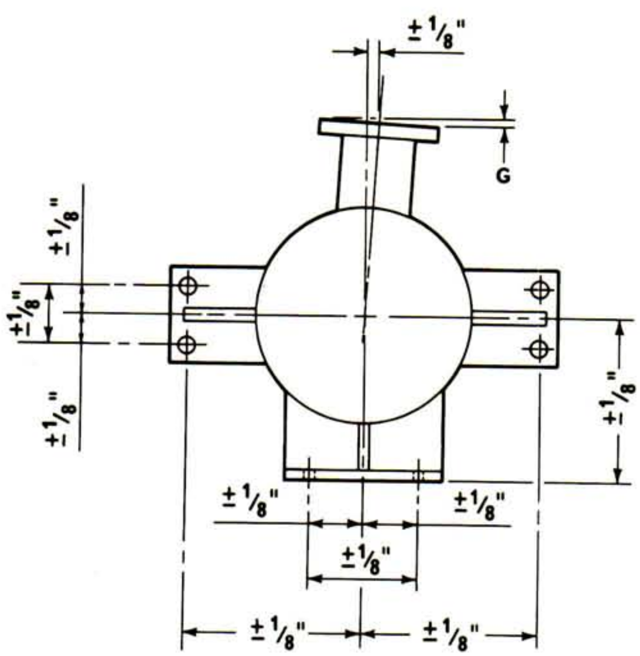
AJW

F-1 EXTERNAL DIMENSIONS, NOZZLE AND SUPPORT LOCATIONS

Standard tolerances for the external dimensions of heat exchangers and for nozzle and support locations are shown in Figure F-1 (Tolerances are not cumulative).

FIGURE F-1





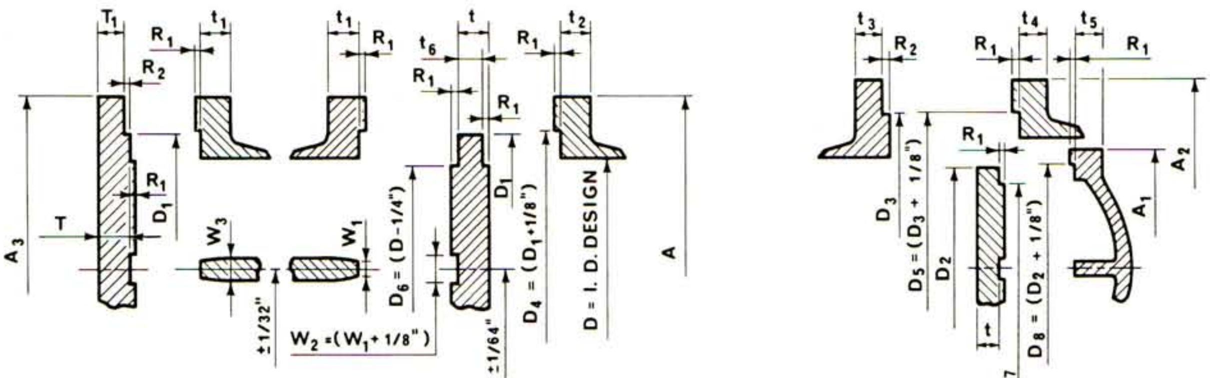
NOMINAL NOZZLE SIZE	G MAX
2"— 4" INCLUSIVE	1/16"
6"–12" INCLUSIVE	3/32"
OVER 12"	3/16"

CONNECTION NOZZLE ALIGNMENT
AND SUPPORT TOLERANCES

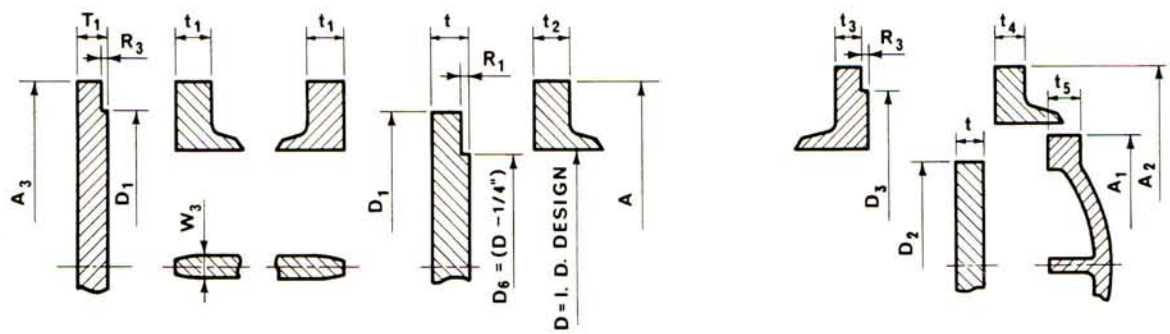
F-2 TUBESHEETS, PARTITIONS, COVERS, AND FLANGES

The standard tolerances applying to tubesheets, partitions, covers, and flanges are shown in Figure F-2.

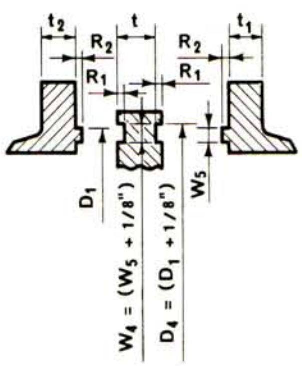
FIGURE F-2



STANDARD CONFINED JOINT CONSTRUCTION



STANDARD UNCONFINED PLAIN FACE JOINT CONSTRUCTION



ALTERNATE
TONGUE AND GROOVE
JOINT

DIMENSIONS	TOLERANCES
A, A_1, A_2, A_3	+ 1/4" − 1/8"
D_1, D_2, D_3, D_4, D_5, D_8	± 1/32"
D_6, D_7	± 1/16"
(R_1 = 3/16")	+ 0" − 1/32"
(R_2 = 1/4", R_3 = 1/16")	+ 1/32" − 0"
t, t_6	± 1/32"
t_1, t_2, t_3, t_4, t_5	± 1/16"
T, T_1	+ 1/8" − 1/32"
W_1, W_3, W_5	± 1/32"
W_2, W_4	+ 1/16" − 0"

FIGURE G-5.1

HEAT EXCHANGER SPECIFICATION SHEET

1			JOB NO.
2	CUSTOMER		REFERENCE NO.
3	ADDRESS		PROPOSAL NO.
4	PLANT LOCATION		DATE
5	SERVICE OF UNIT		ITEM NO.
6	SIZE	TYPE	(HORIZ.) (VERT.) CONNECTED IN
7	SQ. FT. SURF./UNIT (GROSS) (EFF.)	SHELLS/UNIT	SQ. FT. SURF./SHELL (GROSS) (EFF.)
8	PERFORMANCE OF ONE UNIT		
9		SHELL SIDE	TUBE SIDE
10	FLUID CIRCULATED		
11	TOTAL FLUID ENTERING		
12	VAPOR		
13	LIQUID		
14	STEAM		
15	NON-CONDENSABLES		
16	FLUID VAPORIZED OR CONDENSED		
17	STEAM CONDENSED		
18	GRAVITY		
19	VISCOSITY		
20	MOLECULAR WEIGHT		
21	SPECIFIC HEAT	BTU/LB-° F	BTU/LB-° F
22	THERMAL CONDUCTIVITY	BTU/HR-FT-° F	BTU/HR-FT-° F
23	LATENT HEAT	BTU/LB	BTU/LB
24	TEMPERATURE IN	° F	° F
25	TEMPERATURE OUT	° F	° F
26	OPERATING PRESSURE	PSIG	PSIG
27	NO. PASSES PER SHELL		
28	VELOCITY	FT/SEC	FT/SEC
29	PRESSURE DROP	PSI	PSI
30	FOULING RESISTANCE (MIN.)		
31	HEAT EXCHANGED-BTU/HR		MTD CORRECTED-° F
32	TRANSFER RATE—SERVICE		CLEAN
33	CONSTRUCTION OF ONE SHELL		
34	DESIGN PRESSURE	PSI	PSI
35	TEST PRESSURE	PSI	PSI
36	DESIGN TEMPERATURE	° F	° F
37	TUBES NO.	O.D. BWG LENGTH	PITCH
38	SHELL I.D.	O.D.	SHELL COVER (INTEG) (REMOV)
39	CHANNEL OR BONNET		CHANNEL COVER
40	TUBESHEET—STATIONARY		TUBESHEET-FLOATING
41	BAFFLES—CROSS TYPE		FLOATING HEAD COVER
42	BAFFLES—LONG TYPE		IMPINGEMENT PROTECTION
43	TUBE SUPPORTS		
44	TUBE TO TUBESHEET JOINT		
45	GASKETS		
46	CONNECTIONS-SHELL SIDE IN	OUT	RATING
47	CHANNEL SIDE IN	OUT	RATING
48	CORROSION ALLOWANCE—SHELL SIDE	TUBE SIDE	
49	CODE REQUIREMENTS		TEMA CLASS
50	REMARKS		
51			
52			
53			
54			

G-1 SHOP OPERATION

The detailed methods of shop operation are left to the discretion of the manufacturer in conformity with these standards.

G-2 INSPECTION

G-2.1 MANUFACTURER'S INSPECTION

Inspection and testing of units will be provided by the manufacturer unless otherwise specified. The manufacturer shall carry out the inspections required by the ASME Code, and also inspections required by state and local codes when the purchaser specifies the plant location.

G-2.2 PURCHASER'S INSPECTION

The purchaser shall have the right to make inspections during fabrication and to witness any tests when he has so requested. Advance notification shall be given as agreed between the manufacturer and the purchaser. Inspection by the purchaser shall not relieve the manufacturer of his responsibilities.

G-3 NAME PLATES

G-3.1 MANUFACTURER'S NAME PLATE

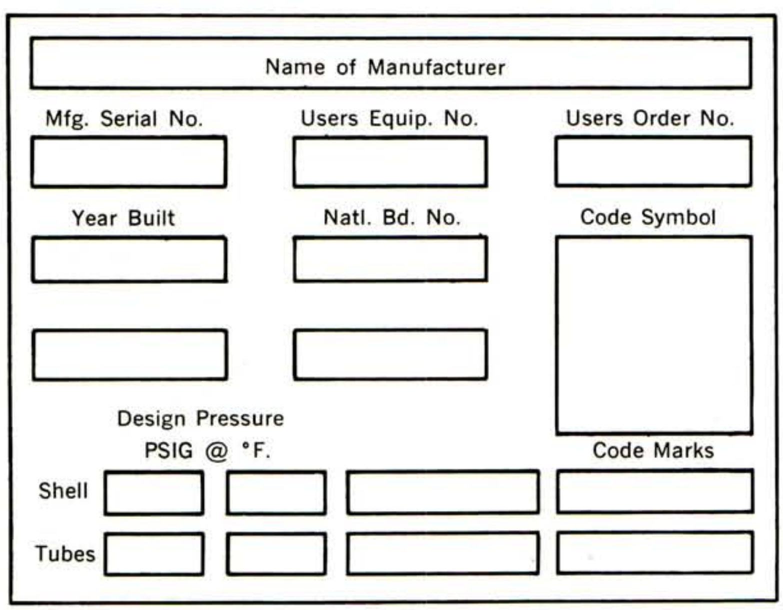
A suitable manufacturer's name plate of corrosion resistant material shall be securely attached to the head end or the shell of each TEMA exchanger. Name plates for exchangers manufactured in accordance with Classes "R" and "B" shall be austenitic (300 series) stainless. When insulation thickness is specified by the purchaser, the name plate shall be attached to a bracket welded to the exchanger.

G-3.11 NAME PLATE DATA

Standard name plate data and arrangement are illustrated in Figure G-3.11. The manufacturer may substitute a name plate of his own design, provided it includes the standard data.

FIGURE G-3.11

STANDARD NAME PLATE DATA AND ARRANGEMENT



G-3 NAME PLATES —(Continued)

G-3.2 PURCHASER'S NAME PLATE

Purchaser's name plates, when used, are to be supplied by the purchaser and supplement rather than replace the manufacturer's name plate.

G-4 DRAWINGS AND ASME CODE DATA REPORTS

G-4.1 DRAWINGS FOR APPROVAL AND CHANGE

The manufacturer shall submit for purchaser's approval three (3) prints of an outline drawing showing nozzle sizes and locations, overall dimensions and supports. Other drawings may be furnished as agreed upon by the purchaser and the manufacturer. It is anticipated that a reasonable number of minor drawing changes may be required at that time. Changes subsequent to receipt of approval may cause additional engineering expense chargeable to the purchaser. Purchaser's approval of drawings does not relieve the manufacturer of responsibility for compliance with this standard and applicable code requirements. The manufacturer shall not make any changes from the approved drawings without express agreement with the purchaser.

G-4.2 DRAWINGS FOR RECORD

After approval of drawings, the manufacturer shall furnish without extra charge six (6) prints or, at his option, a transparency of all approved drawings.

G-4.3 PROPRIETARY RIGHTS TO DRAWINGS

The drawings and the design indicated by them are to be considered the property of the manufacturer and are not to be used or reproduced without his permission, except by the purchaser for his own internal use.

G-4.4 ASME CODE DATA REPORTS

After completion of fabrication and inspection of ASME Code stamped exchangers, the manufacturer shall furnish without extra charge four (4) copies of the Manufacturers' Data Report.

G-5 GUARANTEES

G-5.1 PERFORMANCE

The purchaser shall furnish the manufacturer with all information needed for clear understanding of performance requirements, and with any special requirements not included in the standard. The manufacturer shall guarantee thermal and mechanical performance of a heat exchanger, when operated at the design conditions specified by the purchaser in his order, or shown on the exchanger specification sheet furnished by the manufacturer (Figure G-5.1). This guarantee shall extend for a period of twelve (12) months after shipping date. The manufacturer shall assume no responsibility for excessive fouling of the apparatus by material such as coke, silt, scale, or any foreign substance that may be deposited. The thermal guarantee shall not be applicable to exchangers where the thermal performance rating was made by the purchaser.

G-5.11 THERMAL PERFORMANCE TEST

A performance test shall be made if it is established after operation that the performance of the exchanger is not satisfactory, provided the thermal performance rating was made by the manufacturer. Test conditions and procedures shall be selected by agreement between the purchaser and the manufacturer to permit extrapolation of the test results to the specified design conditions.

G-5.12 DEFECTIVE PARTS

The manufacturer shall repair or replace f.o.b. his plant any parts proven defective within the guarantee period. Finished materials and accessories purchased from other manufacturers, including tubes, are warranted only to the extent of the original manufacturer's warranty to the heat exchanger fabricator.

G-5.2 CONSEQUENTIAL DAMAGE

The manufacturer shall not be held liable for any indirect or consequential damage.

G-5 GUARANTEES — (Continued)

G-5.3 CORROSION AND VIBRATION

The manufacturer assumes no responsibility for deterioration of any part or parts of the equipment due to corrosion, erosion, flow induced tube vibration, or any other causes, regardless of when such deterioration occurs after leaving the manufacturer's premises, except as provided for in paragraphs G-5.1 and G-5.12.

G-5.4 REPLACEMENT AND SPARE PARTS

When replacement or spare tube bundles, shells, or other parts are purchased, the manufacturer is to guarantee satisfactory fit of such parts only if he was the original manufacturer. Parts fabricated to drawings furnished by the purchaser shall be guaranteed to meet the dimensions and tolerances specified.

G-6 PREPARATION OF HEAT EXCHANGERS FOR SHIPMENT

G-6.1 CLEANING

Internal and external surfaces are to be free from loose scale and other foreign material that is readily removable.

G-6.2 DRAINING

Water, oil, or other liquids used for cleaning or hydrostatic testing are to be drained from all units before shipment.

G-6.3 FLANGE PROTECTION

All exposed machined contact surfaces shall be coated with a removable rust preventive and protected against mechanical damage by suitable covers.

G-6.4 THREADED CONNECTION PROTECTION

All threaded connections are to be suitably plugged.

G-6.5 DAMAGE PROTECTION

The exchanger and any spare parts are to be suitably protected to prevent damage during shipment.

G-7 GENERAL CONSTRUCTION FEATURES OF TEMA STANDARD HEAT EXCHANGERS

G-7.1 SUPPORTS

All heat exchangers are to be provided with supports which are designed to avoid undue stress or deflection in supports or shell.

G-7.11 HORIZONTAL UNITS

Horizontal units are provided with at least two supporting saddles with holes for anchor bolts. The holes in at least one of the supports are to be elongated to provide for expansion of the shell.

G-7.12 VERTICAL UNITS

Vertical units are to be provided with supports of sufficient size to carry the unit in a supporting structure of sufficient width to clear shell flanges. At least two supports are to be used when the nominal shell I.D. is 35 inches or less, and four supports when the nominal I.D. is over 35 inches.

G-7.2 LIFTING DEVICES

Channels, bonnets, or covers which weigh over 60 pounds are to be provided with lifting lugs, rings, or tapped holes for eyebolts.

G-7.3 END FLANGE FINISH

All end flanges shall be finish machined where necessary after completion of all welding and postweld heat treatment.

E-1 PERFORMANCE OF HEAT EXCHANGERS

Long and satisfactory operation of heat exchangers can be secured only from units which are properly designed and carefully fabricated. The user should take precautions to insure that the equipment is installed correctly, and cleaned and/or inspected at regularly scheduled intervals.

E-1.1 PERFORMANCE FAILURES

The failure of heat exchanger equipment to perform satisfactorily may be caused by one or more of the following factors:

(1) Excessive fouling.

(2) Air or gas binding resulting from improper piping installation or lack of suitable vents.

(3) Operating conditions differing from design conditions.

(4) Maldistribution of flow in the unit.

(5) Excessive clearances between the baffles and shell and/or tubes, due to corrosion.

(6) Improper thermal design.

The user's best assurance of satisfactory performance lies in dependence upon manufacturers of established competence in the design and fabrication of heat transfer equipment.

E-2 INSTALLATION OF HEAT EXCHANGERS

E-2.1 HEAT EXCHANGER SETTINGS

E-2.11 CLEARANCE FOR DISMANTLING

For straight tube exchangers fitted with removable bundles, provide sufficient clearance at the stationary head end to permit removal of the bundle from the shell and provide a clear space of three or four feet at the rear head end to permit removal of the shell cover and/or floating head cover.

For fixed tubesheet exchangers provide sufficient clearance at one end to permit withdrawal and replacement of the tubes and a space of three or four feet at the opposite end to permit removal of the bonnet or channel cover.

For U-tube heat exchangers provide sufficient clearance at the stationary head end to permit withdrawal of the tube bundle or at the opposite end to permit removal of the shell.

E-2.12 FOUNDATIONS

Foundations must be adequate so that exchangers will not settle and cause the piping to transmit excessive strains to the nozzles of the exchanger. Foundation bolts should be set to allow for setting inaccuracies. In concrete footings, pipe sleeves at least one size larger than bolt diameter slipped over the bolt and cast in place are best for this purpose, as they allow the bolt center to be adjusted after the foundation has set.

E-2.13 FOUNDATION BOLTS

Foundation bolts should be loosened at one end of unit to allow free expansion of shells. Slotted holes in supports are provided for this purpose.

E-2.14 LEVELING

Exchangers must be set level and square so that pipe connections may be made without forcing.

E-2.2 CLEANLINESS PROVISIONS

E-2.21 CONNECTION PROTECTORS

All exchanger openings should be inspected for foreign material. Protective plugs and covers should not be removed until just prior to installation.

E-2 INSTALLATION OF HEAT EXCHANGERS—(Continued)

E-2.22 DIRT REMOVAL

The entire system should be clean before starting operation. Under some conditions, the use of strainers in the piping may be required.

E-2.23 CLEANING FACILITIES

Convenient means should be provided for cleaning the unit as suggested under "Maintenance".

E-2.3 FITTINGS AND PIPING

E-2.31 BY-PASS VALVES

It may be desirable to provide valves and by-passes in the piping system to permit inspection and repairs.

E-2.32 TEST CONNECTIONS

When not integral with the exchanger nozzles, thermometer well and pressure gage connections should be installed close to the exchanger in the inlet and outlet piping.

E-2.33 VENTS

Vent cocks should be provided so units can be purged to prevent or relieve vapor or gas binding.

E-2.34 DRAINS

Drains should discharge to atmosphere or into a vessel at lower pressure. They should not be piped to a common closed manifold.

E-2.35 SURGE DRUMS

In all installations, care should be taken to eliminate or minimize transmission of fluid pulsations and mechanical vibrations to the heat exchangers.

E-3 OPERATION OF HEAT EXCHANGERS

E-3.1 DESIGN AND OPERATING CONDITIONS

Equipment must not be operated at conditions which exceed those specified on the name plate.

E-3.2 OPERATING PROCEDURES

Before placing any exchanger in operation, reference should be made to the exchanger drawings, specification sheet, and name plate for any special instructions. Improper starting up or shutting down sequences, particularly of fixed tubesheet units, may cause leaking of tube-to-tubesheet and/or bolted flanged joints.

E-3.21 STARTING-UP OPERATION

Most exchangers with removable tube bundles may be placed in service by first establishing circulation of the cold medium, followed by the gradual introduction of the hot medium. During start-up all vent valves should be opened and left open until all passages have been purged of air and are completely filled with fluid. For fixed tubesheet exchangers, fluids must be introduced in a manner to minimize differential expansion between the shell and tubes.

E-3.22 SHUTTING-DOWN OPERATION

For exchangers with removable bundles, the units may be shut down by first gradually stopping the flow of the hot medium and then stopping the flow of the cold medium. If it is necessary to stop the flow of cold medium, the circulation of hot medium through the exchanger should also be stopped. For fixed tubesheet exchangers the unit must be shut down in a manner to minimize differential expansion between shell and tubes.

E-3.23 TEMPERATURE SHOCKS

Operation must be started gradually. Hot fluid must not be suddenly introduced when the unit is cold, nor cold fluid suddenly introduced when the unit is hot.

E-3 OPERATION OF HEAT EXCHANGERS—(Continued)

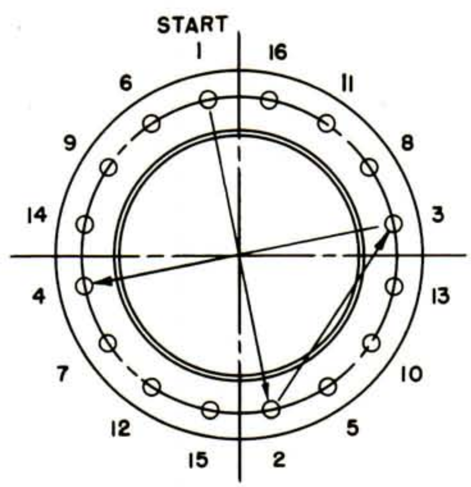
E-3.24 BOLTED JOINTS

Heat exchangers are hydrostatically tested before leaving the manufacturer's shop in accordance with ASME Code requirements. However, normal yielding of gaskets will occur in the interval between hydrostatic testing in the manufacturer's shop and installation at the jobsite. Therefore, all external bolted joints should be properly retightened after installation and, if necessary, after the exchanger has reached operating temperature.

E-3.241 RECOMMENDED BOLT TIGHTENING PROCEDURE

It is important that all bolted joints be tightened uniformly and in a diametrically staggered pattern as illustrated in Figure E-3.241 except for special high pressure closures when the instructions of the manufacturer should be followed.

FIGURE E-3.241



E-3.25 DRAINING UNIT

When shutting down the system, all units should be drained completely to minimize the possibility of freezing and corrosion damage. To guard against water hammer, condensate should be drained from steam heaters and similar apparatus when starting up or when shutting down. To reduce water retention after drainage, the tube side of water cooled exchangers should be blown out with air.

E-4 MAINTENANCE OF HEAT EXCHANGERS

E-4.1 INSPECTION OF UNIT

At regular intervals and as frequently as experience indicates, an examination should be made of the interior and exterior condition of all tubes. Neglect in keeping all tubes clean may result in complete stoppage of flow through some tubes which could cause severe thermal strains and/or leaking tube joints.

E-4.11 INDICATIONS OF FOULING

Exchangers subject to fouling or scaling should be cleaned periodically. A light sludge or scale coating on the tube greatly reduces its efficiency. A marked increase in pressure drop and/or reduction in performance usually indicates cleaning is necessary. The unit should first be checked for air or vapor binding to confirm that this is not the cause for the reduction in performance. Since the difficulty of cleaning increases rapidly as the scale thickness or deposit increases, the intervals between cleanings should not be excessive.

E-4 MAINTENANCE OF HEAT EXCHANGERS—(Continued)

E-4.12 ACCESS TO TUBES

To inspect the inside of the tubes and also make them accessible for cleaning, the following procedures should be used.

(1) Stationary Head End
 (a) Type A, C, & D, remove cover only.
 (b) Type B, remove bonnet.

(2) Rear Head End
 (a) Type L, N, & P, remove cover only.
 (b) Type M, remove bonnet.
 (c) Type S & T, remove shell cover and floating head cover.
 (d) Type W, remove channel cover or bonnet.

Head bolts should not be loosened until the unit has been completely depressurized, vented, and drained.

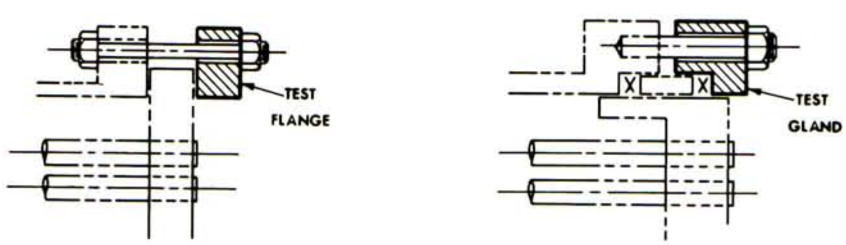
E-4.13 LOCATING LEAKS IN TUBES

The following procedures may be used to locate perforated or split tubes and leaking joints between tubes and tubesheets. In most cases, the entire front face of each tubesheet will be accessible for inspection. The point where water escapes indicates a defective tube or tube-to-tubesheet joint.

(1) Units with channel type head: Remove channel cover and apply hydraulic pressure in the shell.

(2) Units with bonnet type head: On fixed tubesheet units where tubesheets are an integral part of the shell, remove bonnet and apply hydraulic pressure in the shell. On fixed tubesheet units where tubesheets are not an integral part of the shell and on units with removable bundles, remove bonnet, re-bolt tubesheet to shell or install test flange or gland, whichever is applicable and apply hydraulic pressure in the shell. See Fig. E-4.13-1 for typical test flange and test gland.

FIGURE E-4.13-1

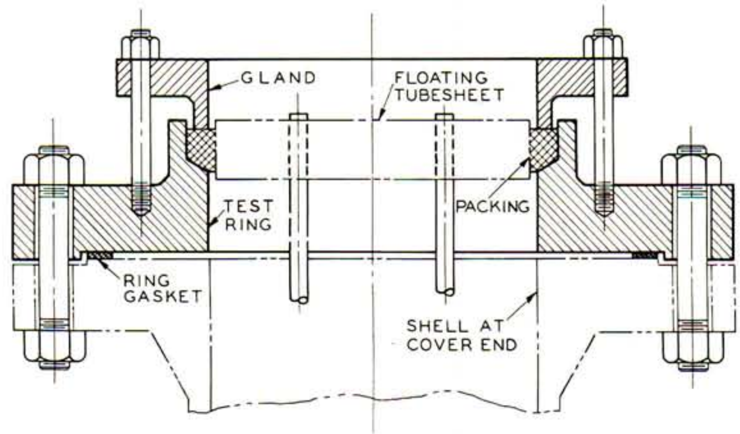


(3) Units with type S or T floating head: Remove channel cover or bonnet, shell cover and floating head cover. Install test ring and bolt in place with gasket and packing. Apply hydraulic pressure in the shell. A typical test ring is shown in Figure E-4.13-2. When a test ring is not available it is possible to locate leaks at the floating head end by removing the shell cover and applying hydraulic pressure in the tubes. Leaking tube joints may then be located by sighting through the tube lanes.

(4) Water for test should be at ambient temperature. Cold water may cause erroneous indications in humid atmospheres because of condensation on the cold metal surfaces. Hot water may cause differential expansion between the tubes and the shell in fixed tubesheet units, resulting in possible damage.

E-4 MAINTENANCE OF HEAT EXCHANGERS—(Continued)

FIGURE E-4.13-2



E-4.2 TUBE BUNDLE REMOVAL

Care should be exercised when removing a tube bundle from the shell, otherwise the bundle and/or the shell may be damaged. The tube bundle should always be supported on the baffles, tube support plates or tubesheets. Never support the bundle on the tubes. The pulling cable should be attached to eyebolts screwed into the tubesheet. Steel rods or cables inserted through the tubes and attached to bearing plates may be used where tubesheets are not tapped for eyebolts.

E-4.21 HANDLING TUBE BUNDLES

Tube bundles should not be handled with hooks or other devices which might damage the tubes. Bundles should be supported on cradles or skids. Horizontal tube bundles should be lifted by means of suitable slings. Baffles can be bent and damaged by dragging a bundle over a rough surface. All gasket and packing contact surfaces should be protected from accidental damage since these areas are generally difficult to repair.

E-4.22 LIFTING AND PULLING MECHANISMS

The following are safe loads for steel rods and eye bolts:

RODS

Size Tubes	Size Rods	Safe Load per Rod
5/8"	3/8"	1000 lbs.
3/4"	1/2"	2000 lbs.
1" or larger	5/8"	3000 lbs.

EYE BOLTS

Size	Safe Load
3/4"	4,000 lbs.
1"	6,000 lbs.
1 1/4"	10,000 lbs.
1 1/2"	15,000 lbs.

E-4 MAINTENANCE OF HEAT EXCHANGERS—(Continued)

E-4.3 CLEANING TUBE BUNDLES

E-4.31 CLEANING METHODS

The heat transfer surfaces of heat exchangers should be kept reasonably clean to assure satisfactory performance. Convenient means for cleaning should be made available.

Heat exchangers may be cleaned by either chemical or mechanical methods. The method selected must be the choice of the operator of the plant and will depend on the type of deposit and the facilities available in the plant. Following are several cleaning procedures that may be considered:

(1) Circulating hot wash oil or light distillate through tubes or shell at high velocity will effectively remove sludge or similar soft deposits.

(2) Some salt deposits may be washed out by circulating hot fresh water.

(3) Commercial cleaning compounds are available for removing sludge or scale provided hot wash oil or water is not available or does not give satisfactory results. Contact compound manufacturer for advice.

(4) Turbine type tube cleaners for removal of deposits inside of tubes.

(5) Scrapers, rotating wire brushes, and other mechanical means for removing hard scale, coke, or other deposits.

(6) Employ services of a qualified organization that provides cleaning services. These organizations will check the nature of the deposits to be removed, furnish proper solvents and/or acid solutions containing inhibitors, and provide equipment and personnel for a complete cleaning job.

E-4.32 CLEANING PRECAUTIONS

(1) Tubes should not be cleaned by blowing steam through individual tubes since this overheats the tube and results in severe expansion strain.

(2) When mechanically cleaning a tube bundle, care should be exercised to avoid damaging the tubes.

E-4.4 TUBE ROLLING

A suitable roller type tube expander should be used to tighten a leaking tube joint. Care should be taken to insure that tubes are not over-rolled.

E-4.5 GASKET REPLACEMENT

Gaskets and gasket surfaces should be thoroughly cleaned and should be free of scratches and other defects. Gaskets should be properly positioned before attempting to retighten bolts. It is recommended that when a heat exchanger is dismantled for any cause, it be reassembled with new gaskets. This will tend to prevent future leaks and/or damage to the gasket seating surfaces of the heat exchanger. Composition gaskets become dried out and brittle so that they do not always provide an effective seal when reused. Metal or metal jacketed gaskets, when compressed initially, flow to match their contact surfaces. In so doing they are work hardened and, if reused, may provide an imperfect seal or result in deformation and damage to the gasket contact surfaces of the exchanger.

E-4.6 SPARE AND REPLACEMENT PARTS

The procurement of spare or replacement parts from the manufacturer will be facilitated if the correct name for the part, as shown in Section 1, Table N-2, of these standards is given, together with the serial number, type, size, and other information from the nameplate. Replacement parts should be secured from the original manufacturer to assure correct fit and good performance.

R-1 SCOPE AND GENERAL REQUIREMENTS

R-1.1 SCOPE OF STANDARDS

R-1.11 DEFINITION OF TEMA CLASS "R" EXCHANGERS

The TEMA Mechanical Standards for Class "R" heat exchangers specify design, fabrication, and materials of unfired shell and tube heat exchangers for the generally severe requirements of petroleum and related processing applications. Equipment fabricated in accordance with these standards is designed for safety and durability under the rigorous service and maintenance conditions in such applications.

R-1.12 CONSTRUCTION CODES

The individual vessels shall comply with the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code, Section VIII, Division 1, hereinafter referred to as the Code. These standards supplement and define the Code for heat exchanger applications. The manufacturer shall comply with the construction requirements of state and local codes when the purchaser specifies the plant location. It shall be the responsibility of the purchaser to inform the manufacturer of any applicable local codes. Application of the Code symbol is required, unless otherwise specified by the purchaser.

R-1.13 MATERIALS—DEFINITION OF TERMS

For purposes of these standards, "carbon steel" shall be construed as any steel or low alloy falling within the scope of Part UCS of the Code. Metals not included by the foregoing (except cast iron) shall be considered as "alloys" unless otherwise specifically named.

R-1.2 PRESSURE CLASSIFICATIONS

R-1.21 STANDARD PRESSURE CLASSIFICATIONS

The following design pressure classifications are standard:

For diameters larger than 23" nominal	75 psi
For all diameters	150 psi
For all diameters	300 psi
For all diameters	450 psi
For all diameters	600 psi

R-1.22 INTERMEDIATE PRESSURE CLASSES

For special circumstances, consideration may be given to intermediate pressure classes.

R-1.23 DESIGN PRESSURES

Design pressures for the shell and tube sides shall be specified separately by the purchaser.

R-1.3 TESTING

R-1.31 STANDARD TEST

The exchanger shall be hydrostatically tested with water. The test pressure shall be held for at least 30 minutes. The shell side and the tube side are to be tested separately in such a manner that leaks at the tube joints can be detected from at least one side. When construction permits, and the tube side design pressure is the higher pressure, the tube bundle shall be tested outside of the shell. Welded joints are to be sufficiently cleaned prior to testing the exchanger to permit proper inspection during the test. The hydrostatic test pressure at room temperature shall be 1.5 times the design pressure, corrected for temperature, except for materials such as cast iron where other Code requirements govern.

R-1 SCOPE AND GENERAL REQUIREMENTS—(Continued)

R-1.311 OTHER LIQUID TESTS

Other liquids in lieu of water may be used as a testing medium, if agreed upon between the purchaser and the manufacturer.

R-1.32 PNEUMATIC TEST

When liquid cannot be tolerated as a test medium, then by agreement between purchaser and manufacturer, the exchanger may be given a pneumatic test in accordance with the Code. It must be recognized that air or gas is hazardous when used as a pressure testing medium. The pneumatic test pressure at room temperature shall be 1.25 times the design pressure, corrected for temperature, except for materials such as cast iron where other Code requirements govern.

R-1.33 SUPPLEMENTARY AIR TEST

When a supplementary air or gas test is specified by the purchaser, it shall be immediately preceded by hydrostatic test required by Par. R-1.31. The test pressure shall be specified by the purchaser, but shall not exceed that required by Par. R-1.32. Leaks may be located by halide probe, or by other means, as agreed upon by the purchaser and manufacturer.

R-1.4 METAL TEMPERATURES

R-1.41 METAL TEMPERATURE LIMITATIONS FOR PRESSURE PARTS

The metal temperature limitations for various metals are those prescribed by the Code.

R-1.42 DESIGN TEMPERATURE OF HEAT EXCHANGER PARTS

Design temperatures for the shell and tube sides shall be specified separately by the purchaser for parts not subject to both fluids. The design temperature of heat exchanger parts subjected to two different fluid temperatures shall be the maximum metal temperature of the part under operating conditions, except when the purchaser specifies some other design metal temperature. In establishing the metal temperatures, due consideration shall be given to such factors as the relative heat transfer coefficients of the two fluids contacting the part and the relative heat transfer area of the parts contacted by the two fluids.

R-1.5 STANDARD CORROSION ALLOWANCES

Corrosion allowances are to be used for the various heat exchanger parts as follows:

R-1.51 CARBON STEEL PARTS

R-1.511 PRESSURE PARTS

All carbon steel pressure parts, except tubes, are to have a corrosion allowance of 1/8" unless the conditions of service make a different allowance more suitable and such allowance is definitely specified.

R-1.512 INTERNAL COVERS

Internal covers are to have the corrosion allowance on each side.

R-1.513 TUBESHEETS

Tubesheets are to have the corrosion allowance on each side with the provision that, on the grooved side of a grooved tubesheet, the depth of the pass partition groove may be considered as available for corrosion allowance.

R-1.514 EXTERNAL COVERS

Where flat external covers are grooved, the depth of the groove may be considered as available for corrosion allowance.

R-1.515 END FLANGES

Corrosion allowance shall be applied only to the inside diameter of flanges.

R-1 SCOPE AND GENERAL REQUIREMENTS—(Continued)

R-1.516 NONPRESSURE PARTS

Nonpressure parts such as tie rods, spacers, baffles, and support plates are to have no allowance for corrosion.

R-1.517 FLOATING HEAD BACKING DEVICES

Floating head backing devices and internal bolting are to have no corrosion allowance.

R-1.52 ALLOY PARTS

No corrosion allowance is to be added to alloy parts except as specified by the purchaser.

R-1.53 CAST IRON PARTS

Cast iron pressure parts shall have a corrosion allowance of ⅛".

R-1.6 SERVICE LIMITATIONS

R-1.61 CAST IRON PARTS

Cast iron shall be used only for water service at pressures not exceeding 150 psi.

R-1.62 PACKED JOINTS

Packed joints shall not be used when the purchaser specifies that the fluid in contact with the joint is lethal or flammable.

R-2 TUBES

R-2.1 TUBE LENGTH

The following tube lengths for both straight and U-tube exchangers, shall be considered as standard: 8, 10, 12, 16, and 20 feet. Other lengths may be used; even lengths are preferred. See also paragraph N-1.12.

R-2.2 TUBE DIAMETERS AND GAGES

R-2.21 BARE TUBES

Table R-2.21 lists standard tube diameters and gages for bare tubes of copper, steel, and alloy.

TABLE R-2.21

STANDARD BARE TUBE DIAMETERS AND GAGES

O. D. Inches	Copper and Copper Alloys		Carbon Steel, Aluminum and Aluminum Alloys		Other Alloys	
	B.W.G. (Min. Wall)	Thickness Inches	B.W.G. (Min. Wall)	Thickness Inches	B.W.G. (Avg. Wall)	Thickness Inches
¾	18	0.049	16	0.065	18	0.049
	16	0.065	**14**	0.083	**16**	0.065
	14	0.083	12	0.109	14	0.083
1	16	0.065	14	0.083	18	0.049
	14	0.083	**12**	0.109	16	0.065
	12	0.109	10	0.134	**14**	0.083
	—	—	—	—	12	0.109
1¼	14	0.083	14	0.083	16	0.065
	12	0.109	12	0.109	14	0.083
	10	0.134	10	0.134	12	0.109
	—	—	—	—	10	0.134
1½	14	0.083	12	0.109	14	0.083
	12	0.109	10	0.134	12	0.109
2	14	0.083	12	0.109	14	0.083
	12	0.109	10	0.134	12	0.109

Notes: 1. Tube diameters and gages in bold face are preferred.

2. Average wall tubes of heavier gage may be used in place of minimum wall tubes, provided the wall thickness is not less than specified.

3. Characteristics of tubing are shown in Table D-7, Page 187.

R-2 TUBES—(Continued)

R-2.22 CIRCUMFERENTIALLY-FINNED TUBES

The nominal fin diameter shall be the same as the O.D. of the unfinned end. The diameter over the fins will not normally exceed the diameter of the unfinned section to insure that fin tubes are interchangeable with standard bare tubes. Specified wall shall be based on the thickness at the root diameter.

R-2.3 U-TUBES

R-2.31 NONUNIFORM THICKNESS BENDS

When U-bends are formed, as is customary, in such a way as to thin the tube wall at the outer radius of the bend, the minimum tube wall thickness in the bent portion **before bending** shall be:

$$t_o = t_1 \left[1 + \frac{d_o}{4R} \right]$$

where t_o = Original tube wall thickness, inches.
t_1 = Minimum tube wall thickness calculated by Code rules for a straight tube subjected to the same pressure and metal temperature, inches.
d_o = Outside tube diameter, inches.
R = Mean radius of bend, inches.

When thinning of the bends cannot be tolerated because of corrosion, and the purchaser so states, then the inner two rows of U-tubes shall have tubes with a wall two gages heavier. Dual-gage tubes may be used.

When U-bends are formed from tube materials which are relatively nonwork hardening and of suitable temper, tube wall thinning in the shortest bends should not exceed a nominal 17% of original tube wall thickness.

U-bends formed from tube materials having low ductility, or materials which are susceptible to work-hardening, may require special consideration. Also refer to Par. R-2.33.

R-2.32 BEND SPACING

R-2.321 CENTER-TO-CENTER DIMENSION

The center-to-center dimensions between parallel legs of U-tubes shall be such that they may be inserted into the baffle assembly without damage to the tubes.

R-2.322 BEND INTERFERENCE

The assembly of bends shall be of workmanlike appearance. Metal-to-metal contact between bends in the same plane shall not be permitted.

R-2.33 HEAT TREATMENT

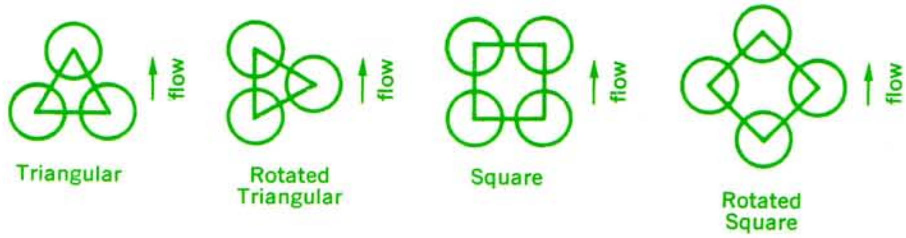
Cold work in forming U-bends may induce embrittlement or susceptibility to stress corrosion in certain materials and/or environments. Heat treatment to alleviate such conditions may be performed by agreement between manufacturer and purchaser. It is generally considered not practical to heat treat austenitic stainless steel tubes.

R-2 TUBES—(Continued)

R-2.4 TUBE PATTERN

Standard tube patterns are shown in Figure R-2.4.

FIGURE R-2.4



Note: Flow arrows are normal to the baffle cut edge.

R-2.41 SQUARE PATTERN

When tubes are laid out on a square or rotated square pitch, tube lanes shall be continuous throughout the bundle.

R-2.42 TRIANGULAR PATTERN

Triangular or rotated triangular pattern should not be used when the shell side is to be cleaned mechanically.

R-2.5 TUBE PITCH

Tubes shall be spaced with a minimum center-to-center distance of 1.25 times the outside diameter of the tube. When tubes are on a square pitch, a minimum cleaning lane of ¼" shall be provided.

R-2.6 TUBE LAYOUT

The tube layout is to be such as to minimize by-passing around the tube bundle.

R-3 SHELLS AND SHELL COVERS

R-3.1 SHELLS

R-3.11 SHELL DIAMETERS

It shall be left to the discretion of each manufacturer to establish a system of standard shell diameters within the TEMA Mechanical Standards in order to achieve the economies peculiar to his individual design and manufacturing facilities. Nothing in the TEMA Standards shall be construed as a limitation on the minimum or maximum shell diameters.

R-3.12 TOLERANCES

R-3.121 PIPE SHELLS

The inside diameter of pipe shells shall be in accordance with applicable ASTM (American Society for Testing and Materials) pipe specifications.

R-3.122 PLATE SHELLS

The inside diameter of any plate shell shall not exceed the design inside diameter by more than 1/8" as determined by circumferential measurement.

R-3.13 MINIMUM THICKNESS OF SHELLS

Shell thickness is determined by the Code design formulas, plus corrosion allowance. but in no case shall the nominal thickness of shells be less than that shown in Table R-3.13. The nominal total thickness for clad or lined shells shall be the same as for carbon steel plate shells.

TABLE R-3.13

MINIMUM SHELL THICKNESS

Nominal Shell Dia.	Minimum Thickness		
	Carbon Steel		Alloy*
	Pipe	Plate	
8" - 12" Inc.	Sch. 30	—	1/8"
13" - 29" Inc.	3/8"	3/8"	3/16"
30" - 39" Inc.	—	7/16"	1/4"
40" - 60" Inc.	—	1/2"	5/16"

* Schedule 5S permissible for 8" shell diameter.

R-3.2 SHELL COVER THICKNESS

Nominal thickness of shell cover heads shall be at least equal to the thickness of the shell as shown in Table R-3.13.

R-3.3 SHELL EXPANSION AND CONTRACTION

Where fixed tubesheet construction is used and the temperature differential between tubes and shell, under the most adverse operating condition specified by the purchaser, including startup, shutdown, and upset conditions, will result in overloading either shell or tubes, suitable provision shall be made for this expansion or contraction.

R-3.31 SHELL AND TUBE LONGITUDINAL STRESSES

Shell and tube stresses, which depend upon the effective pressures determined by paragraphs R-7.151 through R-7.155, shall be calculated by the following paragraphs. A condition of overstress shall be presumed to exist when either shell or tube stress so calculated exceeds the allowable Code tensile stress for the material at design temperature.

R-3 SHELLS AND SHELL COVERS—(Continued)

R-3.311 SHELL LONGITUDINAL STRESS

The effective longitudinal shell stress is given by:

$$S_s = \frac{(D_o - t_s)P_s^*}{4t_s}$$

where

$$\left.\begin{aligned} P_s^* &= (P_i - P_d)/2 \\ \text{or } P_s^* &= -P_d/2 \\ \text{or } P_s^* &= P_i/2 \end{aligned}\right\} \text{ whichever has the greatest absolute value}$$

$$P_i = (P_t - P_t' + P_s')$$

Other symbols are as defined in paragraphs R-7.151, R-7.153, and R-7.154 with $J = 1$, using actual shell and tubesheet thicknesses and retaining algebraic signs.

R-3.312 TUBE LONGITUDINAL STRESS

The maximum effective longitudinal tube stress is given by:

$$S_t = \frac{F_q P_t^* G^2}{4Nt_t(d_o - t_t)}$$

where

$$\left.\begin{aligned} P_t^* &= (P_2 + P_d)/2 \\ \text{or } P_t^* &= -(P_3 - P_d)/2 \\ \dagger \text{ or } P_t^* &= [(P_2 - P_3) + P_d]/2 \end{aligned}\right\} \text{ whichever has the greatest absolute value}$$

$$P_2 = (P_t' - \frac{f_t}{F_q} P_t)$$

$$P_3 = (P_s' - \frac{f_s}{F_q} P_s)$$

Other symbols are as defined in paragraphs R-7.151, R-7.153, R-7.154, and R-7.155 with $J = 1$, using actual shell and tubesheet thicknesses and retaining algebraic signs.

† When differential pressure controls (Par. R-7.155), this formula only applies.

R-3.32 TUBE JOINT AND BUCKLING LOADS

A condition of overload shall be presumed to exist even though the maximum stress levels determined in paragraph R-3.31 are acceptable, if the tubes are unstable as columns under maximum compressive load or if, regardless of load direction, the tube joint shear load holding capability is exceeded. For this purpose the maximum tube load is given by:

$$W_t = \frac{\pi}{2N} F_q G^2 P_t^*$$

where, for tube joint loads, P_t^* is the maximum absolute value defined by paragraph R-3.312 and, for tube buckling loads, is the greatest negative value so defined. Other symbols are as defined in paragraphs R-7.151, R-7.153, and R-7.154 with $J = 1$.

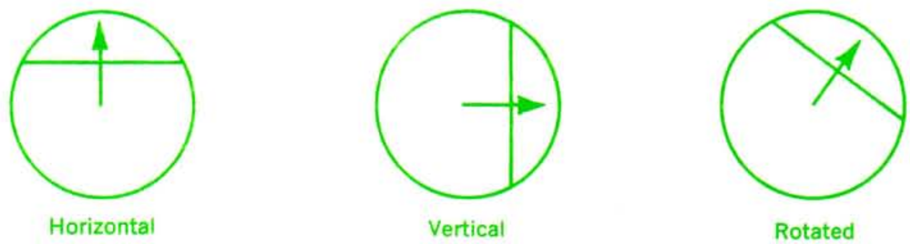
R-4 · BAFFLES AND SUPPORT PLATES

R-4.1 TYPE OF TRANSVERSE BAFFLES

The segmental type of baffle or tube support plate is standard. Double segmental type baffles are permissible. Baffle cut is defined as the segment opening height expressed as a percentage of the shell inside diameter. Baffles shall be cut near the centerline of a row of tubes, of a pass lane, or of a tube lane when square pattern is used, or outside the tube pattern. Baffles shall have a finish of 250 RMS or better on the outside diameter and baffle cut edge. Standard baffle cut is illustrated in Figure R-4.1.

FIGURE R-4.1

BAFFLE CUT



R-4.2 TUBE HOLES

Where the maximum unsupported tube length is 36 inches or less, standard tube holes are drilled 1/32" over the O.D. of the tubes. For unsupported tube lengths greater than 36 inches, standard tube holes are drilled 1/64" over the O.D. of the tubes. For pulsating conditions tube holes may be drilled smaller than standard. Any burrs shall be removed and the tube holes given a workmanlike finish.

R-4.3 TRANSVERSE BAFFLE AND SUPPORT CLEARANCE

The transverse baffle and support plate clearance shall be such that the difference between the shell design inside diameter and the outside diameter of the baffle shall not exceed that indicated in Table R-4.3. However, where such clearance has no significant effect on shell side heat transfer coefficient or mean temperature difference, these maximum clearances may be increased to twice the tabulated values.

TABLE R-4.3

STANDARD CROSS BAFFLE AND SUPPORT PLATE CLEARANCES

Nominal Shell Inside Diameter	Design I.D. of Shell Minus Baffle O.D.
8" - 13" Inc.	0.100"
14" - 17" Inc.	0.125"
18" - 23" Inc.	0.150"
24" - 39" Inc.	0.175"
40" - 54" Inc.	0.225"
55" and over	0.300"

The design inside diameter of a pipe shell is defined as the nominal outside diameter of the pipe, minus twice the nominal wall thickness. The design inside diameter of a plate shell is the specified inside diameter.

R-4 BAFFLES AND SUPPORT PLATES—(Continued)

R-4.4 THICKNESS OF BAFFLES AND SUPPORT PLATES

R-4.41 TRANSVERSE BAFFLES AND SUPPORT PLATES

Table R-4.41 shows the minimum thickness of transverse baffles and support plates applying to all materials for various shell diameters and plate spacings.

TABLE R-4.41

BAFFLE OR SUPPORT PLATE THICKNESS

Nominal Shell I.D.	Plate Thickness—Inches				
	Distance between adjacent segmental plates or ½ distance between full supports				
	12" and Under	Over 12" to 18" Inc.	Over 18" to 24" Inc.	Over 24" to 30" Inc.	Over 30"
8" - 14" Inc.	1/8	3/16	1/4	3/8	3/8
15" - 28" Inc.	3/16	1/4	3/8	3/8	1/2
29" - 38" Inc.	1/4	5/16	3/8	1/2	5/8
39" and over	1/4	3/8	1/2	5/8	5/8

R-4.42 LONGITUDINAL BAFFLES

Longitudinal baffles shall have a minimum total metal thickness of ¼".

R-4.43 SPECIAL PRECAUTIONS

Special consideration must be given to baffles and support plates subjected to pulsations, to baffles and support plates engaging finned tubes, and to longitudinal baffles subjected to large differential pressures due to high shell side fluid pressure drop.

R-4.5 SPACING OF BAFFLES AND SUPPORT PLATES

R-4.51 MINIMUM SPACING

Segmental baffles shall not be spaced closer than ⅕ of the shell I.D., or 2 inches, whichever is greater.

R-4.52 MAXIMUM SPACING

Tube support plates shall be so spaced that the unsupported tube length does not exceed the value indicated in Table R-4.52 for the tube material used.

R-4 BAFFLES AND SUPPORT PLATES—(Continued)

TABLE R-4.52

MAXIMUM UNSUPPORTED STRAIGHT TUBE LENGTH

Tube O.D. Inches	Maximum Unsupported Span—Inches Tube Materials and Temperature Limits (°F) Carbon & High Alloy Steel (750) Low Alloy Steel (850) Nickel-Copper (600) Nickel (850) Nickel-Chromium-Iron (1000)	Aluminum & Aluminum Alloys Copper & Copper Alloys at Code Maximum Allowable Temperature
¾	60	52
1	74	64
1¼	88	76
1½	100	87
2	125	110

Notes: Above the metal temperature limits shown, maximum spans shall be reduced in direct proportion to the fourth root of the ratio of elastic modulus at temperature to elastic modulus at tabulated limit temperature. In the case of circumferentially finned tubes, the tube O.D. shall be the diameter at the root of the fins and the corresponding tabulated or interpolated span shall be reduced in direct proportion to the fourth root of the ratio of the weight per unit length of the tube, if stripped of fins to that of the actual finned tube.

R-4.53 BAFFLE SPACING

Baffles normally shall be spaced uniformly, spanning the effective tube length. When this is not possible, the baffles nearest the ends of the shell, and/or tubesheets, shall be located as close as practical to the shell nozzles. The remaining baffles normally shall be spaced uniformly.

R-4.54 U-TUBE REAR SUPPORT

The support plates or baffles adjacent to the bends in U-tube exchangers shall be so located that, for any individual bend, the sum of the bend diameter plus the straight lengths measured along both legs from supports to bend tangents does not exceed the maximum unsupported span determined from paragraph R-4.52. Where bundle diameter prevents compliance, special provisions in addition to the above shall be made for support of the U-bends.

R-4.55 SPECIAL CASES

When pulsating conditions are specified by the purchaser, unsupported spans shall be as short as pressure drop restrictions permit. If the span under these circumstances approaches the maximum permitted by paragraph R-4.52, consideration should be given to alternative flow arrangements which would permit shorter spans under the same pressure drop restrictions.

R-4.56 TUBE BUNDLE VIBRATION

Flow induced or other damaging tube bundle vibrations may be encountered because of the infinite combinations of geometries related to unsupported tube span, tube arrangement, materials, size, and flow rates used in heat exchanger design. Existing quantitative data are inadequate to ensure that designs will be vibration free.

R-4 BAFFLES AND SUPPORT PLATES—(Continued)

R-4.6 IMPINGEMENT BAFFLES

R-4.61 SHELL SIDE

R-4.611 IMPINGEMENT PROTECTION REQUIREMENTS

An impingement plate, or other means to protect the tube bundle against impinging fluids, shall be provided when entrance line values of ρV^2 exceed the following: noncorrosive, nonabrasive, single phase fluids, 1500; all other liquids, including a liquid at its boiling point, 500. For all other gases and vapors, including all nominally saturated vapors, and for liquid vapor mixtures, impingement protection is required. V is the linear velocity of the fluid in feet per second and ρ is its density in pounds per cubic foot.

R-4.612 BUNDLE ENTRANCE AND EXIT AREAS

In no case shall the total bundle entrance or exit area produce a value of ρV^2 in excess of 4000, where V is the linear velocity of the fluid in feet per second, and ρ is its density in pounds per cubic foot. For purposes of calculating the total bundle entrance or exit area, the actual flow area into or out of the bundle between the tubes, based on the projected cross sectional flow area of the nozzle or dome and/or the actual unrestricted radial flow area from under the nozzle or dome, measured between the tube bundle diameter and the shell inside diameter may be considered. In the case of exchangers where vaporization occurs, special attention shall be given to provision for ample exit area.

R-4.62 TUBE SIDE

When it is necessary to use an axial inlet nozzle, or when liquid velocity in the tubes exceeds 10 feet per second, consideration shall be given to the need for special devices to prevent fluid maldistribution or erosion of the tube ends.

R-4.7 TIE RODS AND SPACERS

Tie rods and spacers, or other equivalent means of tying the baffle system together, shall be provided to retain all transverse baffles and tube support plates securely in position. Tie rods and spacers should be of a material similar to that of the baffles.

R-4.71 NUMBER AND SIZE OF TIE RODS

Table R-4.71 shows suggested tie rod count and diameter for various sizes of heat exchangers. Other combinations of tie rod number and diameter with equivalent metal area are permissible; however, no fewer than four tie rods, and no diameter less than ⅜" shall be used.

TABLE R-4.71

TIE ROD STANDARDS

Nominal Shell Diameter	Tie Rod Diameter	Minimum Number of Tie Rods
8" - 15" Inc.	⅜"	4
16" - 27" Inc.	⅜"	6
28" - 33" Inc.	½"	6
34" - 48" Inc.	½"	8
49" and over	½"	10

R-4.8 SEALING DEVICES

Suitable means, in addition to the baffles, shall be installed when necessary to prevent excessive fluid by-passing around or through the tube bundle. Sealing devices may be seal strips, tie rods with spacers, dummy tubes, or combinations of these.

R-5 FLOATING HEADS

R-5.1 INTERNAL FLOATING HEADS (Types S and T)

R-5.11 MINIMUM INSIDE DEPTH OF FLOATING HEAD COVERS

For multipass floating head covers the inside depth shall be such that the minimum cross-over area for flow between successive tube passes is at least equal to 1.3 times the flow area through the tubes of one pass. For single pass floating head covers the depth at nozzle centerline shall be a minimum of one-third the inside diameter of the nozzle.

R-5.12 POSTWELD HEAT TREATMENT

Fabricated carbon steel floating head covers shall be postweld heat treated after completion of welding. Minor modifications as permitted by the Code may be made without further heat treatment.

R-5.13 FLOATING HEAD BACKING DEVICES

The material of construction for split rings or other internal floating head backing devices shall be equivalent in corrosion resistance to the material used for the shell interior. They shall be furnished without any allowance for corrosion.

R-5.131 INTERNAL BOLTING

The materials of construction for internal bolting for floating heads shall be suitable for the mechanical design and similar in corrosion resistance to the materials used for the shell interior.

R-5.14 TUBE BUNDLE SUPPORTS

A partial support plate, or other suitable means, shall be provided to support the floating head end of the tube bundle. If a plate is used, the thickness shall equal or exceed the support plate thickness specified in Table R-4.41 for spacings over 30".

R-5.15 FLOATING HEAD NOZZLES

The floating head nozzle and packing box for a single pass exchanger shall comply with the requirements of paragraphs R-5.21, R-5.22, and R-5.23.

R-5.16 PASS PARTITION PLATES

The nominal thickness of floating head pass partitions, including corrosion allowance, shall be identical to those shown in paragraph R-8.131 for channels and bonnets.

R-5.2 OUTSIDE PACKED FLOATING HEADS (Type P)

R-5.21 PACKED FLOATING HEADS

The cylindrical surface of packed floating head tubesheets and skirts, where in contact with packing (including allowance for expansion), shall be given a fine machine finish equivalent to 63 RMS (or 70 AA).

R-5 FLOATING HEADS—(Continued)

R-5.22 PACKING BOXES

A machine finish shall be used on the shell or packing box where the floating tubesheet or nozzle passes through. If braided asbestos packing is used, three rings of packing shall be used for 150 psi working pressure and four rings shall be used for 300 psi working pressure. For pressures less than 150 psi, temperatures below 300°F, and nonhazardous service, fewer rings of packing may be used. Figure R-5.22 and Table R-5.22 show typical details and dimensions of packing boxes.

FIGURE R-5.22

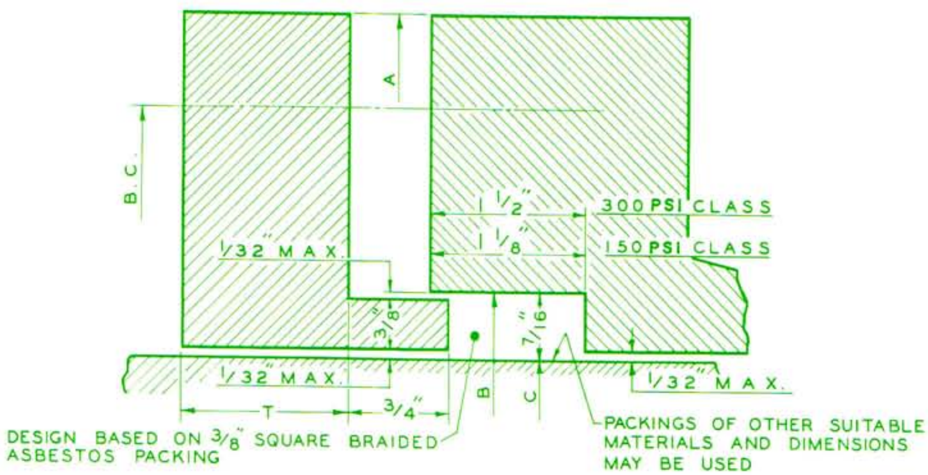


TABLE R-5.22

TYPICAL DIMENSIONS FOR PACKED FLOATING HEADS
150 PSI AND 300 PSI CLASS 600°F MAX. TEMP.

(All dimensions in inches)

Size	A	B	C	T	Bolts		B.C.
					No.	Size	
8	12½	8⅞	8	1	4	⅝	11
10	14⅝	10⅞	10	1	6	⅝	13⅛
12	16⅝	12⅞	12	1	6	⅝	15⅛
13	17⅞	13⅞	13	1	6	⅝	16⅜
15	19⅞	15⅞	15	1¼	8	⅝	18⅜
17	22	17⅞	17	1¼	8	⅝	20½
19	24	19⅞	19	1¼	10	⅝	22½
21	26⅛	21⅞	21	1⅜	10	⅝	24⅝
23	28⅛	23⅞	23	1⅜	12	⅝	26⅝

R-5 FLOATING HEADS—(Continued)

R-5.23 PACKING MATERIAL

Purchaser shall specify packing material which is compatible with the shell fluid.

R-5.24 FLOATING TUBESHEET SKIRT

The floating tubesheet skirt normally shall extend outward. When the skirt must extend inward, then a suitable method shall be used to prevent stagnant areas between the shell side nozzle and the tubesheet.

R-5.25 PASS PARTITION PLATES

The nominal thickness of floating head pass partitions, including corrosion allowance, shall be identical to those shown in paragraph R-8.131 for channels and bonnets.

R-5.3 PACKED LANTERN RING FLOATING HEAD (Type W)

The packed lantern ring type floating head shall be used only for water, steam, air, lubricating oil, or similar services. Design temperature shall not exceed 375°F. Design pressure shall not exceed 300 psi for exchangers up to 24" in diameter, nor 150 psi for exchangers from 24" to 42" in diameter.

R-6 GASKETS

R-6.1 TYPE OF GASKETS

Gaskets shall be made in one piece. This shall not exclude gaskets made integral by welding.

R-6.2 GASKET MATERIALS

Metal jacketed or solid metal gaskets shall be used for internal floating head joints, all joints for pressures of 300 psi and over, and for all joints in contact with hydrocarbons. Other gasket materials may be specified by agreement between purchaser and manufacturer to meet special service conditions and flange design. When two gasketed joints are compressed by the same bolting, gasket materials and areas shall be selected so that both gaskets seal, but neither gasket is crushed at the required bolt load.

R-6.3 PERIPHERAL GASKETS

The minimum width of peripheral ring gaskets for external joints shall be ⅜" for shell sizes through 23" nominal diameter and ½" for all larger shell sizes.

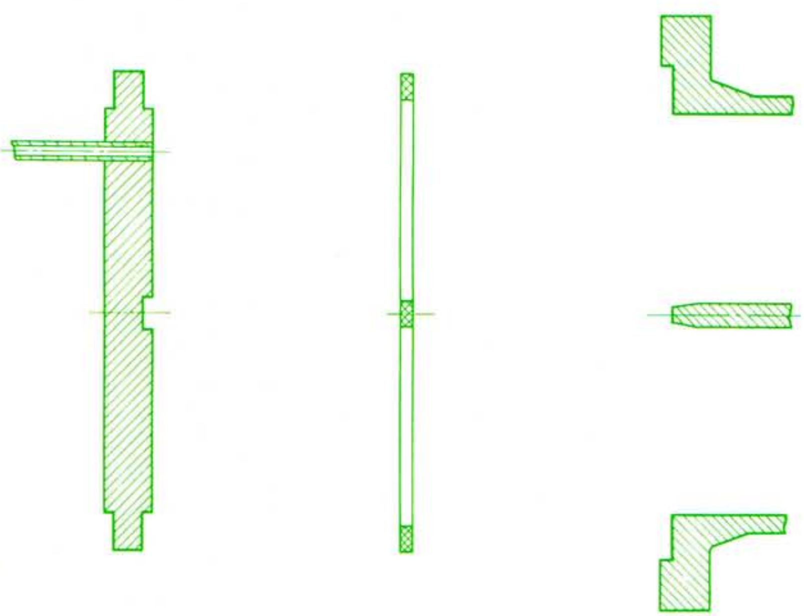
R-6.4 PASS PARTITION GASKETS

The width of gasket web for pass partitions of channels, bonnets, and floating heads shall be not less than ¼" for shell sizes through 23" nominal diameter and not less than ⅜" for all larger shell sizes.

R-6.5 GASKET JOINT DETAILS

Gasketed joints shall be of a confined type.
Figure R-6.5 shows typical details of confined gasketed joints.

FIGURE R-6.5



Confined Gasket

R-7 TUBESHEETS

R-7.1 TUBESHEET THICKNESS

R-7.11 EFFECTIVE TUBESHEET THICKNESS

The effective tubesheet thickness shall be the thickness measured at the bottom of the pass partition groove minus shell side corrosion allowance and corrosion allowance on the tube side in excess of the groove depth.

R-7.111 APPLIED TUBESHEET FACINGS

The thickness of applied facing material shall not be included in the minimum or effective tubesheet thickness.

R-7.112 INTEGRALLY CLAD TUBESHEETS

The thickness of cladding material in integrally clad plates and cladding deposited by welding may be included in the effective tubesheet thickness except as limited by the Code.

R-7.12 REQUIRED EFFECTIVE TUBESHEET THICKNESS

The required effective tubesheet thickness for any type of heat exchanger shall be determined from the following paragraphs, for both tube side and shell side conditions, using whichever thickness is greatest.

R-7.121 MINIMUM TUBESHEET THICKNESS

In no case shall the total thickness minus corrosion allowance of any tubesheet be less than the outside diameter of the tubes.

R-7.122 TUBESHEET FORMULA—BENDING

$$T = \frac{FG}{2}\sqrt{\frac{P}{S}}$$

where T = Effective thickness of tubesheet, inches.

S = Code allowable working stress, in tension, for tubesheet material at design temperature used, psi.

P = Hydrostatic design pressure, psi, shell side or tube side, except as modified by paragraphs R-7.153, R-7.154, R-7.155, and R-7.161.

F and G are defined in subsequent paragraphs.

R-7 TUBESHEETS—(Continued)

R-7.123 TUBESHEET FORMULA—SHEAR

$$T = \frac{0.31\ D_L}{\left(1 - \frac{d_o}{p}\right)}\left(\frac{P}{S}\right)$$

where T = Effective thickness of tubesheet, inches.

D_L = $4\ A/C$ = Equivalent diameter of tube center limit perimeter, inches.

C = Perimeter of tube layout measured stepwise in increments of one tube pitch from center-to-center of the outermost tubes, inches. Figure R-7.123 shows the application to typical triangular and square tube pitch layouts.

A = Total area enclosed by perimeter C, square inches.

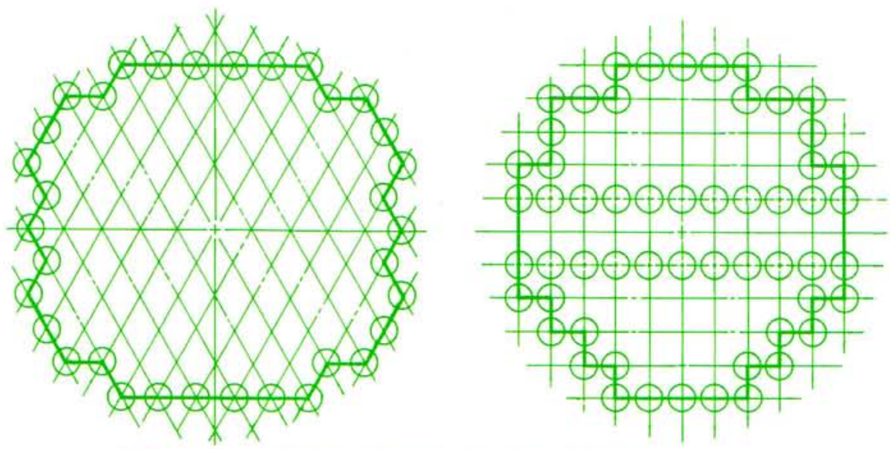
d_o = Outside tube diameter, inches.

p = Tube spacing, center-to-center, inches.

P = Hydrostatic design pressure, psi, shell side or tube side, except as modified by paragraphs R-7.153, R-7.154, and R-7.161.

S = Code allowable working stress, in tension, for tubesheet material at design temperature used, psi.

FIGURE R-7.123



"C" (PERIMETER) IS THE LENGTH OF HEAVY LINE.

R-7.13 GASKETED STATIONARY TUBESHEET EXCHANGERS

This paragraph shall apply whenever a gasketed joint is used between the stationary tubesheet and the adjoining pressure part under consideration, even though the tubesheet may be integral with the other adjoining pressure part, except as limited by paragraph R-7.19.

R-7.131 STATIONARY AND FLOATING TUBESHEET CONSTANTS

G = Mean diameter of gasket at stationary tubesheet, inches.

$F = 1.0$

R-7 TUBESHEETS—(Continued)

R-7.132 U-TUBE STATIONARY TUBESHEET CONSTANTS

G = Mean diameter of gasket at stationary tubesheet, inches.

F = 1.25

R-7.14 INTEGRAL STATIONARY TUBESHEET EXCHANGERS

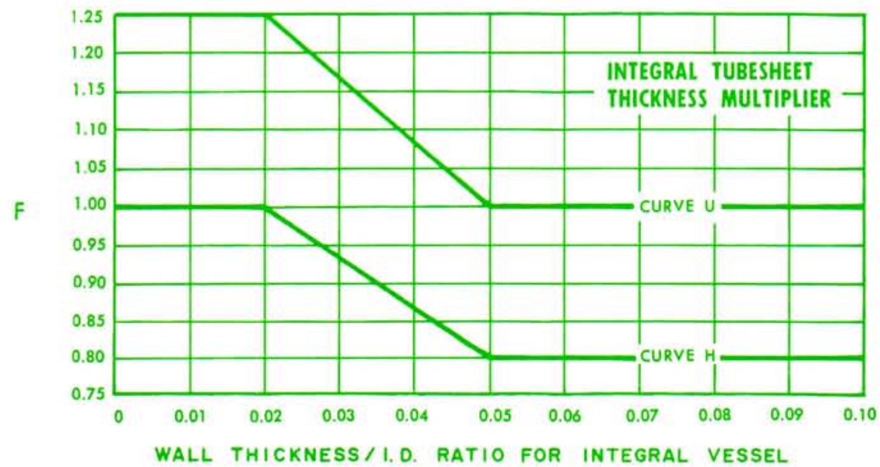
This paragraph shall apply whenever the stationary tubesheet is integral with the adjoining pressure part under consideration, even though the joint with the other adjoining pressure part may be gasketed, except as limited by paragraph R-7.19. With fixed tubesheet exchangers, both tubesheets shall be considered stationary.

R-7.141 STATIONARY TUBESHEET CONSTANTS

G = Inside diameter of integral pressure part, inches.

F = Value given by curve H of Figure R-7.141 for floating head and fixed tubesheet exchangers, or by curve U for U-tube exchangers.

FIGURE R-7.141



R-7.142 FLOATING TUBESHEET CONSTANTS

R-7.1421 GASKETED FLOATING TUBESHEET WITHOUT EDGE BOLTING

G = Same as stationary tubesheet.

F = 1.0

R-7.1422 INTEGRAL FLOATING TUBESHEET

G = Same as stationary tubesheet.

F = Value given by curve H of Figure R-7.141.

R-7 TUBESHEETS—(Continued)

R-7.15 FIXED TUBESHEETS

This paragraph shall apply to exchangers having tubesheets fixed to both ends of the shell, with or without a shell expansion joint, except as limited by paragraph R-7.19. Both tubesheets in a fixed tubesheet exchanger shall have the same thickness. When fixed tubesheet extensions are gasketed and bolted, the extended portion shall be in accordance with Code design practice. The extension and that portion of the tubesheet inside the shell may differ in thickness. Tubesheet thicknesses calculated by these rules are adequate. It is possible, however, that shells, tubes, or tube-to-tubesheet joints may be overstressed unless proper provision is made to accommodate differential thermal expansion. Effective design pressures for use in paragraphs R-3.3, R-7.122, and R-7.123 shall be determined as follows:

R-7.151 EQUIVALENT DIFFERENTIAL EXPANSION PRESSURE

The pressure due to differential thermal expansion, in psi, is given by:

$$P_d = \frac{4\ J\ E_s\ t_s\ (\alpha_s\ \theta_s - \alpha_t\ \theta_t)}{(D_o - 3t_s)\ (1 + JKF_q)}$$

(Algebraic sign must be retained for use in paragraphs R-3.311, R-3.312, R-7.153, R-7.154, and R-7.155.)

where $J = \begin{cases} 1.0 \text{ for shells without expansion joints} \\ 0 \text{ for shells with expansion joints, except as limited by paragraph R-7.19.} \end{cases}$

$$K = \frac{E_s\ t_s\ (D_o - t_s)}{E_t\ t_t\ N\ (d_o - t_t)}$$

$$F_q = 0.25 + (F - 0.6)\left[\frac{300\ t_s\ E_s}{K\ L\ E}\left(\frac{G}{T}\right)^3\right]^{1/4}$$

(Use calculated value of F_q or 1.0, whichever is greater.)

F & G are as defined in paragraph R-7.141.

T = Tubesheet thickness used, but not less than 98½% of the greater of the values defined by Par. R-7.122 or R-7.123. (Value assumed in evaluating F_q must match the final computed value within a tolerance of ± 1.5 percent.) See note.

L = Tube length between inner tubesheet faces, inches.

θ = Metal temperature less 70°F.

E_s = Elastic modulus of shell material at metal temperature, psi.

E_t = Elastic modulus of tube material at metal temperature, psi.

E = Elastic modulus of tubesheet material at metal temperature, psi.

α = Thermal expansion coefficient, in. per in./°F.

N = Number of tubes in shell.

D_o = Outside diameter of shell, inches.

d_o = Outside diameter of tubes, inches.

t = Wall thickness, inches.

Subscripts "s" and "t" refer to shell and tubes respectively.

Note: Tubesheets thicker than computed are permissible provided neither shell nor tubes are overloaded. Refer paragraph R-3.3.

R-7 TUBESHEETS—(Continued)

R-7.152 EQUIVALENT BOLTING PRESSURE

When fixed tubesheets are extended for bolting to heads with ring type gaskets, the equivalent tube side and shell side pressures are given by:

$$P_{Bt} = \frac{6.2}{F^2} \frac{M_1}{G^3}$$

$$P_{Bs} = \frac{6.2}{F^2} \frac{M_2}{G^3}$$

where

F = Value given by Curve H of Fig. R-7.141.

G = Inside diameter of shell, inches.

M_1 = Total moment acting upon the extension under operating conditions, defined by the Code as M_o under flange design, inch-pounds.

M_2 = Total moment acting upon the extension under bolting-up conditions, defined by the Code as M_o under flange design, inch-pounds.

P_{Bt} = Equivalent bolting pressure when tube pressure is acting, pounds per square inch.

P_{Bs} = Equivalent bolting pressure when tube pressure is not acting, pounds per square inch.

R-7 TUBESHEETS—(Continued)

R-7.153 EFFECTIVE SHELL SIDE DESIGN PRESSURE

The effective shell side design pressure is given by:

$$
\left.
\begin{aligned}
P &= \frac{(P_s' - P_d)}{2} \\
\text{or } P &= P_s' \\
\text{or } P &= P_{Bs} \\
\text{or } P &= \frac{(P_s' - P_d - P_{Bs})}{2} \\
\text{or } P &= \frac{(P_{Bs} + P_d)}{2} \\
\text{or } P &= (P_s' - P_{Bs})
\end{aligned}
\right\}
\text{ whichever has the greatest absolute value.}
$$

where

$$P_s' = P_s \left[\frac{0.4J \left[1.5 + K\,(1.5 + f_s) \right] - \left[\left(\frac{1-J}{2} \right) \left(\frac{D_J^2}{G^2} - 1 \right) \right]}{(1 + JKF_q)} \right]$$

P_s = Shell side hydrostatic design pressure, psi.

$$f_s = 1 - N \left(\frac{d_o}{G} \right)^2$$

G = Inside diameter of shell, inches.

D_J = Expansion joint bellows inside diameter, inches.

(D_J = G when no expansion joint is present.)

Other symbols are as defined under Paragraphs R-7.151 and R-7.152.

Notes:
1. Algebraic sign must be retained for use in paragraphs R-3.311, R-3.312, R-7.154, and R-7.155.
2. When J = O, formulas containing P_d cannot control.
3. Formulas containing the term P_{Bs} are not applicable for use in paragraph R-7.123.
4. All pressures in paragraphs R-7.153, R-7.154, and R-7.155 are gauge pressures. For vacuum conditions on either shell or tube side, the pressures should be represented by the appropriate negative values.

R-7 TUBESHEETS—(Continued)

R-7.154 EFFECTIVE TUBE SIDE DESIGN PRESSURE

The effective tube side design pressure is given by:

$$P = \frac{(P_t' + P_{Bt} + P_d)}{2} \quad \text{or} \quad P = (P_t' + P_{Bt})$$

whichever has the greater absolute value, when P_s' is positive.

$$P = \frac{(P_t' - P_s' + P_{Bt} + P_d)}{2} \quad \text{or} \quad P = (P_t' - P_s' + P_{Bt})$$

whichever has the greater absolute value, when P_s' is negative.

where

$$P_t' = P_t \left[\frac{1 + 0.4JK\,(1.5 + f_t)}{(1 + JKF_q)} \right]$$

P_t = Tube side hydrostatic design pressure, psi.

$$f_t = 1 - N \left[\frac{(d_o - 2t_t)}{G} \right]^2$$

G = Inside diameter of shell (tubesheet bolted to stationary head) or inside diameter of stationary head when integral with tubesheet. inches.

Other symbols are as defined under Par. R-7.151, R-7.152, and R-7.153.

Notes:
1. Algebraic sign must be retained for use in paragraphs R-3.311, R-3.312, and R-7.155.
2. When $J = 0$
   (a) Formulas containing P_d cannot control.
   (b) $P = P_t + \frac{P_s}{2}\left[\left(\frac{D_J}{G}\right)^2 - 1\right] + P_{Bt}$
3. Delete the term P_{Bt} in above formulas for use in paragraph R-7.123.

R-7 TUBESHEETS—(Continued)

R-7.155 EFFECTIVE DIFFERENTIAL DESIGN PRESSURE

Under certain circumstances the Code and other regulatory bodies permit design on the basis of simultaneous action of both shell and tube side pressures. The effective differential design pressure for fixed tubesheets under such circumstances is given by:

$$P = (P_t' - P_s' + P_{Bt})$$

$$\text{or } P = \frac{(P_t' - P_s' + P_{Bt} + P_d)}{2}$$

$$\text{or } P = P_{Bs}$$

$$\text{or } P = \frac{(P_{Bs} + P_d)}{2}$$

$$\text{or } P = (P_t' - P_s')$$

$$\text{or } P = \frac{(P_t' - P_s' + P_d)}{2}$$

$$\text{or } P = P_{Bt}$$

whichever has the greatest absolute value

where

P_d, P_{Bs}, P_{Bt}, P_s', and P_t' are as defined in paragraphs R-7.151, R-7.152, R-7.153, and R-7.154 respectively.

Notes: 1. It is not permissible to enter the equation P_s' in paragraph R-7.153 with $(P_s - P_t)$ in place of P_s nor the equation P_t' in paragraph R-7.154 with $(P_t - P_s)$ in place of P_t, to determine an effective shell side or tube side design pressure for fixed tubesheets.

2. When J = O, formulas with the term P_d cannot control.

3. Formulas containing the terms P_{Bt} or P_{Bs} are not applicable for use in paragraph R-7.123.

R-7.16 PACKED FLOATING TUBESHEET TYPE EXCHANGERS

R-7.161 OUTSIDE PACKED FLOATING HEAD (Type P)

The thickness of tubesheets in exchangers whose floating heads are packed at the outside diameter of the tubesheet or a cylindrical extension thereof, shall be calculated as for gasketed stationary tubesheet exchangers, using terms as defined below and the formula shown in paragraph R-7.122 or R-7.123.

$$P = P_t + P_s\left(\frac{D^2 - D_L^2}{D_i^2}\right)$$

where

P = Hydrostatic design pressure, psi.

P_t = Hydrostatic design pressure, psi, tube side.

P_s = Hydrostatic design pressure, psi, shell side.

D = Outside diameter of floating tubesheet, inches.

D_i = Inside diameter of floating tubesheet skirt, inches.

D_L = Equivalent diameter of tube center limit perimeter, inches, as defined in paragraph R-7.123.

F and G are as defined in previous paragraphs considering applicable edge configurations.

R-7 TUBESHEETS—(Continued)

R-7.162 PACKED FLOATING TUBESHEET WITH LANTERN RING (Type W)

The thickness of tubesheets in exchangers whose floating tubesheets are packed at the outside diameter with return bonnet or channel bolted to the shell flange, shall be calculated as for gasketed stationary tubesheet exchangers, using terms as defined below and the formula shown in paragraph R-7.122.

P = Hydrostatic design pressure, psi, tube side.

G = Mean diameter of gasket at stationary tube sheet, inches.

F = 1.0

R-7.163 FLOATING HEAD (Type S) WITH PACKED NOZZLE

The thickness of tubesheets in exchangers with packed floating head nozzles shall be calculated as for gasketed stationary tubesheet exchangers, using terms as defined below and the formula shown in paragraph R-7.122 or R-7.123.

P = Hydrostatic design pressure, psi, shell side or tube side.

F and G are as defined in paragraph R-7.131 or R-7.142, whichever is applicable.

R-7.17 DIVIDED FLOATING HEADS

For divided floating tubesheets, regardless of the type of stationary tubesheet,

G = 1.41 s

F = 1.0

where s = Length of shortest span measured over center lines of gasket, inches.

R-7.18 DOUBLE TUBESHEETS

Double tubesheets may be used where operating conditions indicate their desirability. The diversity of construction types makes it impractical to specify design rules which are universally applicable. It may be stated that the mutual support contributed by each component tubesheet through the tubes connecting them is a generally recognized design principle.

R-7.181 MINIMUM THICKNESS

Neither component of a double tubesheet shall have a thickness less than required by paragraph R-7.121.

R-7.182 VENTS AND DRAINS

Double tubesheets of the edge welded type shall be provided with vent and drain connections at the high and low points of the enclosed space.

R-7.183 SPECIAL PRECAUTIONS

When double tubesheets are used, special attention shall be given to the ability of the tubes to withstand, without damage, the mechanical and thermal loads imposed on them by this construction.

R-7.19 SPECIAL CASES

Special consideration must be given to tubesheets with abnormal conditions of support or loading; e.g., fixed tubesheets in exchangers with expansion joints which require considerable axial loads to produce required movements, such as the flued and flanged type; tubesheets (except fixed tubesheets) with extensions used as flanges; tubesheets with portions not adequately stayed by tubes; e.g., exchangers with large differences in shell and head inside diameters; and exchangers with hydrostatic design pressures greater than 3000 psig. Special consideration may also be given to conditions tending to reduce tubesheet thickness requirements.

R-7 TUBESHEETS—(Continued)

R-7.2 TUBE HOLES IN TUBESHEETS

R-7.21 DIAMETERS AND TOLERANCES

Tube holes in tubesheets shall be finished to the sizes and tolerances shown in Table R-7.21, column (a). For austenitic steel tubes, when used for corrosion resistance, a closer fit between tube O.D. and tube hole I.D. as shown in column (b) may tend to minimize work hardening and attendant loss of corrosion resistance; these clearances will be provided when specified by the purchaser.

TABLE R-7.21

TUBE HOLE DIAMETERS AND TOLERANCES

Nominal Tube O.D. Inches	Nominal Tube Hole Diameter and Under Tolerance—Inches				Over Tolerance-Inches (96% of tube holes must meet value in column (c). Remainder may not exceed value in column (d).)	
	Standard Fit (a)		Special Close Fit (b)			
	Nominal Diameter	Under Tolerance	Nominal Diameter	Under Tolerance	(c)	(d)
3/4	0.760	0.004	0.758	0.002	0.002	0.010
1	1.012	0.004	1.010	0.002	0.002	0.010
1¼	1.264	0.006	1.261	0.003	0.003	0.010
1½	1.518	0.007	1.514	0.003	0.003	0.010
2	2.022	0.007	2.018	0.003	0.003	0.010

R-7.22 TUBESHEET DRILLING TOLERANCES

Table R-7.22 gives permissible tube hole drilling tolerances, drill drift, and recommended maximum tube wall thicknesses.

TABLE R-7.22

TABLE OF TUBESHEET DRILLING TOLERANCES AND MAXIMUM RECOMMENDED TUBE GAGES

(All Dimensions in Inches)

Tube Dia. d_o	Tube Pitch p	p/d_o	$p-d_o$	Heaviest Recommended Tube Gage B.W.G.	Tube Hole Dia. Std. Fit	Nominal Ligament Width	Minimum Std. Ligaments (96% of ligaments must equal or exceed values tabulated below) — Tubesheet Thickness, Inches: 1	1½	2	2½	3	4	5	6	Minimum Permissible Ligament Width
3/4	15/16	1.25	3/16	13	0.760	0.178	.144	.142	.139	.137	.135	.131	.127	.122	.090
	1	1.33	1/4	12		0.240	.206	.204	.201	.199	.197	.193	.189	.184	.120
	1-1/16	1.42	5/16	12		0.302	.268	.266	.263	.261	.259	.255	.251	.246	.150
	1-1/8	1.50	3/8	12		0.365	.331	.329	.326	.324	.322	.318	.314	.309	.185
1	1-1/4	1.25	1/4	10	1.012	0.238	.205	.203	.202	.200	.198	.195	.192	.189	.120
	1-5/16	1.31	5/16	9		0.300	.267	.265	.264	.262	.260	.257	.254	.251	.150
	1-3/8	1.38	3/8	9		0.363	.330	.328	.327	.325	.323	.320	.317	.314	.185
1-1/4	1-9/16	1.25	5/16	9	1.264	0.298	—	.264	.263	.262	.260	.258	.255	.253	.150
1-1/2	1-7/8	1.25	3/8	8	1.518	0.357	—	.324	.323	.322	.321	.318	.316	.314	.180
2	2-1/2	1.25	1/2	6	2.022	0.478	—	—	.445	.444	.443	.442	.440	.438	.250

NOTES: The above table of minimum standard ligaments is based on a ligament tolerance not exceeding the sum of twice the drill drift tolerance plus 0.030".
Drill Drift Tolerance = 0.0016 × (Thickness of Tubesheet in Tube Diameters) In.

R-7 TUBESHEETS—(Continued)

R-7.23 TUBE HOLE FINISH

The inside edges of tube holes in tubesheets shall be free of burrs to prevent cutting of the tubes. Internal surfaces shall be given a workmanlike finish.

R-7.24 TUBE HOLE GROOVING

All tubesheet holes for expanded joints shall be machined with at least two grooves, each approximately 1/8" wide by 1/64" deep. When integrally clad or applied tubesheet facings are used, all grooves shall be in the base material unless otherwise specified by the purchaser.

R-7.3 EXPANDED TUBE JOINTS

Expanded tube-to-tubesheet joints are standard.

R-7.31 LENGTH OF EXPANSION

Tubes shall be expanded into the tubesheet for a length no less than 2", or tubesheet thickness minus 1/8", whichever is smaller. In no case shall the expanded portion extend beyond the shell side face of the tubesheet. When specified by the purchaser tubes may be expanded for the full thickness of the tubesheet.

R-7.32 CONTOUR OF EXPANDED TUBE

The expanding procedure shall be such as to provide substantially uniform expansion throughout the expanded portion of the tube, without sharp transition to the unexpanded portion.

R-7.33 TUBE PROJECTION

Tubes shall extend beyond the face of each tubesheet by 1/8" ± 1/16" except that tubes shall be flush with the top tubesheet in vertical exchangers.

R-7.4 WELDED TUBE JOINTS

When both tubes and tubesheets, or tubesheet facing, are of suitable materials, the tube joints may be welded.

R-7.41 SEAL WELDED JOINTS

When welded tube joints are used for additional leak tightness only, and customary tube loads are carried by the expanded joint, the tube joints shall be subject to the rules of paragraphs R-7.2 through R-7.32.

R-7.42 STRENGTH WELDED JOINTS

When welded tube joints are used as a complete substitute for expanded joints, consideration may be given to modification of the requirements of paragraphs R-7.2 through R-7.33.

R-7.43 FABRICATION AND TESTING PROCEDURE

Welding procedure and testing techniques for either seal welded or strength welded tube joints shall be by agreement between manufacturer and purchaser.

R-7.5 TUBESHEET PASS PARTITION GROOVES

All tubesheets shall be provided with approximately 3/16" deep grooves for pass partitions.

R-7.6 TUBESHEET PULLING EYES

In exchangers with removable tube bundles having a nominal diameter exceeding 12" and/or a tube length exceeding 96", the stationary tubesheet shall be provided with two tapped holes in its face for pulling eyes. These holes shall be protected in service by plugs. Provision for pulling means may have to be modified or waived for special constructions, such as clad tubesheets or manufacturer's standard, by agreement between manufacturer and purchaser.

R-7.7 CLAD AND FACED TUBESHEETS

The nominal cladding thickness at the tube side face of a tubesheet shall not be less than 5/16" when tubes are rolled only, and 1/8" when tubes are welded to the tubesheet. The nominal cladding thickness on the shell side face shall not be less than 3/8". All surfaces exposed to the fluid, including gasket seating surfaces, shall have at least 1/8" nominal thickness of cladding.

R-8 CHANNELS, COVERS, AND BONNETS

R-8.1 CHANNELS AND BONNETS

R-8.11 MINIMUM THICKNESS OF CHANNELS AND BONNETS

Channel and bonnet thickness is determined by the Code design formulas, plus corrosion allowance, but in no case shall the nominal thickness of channels and bonnets be less than the minimum shell thicknesses shown in Table R-3.13. The nominal total thickness for clad or lined channels and bonnets shall be the same as for carbon steel plate channels.

R-8.12 MINIMUM INSIDE DEPTH

For multipass channels and bonnets the inside depth shall be such that the minimum cross-over area for flow between successive tube passes is at least equal to 1.3 times the flow area through the tubes of one pass. When an axial nozzle is used, the depth at the nozzle centerline shall be a minimum of one-third the inside diameter of the nozzle.

R-8.13 PASS PARTITION PLATES

R-8.131 MINIMUM THICKNESS

The nominal thickness of channels or bonnet pass partitions shall not be less than shown in Table R-8.131. Partition plates may be tapered to gasket width at the contact surface.

TABLE R-8.131

MINIMUM PASS PARTITION PLATE THICKNESS, INCLUDING CORROSION ALLOWANCE

Nominal Size Inches	Carbon Steel Inches	Alloy Material Inches
Less than 24	3/8	1/4
24 and over	1/2	3/8

R-8.132 SPECIAL PRECAUTIONS

Special consideration must be given to thickness requirements for internal partitions subjected to pulsating fluids or to large differential pressures under specified operating conditions, or to unusual start-up or maintenance conditions specified by the purchaser.

R-8.14 POSTWELD HEAT TREATMENT

Fabricated carbon steel channels and bonnets shall be postweld heat treated after completion of welding. Minor modifications as permitted by the Code may be made without further heat treatment.

R-8 CHANNELS, COVERS, AND BONNETS—(Continued)

R-8.2 CHANNEL COVERS

R-8.21 EFFECTIVE CHANNEL COVER THICKNESS

The effective thickness of flat channel covers shall be the thickness measured at the bottom of the pass partition groove minus tube side corrosion allowance in excess of the groove depth. The required value shall be either that determined from the appropriate Code formula or from the following equation, whichever is greater:

$$T = \left[5.7P\left(\frac{G}{100}\right)^4 + 2\frac{h_G A_B}{\sqrt{d_B}}\left(\frac{G}{100}\right)\right]^{1/3}$$

where T = Effective channel cover thickness, inches.

P = Design pressure, psi.

G = Mean gasket diameter, inches.

d_B = Nominal bolt diameter, inches.

h_G = Radial distance between mean gasket diameter and bolt circle, inches.

A_B = Actual total cross-sectional area of bolts, square inches.

For gaskets having compression factors of 3.0 or less, the value of "T" obtained by this formula may be reduced by 20 per cent.

Notes:
1. For high alloy steels and nonferrous metals, and for carbon steel at temperatures other than 650°F, the value obtained from this formula shall be multiplied by $(25{,}000{,}000/E)^{1/3}$, where "E" is the elastic modulus of the cover material at the design temperature.
2. For single pass channels, or others in which there is no pass partition gasket seal against the channel cover, only the Code formula need be considered.

R-8.22 CHANNEL COVER PASS PARTITION GROOVES

Channel covers shall be provided with approximately $\frac{3}{16}$" deep grooves for pass partitions. In clad or applied facings, all surfaces exposed to the fluid, including gasket seating surfaces, shall have at least ⅛" nominal thickness of cladding.

R-9 NOZZLES

R-9.1 NOZZLE CONSTRUCTION

Nozzle construction shall be in accordance with Code requirements. Shell nozzles shall not protrude beyond the inside contour of the shell. Channel nozzles may protrude inside the channel provided vent and drain connections are flush with the inside contour of the channel. Flange dimensions and facing shall comply with USA Standard B16.5. Bolt holes shall straddle natural center lines.

R-9.2 NOZZLE INSTALLATION

Radial nozzles shall be considered as standard. Other types of nozzles may be used, by agreement between manufacturer and purchaser.

R-9.3 PIPE TAP CONNECTIONS

All pipe tap connections shall be a minimum of 3000 psi standard couplings or equivalent. Each connection shall be fitted with a bar stock plug of the same material as the connection, except that cast iron plugs shall not be used.

R-9.31 VENT AND DRAIN CONNECTIONS

All high and low points on shell and tube sides of an exchanger not otherwise vented or drained by nozzles shall be provided with ¾" connections for vent and drain. Larger connections may be provided at manufacturer's option.

R-9.32 PRESSURE GAGE CONNECTIONS

All flanged nozzles 2" size or larger shall be provided with one horizontal connection of ¾" minimum size for a pressure gage unless special considerations require it to be omitted. See paragraph R-9.4.

R-9.33 THERMOMETER CONNECTIONS

All flanged nozzles 3" size or larger shall be provided with one ¾" horizontal connection for a thermometer unless special considerations require it to be omitted. See paragraph R-9.4.

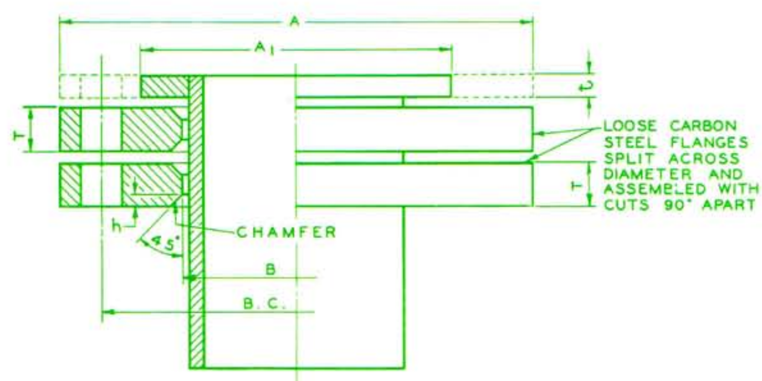
R-9.4 STACKED UNITS

Intermediate nozzles between units shall have flat or raised face flanges. Pressure gage and thermometer connections may be omitted in one of two mating connections of units connected in series.

R-9.5 SPLIT FLANGE DESIGN

Circumstances of fabrication, installation, or maintenance sometimes indicate undesirability of the normal integral or loose full ring nozzle flanges. Under these conditions, double split ring flanges may be used in accordance with the Code. Figure R-9.5 and Table R-9.5 give typical dimensions of such flanges.

FIGURE R-9.5



R-9 NOZZLES — (Continued)

TABLE R-9.5

DESIGN PRESSURE 150 PSI
CARBON STEEL SPLIT TYPE NOZZLE FLANGES
ALL DIMENSIONS ARE IN INCHES

Size Nozzle	A	A_1	t	B.C.	T	No. and Size of Bolts	B	h
2-1/2	7	4-1/8	1/4	5-1/2	7/8	4—5/8	3	5/16
3	7-1/2	5	1/4	6	7/8	4—5/8	3-5/8	3/8
4	9	6-3/16	1/4	7-1/2	15/16	8—5/8	4-5/8	7/16
6	11	8-1/2	5/16	9-1/2	1-1/16	8—3/4	6-3/4	1/2
8	13-1/2	10-5/8	3/8	11-3/4	1-1/8	8—3/4	8-3/4	1/2
10	16	12-3/4	3/8	14-1/4	1-3/8	12—7/8	10-7/8	1/2
12	19	15	3/8	17	1-1/2	12—7/8	12-7/8	1/2
14	21	16-1/4	3/8	18-3/4	1-3/4	12—1	14-1/8	1/2
16	23-1/2	18-1/2	3/8	21-1/4	1-7/8	16—1	16-1/8	1/2
18	25	21	3/8	22-3/4	1-13/16	16—1-1/8	18-1/8	1/2
20	27-1/2	23	3/8	25	2	20—1-1/8	20-1/8	1/2
24	32	27-1/4	3/8	29-1/2	2-1/4	20—1-1/4	24-1/8	1/2

Gaskets—Compressed Asbestos, 1/16" thick
Flange stress, 17,500 psi
Bolt Stress, 20,000 psi

R-10 END FLANGES AND BOLTING

Flanges and bolting for external joints shall be in accordance with Code design rules, subject to the limitations set forth in the following paragraphs.

R-10.1 MINIMUM BOLT SIZE

The minimum permissible bolt diameter shall be ¾". Threads shall be in accordance with USA Standard B1.1 for high strength bolting. Sizes 1" and smaller shall be Coarse Thread Series and larger sizes shall be 8-Pitch Thread Series.

R-10.2 BOLT CIRCLE LAYOUT

R-10.21 MINIMUM RECOMMENDED BOLT SPACING

The minimum recommended spacing between bolt centers shall be as given by Table R-10.3.

R-10.22 MAXIMUM RECOMMENDED BOLT SPACING

The maximum recommended spacing between bolt centers shall be:

$$B_{max} = 2d_B + \frac{6t}{(m + 0.5)}$$

where

B = Bolt spacing, inches.
d_B = Nominal bolt diameter, inches.
t = Flange thickness, inches.
m = Gasket factor used in Code flange calculations.

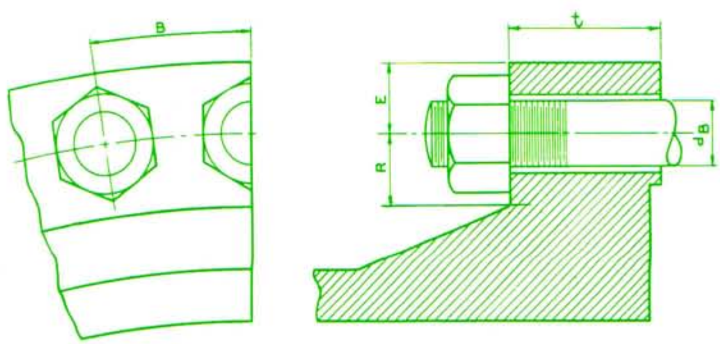
R-10.23 BOLT ORIENTATION

Bolt centers shall evenly straddle both natural centerlines of the exchanger. For horizontal units the natural centerlines shall be considered to be the horizontal and vertical centerlines of the exchanger. In special cases, by agreement between purchaser and manufacturer, the bolt count may be reduced from a multiple of four (as required by the foregoing) to a multiple of two.

R-10.3 MINIMUM RECOMMENDED WRENCH AND NUT CLEARANCES

Minimum recommended radial dimensions "R" and "E", as defined in Figure R-10.3, and minimum recommended bolt spacing B_{min} shall be as given in Table R-10.3.

FIGURE R-10.3



R-10 END FLANGES AND BOLTING —(Continued)

TABLE R-10.3

FLANGE BOLT CLEARANCES

(All Dimensions in Inches)			
d_B	R	E	B_{min}
3/4	1-1/8	13/16	1-3/4
7/8	1-1/4	15/16	2-1/16
1	1-3/8	1-1/16	2-1/4
1-1/8	1-1/2	1-1/8	2-1/2
1-1/4	1-3/4	1-1/4	2-13/16
1-3/8	1-7/8	1-3/8	3-1/16
1-1/2	2	1-1/2	3-1/4
1-5/8	2-1/8	1-5/8	3-1/2
1-3/4	2-1/4	1-3/4	3-3/4
1-7/8	2-3/8	1-7/8	4
2	2-1/2	2	4-1/4

R-10.4 LOAD CONCENTRATION FACTOR

When the distance between bolt centerlines exceeds recommended B_{max}, the total flange moment determined by Code design methods shall be multiplied by a correction factor equal to $\sqrt{B/B_{max}}$ where symbols are defined in paragraph R-10.22.

R-10.5 BOLT TYPE

Except for special design considerations, flanges shall be through-bolted with stud bolts, threaded full length with a removable nut on each end. Stud bolt length shall be such that the nuts are fully engaged and project through the nuts approximately ⅛" on each end.

C-1 SCOPE AND GENERAL REQUIREMENTS

C-1.1 SCOPE OF STANDARDS

C-1.11 DEFINITION OF TEMA CLASS "C" EXCHANGERS

The TEMA Mechanical Standards for Class "C" heat exchangers specify design, fabrication, and materials of unfired shell and tube heat exchangers for the generally moderate requirements of commercial and general process applications. Equipment fabricated in accordance with these standards is designed for the maximum economy and overall compactness consistent with safety and service requirements in such applications.

C-1.12 CONSTRUCTION CODES

The individual vessels shall comply with the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code, Section VIII, Division 1, hereinafter referred to as the Code. These standards supplement and define the Code for heat exchanger applications. The manufacturer shall comply with the construction requirements of state and local codes when the purchaser specifies the plant location. It shall be the responsibility of the purchaser to inform the manufacturer of any applicable local codes. Application of the Code symbol is required, unless otherwise specified by the purchaser.

C-1.13 MATERIALS—DEFINITION OF TERMS

For purposes of these standards, "carbon steel" shall be construed as any steel or low alloy falling within the scope of Part UCS of the Code. Metals not included by the foregoing (except cast iron) shall be considered as "alloys" unless otherwise specifically named.

C-1.2 PRESSURE CLASSIFICATIONS

C-1.21 STANDARD PRESSURE CLASSIFICATIONS

The following design pressure classifications are standard:

For diameters larger than 23" nominal	75 psi
For all diameters	150 psi
For all diameters	300 psi
For all diameters	450 psi
For all diameters	600 psi

C-1.22 INTERMEDIATE PRESSURE CLASSES

For special circumstances, consideration may be given to intermediate pressure classes.

C-1.23 DESIGN PRESSURES

Design pressures for the shell and tube sides shall be specified separately by the purchaser.

C-1.3 TESTING

C-1.31 STANDARD TEST

The exchanger shall be hydrostatically tested with water. The test pressure shall be held for at least 30 minutes. The shell side and the tube side are to be tested separately in such a manner that leaks at the tube joints can be detected from at least one side. When construction permits, and the tube side design pressure is the higher pressure, the tube bundle shall be tested outside of the shell. Welded joints are to be sufficiently cleaned prior to testing the exchanger to permit proper inspection during the test. The hydrostatic test pressure at room temperature shall be 1.5 times the design pressure, corrected for temperature, except for materials such as cast iron where other Code requirements govern.

C-1 SCOPE AND GENERAL REQUIREMENTS—(Continued)

C-1.311 OTHER LIQUID TESTS

Other liquids in lieu of water may be used as a testing medium, if agreed upon between the purchaser and the manufacturer.

C-1.32 PNEUMATIC TEST

When liquid cannot be tolerated as a test medium, then by agreement between purchaser and manufacturer, the exchanger may be given a pneumatic test in accordance with the Code. It must be recognized that air or gas is hazardous when used as a pressure testing medium. The pneumatic test pressure at room temperature shall be 1.25 times the design pressure, corrected for temperature, except for materials such as cast iron where other Code requirements govern.

C-1.33 SUPPLEMENTARY AIR TEST

When a supplementary air or gas test is specified by the purchaser, it shall be immediately preceded by hydrostatic test required by Par. C-1.31. The test pressure shall be specified by the purchaser, but shall not exceed that required by Par. C-1.32. Leaks may be located by halide probe, or by other means, as agreed upon by the purchaser and manufacturer.

C-1.4 METAL TEMPERATURES

C-1.41 METAL TEMPERATURE LIMITATIONS FOR PRESSURE PARTS

The metal temperature limitations for various metals are those prescribed by the Code.

C-1.42 DESIGN TEMPERATURE OF HEAT EXCHANGER PARTS

Design temperatures for the shell and tube sides shall be specified separately by the purchaser for parts not subject to both fluids. The design temperature of heat exchanger parts subjected to two different fluid temperatures shall be the maximum metal temperature of the part under operating conditions, except when the purchaser specifies some other design metal temperature. In establishing the metal temperatures, due consideration shall be given to such factors as the relative heat transfer coefficients of the two fluids contacting the part and the relative heat transfer area of the parts contacted by the two fluids.

C-1.5 STANDARD CORROSION ALLOWANCES

Corrosion allowances are to be used for the various heat exchanger parts as follows:

C-1.51 CARBON STEEL PARTS

C-1.511 PRESSURE PARTS

All carbon steel pressure parts, except tubes, are to have a corrosion allowance of $\frac{1}{16}''$ unless the conditions of service make a different allowance more suitable and such allowance is definitely specified.

C-1.512 INTERNAL COVERS

Internal covers are to have the corrosion allowance on each side.

C-1.513 TUBESHEETS

Tubesheets are to have the corrosion allowance on each side with the provision that, on the grooved side of a grooved tubesheet, the depth of the pass partition groove may be considered as available for corrosion allowance.

C-1.514 EXTERNAL COVERS

Where flat external covers are grooved, the depth of the groove may be considered as available for corrosion allowance.

C-1.515 END FLANGES

Corrosion allowance shall be applied only to the inside diameter of flanges.

C-1 SCOPE AND GENERAL REQUIREMENTS—(Continued)

C-1.516 NONPRESSURE PARTS

Nonpressure parts such as tie rods, spacers, baffles, and support plates are to have no allowance for corrosion.

C-1.517 FLOATING HEAD BACKING DEVICES

Floating head backing devices and internal bolting are to have no corrosion allowance.

C-1.52 ALLOY PARTS

No corrosion allowance is to be added to alloy parts except as specified by the purchaser.

C-1.53 CAST IRON PARTS

Cast iron pressure parts shall have a corrosion allowance of $\frac{1}{16}$".

C-1.6 SERVICE LIMITATIONS

C-1.61 CAST IRON PARTS

Cast iron shall not be used for pressures exceeding 150 psi, nor for lethal or flammable fluids at any pressure.

C-1.62 PACKED JOINTS

Packed joints shall not be used when the purchaser specifies that the fluid in contact with the joint is lethal or flammable.

C-2 TUBES

C-2.1 TUBE LENGTH

The following tube lengths for both straight and U-tube exchangers, shall be considered as standard: 8, 10, 12, 16, and 20 feet. Other lengths may be used; even lengths are preferred. See also paragraph N-1.12.

C-2.2 TUBE DIAMETERS AND GAGES

C-2.21 BARE TUBES

Table C-2.21 lists standard tube diameters and gages for bare tubes of copper, steel, and alloy.

TABLE C-2.21

STANDARD BARE TUBE DIAMETERS AND GAGES

O. D. Inches	Copper and Copper Alloys		Carbon Steel, Aluminum and Aluminum Alloys		Other Alloys	
	B.W.G. (Min. Wall)	Thickness Inches	B.W.G. (Min. Wall)	Thickness Inches	B.W.G. (Avg. Wall)	Thickness Inches
¼	27	0.016	—	—	27	0.016
	24	0.022	—	—	24	0.022
	22	0.028	—	—	22	0.028
⅜	**22**	0.028	—	—	22	0.028
	20	0.035	—	—	20	0.035
	18	0.049	—	—	18	0.049
½	**20**	0.035	—	—	20	0.035
	18	0.049	—	—	18	0.049
⅝	20	0.035	18	0.049	20	0.035
	18	0.049	16	0.065	18	0.049
	16	0.065	14	0.083	16	0.065
¾	18	0.049	16	0.065	20	0.035
	16	0.065	**14**	0.083	**18**	0.049
	14	0.083	—	—	16	0.065
1	**16**	0.065	**14**	0.083	18	0.049
	14	0.083	12	0.109	**16**	0.065
	12	0.109	—	—	14	0.083
1¼	14	0.083	**14**	0.083	16	0.065
	12	0.109	12	0.109	14	0.083
1½	14	0.083	14	0.083	16	0.065
	12	0.109	12	0.109	14	0.083
2	14	0.083	14	0.083	14	0.083
	12	0.109	12	0.109	12	0.109

Notes:
1. Tube gages in bold face are preferred.
2. Average wall tubes of heavier gage may be used in place of minimum wall tubes, provided the wall thickness is not less than specified.
3. Characteristics of tubing are shown in Table D-7, Page 187.

C-2 TUBES—(Continued)

C-2.22 CIRCUMFERENTIALLY-FINNED TUBES

The nominal fin diameter shall be the same as the O.D. of the unfinned end. The diameter over the fins will not normally exceed the diameter of the unfinned section to insure that fin tubes are interchangeable with standard bare tubes. Specified wall shall be based on the thickness at the root diameter.

C-2.3 U-TUBES

C-2.31 NONUNIFORM THICKNESS BENDS

When U-bends are formed, as is customary, in such a way as to thin the tube wall at the outer radius of the bend, the minimum tube wall thickness in the bent portion **before bending** shall be:

$$t_o = t_1 \left[1 + \frac{d_o}{4R} \right]$$

where t_o = Original tube wall thickness, inches.

t_1 = Minimum tube wall thickness calculated by Code rules for a straight tube subjected to the same pressure and metal temperature, inches.

d_o = Outside tube diameter, inches.

R = Mean radius of bend, inches.

When thinning of the bends cannot be tolerated because of corrosion, and the purchaser so states, then the inner two rows of U-tubes shall have tubes with a wall two gages heavier. Dual-gage tubes may be used.

When U-bends are formed from tube materials which are relatively nonwork hardening and of suitable temper, tube wall thinning in the shortest bends should not exceed a nominal 17% of original tube wall thickness.

U-bends formed from tube materials having low ductility, or materials which are susceptible to work-hardening, may require special consideration. Also refer to Par. C-2.33.

C-2.32 BEND SPACING

C-2.321 CENTER-TO-CENTER DIMENSION

The center-to-center dimensions between parallel legs of U-tubes shall be such that they may be inserted into the baffle assembly without damage to the tubes.

C-2.322 BEND INTERFERENCE

The assembly of bends shall be of workmanlike appearance. Metal-to-metal contact between bends in the same plane shall not be permitted.

C-2.33 HEAT TREATMENT

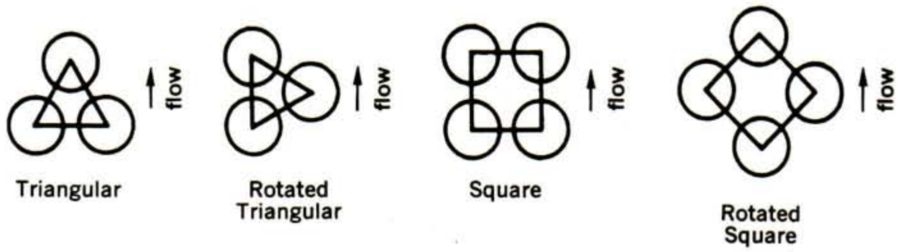
Cold work in forming U-bends may induce embrittlement or susceptibility to stress corrosion in certain materials and/or environments. Heat treatment to alleviate such conditions may be performed by agreement between manufacturer and purchaser. It is generally considered not practical to heat treat austenitic stainless steel tubes.

C-2 TUBES—(Continued)

C-2.4 TUBE PATTERN

Standard tube patterns are shown in Figure C-2.4.

FIGURE C-2.4



Note: Flow arrows are normal to the baffle cut edge.

C-2.41 SQUARE PATTERN

When tubes are laid out on a square or rotated square pitch, tube lanes shall be continuous throughout the bundle.

C-2.42 TRIANGULAR PATTERN

Triangular or rotated triangular pattern should not be used when the shell side is to be cleaned mechanically.

C-2.5 TUBE PITCH

Tubes shall be spaced with a minimum center-to-center distance of 1.25 times the outside diameter of the tube. Where tube diameters are ⅝" or less and tubes are rolled only into tubesheets, minimum center-to-center distance may be reduced to 1.20 times the tube outside diameter.

C-2.6 TUBE LAYOUT

The tube layout is to be such as to minimize by-passing around the tube bundle.

C-3 SHELLS AND SHELL COVERS

C-3.1 SHELLS

C-3.11 SHELL DIAMETERS

It shall be left to the discretion of each manufacturer to establish a system of standard shell diameters within the TEMA Mechanical Standards in order to achieve the economies peculiar to his individual design and manufacturing facilities. Nothing in the TEMA Standards shall be construed as a limitation on the minimum or maximum shell diameters.

C-3.12 TOLERANCES

C-3.121 PIPE SHELLS

The inside diameter of pipe shells shall be in accordance with applicable ASTM (American Society for Testing and Materials) pipe specifications.

C-3.122 PLATE SHELLS

The inside diameter of any plate shell shall not exceed the design inside diameter by more than 1/8" as determined by circumferential measurement.

C-3.13 MINIMUM THICKNESS OF SHELLS

Shell thickness is determined by the Code design formulas, plus corrosion allowance, but in no case shall the nominal thickness of shells be less than that shown in Table C-3.13. The nominal total thickness for clad or lined shells shall be the same as for carbon steel plate shells.

TABLE C-3.13

MINIMUM SHELL THICKNESS

Nominal Shell Dia.	Minimum Thickness		
	Carbon Steel		Alloy*
	Pipe	Plate	
6"	Sch. 40	—	1/8"
8" - 12" Inc.	Sch. 30	—	1/8"
13" - 23" Inc.	Sch. 20	5/16"	1/8"
24" - 29" Inc.	—	5/16"	3/16"
30" - 39" Inc.	—	3/8"	1/4"
40" - 60" Inc.	—	7/16"	1/4"

* Schedule 5S permissible for 6" and 8" shell diameter.

C-3.2 SHELL COVER THICKNESS

Nominal thickness of shell cover heads shall be at least equal to the thickness of the shell as shown in Table C-3.13.

C-3.3 SHELL EXPANSION AND CONTRACTION

Where fixed tubesheet construction is used and the temperature differential between tubes and shell, under the most adverse operating condition specified by the purchaser, including startup, shutdown, and upset conditions, will result in overloading either shell or tubes, suitable provision shall be made for this expansion or contraction.

C-3.31 SHELL AND TUBE LONGITUDINAL STRESSES

Shell and tube stresses, which depend upon the effective pressures determined by paragraphs C-7.151 through C-7.155, shall be calculated by the following paragraphs. A condition of overstress shall be presumed to exist when either shell or tube stress so calculated exceeds the allowable Code tensile stress for the material at design temperature.

C-3 SHELLS AND SHELL COVERS — (Continued)

C-3.311 SHELL LONGITUDINAL STRESS

The effective longitudinal shell stress is given by:

$$S_s = \frac{(D_o - t_s)P_s^*}{4t_s}$$

where

$$\left.\begin{aligned} P_s^* &= (P_l - P_d)/2 \\ \text{or } P_s^* &= -P_d/2 \\ P_s^* &= P_l/2 \end{aligned}\right\} \text{ whichever has the greatest absolute value}$$

$$\text{or } P_l = (P_t - P_t' + P_s')$$

Other symbols are as defined in paragraphs C-7.151, C-7.153, and C-7.154 with $J = 1$, using actual shell and tubesheet thicknesses and retaining algebraic signs.

C-3.312 TUBE LONGITUDINAL STRESS

The maximum effective longitudinal tube stress is given by:

$$S_t = \frac{F_q \, P_t^* \, G^2}{4Nt_t \, (d_o - t_t)}$$

where

$$\left.\begin{aligned} P_t^* &= (P_2 + P_d)/2 \\ \text{or } P_t^* &= -(P_3 - P_d)/2 \\ \dagger \text{ or } P_t^* &= [(P_2 - P_3) + P_d]/2 \end{aligned}\right\} \text{ whichever has the greatest absolute value}$$

$$P_2 = (P_t' - \frac{f_t}{F_q} P_t)$$

$$P_3 = (P_s' - \frac{f_s}{F_q} P_s)$$

Other symbols are as defined in paragraphs C-7.151, C-7.153, C-7.154, and C-7.155 with $J = 1$, using actual shell and tubesheet thicknesses and retaining algebraic signs.

† When differential pressure controls (Par. C-7.155), this formula only applies.

C-3.32 TUBE JOINT AND BUCKLING LOADS

A condition of overload shall be presumed to exist even though the maximum stress levels determined in paragraph C-3.31 are acceptable, if the tubes are unstable as columns under maximum compressive load or if, regardless of load direction, the tube joint shear load holding capability is exceeded. For this purpose the maximum tube load is given by:

$$W_t = \frac{\pi}{2N} F_q G^2 P_t^*$$

where, for tube joint loads, P_t^* is the maximum absolute value defined by paragraph C-3.312 and, for tube buckling loads, is the greatest negative value so defined. Other symbols are as defined in paragraphs C-7.151, C-7.153, and C-7.154 with $J = 1$.

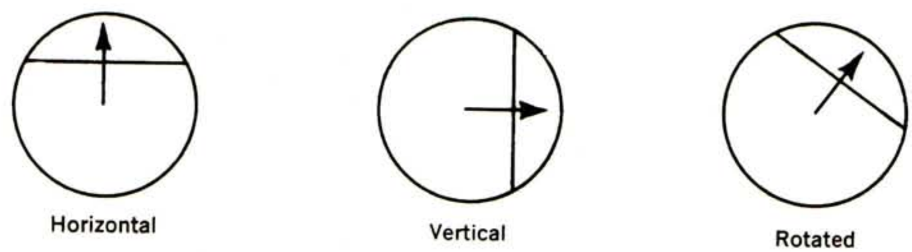
C-4 BAFFLES AND SUPPORT PLATES

C-4.1 TYPE OF TRANSVERSE BAFFLES

The segmental type of baffle or tube support plate is standard. Double segmental type baffles are permissible. Baffle cut is defined as the segment opening height expressed as a percentage of the shell inside diameter. Baffles shall be cut near the centerline of a row of tubes, of a pass lane, or of a tube lane when square pattern is used, or outside the tube pattern. Baffles shall have a finish of 250 RMS or better on the outside diameter and baffle cut edge. Standard baffle cut is illustrated in Figure C-4.1.

FIGURE C-4.1

BAFFLE CUT



C-4.2 TUBE HOLES

Where the maximum unsupported tube length is 36 inches or less, standard tube holes are drilled 1/32" over the O.D. of the tubes. For unsupported tube lengths greater than 36 inches, standard tube holes are drilled 1/64" over the O.D. of the tubes. For pulsating conditions tube holes may be drilled smaller than standard. Any burrs shall be removed and the tube holes given a workmanlike finish.

C-4.3 TRANSVERSE BAFFLE AND SUPPORT CLEARANCE

The transverse baffle and support plate clearance shall be such that the difference between the shell design inside diameter and the outside diameter of the baffle shall not exceed that indicated in Table C-4.3. However, where such clearance has no significant effect on shell side heat transfer coefficient or mean temperature difference, these maximum clearances may be increased to twice the tabulated values.

TABLE C-4.3

STANDARD CROSS BAFFLE AND SUPPORT PLATE CLEARANCES

Nominal Shell Inside Diameter	Design I.D. of Shell Minus Baffle O.D.
6" - 13" Inc.	0.100"
14" - 17" Inc.	0.125"
18" - 23" Inc.	0.150"
24" - 39" Inc.	0.175"
40" - 54" Inc.	0.225"
55" and over	0.300"

The design inside diameter of a pipe shell is defined as the nominal outside diameter of the pipe, minus twice the nominal wall thickness. The design inside diameter of a plate shell is the specified inside diameter.

C-4 BAFFLES AND SUPPORT PLATES—(Continued)

C-4.4 THICKNESS OF BAFFLES AND SUPPORT PLATES

C-4.41 TRANSVERSE BAFFLES AND SUPPORT PLATES

Table C-4.41 shows the minimum thickness of transverse baffles and support plates applying to all materials for various shell diameters and plate spacings.

TABLE C-4.41

BAFFLE OR SUPPORT PLATE THICKNESS

Nominal Shell I.D.	Plate Thickness—Inches					
	Distance between adjacent segmental plates or ½ distance between full supports					
	6" and Under	Over 6" to 12" Inc.	Over 12" to 18" Inc.	Over 18" to 24" Inc.	Over 24" to 30" Inc.	Over 30"
6" - 14" Inc.	1/16	1/8	3/16	1/4	3/8	3/8
15" - 28" Inc.	1/8	3/16	1/4	3/8	3/8	1/2
29" - 38" Inc.	3/16	1/4	5/16	3/8	1/2	5/8
39" and over	—	1/4	3/8	1/2	5/8	5/8

C-4.42 LONGITUDINAL BAFFLES

Longitudinal carbon steel baffles shall have a minimum total metal thickness of ¼". Longitudinal alloy baffles shall have a minimum total metal thickness of ⅛".

C-4.43 SPECIAL PRECAUTIONS

Special consideration must be given to baffles and support plates subjected to pulsations, to baffles and support plates engaging finned tubes, and to longitudinal baffles subjected to large differential pressures due to high shell side fluid pressure drop.

C-4.5 SPACING OF BAFFLES AND SUPPORT PLATES

C-4.51 MINIMUM SPACING

Segmental baffles shall not be spaced closer than ⅕ of the shell I.D., or 2 inches, whichever is greater.

C-4.52 MAXIMUM SPACING

Tube support plates shall be so spaced that the unsupported tube length does not exceed the value indicated in Table C-4.52 for the tube material used.

C-4 BAFFLES AND SUPPORT PLATES—(Continued)

TABLE C-4.52

MAXIMUM UNSUPPORTED STRAIGHT TUBE LENGTH

Tube O.D. Inches	Maximum Unsupported Span—Inches Tube Materials and Temperature Limits (°F) Carbon & High Alloy Steel (750) Low Alloy Steel (850) Nickel-Copper (600) Nickel (850) Nickel-Chromium-Iron (1000)	Aluminum & Aluminum Alloys Copper & Copper Alloys · at Code Maximum Allowable Temperature
1/4	26	22
3/8	35	30
1/2	44	38
5/8	52	45
3/4	60	52
1	74	64
1 1/4	88	76
1 1/2	100	87
2	125	110

Notes: Above the metal temperature limits shown, maximum spans shall be reduced in direct proportion to the fourth root of the ratio of elastic modulus at temperature to elastic modulus at tabulated limit temperature. In the case of circumferentially finned tubes, the tube O.D. shall be the diameter at the root of the fins and the corresponding tabulated or interpolated span shall be reduced in direct proportion to the fourth root of the ratio of the weight per unit length of the tube, if stripped of fins to that of the actual finned tube.

C-4.53 BAFFLE SPACING

Baffles normally shall be spaced uniformly, spanning the effective tube length. When this is not possible, the baffles nearest the ends of the shell, and/or tubesheets, shall be located as close as practical to the shell nozzles. The remaining baffles normally shall be spaced uniformly.

C-4.54 U-TUBE REAR SUPPORT

The support plates or baffles adjacent to the bends in U-tube exchangers shall be so located that, for any individual bend, the sum of the bend diameter plus the straight lengths measured along both legs from supports to bend tangents does not exceed the maximum unsupported span determined from paragraph C-4.52. Where bundle diameter prevents compliance, special provisions in addition to the above shall be made for support of the U-bends.

C-4.55 SPECIAL CASES

When pulsating conditions are specified by the purchaser, unsupported spans shall be as short as pressure drop restrictions permit. If the span under these circumstances approaches the maximum permitted by paragraph C-4.52, consideration should be given to alternative flow arrangements which would permit shorter spans under the same pressure drop restrictions.

C-4.56 TUBE BUNDLE VIBRATION

Flow induced or other damaging tube bundle vibrations may be encountered because of the infinite combinations of geometries related to unsupported tube span, tube arrangement, materials, size, and flow rates used in heat exchanger design. Existing quantitative data are inadequate to ensure that designs will be vibration free.

C-4 BAFFLES AND SUPPORT PLATES—(Continued)

C-4.6 IMPINGEMENT BAFFLES

C-4.61 SHELL SIDE

C-4.611 IMPINGEMENT PROTECTION REQUIREMENTS

An impingement plate, or other means to protect the tube bundle against impinging fluids, shall be provided when entrance line values of ρV^2 exceed the following: noncorrosive, nonabrasive, single phase fluids, 1500; all other liquids, including a liquid at its boiling point, 500, For all other gases and vapors, including all nominally saturated vapors, and for liquid vapor mixtures, impingement protection is required. V is the linear velocity of the fluid in feet per second and ρ is its density in pounds per cubic foot.

C-4.612 BUNDLE ENTRANCE AND EXIT AREAS

In no case shall the total bundle entrance or exit area produce a value of ρV^2 in excess of 4000, where V is the linear velocity of the fluid in feet per second, and ρ is its density in pounds per cubic foot. For purposes of calculating the total bundle entrance or exit area, the actual flow area into or out of the bundle between the tubes, based on the projected cross sectional flow area of the nozzle or dome and/or the actual unrestricted radial flow area from under the nozzle or dome, measured between the tube bundle diameter and the shell inside diameter may be considered. In the case of exchangers where vaporization occurs, special attention shall be given to provision for ample exit area.

C-4.62 TUBE SIDE

When it is necessary to use an axial inlet nozzle, or when liquid velocity in the tubes exceeds 10 feet per second, consideration shall be given to the need for special devices to prevent fluid maldistribution or erosion of the tube ends.

C-4.7 TIE RODS AND SPACERS

Tie rods and spacers, or other equivalent means of tying the baffle system together, shall be provided to retain all transverse baffles and tube support plates securely in position. Tie rods and spacers should be of a material similar to that of the baffles.

C-4.71 NUMBER AND SIZE OF TIE RODS

Table C-4.71 shows suggested tie rod count and diameter for various sizes of heat exchangers. Other combinations of tie rod number and diameter with equivalent metal area are permissible; however, no fewer than four tie rods, and no diameter less than ⅜" shall be used above 15" shell diameter.

TABLE C-4.71

TIE ROD STANDARDS

Nominal Shell Diameter	Tie Rod Diameter	Minimum Number of Tie Rods
6" - 15" Inc.	¼"	4
16" - 27" Inc.	⅜"	6
28" - 33" Inc.	½"	6
34" - 48" Inc.	½"	8
49" and over	½"	10

C-4.8 SEALING DEVICES

Suitable means, in addition to the baffles, shall be installed when necessary to prevent excessive fluid by-passing around or through the tube bundle. Sealing devices may be seal strips, tie rods with spacers, dummy tubes, or combinations of these.

C-5 FLOATING HEADS

C-5.1 INTERNAL FLOATING HEADS (Types S and T)

C-5.11 MINIMUM INSIDE DEPTH OF FLOATING HEAD COVERS

For multipass floating head covers the inside depth shall be such that the minimum crossover area for flow between successive tube passes is at least equal to the flow area through the tubes of one pass. For single pass floating head covers the depth at nozzle centerline shall be a minimum of one-third the inside diameter of the nozzle.

C-5.12 POSTWELD HEAT TREATMENT

Fabricated floating head covers shall be postweld heat treated in accordance with Code requirements, or as specified by purchaser.

C-5.13 FLOATING HEAD BACKING DEVICES

The material of construction for split rings or other internal floating head backing devices shall be equivalent in corrosion resistance to the material used for the shell interior. They shall be furnished without any allowance for corrosion.

C-5.131 INTERNAL BOLTING

The materials of construction for internal bolting for floating heads shall be suitable for the mechanical design and similar in corrosion resistance to the materials used for the shell interior.

C-5.14 TUBE BUNDLE SUPPORTS

A partial support plate, or other suitable means, shall be provided to support the floating head end of the tube bundle. If a plate is used, the thickness shall equal or exceed the support plate thickness specified in Table C-4.41 for spacings over 30".

C-5.15 FLOATING HEAD NOZZLES

The floating head nozzle and packing box for a single pass exchanger shall comply with the requirements of paragraphs C-5.21, C-5.22, and C-5.23.

C-5.16 PASS PARTITION PLATES

The nominal thickness of floating head pass partitions, including corrosion allowance, shall be identical to those shown in paragraph C-8.131 for channels and bonnets.

C-5.2 OUTSIDE PACKED FLOATING HEADS (Type P)

C-5.21 PACKED FLOATING HEADS

The cylindrical surface of packed floating head tubesheets and skirts, where in contact with packing (including allowance for expansion), shall be given a fine machine finish equivalent to 63 RMS (or 70 AA).

C-5 FLOATING HEADS—(Continued)

C-5.22 PACKING BOXES

A machine finish shall be used on the shell or packing box where the floating tube-sheet or nozzle passes through. If braided asbestos packing is used, three rings of packing shall be used for 150 psi working pressure and four rings shall be used for 300 psi working pressure. For pressures less than 150 psi, temperatures below 300°F, and nonhazardous service, fewer rings of packing may be used. Figure C-5.22 and Table C-5.22 show typical details and dimensions of packing boxes.

FIGURE C-5.22

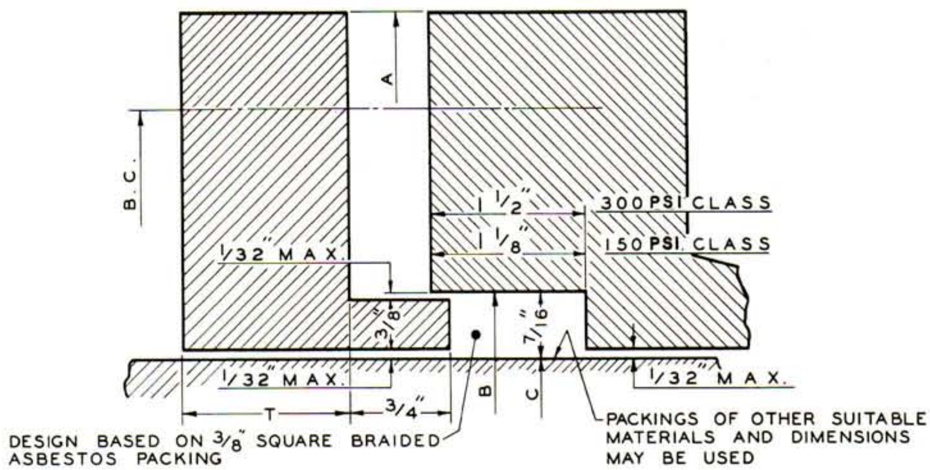


TABLE C-5.22

TYPICAL DIMENSIONS FOR PACKED FLOATING HEADS
150 PSI AND 300 PSI CLASS 600°F MAX. TEMP.

(All dimensions in inches)

Size	A	B	C	T	Bolts		B.C.
					No.	Size	
6	10½	6⅞	6	1	4	⅝	9
8	12½	8⅞	8	1	4	⅝	11
10	14⅝	10⅞	10	1	6	⅝	13⅛
12	16⅝	12⅞	12	1	6	⅝	15⅛
13	17⅞	13⅞	13	1	6	⅝	16⅜
15	19⅞	15⅞	15	1¼	8	⅝	18⅜
17	22	17⅞	17	1¼	8	⅝	20½
19	24	19⅞	19	1¼	10	⅝	22½
21	26⅛	21⅞	21	1⅜	10	⅝	24⅝
23	28⅛	23⅞	23	1⅜	12	⅝	26⅝

C-5 FLOATING HEADS—(Continued)

C-5.23 PACKING MATERIAL

Purchaser shall specify packing material which is compatible with the shell fluid.

C-5.24 FLOATING TUBESHEET SKIRT

The floating tubesheet skirt normally shall extend outward. When the skirt must extend inward, then a suitable method shall be used to prevent stagnant areas between the shell side nozzle and the tubesheet.

C-5.25 PASS PARTITION PLATES

The nominal thickness of floating head pass partitions, including corrosion allowance, shall be identical to those shown in paragraph C-8.131 for channels and bonnets.

C-5.3 PACKED LANTERN RING FLOATING HEAD (Type W)

The packed lantern ring type floating head shall be used only for water, steam, air, lubricating oil, or similar services. Design temperature shall not exceed 375°F. Design pressure shall not exceed 300 psi for exchangers up to 24" in diameter, nor 150 psi for exchangers from 24" to 42" in diameter.

C-6 GASKETS

C-6.1 TYPE OF GASKETS

Gaskets shall be made in one piece. This shall not exclude gaskets made integral by welding.

C-6.2 GASKET MATERIALS

For design pressures of 300 psi and lower, asbestos composition gaskets may be used for external joints, unless temperature or corrosive nature of contained fluid indicates otherwise. Metal jacketed or filled gaskets or solid metal gaskets shall be used for all joints for design pressures greater than 300 psi, and for internal floating head joints. Other gasket materials may be specified by agreement between purchaser and manufacturer to meet special service conditions and flange design. When two gasketed joints are compressed by the same bolting, gasket materials and areas shall be selected so that both gaskets seal, but neither gasket is crushed at the required bolt load.

C-6.3 PERIPHERAL GASKETS

The minimum width of peripheral ring gaskets for external joints shall be ⅜" for shell sizes through 23" nominal diameter and ½" for all larger shell sizes.

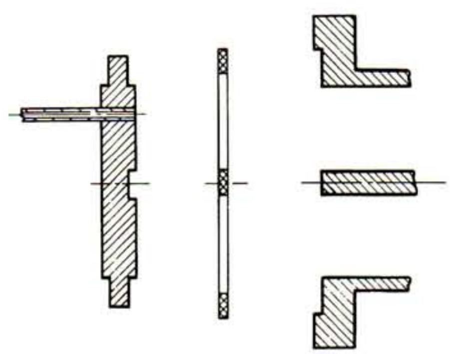
C-6.4 PASS PARTITION GASKETS

The width of gasket web for pass partitions of channels, bonnets, and floating heads shall be not less than ¼" for shell sizes through 23" nominal diameter and not less than ⅜" for all larger shell sizes.

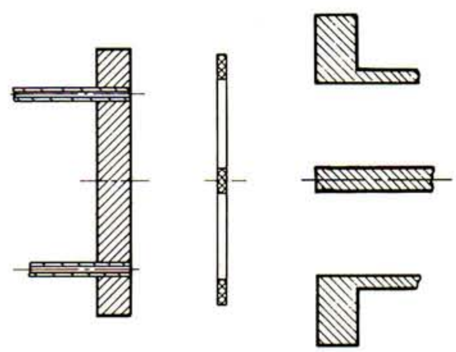
C-6.5 GASKET JOINT DETAILS

Figure C-6.5 shows typical details of both confined and unconfined gasketed joints.

FIGURE C-6.5



Confined Gasket



Unconfined Gasket

C-7 TUBESHEETS

C-7.1 TUBESHEET THICKNESS

C-7.11 EFFECTIVE TUBESHEET THICKNESS

The effective tubesheet thickness shall be the thickness measured at the bottom of the pass partition groove minus shell side corrosion allowance and corrosion allowance on the tube side in excess of the groove depth.

C-7.111 APPLIED TUBESHEET FACINGS

The thickness of applied facing material shall not be included in the minimum or effective tubesheet thickness.

C-7.112 INTEGRALLY CLAD TUBESHEETS

The thickness of cladding material in integrally clad plates and cladding deposited by welding may be included in the effective tubesheet thickness except as limited by the Code.

C-7.12 REQUIRED EFFECTIVE TUBESHEET THICKNESS

The required effective tubesheet thickness for any type of heat exchanger shall be determined from the following paragraphs, for both tube side and shell side conditions, using whichever thickness is greatest.

C-7.121 MINIMUM TUBESHEET THICKNESS

In no case shall the total thickness minus corrosion allowance of any tubesheet be less than three-fourths of the tube diameter for tubes of 1" and smaller O.D., ⅞" for 1¼" O.D., 1" for 1½" O.D. or 1¼" for 2" O.D.

C-7.122 TUBESHEET FORMULA—BENDING

$$T = \frac{FG}{2}\sqrt{\frac{P}{S}}$$

where T = Effective thickness of tubesheet, inches.

S = Code allowable working stress, in tension, for tubesheet material at design temperature used, psi.

P = Hydrostatic design pressure, psi, shell side or tube side, except as modified by paragraphs C-7.153, C-7.154, C-7.155, and C-7.161.

F and G are defined in subsequent paragraphs.

C-7 TUBESHEETS—(Continued)

C-7.123 TUBESHEET FORMULA—SHEAR

$$T = \frac{0.31\, D_L}{\left(1 - \frac{d_o}{p}\right)} \left(\frac{P}{S}\right)$$

where T = Effective thickness of tubesheet, inches.

D_L = 4 A/C = Equivalent diameter of tube center limit perimeter, inches.

C = Perimeter of tube layout measured stepwise in increments of one tube pitch from center-to-center of the outermost tubes, inches. Figure C-7.123 shows the application to typical triangular and square tube pitch layouts.

A = Total area enclosed by perimeter C, square inches.

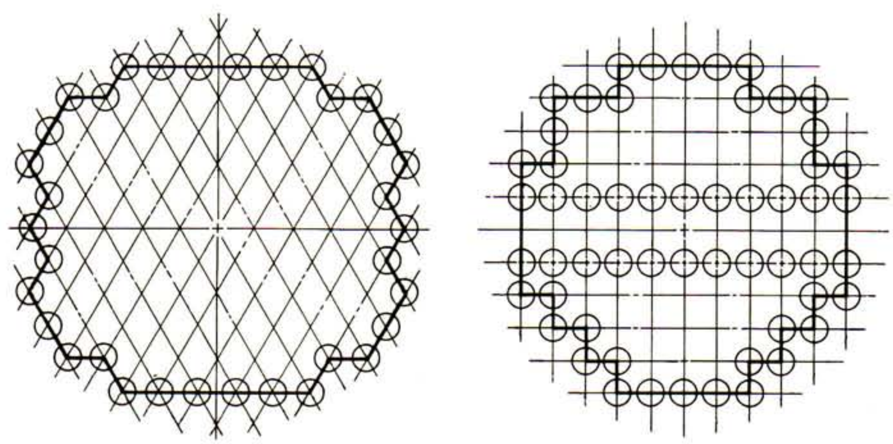
d_o = Outside tube diameter, inches.

p = Tube spacing, center-to-center, inches.

P = Hydrostatic design pressure, psi, shell side or tube side, except as modified by paragraphs C-7.153, C-7.154, and C-7.161.

S = Code allowable working stress, in tension, for tubesheet material at design temperature used, psi.

FIGURE C-7.123



"C" (PERIMETER) IS THE LENGTH OF HEAVY LINE.

C-7.13 GASKETED STATIONARY TUBESHEET EXCHANGERS

This paragraph shall apply whenever a gasketed joint is used between the stationary tubesheet and the adjoining pressure part under consideration, even though the tubesheet may be integral with the other adjoining pressure part, except as limited by paragraph C-7.19.

C-7.131 STATIONARY AND FLOATING TUBESHEET CONSTANTS

G = Mean diameter of gasket at stationary tubesheet, inches.

F = 1.0

C-7 TUBESHEETS—(Continued)

C-7.132 U-TUBE STATIONARY TUBESHEET CONSTANTS

G = Mean diameter of gasket at stationary tubesheet, inches.

F = 1.25

C-7.14 INTEGRAL STATIONARY TUBESHEET EXCHANGERS

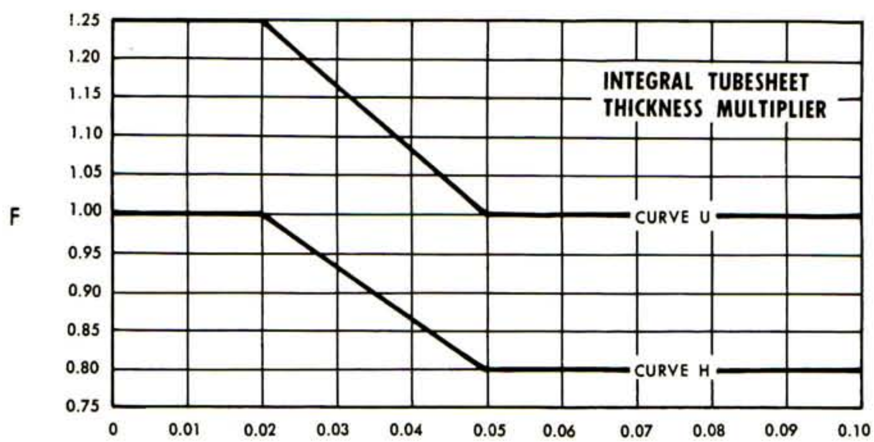
This paragraph shall apply whenever the stationary tubesheet is integral with the adjoining pressure part under consideration, even though the joint with the other adjoining pressure part may be gasketed, except as limited by paragraph C-7.19. With fixed tubesheet exchangers, both tubesheets shall be considered stationary.

C-7.141 STATIONARY TUBESHEET CONSTANTS

G = Inside diameter of integral pressure part, inches

F = Value given by curve H of Figure C-7.141 for floating head and fixed tubesheet exchangers, or by curve U for U-tube exchangers.

FIGURE C-7.141



C-7.142 FLOATING TUBESHEET CONSTANTS

C-7.1421 GASKETED FLOATING TUBESHEET WITHOUT EDGE BOLTING

G = Same as stationary tubesheet.

F = 1.0

C-7.1422 INTEGRAL FLOATING TUBESHEET

G = Same as stationary tubesheet.

F = Value given by curve H of Figure C-7.141.

C-7 TUBESHEETS—(Continued)

C-7.15 FIXED TUBESHEETS

This paragraph shall apply to exchangers having tubesheets fixed to both ends of the shell, with or without a shell expansion joint, except as limited by paragraph C-7.19. Both tubesheets in a fixed tubesheet exchanger shall have the same thickness. When fixed tubesheet extensions are gasketed and bolted, the extended portion shall be in accordance with Code design practice. The extension and that portion of the tubesheet inside the shell may differ in thickness. Tubesheet thicknesses calculated by these rules are adequate. It is possible, however, that shells, tubes, or tube-to-tubesheet joints may be overstressed unless proper provision is made to accommodate differential thermal expansion. Effective design pressures for use in paragraphs C-3.3, C-7.122, and C-7.123 shall be determined as follows:

C-7.151 EQUIVALENT DIFFERENTIAL EXPANSION PRESSURE

The pressure due to differential thermal expansion, in psi, is given by:

$$P_d = \frac{4\ J\ E_s\ t_s\ (\alpha_s\ \theta_s - \alpha_t\ \theta_t)}{(D_o - 3t_s)\ (1 + JKF_q)}$$

(Algebraic sign must be retained for use in paragraphs C-3.311, C-3.312, C-7.153, C-7.154, and C-7.155.)

where $J = \begin{cases} 1.0 \text{ for shells without expansion joints} \\ 0 \text{ for shells with expansion joints, except as limited by paragraph C-7.19.} \end{cases}$

$$K = \frac{E_s\ t_s\ (D_o - t_s)}{E_t\ t_t\ N\ (d_o - t_t)}$$

$$F_q = 0.25 + (F - 0.6)\left[\frac{300\ t_s\ E_s}{K\ L\ E}\left(\frac{G}{T}\right)^3\right]^{1/4}$$

(Use calculated value of F_q or 1.0, whichever is greater.)

F & G are as defined in paragraph C-7.141.

T = Tubesheet thickness used, but not less than 98½% of the greater of the values defined by Par. C-7.122 or C-7.123. (Value assumed in evaluating F_q must match the final computed value within a tolerance of ± 1.5 percent.) See note.

L = Tube length between inner tubesheet faces, inches.

θ = Metal temperature less 70°F.

E_s = Elastic modulus of shell material at metal temperature, psi.

E_t = Elastic modulus of tube material at metal temperature, psi.

E = Elastic modulus of tubesheet material at metal temperature, psi.

α = Thermal expansion coefficient, in. per in./°F.

N = Number of tubes in shell.

D_o = Outside diameter of shell, inches.

d_o = Outside diameter of tubes, inches.

t = Wall thickness, inches.

Subscripts "s" and "t" refer to shell and tubes respectively.

Note: Tubesheets thicker than computed are permissible provided neither shell nor tubes are overloaded. Refer paragraph C-3.3.

C-7 TUBESHEETS—(Continued)

C-7.152 EQUIVALENT BOLTING PRESSURE

When fixed tubesheets are extended for bolting to heads with ring type gaskets, the equivalent tube side and shell side pressures are given by:

$$P_{Bt} = \frac{6.2}{F^2} \frac{M_1}{G^3}$$

$$P_{Bs} = \frac{6.2}{F^2} \frac{M_2}{G^3}$$

where

F = Value given by Curve H of Fig. C-7.141.

G = Inside diameter of shell, inches.

M_1 = Total moment acting upon the extension under operating conditions, defined by the Code as M_o under flange design, inch-pounds.

M_2 = Total moment acting upon the extension under bolting-up conditions, defined by the Code as M_o under flange design, inch-pounds.

P_{Bt} = Equivalent bolting pressure when tube pressure is acting, pounds per square inch.

P_{Bs} = Equivalent bolting pressure when tube pressure is not acting, pounds per square inch.

C-7 TUBESHEETS—(Continued)

C-7.153 EFFECTIVE SHELL SIDE DESIGN PRESSURE

The effective shell side design pressure is given by:

$$P = \frac{(P_s' - P_d)}{2}$$

$$\text{or } P = P_s'$$

$$\text{or } P = P_{Bs}$$

$$\text{or } P = \frac{(P_s' - P_d - P_{Bs})}{2}$$

$$\text{or } P = \frac{(P_{Bs} + P_d)}{2}$$

$$\text{or } P = (P_s' - P_{Bs})$$

whichever has the greatest absolute value.

where

$$P_s' = P_s \left[\frac{0.4J\left[1.5 + K\,(1.5 + f_s)\right] - \left[\left(\frac{1-J}{2}\right)\left(\frac{D_J^2}{G^2} - 1\right)\right]}{(1 + JKF_q)} \right]$$

P_s = Shell side hydrostatic design pressure, psi.

$$f_s = 1 - N\left(\frac{d_o}{G}\right)^2$$

G = Inside diameter of shell, inches.

D_J = Expansion joint bellows inside diameter, inches.

(D_J = G when no expansion joint is present.)

Other symbols are as defined under Paragraphs C-7.151 and C-7.152.

Notes:

1. Algebraic sign must be retained for use in paragraphs C-3.311, C-3.312, C-7.154, and C-7.155.
2. When J = O, formulas containing P_d cannot control.
3. Formulas containing the term P_{Bs} are not applicable for use in paragraph C-7.123.
4. All pressures in paragraphs C-7.153, C-7.154, and C-7.155 are gauge pressures. For vacuum conditions on either shell or tube side, the pressures should be represented by the appropriate negative values.

C-7 TUBESHEETS—(Continued)

C-7.154 EFFECTIVE TUBE SIDE DESIGN PRESSURE

The effective tube side design pressure is given by:

$$P = \frac{(P_t' + P_{Bt} + P_d)}{2} \quad \text{or} \quad P = (P_t' + P_{Bt})$$

whichever has the greater absolute value, when P_s' is positive.

$$P = \frac{(P_t' - P_s' + P_{Bt} + P_d)}{2} \quad \text{or} \quad P = (P_t' - P_s' + P_{Bt})$$

whichever has the greater absolute value, when P_s' is negative.

where

$$P_t' = P_t \left[\frac{1 + 0.4JK\,(1.5 + f_t)}{(1 + JKF_q)} \right]$$

P_t = Tube side hydrostatic design pressure, psi.

$$f_t = 1 - N \left[\frac{(d_o - 2t_t)}{G} \right]^2$$

G = Inside diameter of shell (tubesheet bolted to stationary head) or inside diameter of stationary head when integral with tubesheet, inches.

Other symbols are as defined under Par. C-7.151, C-7.152, and C-7.153.

Notes: 1. Algebraic sign must be retained for use in paragraphs C-3.311, C-3.312, and C-7.155.

2. When $J = 0$

(a) Formulas containing P_d cannot control.

(b) $P = P_t + \frac{P_s}{2} \left[\left(\frac{D_J}{G} \right)^2 - 1 \right] + P_{Bt}$

3. Delete the term P_{Bt} in above formulas for use in paragraph C-7.123.

C-7 TUBESHEETS—(Continued)

C-7.155 EFFECTIVE DIFFERENTIAL DESIGN PRESSURE

Under certain circumstances the Code and other regulatory bodies permit design on the basis of simultaneous action of both shell and tube side pressures. The effective differential design pressure for fixed tubesheets under such circumstances is given by:

$$P = (P_t' - P_s' + P_{Bt})$$

$$\text{or } P = \frac{(P_t' - P_s' + P_{Bt} + P_d)}{2}$$

$$\text{or } P = P_{Bs}$$

$$\text{or } P = \frac{(P_{Bs} + P_d)}{2}$$

$$\text{or } P = (P_t' - P_s')$$

$$\text{or } P = \frac{(P_t' - P_s' + P_d)}{2}$$

$$\text{or } P = P_{Bt}$$

whichever has the greatest absolute value

where

P_d, P_{Bs}, P_{Bt}, P_s', and P_t' are as defined in paragraphs C-7.151, C-7.152, C-7.153, and C-7.154 respectively.

Notes: 1. It is not permissible to enter the equation P_s' in paragraph C-7.153 with $(P_s - P_t)$ in place of P_s nor the equation P_t' in paragraph C-7.154 with $(P_t - P_s)$ in place of P_t, to determine an effective shell side or tube side design pressure for fixed tubesheets.

2. When $J = 0$, formulas with the term P_d cannot control.

3. Formulas containing the terms P_{Bt} or P_{Bs} are not applicable for use in paragraph C-7.123.

C-7.16 PACKED FLOATING TUBESHEET TYPE EXCHANGERS

C-7.161 OUTSIDE PACKED FLOATING HEAD (Type P)

The thickness of tubesheets in exchangers whose floating heads are packed at the outside diameter of the tubesheet or a cylindrical extension thereof. shall be calculated as for gasketed stationary tubesheet exchangers, using terms as defined below and the formula shown in paragraph C-7.122 or C-7.123.

$$P = P_t + P_s \left(\frac{D^2 - D_L^2}{D_l^2}\right)$$

where

P = Hydrostatic design pressure, psi.

P_t = Hydrostatic design pressure, psi, tube side.

P_s = Hydrostatic design pressure, psi, shell side.

D = Outside diameter of floating tubesheet, inches.

D_l = Inside diameter of floating tubesheet skirt, inches.

D_L = Equivalent diameter of tube center limit perimeter, defined in paragraph C-7.123.

F and G are as defined in previous paragraphs considering applicable edge configurations.

C-7 TUBESHEETS—(Continued)

C-7.162 PACKED FLOATING TUBESHEET WITH LANTERN RING (Type W)

The thickness of tubesheets in exchangers whose floating tubesheets are packed at the outside diameter with return bonnet or channel bolted to the shell flange, shall be calculated as for gasketed stationary tubesheet exchangers, using terms as defined below and the formula shown in paragraph C-7.122.

P = Hydrostatic design pressure, psi, tube side.

G = Mean diameter of gasket at stationary tube sheet, inches.

F = 1.0

C-7.163 FLOATING HEAD (Type S) WITH PACKED NOZZLE

The thickness of tubesheets in exchangers with packed floating head nozzles shall be calculated as for gasketed stationary tubesheet exchangers, using terms as defined below and the formula shown in paragraph C-7.122 or C-7.123.

P = Hydrostatic design pressure, psi, shell side or tube side.

F and G are as defined in paragraph C-7.131 or C-7.142, whichever is applicable.

C-7.17 DIVIDED FLOATING HEADS

For divided floating tubesheets, regardless of the type of stationary tubesheet,

G = 1.41 s

F = 1.0

where s = Length of shortest span measured over center lines of gasket, inches.

C-7.18 DOUBLE TUBESHEETS

Double tubesheets may be used where operating conditions indicate their desirability. The diversity of construction types makes it impractical to specify design rules which are universally applicable. It may be stated that the mutual support contributed by each component tubesheet through the tubes connecting them is a generally recognized design principle.

C-7.181 MINIMUM THICKNESS

Neither component of a double tubesheet shall have a thickness less than required by paragraph C-7.121.

C-7.182 VENTS AND DRAINS

Double tubesheets of the edge welded type shall be provided with vent and drain connections at the high and low points of the enclosed space.

C-7.183 SPECIAL PRECAUTIONS

When double tubesheets are used, special attention shall be given to the ability of the tubes to withstand, without damage, the mechanical and thermal loads imposed on them by this construction.

C-7.19 SPECIAL CASES

Special consideration must be given to tubesheets with abnormal conditions of support or loading; e.g., fixed tubesheets in exchangers with expansion joints which require considerable axial loads to produce required movements, such as the flued and flanged type; tubesheets (except fixed tubesheets) with extensions used as flanges; tubesheets with portions not adequately stayed by tubes; e.g., exchangers with large differences in shell and head inside diameters; and exchangers with hydrostatic design pressures greater than 3000 psig. Special consideration may also be given to conditions tending to reduce tubesheet thickness requirements.

C-7 TUBESHEETS—(Continued)

C-7.2 TUBE HOLES IN TUBESHEETS

C-7.21 DIAMETERS AND TOLERANCES

Tube holes in tubesheets shall be finished to the sizes and tolerances shown in Table C-7.21, column (a). For austenitic steel tubes, when used for corrosion resistance, a closer fit between tube O.D. and tube hole I.D. as shown in column (b) may tend to minimize work hardening and attendant loss of corrosion resistance; these clearances will be provided when specified by the purchaser.

TABLE C-7.21

TUBE HOLE DIAMETERS AND TOLERANCES

Nominal Tube O.D. Inches	Nominal Tube Hole Diameter and Under Tolerance—Inches				Over Tolerance-Inches (96% of tube holes must meet value in column (c). Remainder may not exceed value in column (d).)	
	Standard Fit (a)		Special Close Fit (b)			
	Nominal Diameter	Under Tolerance	Nominal Diameter	Under Tolerance	(c)	(d)
1/4	0.259	0.004	0.257	0.002	0.002	0.007
3/8	0.384	0.004	0.382	0.002	0.002	0.007
1/2	0.510	0.004	0.508	0.002	0.002	0.008
5/8	0.635	0.004	0.633	0.002	0.002	0.010
3/4	0.760	0.004	0.758	0.002	0.002	0.010
1	1.012	0.004	1.010	0.002	0.002	0.010
1 1/4	1.264	0.006	1.261	0.003	0.003	0.010
1 1/2	1.518	0.007	1.514	0.003	0.003	0.010
2	2.022	0.007	2.018	0.003	0.003	0.010

C-7.22 TUBESHEET DRILLING TOLERANCES

Table C-7.22 gives permissible tube hole drilling tolerances, drill drift, and recommended maximum tube wall thicknesses.

TABLE C-7.22

TABLE OF TUBESHEET DRILLING TOLERANCES AND MAXIMUM RECOMMENDED TUBE GAGES

(All Dimensions in Inches)

Tube Dia. d_o	Tube Pitch p	$\frac{p}{d_o}$	$p-d_o$	Heaviest Recommended Tube Gage B.W.G.	Tube Hole Dia. Std. Fit	Nominal Ligament Width	Minimum Std. Ligaments (96% of ligaments must equal or exceed values tabulated below) — Tubesheet Thickness, Inches: 1	1½	2	2½	3	4	5	6	Minimum Permissible Ligament Width
1/4	5/16	1.25	1/16	22	0.259	0.053	.025	.025	.025	.025	—	—	—	—	.025
	3/8	1.50	1/8	20		0.116	.083	.077	.070	.064	—	—	—	—	.060
3/8	1/2	1.33	1/8	18	0.384	0.116	.087	.083	.079	.075	.070	.062	—	—	.060
	17/32	1.42	5/32	18		0.147	.118	.114	.110	.106	.101	.093	.084	.076	.075
1/2	5/8	1.25	1/8	18	0.510	0.115	.089	.085	.082	.079	.076	.069	.063	—	.060
	21/32	1.31	5/32	16		0.146	.120	.116	.113	.110	.107	.100	.094	.088	.075
	11/16	1.38	3/16	16		0.178	.152	.148	.145	.142	.139	.132	.126	.120	.090
5/8	25/32	1.25	5/32	15	0.635	0.146	.111	.108	.106	.103	.101	.095	.090	.085	.075
	13/16	1.30	3/16	14		0.178	.143	.140	.138	.135	.133	.127	.122	.117	.090
	7/8	1.40	1/4	14		0.240	.205	.202	.200	.197	.195	.189	.184	.179	.120
3/4	15/16	1.25	3/16	13	0.760	0.178	.144	.142	.139	.137	.135	.131	.127	.122	.090
	1	1.33	1/4	12		0.240	.206	.204	.201	.199	.197	.193	.189	.184	.120
	1-1/16	1.42	5/16	12		0.302	.268	.266	.263	.261	.259	.255	.251	.246	.150
	1-1/8	1.50	3/8	12		0.365	.331	.329	.326	.324	.322	.318	.314	.309	.185
1	1-1/4	1.25	1/4	10	1.012	0.238	.205	.203	.202	.200	.198	.195	.192	.189	.120
	1-5/16	1.31	5/16	9		0.300	.267	.265	.264	.262	.260	.257	.254	.251	.150
	1-3/8	1.38	3/8	9		0.363	.330	.328	.327	.325	.323	.320	.317	.314	.185
1-1/4	1-9/16	1.25	5/16	9	1.264	0.298	.265	.264	.263	.262	.260	.258	.255	.253	.150
1-1/2	1-7/8	1.25	3/8	8	1.518	0.357	.325	.324	.323	.322	.321	.318	.316	.314	.180
2	2-1/2	1.25	1/2	6	2.022	0.478	—	.446	.445	.444	.443	.442	.440	438	.250

NOTES: The above table of minimum standard ligaments is based on a ligament tolerance not exceeding the sum of twice the drill drift tolerance plus 0.020" for tubes less than 5/8" O.D. and 0.030" for tube holes 5/8" O.D. and larger.
Drill drift tolerance = 0.0016 × (thickness of tubesheet in tube diameters) inches.

C-7 TUBESHEETS—(Continued)

C-7.23 TUBE HOLE FINISH

The inside edges of tube holes in tubesheets shall be free of burrs to prevent cutting of the tubes. Internal surfaces shall be given a workmanlike finish.

C-7.24 TUBE HOLE GROOVING

For design pressures over 300 psi and/or temperatures in excess of 350°F, the tube holes for expanded joints for tubes 5/8" O.D. and larger shall be machined with at least two grooves, each approximately 1/8" wide by 1/64" deep. When integrally clad or applied tubesheet facings are used, all grooves shall be in the base material unless otherwise specified by the purchaser.

C-7.3 EXPANDED TUBE JOINTS

Expanded tube-to-tubesheet joints are standard.

C-7.31 LENGTH OF EXPANSION

Tubes shall be expanded into the tubesheet for a length no less than two tube diameters, 2", or tubesheet thickness minus 1/8", whichever is smallest. In no case shall the expanded portion extend beyond the shell side face of the tubesheet. When specified by the purchaser tubes may be expanded for the full thickness of the tubesheet.

C-7.32 CONTOUR OF EXPANDED TUBE

The expanding procedure shall be such as to provide substantially uniform expansion throughout the expanded portion of the tube, without sharp transition to the unexpanded portion.

C-7.4 WELDED TUBE JOINTS

When both tubes and tubesheets, or tubesheet facing, are of suitable materials, the tube joints may be welded.

C-7.41 SEAL WELDED JOINTS

When welded tube joints are used for additional leak tightness only, and customary tube loads are carried by the expanded joint, the tube joints shall be subject to the rules of paragraphs C-7.2 through C-7.32.

C-7.42 STRENGTH WELDED JOINTS

When welded tube joints are used as a complete substitute for expanded joints, consideration may be given to modification of the requirements of paragraphs C-7.2 through C-7.32.

C-7.43 FABRICATION AND TESTING PROCEDURE

Welding procedure and testing techniques for either seal welded or strength welded tube joints shall be by agreement between manufacturer and purchaser.

C-7.5 TUBESHEET PASS PARTITION GROOVES

For design pressures over 300 psi, tubesheets shall be provided with pass partition grooves approximately 3/16" deep, or other suitable means for retaining gaskets in place.

C-7.6 TUBESHEET PULLING EYES

In exchangers with removable tube bundles having a nominal diameter exceeding 12" and/or a tube length exceeding 96", the stationary tubesheet shall be provided with two tapped holes in its face for pulling eyes. These holes shall be protected in service by plugs. Provision for pulling means may have to be modified or waived for special constructions, such as clad tubesheets or manufacturer's standard, by agreement between manufacturer and purchaser.

C-7.7 CLAD AND FACED TUBESHEETS

The nominal cladding thickness at the tube side face of a tubesheet shall not be less than 3/16" when tubes are rolled only, and 1/8" when tubes are welded to the tubesheet. The nominal cladding thickness on the shell side face shall not be less than 3/8". All surfaces exposed to the fluid, including gasket seating surfaces, shall have at least 1/8" nominal thickness of cladding.

C-8 CHANNELS, COVERS, AND BONNETS

C-8.1 CHANNELS AND BONNETS

C-8.11 MINIMUM THICKNESS OF CHANNELS AND BONNETS

Channel and bonnet thickness is determined by the Code design formulas, plus corrosion allowance, but in no case shall the nominal thickness of channels and bonnets be less than the minimum shell thicknesses shown in Table C-3.13. The nominal total thickness for clad or lined channels and bonnets shall be the same as for carbon steel plate channels.

C-8.12 MINIMUM INSIDE DEPTH

For multipass channels and bonnets the inside depth shall be such that the minimum cross-over area for flow between successive tube passes is at least equal to the flow area through the tubes of one pass. When an axial nozzle is used, the depth at the nozzle centerline shall be a minimum of one-third the inside diameter of the nozzle.

C-8.13 PASS PARTITION PLATES

C-8.131 MINIMUM THICKNESS

The nominal thickness of channels or bonnet pass partitions shall not be less than shown in Table C-8.131. Partition plates may be tapered to gasket width at the contact surface.

TABLE C-8.131

MINIMUM PASS PARTITION PLATE THICKNESS, INCLUDING CORROSION ALLOWANCE

Nominal Size Inches	Carbon Steel Inches	Alloy Material Inches
Less than 24	3/8	1/4
24 and over	1/2	3/8

C-8.132 SPECIAL PRECAUTIONS

Special consideration must be given to thickness requirements for internal partitions subjected to pulsating fluids or to large differential pressures under specified operating conditions, or to unusual start-up or maintenance conditions specified by the purchaser.

C-8.14 POSTWELD HEAT TREATMENT

Fabricated channels and bonnets shall be postweld heat treated in accordance with Code requirements, or as specified by the purchaser.

C-8 CHANNELS, COVERS, AND BONNETS—(Continued)

C-8.2 CHANNEL COVERS

C-8.21 EFFECTIVE CHANNEL COVER THICKNESS

The effective thickness of flat channel covers shall be the thickness measured at the bottom of the pass partition groove minus tube side corrosion allowance in excess of the groove depth. The required value shall be either that determined from the appropriate Code formula or from the following equation, whichever is greater:

$$T = \left[5.7P\left(\frac{G}{100}\right)^4 + 2\frac{h_G A_B}{\sqrt{d_B}}\left(\frac{G}{100}\right)\right]^{1/3}$$

where T = Effective channel cover thickness, inches.

P = Design pressure, psi.

G = Mean gasket diameter, inches.

d_B = Nominal bolt diameter, inches.

h_G = Radial distance between mean gasket diameter and bolt circle, inches.

A_B = Actual total cross-sectional area of bolts, square inches.

For gaskets having compression factors of 3.0 or less, the value of "T" obtained by this formula may be reduced by 20 per cent.

Notes:

1. For high alloy steels and nonferrous metals, and for carbon steel at temperatures other than 650°F, the value obtained from this formula shall be multiplied by $(25{,}000{,}000/E)^{1/3}$, where "E" is the elastic modulus of the cover material at the design temperature.
2. For single pass channels, or others in which there is no pass partition gasket seal against the channel cover, only the Code formula need be considered.

C-8.22 CHANNEL COVER PASS PARTITION GROOVES

For design pressures over 300 psi, channel covers shall be provided with approximately 3/16" deep grooves for pass partitions, or other suitable means for holding the gasket in place. In clad or applied facings, all surfaces exposed to fluid, including gasket seating surfaces, shall have at least 1/8" nominal thickness of cladding.

C-9 NOZZLES

C-9.1 NOZZLE CONSTRUCTION

Nozzle construction shall be in accordance with Code requirements. Shell nozzles shall not protrude beyond the inside contour of the shell. Channel nozzles may protrude inside the channel provided vent and drain connections are flush with the inside contour of the channel. Flange dimensions and facing shall comply with USA Standard B16.5. Bolt holes shall straddle natural center lines.

C-9.2 NOZZLE INSTALLATION

Radial nozzles shall be considered as standard. Other types of nozzles may be used, by agreement between manufacturer and purchaser.

C-9.3 PIPE TAP CONNECTIONS

All pipe tap connections shall be a minimum of 3000 psi standard couplings or equivalent.

C-9.31 VENT AND DRAIN CONNECTIONS

All high and low points on shell and tube sides of an exchanger not otherwise vented or drained by nozzles shall be provided with ¾" connections for vent and drain. Larger connections may be provided at manufacturer's option.

C-9.32 PRESSURE GAGE CONNECTIONS

Pressure connections shall be as specified by the purchaser. See paragraph C-9.4.

C-9.33 THERMOMETER CONNECTIONS

Thermometer connections shall be as specified by the purchaser. See paragraph C-9.4.

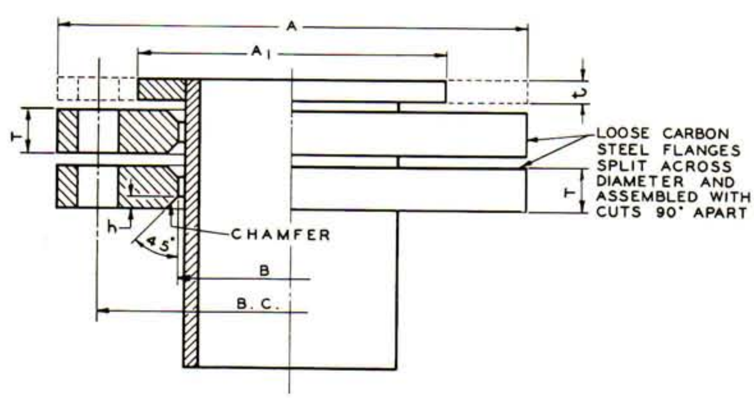
C-9.4 STACKED UNITS

Intermediate nozzles between units shall have flat or raised face flanges. Pressure gage and thermometer connections may be omitted in one of two mating connections of units connected in series.

C-9.5 SPLIT FLANGE DESIGN

Circumstances of fabrication, installation, or maintenance sometimes indicate undesirability of the normal integral or loose full ring nozzle flanges. Under these conditions, double split ring flanges may be used in accordance with the Code. Figure C-9.5 and Table C-9.5 give typical dimensions of such flanges.

FIGURE C-9.5



C-9 NOZZLES —(Continued)

TABLE C-9.5

DESIGN PRESSURE 150 PSI
CARBON STEEL SPLIT TYPE NOZZLE FLANGES
ALL DIMENSIONS ARE IN INCHES

Size Nozzle	A	A_1	t	B.C.	T	No. and Size of Bolts	B	h
2-1/2	7	4-1/8	1/4	5-1/2	7/8	4—5/8	3	5/16
3	7-1/2	5	1/4	6	7/8	4—5/8	3-5/8	3/8
4	9	6-3/16	1/4	7-1/2	15/16	8—5/8	4-5/8	7/16
6	11	8-1/2	5/16	9-1/2	1-1/16	8—3/4	6-3/4	1/2
8	13-1/2	10-5/8	3/8	11-3/4	1-1/8	8—3/4	8-3/4	1/2
10	16	12-3/4	3/8	14-1/4	1-3/8	12—7/8	10-7/8	1/2
12	19	15	3/8	17	1-1/2	12—7/8	12-7/8	1/2
14	21	16-1/4	3/8	18-3/4	1-3/4	12—1	14-1/8	1/2
16	23-1/2	18-1/2	3/8	21-1/4	1-7/8	16—1	16-1/8	1/2
18	25	21	3/8	22-3/4	1-13/16	16—1-1/8	18-1/8	1/2
20	27-1/2	23	3/8	25	2	20—1-1/8	20-1/8	1/2
24	32	27-1/4	3/8	29-1/2	2-1/4	20—1-1/4	24-1/8	1/2

Gaskets—Compressed Asbestos, 1/16" thick
Flange stress, 17,500 psi
Bolt Stress, 20,000 psi

C-10 END FLANGES AND BOLTING

Flanges and bolting for external joints shall be in accordance with Code design rules, subject to the limitations set forth in the following paragraphs.

C-10.1 MINIMUM BOLT SIZE

The minimum permissible bolt diameter shall be ½" for exchangers with a nominal shell diameter of 12" or less, and ⅝" for all other sizes.

C-10.2 BOLT CIRCLE LAYOUT

C-10.21 MINIMUM RECOMMENDED BOLT SPACING

The minimum recommended spacing between bolt centers shall be as given by Table C-10.3.

C-10.22 MAXIMUM RECOMMENDED BOLT SPACING

The maximum recommended spacing between bolt centers shall be:

$$B_{max} = 2d_B + \frac{6t}{(m + 0.5)}$$

where

B = Bolt spacing, inches.
d_B = Nominal bolt diameter, inches.
t = Flange thickness, inches.
m = Gasket factor used in Code flange calculations.

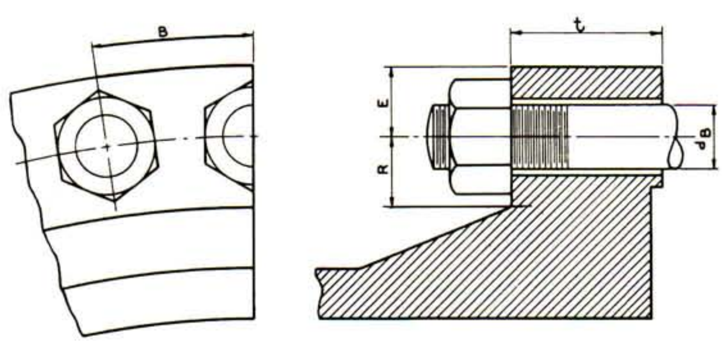
C-10.23 BOLT ORIENTATION

Bolt centers shall evenly straddle both natural centerlines of the exchanger. For horizontal units the natural centerlines shall be considered to be the horizontal and vertical centerlines of the exchanger. In special cases, by agreement between purchaser and manufacturer, the bolt count may be reduced from a multiple of four (as required by the foregoing) to a multiple of two.

C-10.3 MINIMUM RECOMMENDED WRENCH AND NUT CLEARANCES

Minimum recommended radial dimensions "R" and "E", as defined in Figure C-10.3, and minimum recommended bolt spacing B_{min} shall be as given in Table C-10.3.

FIGURE C-10.3



C-10 END FLANGES AND BOLTING—(Continued)

TABLE C-10.3

FLANGE BOLT CLEARANCES

(All Dimensions in Inches)			
d_B	R	E	B_{min}
1/2	13/16	5/8	1-1/4
5/8	15/16	3/4	1-1/2
3/4	1-1/8	13/16	1-3/4
7/8	1-1/4	15/16	2-1/16
1	1-3/8	1-1/16	2-1/4
1-1/8	1-1/2	1-1/8	2-1/2
1-1/4	1-3/4	1-1/4	2-13/16
1-3/8	1-7/8	1-3/8	3-1/16
1-1/2	2	1-1/2	3-1/4
1-5/8	2-1/8	1-5/8	3-1/2
1-3/4	2-1/4	1-3/4	3-3/4
1-7/8	2-3/8	1-7/8	4
2	2-1/2	2	4-1/4

C-10.4 LOAD CONCENTRATION FACTOR

When the distance between bolt centerlines exceeds recommended B_{max}, the total flange moment determined by Code design methods shall be multiplied by a correction factor equal to $\sqrt{B/B_{max}}$ where symbols are defined in paragraph C-10.22.

C-10.5 BOLT TYPE

Except for special design considerations, flanges shall be through-bolted with stud bolts, threaded full length with a removable nut on each end. Stud bolt length shall be such that the nuts are fully engaged and project through the nuts approximately ⅛" on each end.

B-1 SCOPE AND GENERAL REQUIREMENTS

B-1.1 SCOPE OF STANDARDS

B-1.11 DEFINITION OF CLASS "B" EXCHANGERS

The Mechanical Standards for Class "B" heat exchangers specify design, fabrication, and materials of unfired shell and tube heat exchangers for chemical process service. Equipment fabricated in accordance with these standards is designed for the maximum economy and overall compactness consistent with safety and service requirements in such applications.

B-1.12 CONSTRUCTION CODES

The individual vessels shall comply with the 1968* ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code, Section VIII, Division 1, hereinafter referred to as the Code. These standards supplement and define the Code for heat exchanger applications. Heat exchangers shall comply with the construction requirements of state and local codes when the plant location is specified. Application of the Code symbol is required, unless otherwise specified.

B-1.13 MATERIALS—DEFINITION OF TERMS

For purposes of these standards, "carbon steel" shall be construed as any steel or low alloy falling within the scope of Part UCS of the Code. Metals not included by the foregoing (except cast iron) shall be considered as "alloys" unless otherwise specifically named.

B-1.2 PRESSURE CLASSIFICATIONS

B-1.21 STANDARD PRESSURE CLASSIFICATIONS

The following design pressure classifications are standard:

For diameters larger than 23" nominal	75 psi
For all diameters	150 psi
For all diameters	300 psi
For all diameters	450 psi
For all diameters	600 psi

B-1.22 INTERMEDIATE PRESSURE CLASSES

For special circumstances, consideration may be given to intermediate pressure classes.

B-1.23 DESIGN PRESSURES

Design pressures for the shell and tube sides shall be specified separately.

B-1.3 TESTING

B-1.31 STANDARD TEST

The exchanger shall be hydrostatically tested with water. The test pressure shall be held for at least 30 minutes. The shell side and the tube side are to be tested separately in such a manner that leaks at the tube joints can be detected from at least one side. When construction permits, and the tube side design pressure is the higher pressure, the tube bundle shall be tested outside of the shell. Welded joints are to be sufficiently cleaned prior to testing the exchanger to permit proper inspection during the test. The hydrostatic test pressure at room temperature shall be 1.5 times the design pressure, corrected for temperature, except for materials such as cast iron where other Code requirements govern.

*The latest edition may be used when specified.

B-1 SCOPE AND GENERAL REQUIREMENTS—(Continued)

B-1.311 OTHER LIQUID TESTS

When specified, other liquids in lieu of water may be used as a testing medium.

B-1.32 PNEUMATIC TEST

When liquid cannot be tolerated as a test medium, the exchanger may be given a pneumatic test in accordance with the Code. It must be recognized that air or gas is hazardous when used as a pressure testing medium. The pneumatic test pressure at room temperature shall be 1.25 times the design pressure, corrected for temperature, except for materials such as cast iron where other Code requirements govern.

B-1.33 SUPPLEMENTARY AIR TEST

When a supplementary air or gas test is specified, it shall be immediately preceded by the hydrostatic test required by Par. B-1.31. The test pressure shall not exceed that required by Par. B-1.32. Leaks may be located by halide probe, or by other means.

B-1.4 METAL TEMPERATURES

B-1.41 METAL TEMPERATURE LIMITATIONS FOR PRESSURE PARTS

The metal temperature limitations for various metals are those prescribed by the Code.

B-1.42 DESIGN TEMPERATURE OF HEAT EXCHANGER PARTS

Design temperatures for the shell and tube sides shall be specified separately for parts not subject to both fluids. The design temperature of heat exchanger parts subjected to two different fluid temperatures shall be the maximum metal temperature of the part under operating conditions, except when some other design metal temperature is specified. In establishing the metal temperatures, due consideration shall be given to such factors as the relative heat transfer coefficients of the two fluids contacting the part and the relative heat transfer area of the parts contacted by the two fluids.

B-1.5 STANDARD CORROSION ALLOWANCES

Corrosion allowances are to be used for the various heat exchanger parts as follows:

B-1.51 CARBON STEEL PARTS

B-1.511 PRESSURE PARTS

All carbon steel pressure parts, except tubes, are to have a corrosion allowance of $\frac{1}{16}''$ unless the conditions of service make a different allowance more suitable and such allowance is definitely specified.

B-1.512 INTERNAL COVERS

Internal covers are to have the corrosion allowance on each side.

B-1.513 TUBESHEETS

Tubesheets are to have the corrosion allowance on each side with the provision that, on the grooved side of a grooved tubesheet, the depth of the pass partition groove may be considered as available for corrosion allowance.

B-1.514 EXTERNAL COVERS

Where flat external covers are grooved, the depth of the groove may be considered as available for corrosion allowance.

B-1.515 END FLANGES

Corrosion allowance shall be applied only to the inside diameter of flanges.

B-1 SCOPE AND GENERAL REQUIREMENTS—(Continued)

B-1.516 NONPRESSURE PARTS

Nonpressure parts such as tie rods, spacers, baffles, and support plates are to have no allowance for corrosion.

B-1.517 FLOATING HEAD BACKING DEVICES

Floating head backing devices and internal bolting are to have no corrosion allowance.

B-1.52 ALLOY PARTS

No corrosion allowance is to be added to alloy parts except as specified.

B-1.53 CAST IRON PARTS

Cast iron pressure parts shall have a corrosion allowance of 1/16".

B-1.6 SERVICE LIMITATIONS

B-1.61 CAST IRON PARTS

Cast iron shall be used only for water service at pressures not exceeding 150 psi.

B-1.62 PACKED JOINTS

Packed joints shall not be used when the fluid in contact with the joint is lethal or flammable.

B-2 TUBES

B-2.1 TUBE LENGTH

The following tube lengths for both straight and U-tube exchangers, shall be considered as standard: 8, 10, 12, 16, and 20 feet. Other lengths may be used; even lengths are preferred. See also paragraph N-1.12.

B-2.2 TUBE DIAMETERS AND GAGES

B-2.21 BARE TUBES

Table B-2.21 lists standard tube diameters and gages for bare tubes of copper, steel, and alloy.

TABLE B-2.21

STANDARD BARE TUBE DIAMETERS AND GAGES

O. D. Inches	Copper and Copper Alloys		Carbon Steel, Aluminum and Aluminum Alloys		Other Alloys	
	B.W.G. (Min. Wall)	Thickness Inches	B.W.G. (Min. Wall)	Thickness Inches	B.W.G. (Avg. Wall)	Thickness Inches
⅝	20	0.035	18	0.049	20	0.035
	18	0.049	**16**	0.065	**18**	0.049
	16	0.065	14	0.083	16	0.065
¾	—	——	—	——	20	0.035
	18	0.049	16	0.065	18	0.049
	16	0.065	**14**	0.083	**16**	0.065
1	**16**	0.065	16	0.065	18	0.049
	14	0.083	**14**	0.083	**16**	0.065
	12	0.109	12	0.109	14	0.083
1¼	16	0.065	16	0.065	**16**	0.065
	14	0.083	**14**	0.083	**14**	0.083
	12	0.109	12	0.109	—	——
1½	14	0.083	14	0.083	16	0.065
	12	0.109	12	0.109	14	0.083
2	14	0.083	14	0.083	14	0.083
	12	0.109	12	0.109	12	0.109

Notes: 1. Tube diameters and gages in bold face are preferred.

2. Average wall tubes of heavier gage may be used in place of minimum wall tubes, provided the wall thickness is not less than specified.

3. Characteristics of tubing are shown in Table D-7, Page 187.

B-2 TUBES—(Continued)

B-2.22 CIRCUMFERENTIALLY-FINNED TUBES

The nominal fin diameter shall be the same as the O.D. of the unfinned end. The diameter over the fins will not normally exceed the diameter of the unfinned section to insure that fin tubes are interchangeable with standard bare tubes. Specified wall shall be based on the thickness at the root diameter.

B-2.3 U-TUBES

B-2.31 NONUNIFORM THICKNESS BENDS

When U-bends are formed, as is customary, in such a way as to thin the tube wall at the outer radius of the bend, the minimum tube wall thickness in the bent portion **before bending** shall be:

$$t_o = t_1 \left[1 + \frac{d_o}{4R} \right]$$

where t_o = Original tube wall thickness, inches.
t_1 = Minimum tube wall thickness calculated by Code rules for a straight tube subjected to the same pressure and metal temperature, inches.
d_o = Outside tube diameter, inches.
R = Mean radius of bend, inches.

When thinning of the bends cannot be tolerated because of corrosion, then the inner two rows of U-tubes shall have tubes with a wall two gages heavier. Dual-gage tubes may be used.

When U-bends are formed from tube materials which are relatively nonwork hardening and of suitable temper, tube wall thinning in the shortest bends should not exceed a nominal 17% of original tube wall thickness.

U-bends formed from tube materials having low ductility, or materials which are susceptible to work-hardening, may require special consideration. Also refer to Par. B-2.33.

B-2.32 BEND SPACING

B-2.321 CENTER-TO-CENTER DIMENSION

The center-to-center dimensions between parallel legs of U-tubes shall be such that they may be inserted into the baffle assembly without damage to the tubes.

B-2.322 BEND INTERFERENCE

The assembly of bends shall be of workmanlike appearance. Metal-to-metal contact between bends in the same plane shall not be permitted.

B-2.33 HEAT TREATMENT

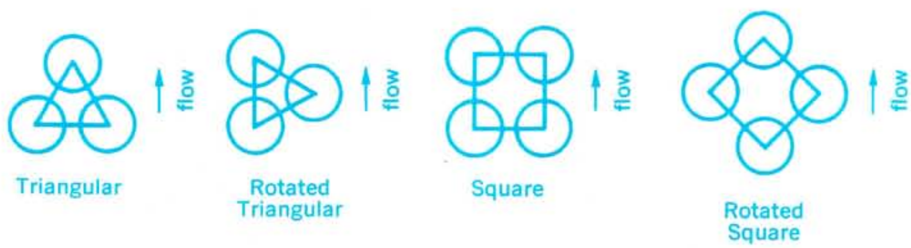
Cold work in forming U-bends may induce embrittlement or susceptibility to stress corrosion in certain materials and/or environments. Heat treatment may be performed to alleviate such conditions. It is generally considered not practical to heat treat austenitic stainless steel tubes.

B-2 TUBES — (Continued)

B-2.4 TUBE PATTERN

Standard tube patterns are shown in Figure B-2.4.

FIGURE B-2.4



Note: Flow arrows are normal to the baffle cut edge.

B-2.41 SQUARE PATTERN

When tubes are laid out on a square or rotated square pitch, tube lanes shall be continuous throughout the bundle.

B-2.42 TRIANGULAR PATTERN

Triangular or rotated triangular pattern should not be used when the shell side is to be cleaned mechanically.

B-2.5 TUBE PITCH

Minimum tube pitches are given in Table B-2.5.

TABLE B-2.5

MINIMUM TUBE PITCHES

Tube O.D. Inches	Tube Pitch, Inches*	
	Triangular & Rotated Triangular Pattern	Square & Rotated Square Pattern
5/8	25/32	7/8**
3/4	15/16	1**
1	1-1/4	1-1/4
1-1/4	1-9/16	1-9/16
1-1/2	1-7/8	1-7/8
2	2-1/2	2-1/2

* Tolerances shown in paragraph B-7.2 will apply.

** When the nominal shell diameter is 12" or less, this pitch may be reduced to 13/16" for 5/8" O.D. tubes and to 15/16" for 3/4" O.D. tubes.

B-2.6 TUBE LAYOUT

The tube layout is to be such as to minimize by-passing around the tube bundle.

B-3 SHELLS AND SHELL COVERS

B-3.1 SHELLS

B-3.11 SHELL DIAMETERS

Nothing in this standard shall be construed as a limitation on the minimum or maximum shell diameters.

B-3.12 TOLERANCES

B-3.121 PIPE SHELLS

The inside diameter of pipe shells shall be in accordance with applicable ASTM (American Society for Testing and Materials) pipe specifications.

B-3.122 PLATE SHELLS

The inside diameter of any plate shell shall not exceed the design inside diameter by more than 1/8" as determined by circumferential measurement.

B-3.13 MINIMUM THICKNESS OF SHELLS

Shell thickness is determined by the Code design formulas, plus corrosion allowance, but in no case shall the nominal thickness of shells be less than that shown in Table B-3.13. The nominal total thickness for clad or lined shells shall be the same as for carbon steel plate shells.

TABLE B-3.13

MINIMUM SHELL THICKNESS

Nominal Shell Dia.	Minimum Thickness		
	Carbon Steel		Alloy*
	Pipe	Plate	
6"	Sch. 40	—	1/8"
8" - 12" Inc.	Sch. 30	—	1/8"
13" - 23" Inc.	Sch. 20	5/16"	1/8"
24" - 29" Inc.	—	5/16"	3/16"
30" - 39" Inc.	—	3/8"	1/4"
40" - 60" Inc.	—	7/16"	1/4"

* Schedule 5S permissible for 6" and 8" shell diameter.

B-3.2 SHELL COVER THICKNESS

Nominal thickness of shell cover heads shall be at least equal to the shell as shown in Table B-3.13.

B-3.3 SHELL EXPANSION AND CONTRACTION

Where fixed tubesheet construction is used and the temperature differential between tubes and shell, under the most adverse operating condition specified by the purchaser, including startup, shutdown, and upset conditions, will result in overloading either shell or tubes, suitable provision shall be made for this expansion or contraction.

B-3.31 SHELL AND TUBE LONGITUDINAL STRESSES

Shell and tube stresses, which depend upon the effective pressures determined by paragraphs B-7.151 through B-7.155, shall be calculated by the following paragraphs. A condition of overstress shall be presumed to exist when either shell or tube stress so calculated exceeds the allowable Code tensile stress for the material at design temperature.

B-3 SHELLS AND SHELL COVERS—(Continued)

B-3.311 SHELL LONGITUDINAL STRESS

The effective longitudinal shell stress is given by:

$$S_s = \frac{(D_o - t_s)P_s^*}{4t_s}$$

where

$$\left.\begin{aligned} P_s^* &= (P_i - P_d)/2 \\ \text{or } P_s^* &= -P_d/2 \\ \text{or } P_s^* &= P_i/2 \end{aligned}\right\} \text{ whichever has the greatest absolute value}$$

$$P_i = (P_t - P_t' + P_s')$$

Other symbols are as defined in paragraphs B-7.151, B-7.153, and B-7.154 with $J = 1$, using actual shell and tubesheet thicknesses and retaining algebraic signs.

B-3.312 TUBE LONGITUDINAL STRESS

The maximum effective longitudinal tube stress is given by:

$$S_t = \frac{F_q P_t^* G^2}{4Nt_t(d_o - t_t)}$$

where

$$\left.\begin{aligned} P_t^* &= (P_2 + P_d)/2 \\ \text{or } P_t^* &= -(P_3 - P_d)/2 \\ \dagger \text{ or } P_t^* &= [(P_2 - P_3) + P_d]/2 \end{aligned}\right\} \text{ whichever has the greatest absolute value}$$

$$P_2 = (P_t' - \frac{f_t}{F_q} P_t)$$

$$P_3 = (P_s' - \frac{f_s}{F_q} P_s)$$

Other symbols are as defined in paragraphs B-7.151, B-7.153, B-7.154, and B-7.155 with $J = 1$, using actual shell and tubesheet thicknesses and retaining algebraic signs.

† When differential pressure controls (Par. B-7.155), this formula only applies.

B-3.32 TUBE JOINT AND BUCKLING LOADS

A condition of overload shall be presumed to exist even though the maximum stress levels determined in paragraph B-3.31 are acceptable, if the tubes are unstable as columns under maximum compressive load or if, regardless of load direction, the tube joint shear load holding capability is exceeded. For this purpose the maximum tube load is given by:

$$W_t = \frac{\pi}{2N} F_q G^2 P_t^*$$

where, for tube joint loads, P_t^* is the maximum absolute value defined by paragraph B-3.312 and, for tube buckling loads, is the greatest negative value so defined. Other symbols are as defined in paragraphs B-7.151, B-7.153, and B-7.154 with $J = 1$.

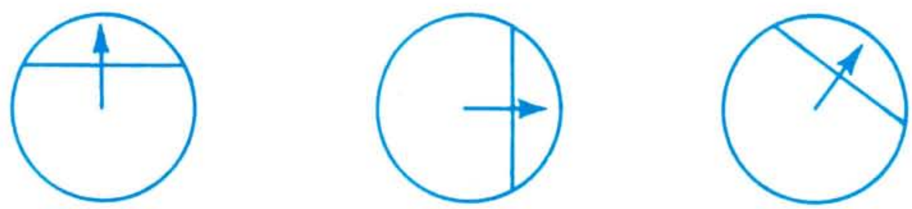
B-4 BAFFLES AND SUPPORT PLATES

B-4.1 TYPE OF TRANSVERSE BAFFLES

The segmental type of baffle or tube support plate is standard. Double segmental type baffles are permissible. Baffle cut is defined as the segment opening height expressed as a percentage of the shell inside diameter. Baffles shall be cut near the centerline of a row of tubes, of a pass lane, or of a tube lane when square pattern is used, or outside the tube pattern. Baffles shall have a finish of 250 RMS or better on the outside diameter and baffle cut edge. Standard baffle cut is illustrated in Figure B-4.1.

FIGURE B-4.1

BAFFLE CUT



B-4.2 TUBE HOLES

Where the maximum unsupported tube length is 36 inches or less, standard tube holes are drilled $\frac{1}{32}$" over the O.D. of the tubes. For unsupported tube lengths greater than 36 inches, standard tube holes are drilled $\frac{1}{64}$" over the O.D. of the tubes. For pulsating conditions tube holes may be drilled smaller than standard. Any burrs shall be removed and the tube holes given a workmanlike finish.

B-4.3 TRANSVERSE BAFFLE AND SUPPORT CLEARANCE

The transverse baffle and support plate clearance shall be such that the difference between the shell design inside diameter and the outside diameter of the baffle shall not exceed that indicated in Table B-4.3. However, where such clearance has no significant effect on shell side heat transfer coefficient or mean temperature difference, these maximum clearances may be increased to twice the tabulated values.

TABLE B-4.3

STANDARD CROSS BAFFLE AND SUPPORT PLATE CLEARANCES

Nominal Shell Inside Diameter	Design I.D. of Shell Minus Baffle O.D.
6" - 13" Inc.	0.100"
14" - 17" Inc.	0.125"
18" - 23" Inc.	0.150"
24" - 39" Inc.	0.175"
40" - 54" Inc.	0.225"
55" and over	0.300"

The design inside diameter of a pipe shell is defined as the nominal outside diameter of the pipe, minus twice the nominal wall thickness. The design inside diameter of a plate shell is the specified inside diameter.

B-4 BAFFLES AND SUPPORT PLATES—(Continued)

B-4.4 THICKNESS OF BAFFLES AND SUPPORT PLATES

B-4.41 TRANSVERSE BAFFLES AND SUPPORT PLATES

Table B-4.41 shows the minimum thickness of transverse baffles and support plates applying to all materials for various shell diameters and plate spacings.

TABLE B-4.41

BAFFLE OR SUPPORT PLATE THICKNESS

Nominal Shell I.D.	Plate Thickness—Inches					
	Distance between adjacent segmental plates or ½ distance between full supports					
	6" and Under	Over 6" to 12" Inc.	Over 12" to 18" Inc.	Over 18" to 24" Inc.	Over 24" to 30" Inc.	Over 30"
6" - 14" Inc.	1/8	1/8	3/16	1/4	3/8	3/8
15" - 28" Inc.	1/8	3/16	1/4	3/8	3/8	1/2
29" - 38" Inc.	3/16	1/4	5/16	3/8	1/2	5/8
39" and over	—	1/4	3/8	1/2	5/8	5/8

B-4.42 LONGITUDINAL BAFFLES

Longitudinal carbon steel baffles shall have a minimum total metal thickness of ¼". Longitudinal alloy baffles shall have a minimum total metal thickness of ⅛".

B-4.43 SPECIAL PRECAUTIONS

Special consideration must be given to baffles and support plates subjected to pulsations, to baffles and support plates engaging finned tubes, and to longitudinal baffles subjected to large differential pressures due to high shell side fluid pressure drop.

B-4.5 SPACING OF BAFFLES AND SUPPORT PLATES

B-4.51 MINIMUM SPACING

Segmental baffles shall not be spaced closer than ⅕ of the shell I.D., or 2 inches, whichever is greater.

B-4.52 MAXIMUM SPACING

Tube support plates shall be so spaced that the unsupported tube length does not exceed the value indicated in Table B-4.52 for the tube material used.

B-4 BAFFLES AND SUPPORT PLATES—(Continued)

TABLE B-4.52

MAXIMUM UNSUPPORTED STRAIGHT TUBE LENGTH

Tube O.D. Inches	Maximum Unsupported Span—Inches Tube Materials and Temperature Limits (°F) Carbon & High Alloy Steel (750) Low Alloy Steel (850) Nickel-Copper (600) Nickel (850) Nickel-Chromium-Iron (1000)	Aluminum & Aluminum Alloys Copper & Copper Alloys - at Code Maximum Allowable Temperature
5/8	52	45
3/4	60	52
1	74	64
1 1/4	88	76
1 1/2	100	87
2	125	110

Notes: Above the metal temperature limits shown, maximum spans shall be reduced in direct proportion to the fourth root of the ratio of elastic modulus at temperature to elastic modulus at tabulated limit temperature. In the case of circumferentially finned tubes, the tube O.D. shall be the diameter at the root of the fins and the corresponding tabulated or interpolated span shall be reduced in direct proportion to the fourth root of the ratio of the weight per unit length of the tube, if stripped of fins to that of the actual finned tube.

B-4.53 BAFFLE SPACING

Baffles normally shall be spaced uniformly, spanning the effective tube length. When this is not possible, the baffles nearest the ends of the shell, and/or tubesheets, shall be located as close as practical to the shell nozzles. The remaining baffles normally shall be spaced uniformly.

B-4.54 U-TUBE REAR SUPPORT

The support plates or baffles adjacent to the bends in U-tube exchangers shall be so located that, for any individual bend, the sum of the bend diameter plus the straight lengths measured along both legs from supports to bend tangents does not exceed the maximum unsupported span determined from paragraph B-4.52. Where bundle diameter prevents compliance, special provisions in addition to the above shall be made for support of the U-bends.

B-4.55 SPECIAL CASES

When pulsating conditions are specified, unsupported spans shall be as short as pressure drop restrictions permit. If the span under these circumstances approaches the maximum permitted by paragraph B-4.52, consideration should be given to alternative flow arrangements which would permit shorter spans under the same pressure drop restrictions.

B-4.56 TUBE BUNDLE VIBRATION

Flow induced or other damaging tube bundle vibrations may be encountered because of the infinite combinations of geometries related to unsupported tube span, tube arrangement, materials, size, and flow rates used in heat exchanger design. Existing quantitative data are inadequate to ensure that designs will be vibration free.

B-4 BAFFLES AND SUPPORT PLATES—(Continued)

B-4.6 IMPINGEMENT BAFFLES

B-4.61 SHELL SIDE

B-4.611 IMPINGEMENT PROTECTION REQUIREMENTS

An impingement plate, or other means to protect the tube bundle against impinging fluids, shall be provided when entrance line values of ρV^2 exceed the following: noncorrosive, nonabrasive, single phase fluids, 1500; all other liquids, including a liquid at its boiling point, 500. For all other gases and vapors, including all nominally saturated vapors, and for liquid vapor mixtures, impingement protection is required. V is the linear velocity of the fluid in feet per second and ρ is its density in pounds per cubic foot.

B-4.612 BUNDLE ENTRANCE AND EXIT AREAS

In no case shall the total bundle entrance or exit area produce a value of ρV^2 in excess of 4000, where V is the linear velocity of the fluid in feet per second, and ρ is its density in pounds per cubic foot. For purposes of calculating the total bundle entrance or exit area, the actual flow area into or out of the bundle between the tubes, based on the projected cross sectional flow area of the nozzle or dome and/or the actual unrestricted radial flow area from under the nozzle or dome, measured between the tube bundle diameter and the shell inside diameter may be considered. In the case of exchangers where vaporization occurs, special attention shall be given to provision for ample exit area.

B-4.62 TUBE SIDE

When it is necessary to use an axial inlet nozzle, or when liquid velocity in the tubes exceeds 10 feet per second, consideration shall be given to the need for special devices to prevent fluid maldistribution or erosion of the tube ends.

B-4.7 TIE RODS AND SPACERS

Tie rods and spacers, or other equivalent means of tying the baffle system together, shall be provided to retain all transverse baffles and tube support plates securely in position. Tie rods and spacers should be of a material similar to that of the baffles.

B-4.71 NUMBER AND SIZE OF TIE RODS

Table B-4.71 shows suggested tie rod count and diameter for various sizes of heat exchangers. Other combinations of tie rod number and diameter with equivalent metal area are permissible; however, no fewer than four tie rods, and no diameter less than ⅜" shall be used above 15" shell diameter.

TABLE B-4.71

TIE ROD STANDARDS

Nominal Shell Diameter	Tie Rod Diameter	Minimum Number of Tie Rods
6" - 15" Inc.	¼"	4
16" - 27" Inc.	⅜"	6
28" - 33" Inc.	½"	6
34" - 48" Inc.	½"	8
49" and over	½"	10

B-4.8 SEALING DEVICES

Suitable means, in addition to the baffles, shall be installed when necessary to prevent excessive fluid by-passing around or through the tube bundle. Sealing devices may be seal strips, tie rods with spacers, dummy tubes, or combinations of these.

B-5 FLOATING HEADS

B-5.1 INTERNAL FLOATING HEADS (Types S and T)

B-5.11 MINIMUM INSIDE DEPTH OF FLOATING HEAD COVERS

For multipass floating head covers the inside depth shall be such that the minimum crossover area for flow between successive tube passes is at least equal to the flow area through the tubes of one pass. For single pass floating head covers the depth at nozzle centerline shall be a minimum of one-third the inside diameter of the nozzle.

B-5.12 POSTWELD HEAT TREATMENT

Fabricated floating head covers shall be postweld heat treated in accordance with Code requirements, or as specified.

B-5.13 FLOATING HEAD BACKING DEVICES

The material of construction for split rings or other internal floating head backing devices shall be equivalent in corrosion resistance to the material used for the shell interior. They shall be furnished without any allowance for corrosion.

B-5.131 INTERNAL BOLTING

The materials of construction for internal bolting for floating heads shall be suitable for the mechanical design and similar in corrosion resistance to the materials used for the shell interior.

B-5.14 TUBE BUNDLE SUPPORTS

A partial support plate, or other suitable means, shall be provided to support the floating head end of the tube bundle. If a plate is used, the thickness shall equal or exceed the support plate thickness specified in Table B-4.41 for spacings over 30".

B-5.15 FLOATING HEAD NOZZLES

The floating head nozzle and packing box for a single pass exchanger shall comply with the requirements of paragraphs B-5.21, B-5.22, and B-5.23.

B-5.16 PASS PARTITION PLATES

The nominal thickness of floating head pass partitions, including corrosion allowance, shall be identical to those shown in paragraph B-8.131 for channels and bonnets.

B-5.2 OUTSIDE PACKED FLOATING HEADS (Type P)

B-5.21 PACKED FLOATING HEADS

The cylindrical surface of packed floating head tubesheets and skirts, where in contact with packing (including allowance for expansion), shall be given a fine machine finish equivalent to 63 RMS (or 70 AA).

B-5 FLOATING HEADS—(Continued)

B-5.22 PACKING BOXES

A machine finish shall be used on the shell or packing box where the floating tubesheet or nozzle passes through. If braided asbestos packing is used, three rings of packing shall be used for 150 psi working pressure and four rings shall be used for 300 psi working pressure. For pressures less than 150 psi, temperatures below 300°F, and nonhazardous service, fewer rings of packing may be used. Figure B-5.22 and Table B-5.22 show typical details and dimensions of packing boxes.

FIGURE B-5.22

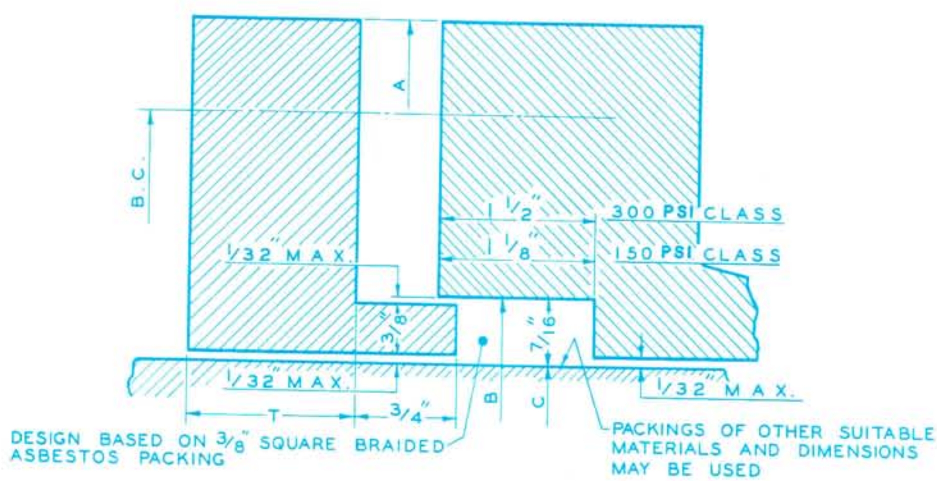


TABLE B-5.22

TYPICAL DIMENSIONS FOR PACKED FLOATING HEADS
150 PSI AND 300 PSI CLASS 600°F MAX. TEMP.
(All dimensions in inches)

Size	A	B	C	T	Bolts		B.C.
					No.	Size	
6	10½	6⅞	6	1	4	⅝	9
8	12½	8⅞	8	1	4	⅝	11
10	14⅝	10⅞	10	1	6	⅝	13⅛
12	16⅝	12⅞	12	1	6	⅝	15⅛
13	17⅞	13⅞	13	1	6	⅝	16⅜
15	19⅞	15⅞	15	1¼	8	⅝	18⅜
17	22	17⅞	17	1¼	8	⅝	20½
19	24	19⅞	19	1¼	10	⅝	22½
21	26⅛	21⅞	21	1⅜	10	⅝	24⅝
23	28⅛	23⅞	23	1⅜	12	⅝	26⅝

B-5 FLOATING HEADS—(Continued)

B-5.23 PACKING MATERIAL

Packing material shall be compatible with the shell fluid.

B-5.24 FLOATING TUBESHEET SKIRT

The floating tubesheet skirt normally shall extend outward. When the skirt must extend inward, then a suitable method shall be used to prevent stagnant areas between the shell side nozzle and the tubesheet.

B-5.25 PASS PARTITION PLATES

The nominal thickness of floating head pass partitions, including corrosion allowance, shall be identical to those shown in paragraph B-8.131 for channels and bonnets.

B-5.26 SAFETY STOP

A safety stop shall be used on exchangers which have less than 50 tubes when the shell side fluid is steam at any pressure, or gas at temperatures over 130°F, or pressures over 75 psig.

B-5.3 PACKED LANTERN RING FLOATING HEAD (Type W)

The packed lantern ring type floating head shall be used only for water, steam, air, lubricating oil, or similar services. Design temperature shall not exceed 375°F. Design pressure shall not exceed 300 psi for exchangers up to 24" in diameter, nor 150 psi for exchangers from 24" to 42" in diameter.

B-6 GASKETS

B-6.1 TYPE OF GASKETS

Gaskets shall be made in one piece. This shall not exclude gaskets made integral by welding.

B-6.2 GASKET MATERIALS

For design pressures of 300 psi and lower, asbestos composition gaskets may be used for external joints, unless temperature or corrosive nature of contained fluid indicates otherwise. Metal jacketed or filled gaskets or solid metal gaskets shall be used for all joints for design pressures greater than 300 psi, and for internal floating head joints. Other gasket materials may be specified to meet special service conditions and flange design. When two gasketed joints are compressed by the same bolting, gasket materials and areas shall be selected so that both gaskets seal, but neither gasket is crushed at the required bolt load.

B-6.3 PERIPHERAL GASKETS

The minimum width of peripheral ring gaskets for external joints shall be ⅜" for shell sizes through 23" nominal diameter and ½" for all larger shell sizes. Full face gaskets shall be used for all cast iron flanges.

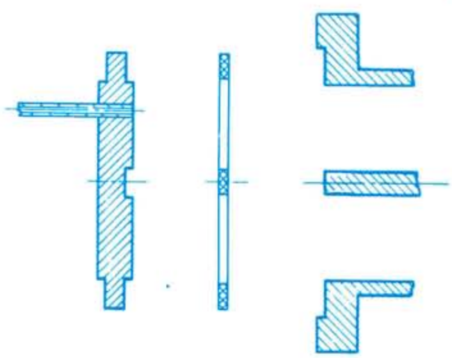
B-6.4 PASS PARTITION GASKETS

The width of gasket web for pass partitions of channels, bonnets, and floating heads shall be not less than ¼" for shell sizes through 23" nominal diameter and not less than ⅜" for all larger shell sizes.

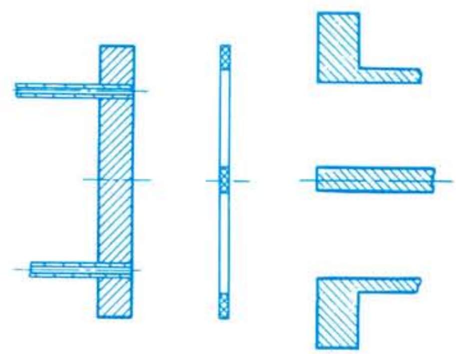
B-6.5 GASKET JOINT DETAILS

Figure B-6.5 shows typical details of both confined and unconfined gasketed joints.

FIGURE B-6.5



Confined Gasket



Unconfined Gasket

B-7 TUBESHEETS

B-7.1 TUBESHEET THICKNESS

B-7.11 EFFECTIVE TUBESHEET THICKNESS

The effective tubesheet thickness shall be the thickness measured at the bottom of the pass partition groove minus shell side corrosion allowance and corrosion allowance on the tube side in excess of the groove depth.

B-7.111 APPLIED TUBESHEET FACINGS

The thickness of applied facing material shall not be included in the minimum or effective tubesheet thickness.

B-7.112 INTEGRALLY CLAD TUBESHEETS

The thickness of cladding material in integrally clad plates and cladding deposited by welding may be included in the effective tubesheet thickness except as limited by the Code.

B-7.12 REQUIRED EFFECTIVE TUBESHEET THICKNESS

The required effective tubesheet thickness for any type of heat exchanger shall be determined from the following paragraphs, for both tube side and shell side conditions, using whichever thickness is greatest.

B-7.121 MINIMUM TUBESHEET THICKNESS

The total thickness of any tubesheet, minus corrosion allowance, shall not be less than three-fourths of the tube outside diameter for ⅝", ¾" and 1" O.D. tubes, ⅞" for 1¼" O.D., 1" for 1½" O.D., or 1¼" for 2" O.D.; but in no case shall a total thickness, including corrosion allowance, be less than ¾".

B-7.122 TUBESHEET FORMULA—BENDING

$$T = \frac{FG}{2}\sqrt{\frac{P}{S}}$$

where T = Effective thickness of tubesheet, inches.

S = Code allowable working stress, in tension, for tubesheet material at design temperature used, psi.

P = Hydrostatic design pressure, psi, shell side or tube side, except as modified by paragraphs B-7.153, B-7.154, B-7.155, and B-7.161.

F and G are defined in subsequent paragraphs.

B-7 TUBESHEETS—(Continued)

B-7.123 TUBESHEET FORMULA—SHEAR

$$T = \frac{0.31\, D_L}{\left(1 - \frac{d_o}{p}\right)}\left(\frac{P}{S}\right)$$

where T = Effective thickness of tubesheet, inches.

D_L = 4 A/C = Equivalent diameter of tube center limit perimeter, inches.

C = Perimeter of tube layout measured stepwise in increments of one tube pitch from center-to-center of the outermost tubes, inches. Figure B-7.123 shows the application to typical triangular and square tube pitch layouts.

A = Total area enclosed by perimeter C, square inches.

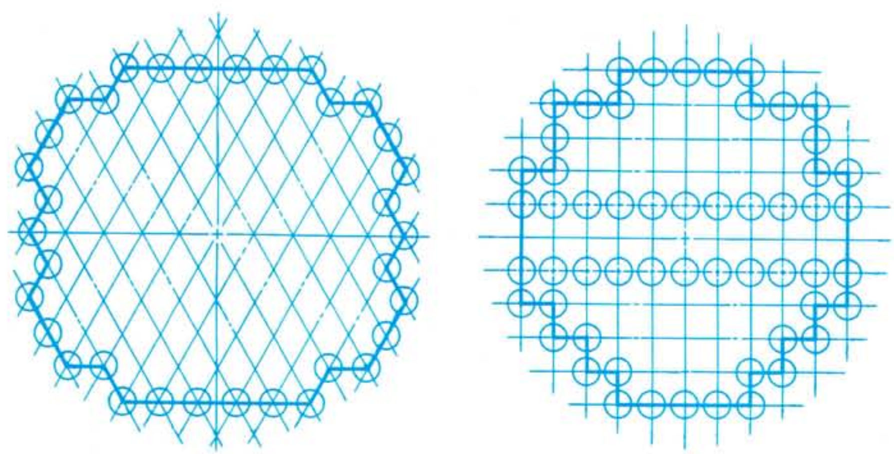
d_o = Outside tube diameter, inches.

p = Tube spacing, center-to-center, inches.

P = Hydrostatic design pressure, psi, shell side or tube side, except as modified by paragraphs B-7.153, B-7.154, and B-7.161.

S = Code allowable working stress, in tension, for tubesheet material at design temperature used, psi.

FIGURE B-7.123



"C" (PERIMETER) IS THE LENGTH OF HEAVY LINE.

B-7.13 GASKETED STATIONARY TUBESHEET EXCHANGERS

This paragraph shall apply whenever a gasketed joint is used between the stationary tubesheet and the adjoining pressure part under consideration, even though the tubesheet may be integral with the other adjoining pressure part, except as limited by paragraph B-7.19.

B-7.131 STATIONARY AND FLOATING TUBESHEET CONSTANTS

G = Mean diameter of gasket at stationary tubesheet, inches.

F = 1.0

B-7 TUBESHEETS—(Continued)

B-7.132 U-TUBE STATIONARY TUBESHEET CONSTANTS

G = Mean diameter of gasket at stationary tubesheet, inches.

F = 1.25

B-7.14 INTEGRAL STATIONARY TUBESHEET EXCHANGERS

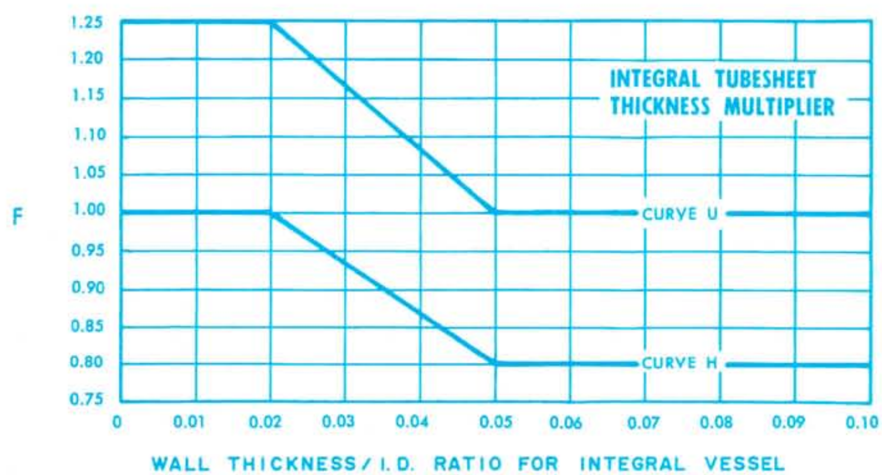
This paragraph shall apply whenever the stationary tubesheet is integral with the adjoining pressure part under consideration, even though the joint with the other adjoining pressure part may be gasketed, except as limited by paragraph B-7.19. With fixed tubesheet exchangers, both tubesheets shall be considered stationary.

B-7.141 STATIONARY TUBESHEET CONSTANTS

G = Inside diameter of integral pressure part, inches.

F = Value given by curve H of Figure B-7.141 for floating head and fixed tubesheet exchangers, or by curve U for U-tube exchangers.

FIGURE B-7.141



B-7.142 FLOATING TUBESHEET CONSTANTS

B-7.1421 GASKETED FLOATING TUBESHEET WITHOUT EDGE BOLTING

G = Same as stationary tubesheet.

F = 1.0

B-7.1422 INTEGRAL FLOATING TUBESHEET

G = Same as stationary tubesheet.

F = Value given by curve H of Figure B-7.141.

B-7 TUBESHEETS—(Continued)

B-7.15 FIXED TUBESHEETS

This paragraph shall apply to exchangers having tubesheets fixed to both ends of the shell, with or without a shell expansion joint, except as limited by paragraph B-7.19. Both tubesheets in a fixed tubesheet exchanger shall have the same thickness. When fixed tubesheet extensions are gasketed and bolted, the extended portion shall be in accordance with Code design practice. The extension and that portion of the tubesheet inside the shell may differ in thickness. Tubesheet thicknesses calculated by these rules are adequate. It is possible, however, that shells, tubes, or tube-to-tubesheet joints may be overstressed unless proper provision is made to accommodate differential thermal expansion. Effective design pressures for use in paragraphs B-3.3, B-7.122, and B-7.123 shall be determined as follows:

B-7.151 EQUIVALENT DIFFERENTIAL EXPANSION PRESSURE

The pressure due to differential thermal expansion, in psi, is given by:

$$P_d = \frac{4\,J\,E_s\,t_s\,(\alpha_s\,\Theta_s - \alpha_t\,\Theta_t)}{(D_o - 3t_s)\,(1 + JKF_q)}$$

(Algebraic sign must be retained for use in paragraphs B-3.311, B-3.312, B-7.153, B-7.154, and B-7.155.)

where $J = \begin{cases} 1.0 \text{ for shells without expansion joints} \\ 0 \text{ for shells with expansion joints, except as limited by paragraph B-7.19.} \end{cases}$

$$K = \frac{E_s\,t_s\,(D_o - t_s)}{E_t\,t_t\,N\,(d_o - t_t)}$$

$$F_q = 0.25 + (F - 0.6)\left[\frac{300\,t_s\,E_s}{K\,L\,E}\left(\frac{G}{T}\right)^3\right]^{1/4}$$

(Use calculated value of F_q or 1.0, whichever is greater.)

F & G are as defined in paragraph B-7.141.

T = Tubesheet thickness used, but not less than 98½% of the greater of the values defined by Par. B-7.122 or B-7.123. (Value assumed in evaluating F_q must match the final computed value within a tolerance of ± 1.5 percent.) See note.

L = Tube length between inner tubesheet faces, inches.

Θ = Metal temperature less 70°F.

E_s = Elastic modulus of shell material at metal temperature, psi.

E_t = Elastic modulus of tube material at metal temperature, psi.

E = Elastic modulus of tubesheet material at metal temperature, psi.

α = Thermal expansion coefficient, in. per in./°F.

N = Number of tubes in shell.

D_o = Outside diameter of shell, inches.

d_o = Outside diameter of tubes, inches.

t = Wall thickness, inches.

Subscripts "s" and "t" refer to shell and tubes respectively.

Note: Tubesheets thicker than computed are permissible provided neither shell nor tubes are overloaded. Refer paragraph B-3.3.

B-7 TUBESHEETS—(Continued)

B-7.152 EQUIVALENT BOLTING PRESSURE

When fixed tubesheets are extended for bolting to heads with ring type gaskets, the equivalent tube side and shell side pressures are given by:

$$P_{Bt} = \frac{6.2}{F^2}\,\frac{M_1}{G^3}$$

$$P_{Bs} = \frac{6.2}{F^2}\,\frac{M_2}{G^3}$$

where

F = Value given by Curve H of Fig. B-7.141.

G = Inside diameter of shell, inches.

M_1 = Total moment acting upon the extension under operating conditions, defined by the Code as M_o under flange design, inch-pounds.

M_2 = Total moment acting upon the extension under bolting-up conditions, defined by the Code as M_o under flange design, inch-pounds.

P_{Bt} = Equivalent bolting pressure when tube pressure is acting, pounds per square inch.

P_{Bs} = Equivalent bolting pressure when tube pressure is not acting, pounds per square inch.

B-7 TUBESHEETS—(Continued)

B-7.153 EFFECTIVE SHELL SIDE DESIGN PRESSURE

The effective shell side design pressure is given by:

$$P = \frac{(P_s' - P_d)}{2}$$

$$\text{or } P = P_s'$$

$$\text{or } P = P_{Bs}$$

$$\text{or } P = \frac{(P_s' - P_d - P_{Bs})}{2}$$

$$\text{or } P = \frac{(P_{Bs} + P_d)}{2}$$

$$\text{or } P = (P_s' - P_{Bs})$$

whichever has the greatest absolute value.

where

$$P_s' = P_s \left[\frac{0.4J \left[1.5 + K(1.5 + f_s) \right] - \left[\left(\frac{1-J}{2} \right) \left(\frac{D_J^2}{G^2} - 1 \right) \right]}{(1 + JKF_q)} \right]$$

P_s = Shell side hydrostatic design pressure, psi.

$$f_s = 1 - N\left(\frac{d_o}{G}\right)^2$$

G = Inside diameter of shell, inches.

D_J = Expansion joint bellows inside diameter, inches.

($D_J = G$ when no expansion joint is present.)

Other symbols are as defined under Paragraphs B-7.151 and B-7.152.

Notes:

1. Algebraic sign must be retained for use in paragraphs B-3.311, B-3.312, B-7.154, and B-7.155.
2. When $J = 0$, formulas containing P_d cannot control.
3. Formulas containing the term P_{Bs} are not applicable for use in paragraph B-7.123.
4. All pressures in paragraphs B-7.153, B-7.154, and B-7.155 are gauge pressures. For vacuum conditions on either shell or tube side, the pressures should be represented by the appropriate negative values.

B-7 TUBESHEETS—(Continued)

B-7.154 EFFECTIVE TUBE SIDE DESIGN PRESSURE

The effective tube side design pressure is given by:

$$P = \frac{(P_t' + P_{Bt} + P_d)}{2} \quad \text{or} \quad P = (P_t' + P_{Bt})$$

whichever has the greater absolute value, when P_s' is positive.

$$P = \frac{(P_t' - P_s' + P_{Bt} + P_d)}{2} \quad \text{or} \quad P = (P_t' - P_s' + P_{Bt})$$

whichever has the greater absolute value, when P_s' is negative.

where

$$P_t' = P_t \left[\frac{1 + 0.4JK\,(1.5 + f_t)}{(1 + JKF_q)} \right]$$

P_t = Tube side hydrostatic design pressure, psi.

$$f_t = 1 - N \left[\frac{(d_o - 2t_t)}{G} \right]^2$$

G = Inside diameter of shell (tubesheet bolted to stationary head) or inside diameter of stationary head when integral with tubesheet, inches.

Other symbols are as defined under Par. B-7.151, B-7.152, and B-7.153.

Notes:
1. Algebraic sign must be retained for use in paragraphs B-3.311, B-3.312, and B-7.155.
2. When J = O
   (a) Formulas containing P_d cannot control.
   (b) $P = P_t + \frac{P_s}{2}\left[\left(\frac{D_J}{G}\right)^2 - 1\right] + P_{Bt}$
3. Delete the term P_{Bt} in above formulas for use in paragraph B-7.123.

B-7 TUBESHEETS—(Continued)

B-7.155 EFFECTIVE DIFFERENTIAL DESIGN PRESSURE

Under certain circumstances the Code and other regulatory bodies permit design on the basis of simultaneous action of both shell and tube side pressures. The effective differential design pressure for fixed tubesheets under such circumstances is given by:

$$P = (P_t' - P_s' + P_{Bt})$$

$$\text{or } P = \frac{(P_t' - P_s' + P_{Bt} + P_d)}{2}$$

$$\text{or } P = P_{Bs}$$

$$\text{or } P = \frac{(P_{Bs} + P_d)}{2}$$

$$\text{or } P = (P_t' - P_s')$$

$$\text{or } P = \frac{(P_t' - P_s' + P_d)}{2}$$

$$\text{or } P = P_{Bt}$$

whichever has the greatest absolute value

where

P_d, P_{Bs}, P_{Bt}, P_s', and P_t' are as defined in paragraphs B-7.151, B-7.152, B-7.153, and B-7.154 respectively.

Notes: 1. It is not permissible to enter the equation P_s' in paragraph B-7.153 with $(P_s - P_t)$ in place of P_s nor the equation P_t' in paragraph B-7.154 with $(P_t - P_s)$ in place of P_t, to determine an effective shell side or tube side design pressure for fixed tubesheets.

2. When J = O, formulas with the term P_d cannot control.

3. Formulas containing the terms P_{Bt} or P_{Bs} are not applicable for use in paragraph B-7.123.

B-7.16 PACKED FLOATING TUBESHEET TYPE EXCHANGERS

B-7.161 OUTSIDE PACKED FLOATING HEAD (Type P)

The thickness of tubesheets in exchangers whose floating heads are packed at the outside diameter of the tubesheet or a cylindrical extension thereof, shall be calculated as for gasketed stationary tubesheet exchangers, using terms as defined below and the formula shown in paragraph B-7.122 or B-7.123.

$$P = P_t + P_s \left(\frac{D^2 - D_L^2}{D_i^2} \right)$$

where

P = Hydrostatic design pressure, psi.

P_t = Hydrostatic design pressure, psi, tube side.

P_s = Hydrostatic design pressure, psi, shell side.

D = Outside diameter of floating tubesheet, inches.

D_i = Inside diameter of floating tubesheet skirt, inches.

D_L = Equivalent diameter of tube center limit perimeter, defined in paragraph B-7.123.

F and G are as defined in previous paragraphs considering applicable edge configurations.

B-7 TUBESHEETS—(Continued)

B-7.162 PACKED FLOATING TUBESHEET WITH LANTERN RING (Type W)

The thickness of tubesheets in exchangers whose floating tubesheets are packed at the outside diameter with return bonnet or channel bolted to the shell flange, shall be calculated as for gasketed stationary tubesheet exchangers, using terms as defined below and the formula shown in paragraph B-7.122.

P = Hydrostatic design pressure, psi, tube side.

G = Mean diameter of gasket at stationary tube sheet, inches.

F = 1.0

B-7.163 FLOATING HEAD (Type S) WITH PACKED NOZZLE

The thickness of tubesheets in exchangers with packed floating head nozzles shall be calculated as for gasketed stationary tubesheet exchangers, using terms as defined below and the formula shown in paragraph B-7.122 or B-7.123.

P = Hydrostatic design pressure, psi, shell side or tube side.

F and G are as defined in paragraph B-7.131 or B-7.142, whichever is applicable.

B-7.17 DIVIDED FLOATING HEADS

For divided floating tubesheets, regardless of the type of stationary tubesheet,

G = 1.41 s

F = 1.0

where s = Length of shortest span measured over center lines of gasket, inches.

B-7.18 DOUBLE TUBESHEETS

Double tubesheets may be used where operating conditions indicate their desirability. The diversity of construction types makes it impractical to specify design rules which are universally applicable. It may be stated that the mutual support contributed by each component tubesheet through the tubes connecting them is a generally recognized design principle.

B-7.181 MINIMUM THICKNESS

Neither component of a double tubesheet shall have a thickness less than required by paragraph B-7.121.

B-7.182 VENTS AND DRAINS

Double tubesheets of the edge welded type shall be provided with vent and drain connections at the high and low points of the enclosed space.

B-7.183 SPECIAL PRECAUTIONS

When double tubesheets are used, special attention shall be given to the ability of the tubes to withstand, without damage, the mechanical and thermal loads imposed on them by this construction.

B-7.19 SPECIAL CASES

Special consideration must be given to tubesheets with abnormal conditions of support or loading; e.g., fixed tubesheets in exchangers with expansion joints which require considerable axial loads to produce required movements, such as the flued and flanged type; tubesheets (except fixed tubesheets) with extensions used as flanges; tubesheets with portions not adequately stayed by tubes; e.g., exchangers with large differences in shell and head inside diameters; and exchangers with hydrostatic design pressures greater than 3000 psig. Special consideration may also be given to conditions tending to reduce tubesheet thickness requirements.

B-7 TUBESHEETS—(Continued)

B-7.2 TUBE HOLES IN TUBESHEETS

B-7.21 DIAMETERS AND TOLERANCES

Tube holes in tubesheets shall be finished to the sizes and tolerances shown in Table B-7.21, column (a). For austenitic steel tubes, when used for corrosion resistance, a closer fit between tube O.D. and tube hole I.D. as shown in column (b) may tend to minimize work hardening and attendant loss of corrosion resistance; these clearances will be provided when specified.

TABLE B-7.21

TUBE HOLE DIAMETERS AND TOLERANCES

Nominal Tube O.D. Inches	Nominal Tube Hole Diameter and Under Tolerance-Inches				Over Tolerance-Inches (96% of tube holes must meet value in column (c). Remainder may not exceed value in column (d).)	
	Standard Fit (a)		Special Close Fit (b)			
	Nominal Diameter	Under Tolerance	Nominal Diameter	Under Tolerance	(c)	(d)
5/8	0.635	0.004	0.633	0.002	0.002	0.010
3/4	0.760	0.004	0.758	0.002	0.002	0.010
1	1.012	0.004	1.010	0.002	0.002	0.010
1 1/4	1.264	0.006	1.261	0.003	0.003	0.010
1 1/2	1.518	0.007	1.514	0.003	0.003	0.010
2	2.022	0.007	2.018	0.003	0.003	0.010

B-7.22 TUBESHEET DRILLING TOLERANCES

Table B-7.22 gives permissible tube hole drilling tolerances, drill drift, and recommended maximum tube wall thicknesses.

TABLE B-7.22

TABLE OF TUBESHEET DRILLING TOLERANCES AND MAXIMUM RECOMMENDED TUBE GAGES

(All Dimensions in Inches)

Tube Dia. d_o	Tube Pitch p	$\frac{p}{d_o}$	$p-d_o$	Heaviest Recommended Tube Gage B.W.G.	Tube Hole Dia. Std. Fit	Nominal Ligament Width	Minimum Std. Ligaments (96% of ligaments must equal or exceed values tabulated below) — Tubesheet Thickness, Inches: 1	1 1/2	2	2 1/2	3	4	5	6	Minimum Permissible Ligament Width
5/8	25/32	1.25	5/32	15	0.635	0.146	.111	.108	.106	.103	.101	.095	.090	.085	.075
	13/16	1.30	3/16	14		0.178	.143	.140	.138	.135	.133	.127	.122	.117	.090
	7/8	1.40	1/4	14		0.240	.205	.202	.200	.197	.195	.189	.184	.179	.120
3/4	15/16	1.25	3/16	13	0.760	0.178	.144	.142	.139	.137	.135	.131	.127	.122	.090
	1	1.33	1/4	12		0.240	.206	.204	.201	.199	.197	.193	.189	.184	.120
	1-1/16	1.42	5/16	12		0.302	.268	.266	.263	.261	.259	.255	.251	.246	.150
	1-1/8	1.50	3/8	12		0.365	.331	.329	.326	.324	.322	.318	.314	.309	.185
1	1-1/4	1.25	1/4	10	1.012	0.238	.205	.203	.202	.200	.198	.195	.192	.189	.120
	1-5/16	1.31	5/16	9		0.300	.267	.265	.264	.262	.260	.257	.254	.251	.150
	1-3/8	1.38	3/8	9		0.363	.330	.328	.327	.325	.323	.320	.317	.314	.185
1-1/4	1-9/16	1.25	5/16	9	1.264	0.298	.265	.264	.263	.262	.260	.258	.255	.253	.150
1-1/2	1-7/8	1.25	3/8	8	1.518	0.357	.325	.324	.323	.322	.321	.318	.316	.314	.180
2	2-1/2	1.25	1/2	6	2.022	0.478	—	.446	.445	.444	.443	.442	.440	.438	.250

NOTES: The above table of minimum standard ligaments is based on a ligament tolerance not exceeding the sum of twice the drill drift tolerance plus 0.030".
Drill drift tolerance = 0.0016 × (thickness of tubesheet in tube diameters) inches.

B-7 TUBESHEETS—(Continued)

B-7.23 TUBE HOLE FINISH

The inside edges of tube holes in tubesheets shall be free of burrs to prevent cutting of the tubes. Internal surfaces shall be given a workmanlike finish.

B-7.24 TUBE HOLE GROOVING

All tubesheet holes for expanded joints shall be machined with at least two grooves, each approximately 1/8" wide by 1/64" deep. When integrally clad or applied tubesheet facings are used, all grooves shall be in the base material unless otherwise specified.

B-7.3 EXPANDED TUBE JOINTS

Expanded tube-to-tubesheet joints are standard.

B-7.31 LENGTH OF EXPANSION

Tubes shall be expanded into the tubesheet for a length no less than 2", or tubesheet thickness minus 1/8", whichever is smaller. In no case shall the expanded portion extend beyond the shell side face of the tubesheet. When specified, tubes may be expanded for the full thickness of the tubesheet.

B-7.32 CONTOUR OF EXPANDED TUBE

The expanding procedure shall be such as to provide substantially uniform expansion throughout the expanded portion of the tube, without sharp transition to the unexpanded portion.

B-7.33 TUBE PROJECTION

Tubes shall extend beyond the face of each tubesheet by 1/8" ± 1/16" except that tubes shall be flush with the top tubesheet in vertical exchangers.

B-7.4 WELDED TUBE JOINTS

When both tubes and tubesheets, or tubesheet facing, are of suitable materials, the tube joints may be welded.

B-7.41 SEAL WELDED JOINTS

When welded tube joints are used for additional leak tightness only, and customary tube loads are carried by the expanded joint, the tube joints shall be subject to the rules of paragraphs B-7.2 through B-7.32.

B-7.42 STRENGTH WELDED JOINTS

When welded tube joints are used as a complete substitute for expanded joints, consideration may be given to modification of the requirements of paragraphs B-7.2 through B-7.33.

B-7.5 TUBESHEET PASS PARTITION GROOVES

For design pressures over 300 psi, tubesheets shall be provided with pass partition grooves approximately 3/16" deep, or other suitable means for retaining gaskets in place.

B-7.6 TUBESHEET PULLING EYES

In exchangers with removable tube bundles having a nominal diameter exceeding 12" and/or a tube length exceeding 96", the stationary tubesheet shall be provided with two tapped holes in its face for pulling eyes. These holes shall be protected in service by plugs. Provision for pulling means may have to be modified or waived for special constructions, such as clad tubesheets.

B-7.7 CLAD AND FACED TUBESHEETS

The nominal cladding thickness at the tube side face of a tubesheet shall not be less than 5/16" when tubes are rolled only, and 1/8" when tubes are welded to the tubesheet. The nominal cladding thickness on the shell side face shall not be less than 3/8". All surfaces exposed to the fluid, including gasket seating surfaces, shall have at least 1/8" nominal thickness of cladding.

B-8 CHANNELS, COVERS, AND BONNETS

B-8.1 CHANNELS AND BONNETS

B-8.11 MINIMUM THICKNESS OF CHANNELS AND BONNETS

Channel and bonnet thickness is determined by the Code design formulas, plus corrosion allowance, but in no case shall the nominal thickness of channels and bonnets be less than the minimum shell thicknesses shown in Table B-3.13. The nominal total thickness for clad or lined channels and bonnets shall be the same as for carbon steel plate channels.

B-8.12 MINIMUM INSIDE DEPTH

For multipass channels and bonnets the inside depth shall be such that the minimum cross-over area for flow between successive tube passes is at least equal to the flow area through the tubes of one pass. When an axial nozzle is used, the depth at the nozzle centerline shall be a minimum of one-third the inside diameter of the nozzle.

B-8.13 PASS PARTITION PLATES

B-8.131 MINIMUM THICKNESS

The nominal thickness of channels or bonnet pass partitions shall not be less than shown in Table B-8.131. Partition plates may be tapered to gasket width at the contact surface.

TABLE B-8.131

MINIMUM PASS PARTITION PLATE THICKNESS, INCLUDING CORROSION ALLOWANCE

Nominal Size Inches	Carbon Steel Inches	Alloy Material Inches
Less than 24	3/8	1/4
24 and over	1/2	3/8

B-8.132 SPECIAL PRECAUTIONS

Special consideration must be given to thickness requirements for internal partitions subjected to pulsating fluids or to large differential pressures under specified operating conditions, or to unusual start-up or maintenance conditions specified.

B-8.14 POSTWELD HEAT TREATMENT

Fabricated channels and bonnets shall be postweld heat treated in accordance with Code requirements, or as specified.

B-8 CHANNELS, COVERS, AND BONNETS —(Continued)

B-8.2 CHANNEL COVERS

B-8.21 EFFECTIVE CHANNEL COVER THICKNESS

The effective thickness of flat channel covers shall be the thickness measured at the bottom of the pass partition groove minus tube side corrosion allowance in excess of the groove depth. The required value shall be either that determined from the appropriate Code formula or from the following equation, whichever is greater:

$$T = \left[5.7P\left(\frac{G}{100}\right)^4 + 2\frac{h_G A_B}{\sqrt{d_B}}\left(\frac{G}{100}\right)\right]^{1/3}$$

where T = Effective channel cover thickness, inches.

P = Design pressure, psi.

G = Mean gasket diameter, inches.

d_B = Nominal bolt diameter, inches.

h_G = Radial distance between mean gasket diameter and bolt circle, inches.

A_B = Actual total cross-sectional area of bolts, square inches.

For gaskets having compression factors of 3.0 or less, the value of "T" obtained by this formula may be reduced by 20 per cent.

Notes:

1. For high alloy steels and nonferrous metals, and for carbon steel at temperatures other than 650°F, the value obtained from this formula shall be multiplied by $(25{,}000{,}000/E)^{1/3}$, where "E" is the elastic modulus of the cover material at the design temperature.
2. For single pass channels, or others in which there is no pass partition gasket seal against the channel cover, only the Code formula need be considered.

B-8.22 CHANNEL COVER PASS PARTITION GROOVES

For design pressures over 300 psi, channel covers shall be provided with approximately 3/16" deep grooves for pass partitions, or other suitable means for holding the gasket in place. In clad or applied facings, all surfaces exposed to fluid, including gasket seating surfaces, shall have at least 1/8" nominal thickness of cladding.

B-9 NOZZLES

B-9.1 NOZZLE CONSTRUCTION

Nozzle construction shall be in accordance with Code requirements. Shell nozzles shall not protrude beyond the inside contour of the shell. Channel nozzles may protrude inside the channel provided vent and drain connections are flush with the inside contour of the channel. All nozzles larger than 1" IPS shall be flanged. Flange dimensions and facing shall comply with USA Standard B16.5-1961.* Bolt holes shall straddle natural center lines. Screwed flanges are not permitted.

B-9.2 NOZZLE INSTALLATION

Radial nozzles shall be considered as standard. Other types of nozzles may be used when specified.

B-9.3 PIPE TAP CONNECTIONS

All pipe tap connections shall be a minimum of 3000 psi standard couplings or equivalent. Each connection shall be fitted with a bar stock plug of the same material as the connection, except that cast iron plugs shall not be used.

B-9.31 VENT AND DRAIN CONNECTIONS

All high and low points on shell and tube sides of an exchanger not otherwise vented or drained by nozzles shall be provided with ¾" connections for vent and drain.

B-9.32 PRESSURE GAGE CONNECTIONS

All flanged nozzles 2" size or larger shall be provided with one horizontal connection of ½" minimum size for a pressure gage unless special considerations require it to be omitted. See paragraph B-9.4.

B-9.33 THERMOMETER CONNECTIONS

All flanged nozzles 3" size or larger shall be provided with one ¾" horizontal connection for a thermometer unless special considerations require it to be omitted. See paragraph B-9.4.

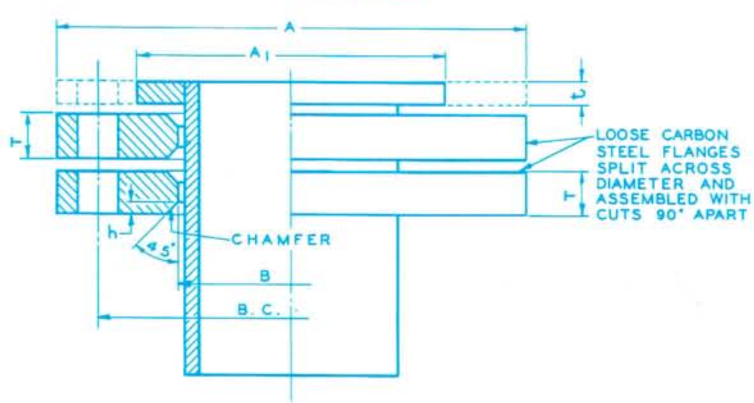
B-9.4 STACKED UNITS

Intermediate nozzles between units shall have flat or raised face flanges. Pressure gage and thermometer connections may be omitted in one of two mating connections of units connected in series.

B-9.5 SPLIT FLANGE DESIGN

Circumstances of fabrication, installation, or maintenance sometimes indicate undesirability of the normal integral or loose full ring nozzle flanges. Under these conditions, double split ring flanges may be used in accordance with the Code. Figure B-9.5 and Table B-9.5 give typical dimensions of such flanges.

FIGURE B-9.5



* The latest edition may be used when specified.

B-9 NOZZLES—(Continued)

TABLE B-9.5

DESIGN PRESSURE 150 PSI
CARBON STEEL SPLIT TYPE NOZZLE FLANGES
ALL DIMENSIONS ARE IN INCHES

Size Nozzle	A	A_1	t	B.C.	T	No. and Size of Bolts	B	h
2-1/2	7	4-1/8	1/4	5-1/2	7/8	4—5/8	3	5/16
3	7-1/2	5	1/4	6	7/8	4—5/8	3-5/8	3/8
4	9	6-3/16	1/4	7-1/2	15/16	8—5/8	4-5/8	7/16
6	11	8-1/2	5/16	9-1/2	1-1/16	8—3/4	6-3/4	1/2
8	13-1/2	10-5/8	3/8	11-3/4	1-1/8	8—3/4	8-3/4	1/2
10	16	12-3/4	3/8	14-1/4	1-3/8	12—7/8	10-7/8	1/2
12	19	15	3/8	17	1-1/2	12—7/8	12-7/8	1/2
14	21	16-1/4	3/8	18-3/4	1-3/4	12—1	14-1/8	1/2
16	23-1/2	18-1/2	3/8	21-1/4	1-7/8	16—1	16-1/8	1/2
18	25	21	3/8	22-3/4	1-13/16	16—1-1/8	18-1/8	1/2
20	27-1/2	23	3/8	25	2	20—1-1/8	20-1/8	1/2
24	32	27-1/4	3/8	29-1/2	2-1/4	20—1-1/4	24-1/8	1/2

Gaskets—Compressed Asbestos, 1/16" thick
Flange stress, 17,500 psi
Bolt Stress, 20,000 psi

B-10 END FLANGES AND BOLTING

Flanges and bolting for external joints shall be in accordance with Code design rules, subject to the limitations set forth in the following paragraphs.

B-10.1 MINIMUM BOLT SIZE

The minimum permissible bolt diameter shall be ⅝".

B-10.2 BOLT CIRCLE LAYOUT

B-10.21 MINIMUM RECOMMENDED BOLT SPACING

The minimum recommended spacing between bolt centers shall be as given by Table B-10.3.

B-10.22 MAXIMUM RECOMMENDED BOLT SPACING

The maximum recommended spacing between bolt centers shall be:

$$B_{max} = 2d_B + \frac{6t}{(m + 0.5)}$$

where

B = Bolt spacing, inches.
d_B = Nominal bolt diameter, inches.
t = Flange thickness, inches.
m = Gasket factor used in Code flange calculations.

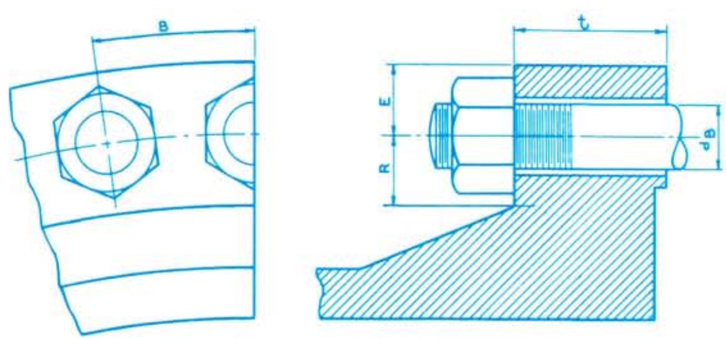
B-10.23 BOLT ORIENTATION

Bolt centers shall evenly straddle both natural centerlines of the exchanger. For horizontal units the natural centerlines shall be considered to be the horizontal and vertical centerlines of the exchanger. In special cases, the bolt count may be reduced from a multiple of four (as required by the foregoing) to a multiple of two.

B-10.3 MINIMUM RECOMMENDED WRENCH AND NUT CLEARANCES

Minimum recommended radial dimensions "R" and "E", as defined in Figure B-10.3, and minimum recommended bolt spacing B_{min} shall be as given in Table B-10.3.

FIGURE B-10.3



B-10 END FLANGES AND BOLTING —(Continued)

TABLE B-10.3

FLANGE BOLT CLEARANCES

(All Dimensions in Inches)

d_B	R	E	B_{min}
5/8	15/16	3/4	1-1/2
3/4	1-1/8	13/16	1-3/4
7/8	1-1/4	15/16	2-1/16
1	1-3/8	1-1/16	2-1/4
1-1/8	1-1/2	1-1/8	2-1/2
1-1/4	1-3/4	1-1/4	2-13/16
1-3/8	1-7/8	1-3/8	3-1/16
1-1/2	2	1-1/2	3-1/4
1-5/8	2-1/8	1-5/8	3-1/2
1-3/4	2-1/4	1-3/4	3-3/4
1-7/8	2-3/8	1-7/8	4
2	2-1/2	2	4-1/4

B-10.4 LOAD CONCENTRATION FACTOR

When the distance between bolt centerlines exceeds recommended B_{max}, the total flange moment determined by Code design methods shall be multiplied by a correction factor equal to $\sqrt{B/B_{max}}$ where symbols are defined in paragraph B-10.22.

B-10.5 BOLT TYPE

Except for special design considerations, flanges shall be through-bolted with stud bolts, threaded full length with a removable nut on each end. Stud bolt length shall be such that the nuts are fully engaged and project through the nuts approximately ⅛" on each end.

M-1 GENERAL

Materials should be specified by the purchaser. Materials listed are to be considered as the minimum qualities of their kinds and such specifications do not exclude the use of any Code approved material of an equivalent or superior quality for pressure parts.

M-2 TUBES

M-2.1 SEAMLESS

M-2.11 CARBON STEEL
ASME SA-179 cold drawn.
ASME SA-210, specify grade.

M-2.12 LOW ALLOY STEEL
ASME SA-209.
ASME SA-199, specify grade.

M-2.13 HIGH ALLOY STEEL
ASME SA-213, specify grade.
ASME SA-268, specify grade.

M-2.14 NICKEL AND NICKEL ALLOY
ASME SB-163, specify alloy and temper.

M-2.15 ALUMINUM AND ALUMINUM ALLOY
ASME SB-234, specify alloy and temper.

M-2.16 COPPER AND COPPER ALLOY
ASME SB-111, specify alloy and temper.
ASME SB-395, specify alloy and temper.

M-2.2 WELDED

M-2.21 CARBON STEEL
ASME SA-214, electric resistance welded.

M-2.22 HIGH ALLOY STEEL
ASME SA-249, specify grade.

M-3 SHELLS, CHANNELS, COVERS, FLOATING HEADS, TUBESHEETS, AND FLANGES

M-3.1 PIPE

M-3.11 CARBON STEEL
ASME SA-106 seamless, Grade B or Grade A.
ASME SA-53 Grade B or Grade A.

M-3.12 LOW ALLOY STEEL
ASME SA-335, specify grade.

M-3.13 HIGH ALLOY STEEL
ASME SA-376, specify grade.
ASME SA-312, specify grade.

M-3.14 ALUMINUM AND ALUMINUM ALLOY
ASME SB-241, specify alloy and temper.

M-3.15 COPPER AND COPPER ALLOY
ASME SB-42.
ASME SB-43, specify temper.

M-3 SHELLS, CHANNELS, COVERS, FLOATING HEADS, TUBESHEETS, AND FLANGES—(Continued)

M-3.2 PLATE

M-3.21 CARBON STEEL
ASME SA-285 Grade C for plates up to 2" thick.
ASME SA-515, specify grade.
ASME SA-516, specify grade.

M-3.22 LOW ALLOY STEEL
ASME SA-204 firebox quality, specify grade.
ASME SA-203 Grade B firebox quality for plates up to 6" thick.
ASME SA-387, specify grade.
ASME SA-357

M-3.23 HIGH ALLOY STEEL
ASME SA-240, specify type.

M-3.24 NICKEL AND NICKEL ALLOY
ASME SB-162, specify temper.
ASME SB-127, specify temper.
ASME SB-168, specify temper.

M-3.25 ALUMINUM AND ALUMINUM ALLOY
ASME SB-209, specify alloy and temper.

M-3.26 COPPER AND COPPER ALLOY
ASME SB-11, specify type.
ASME SB-96, specify alloy.
ASME SB-169, specify alloy and temper.
ASME SB-171, specify alloy.
ASME SB-402, specify alloy.

M-3.3 CASTINGS

M-3.31 CARBON STEEL
ASME SA-216, specify grade.
ASME SA-352.

M-3.32 LOW ALLOY STEEL
ASME SA-217, specify grade.
ASME SA-352, specify grade.

M-3.33 HIGH ALLOY STEEL
ASME SA-351, specify grade.

M-3.34 COPPER ALLOY
ASME SB-61 valve bronze.
ASME SB-62 cast brass.

M-3.35 GRAY IRON
ASME SA-278 Class 30.

M-3.36 ALUMINUM AND ALUMINUM ALLOY
ASME SB-26.

M-3 SHELLS, CHANNELS, COVERS, FLOATING HEADS, TUBESHEETS, AND FLANGES—(Continued)

M-3.4 FORGINGS

M-3.41 CARBON STEEL

ASME SA-105 Grade I or II.
ASME SA-181 Grade I or II.
ASME SA-266 Class 1 or 2.

M-3.42 LOW AND HIGH ALLOY STEEL

ASME SA-182, specify grade.
ASME SA-336, specify class.

M-3.43 NICKEL AND NICKEL ALLOY

ASME SB-160, specify temper.
ASME SB-164, specify temper and class.
ASME SB-166, specify temper.

M-3.44 ALUMINUM AND ALUMINUM ALLOY

ASME SB-247, specify alloy and temper.

M-4 BAFFLES, SUPPORT PLATES, TIE RODS, AND SPACERS

M-4.1 BAFFLES AND SUPPORT PLATES

Commercial quality.

M-4.2 TIE RODS

Commercial quality.

M-4.3 SPACERS

Commercial quality.

M-5 GASKETS

Commercial quality.

M-6 BOLTING

M-6.1 STUDS AND STUD BOLTS

M-6.11 ALLOY STEEL

ASME SA-193, specify grade.

M-6.12 NICKEL AND NICKEL ALLOY

ASME SB-160, specify temper.
ASME SB-164, specify temper and class.
ASME SB-166, specify temper.

M-6.13 ALUMINUM AND ALUMINUM ALLOY

ASME SB-211, specify alloy and temper.

M-6 BOLTING—(Continued)

M-6.2 NUTS

M-6.21 CARBON STEEL
ASME SA-194 Grade 2H, minimum requirement.

M-6.22 ALLOY STEEL
ASME SA-194, specify grade.

M-6.23 NICKEL AND NICKEL ALLOY
ASME SB-160, specify temper.
ASME SB-164, specify temper and class.
ASME SB-166, specify temper.

M-6.24 ALUMINUM AND ALUMINUM ALLOY
ASME SB-211, specify alloy and temper.

T-1 SCOPE AND BASIC RELATIONS

T-1.1 SCOPE

This section outlines calculation procedures for determining mean temperature differences, and presents typical fouling resistances for calculation of overall heat transfer coefficients.

T-1.2 BASIC HEAT TRANSFER RELATION

$$A_o = \frac{Q}{U \Delta t_m}$$

where A_o = Required effective outside heat transfer surface based on length of tubes measured between inner faces of tubesheets.

Q = Total heat to be transferred.

U = Overall heat transfer coefficient.

Δt_m = Corrected mean temperature difference.

T-1.3 DETERMINATION OF OVERALL HEAT TRANSFER COEFFICIENT

The overall heat transfer coefficient U including fouling shall be calculated as follows:

$$U = \frac{1}{\left[\frac{1}{h_o} + r_o + r_w + r_i\left(\frac{A_o}{A_i}\right) + \frac{1}{h_i}\left(\frac{A_o}{A_i}\right)\right]}$$

where U = Overall heat transfer coefficient (fouled) — BTU/(hr.) (deg. F) (sq. ft. outside surface)

h_o = Film coefficient of fluid outside tubes — BTU/(hr.) (deg. F) (sq. ft. outside surface)

h_i = Film coefficient of fluid inside tubes — BTU/(hr.) (deg. F) (sq. ft. inside surface)

r_o = Fouling resistance on outside of tubes — $\frac{\text{(hr.) (deg. F) (sq. ft. outside surface)}}{\text{BTU}}$

r_i = Fouling resistance on inside of tubes — $\frac{\text{(hr.) (deg. F) (sq. ft. inside surface)}}{\text{BTU}}$

r_w = Resistance of tube wall referred to outside surface of tube wall, including extended surface if present. — $\frac{\text{(hr.) (deg. F) (sq. ft. outside surface)}}{\text{BTU}}$

$\frac{A_o}{A_i}$ = Ratio of outside to inside surface of tubing.

T-1.31 WALL RESISTANCE INTEGRAL

The wall resistance of integral circumferentially finned tubes shall be calculated as follows:

$$r_w = \frac{t_w}{12k_w} \frac{[d + 2Nw(d + w)]}{(d - t_w)} + \frac{Nw^2}{18k_f t_f} \frac{(d + 2w)(2w + t_f)}{[d + 2Nw(d + w)]}$$

where d = O.D. of tube or root diameter of fin, inches.

w = Fin height, inches.

t_w = Tube wall thickness, inches.

t_f = Average fin thickness, inches.

N = Number of fins per inch.

k = Thermal conductivity, BTU/hr. × sq. ft./(°F/ft.).

T-1 SCOPE AND BASIC RELATIONS—(Continued)

Subscripts "w" and "f" refer to tube and fin respectively. The same formula, with N = 0, applies to bare tubes.

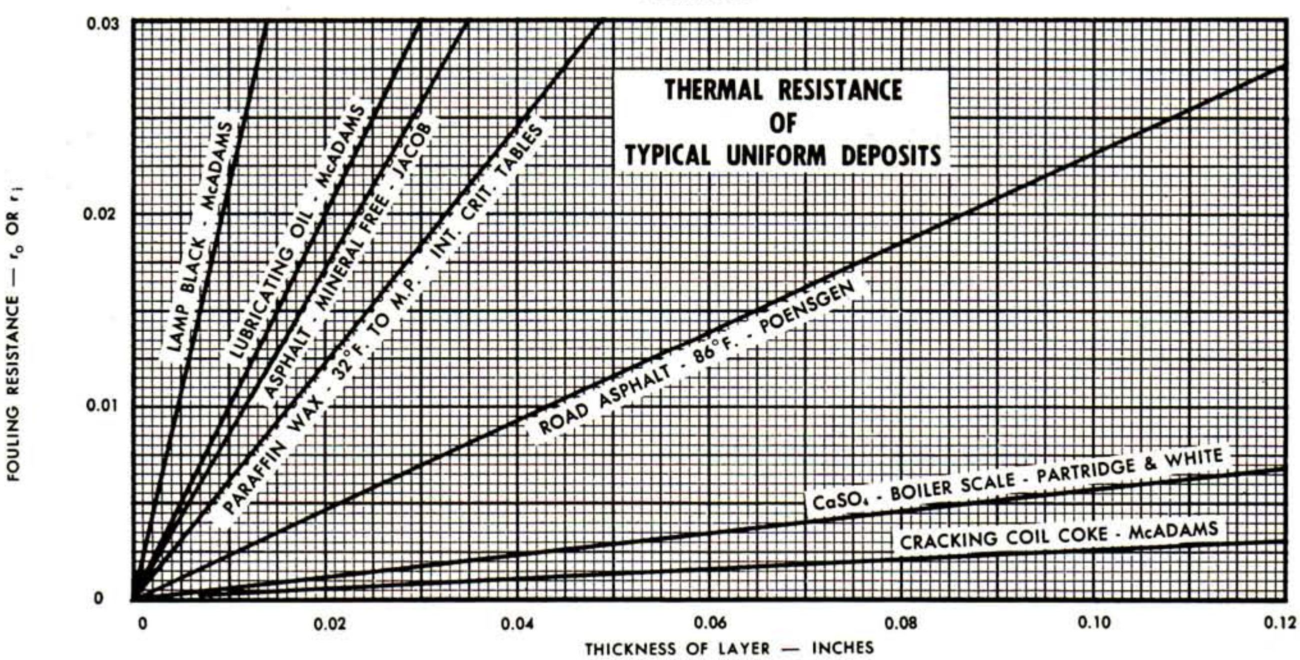
Note: The wall resistance formula above is strictly valid only when the second term on the right is less than $[r_o + (1/h_o)]/3$. It becomes increasingly conservative for higher values of this term.

T-2 FOULING RESISTANCES

T-2.1 EFFECT OF FOULING

Products of corrosion, dirt, or other foreign materials which deposit on heat transfer surface increase the overall thermal resistance and lower the overall heat transfer coefficient of the heat exchanger. (Figure T-2.1 shows the effect of fouling thickness upon resistance for several types of deposits.) In order that heat exchangers shall have sufficient surface to maintain satisfactory performance in normal operation, with reasonable service time between cleanings, it is important in design to provide a fouling allowance appropriate to the expected operating and maintenance conditions.

FIGURE T-2.1



T-2.2 CONSIDERATIONS IN FOULING RESISTANCE EVALUATION

The determination of appropriate values for fouling resistances involves both physical and economic factors, many of which vary from user to user, even for identical services.

T-2.21 PHYSICAL CONSIDERATIONS

Among physical factors influencing the extent of heat exchanger fouling are:

Nature of fluid and material deposited.
Temperature of fluid.
Temperature of tube wall.
Tube wall material and finish.
Fluid velocity.
Operating time since last cleaning.

T-2 FOULING RESISTANCES—(Continued)

T-2.22 ECONOMIC CONSIDERATIONS

Economic factors entering into the determination of permissible extent of fouling are:

- Initial cost of exchanger.
- Variation of cost with size.
- Frequency of cleanings required.
- Cost of cleaning, including loss of production.
- Depreciation rate.
- Tax rate.
- Maintenance rate (exclusive of cleaning costs).
- Fluid pumping charges.
- Desired net return on investment.

T-2.3 OPTIMUM DESIGN FOULING RESISTANCES

The best design fouling resistance, chosen with all physical and economic factors properly evaluated, will result in a minimum cost based on fixed charges of the initial investment (which increase with added fouling resistance) and on cleaning and down-time expenses (which decrease with added fouling resistance). By the very nature of the factors involved, the manufacturer is seldom in a position to determine optimum fouling resistances. The user, therefore, on the basis of past experience and current or projected costs, should specify the design fouling resistances for his particular services.

T-2.4 TYPICAL FOULING RESISTANCES

The following tables present typical fouling resistances referred to the surface on which they occur. In the absence of specific data for setting proper resistances as described in paragraphs T-2.2 and T-2.3, the user may be guided by the values tabulated below. In the case of inside surface fouling, these values must be multiplied by the outside/inside surface ratio, as indicated in Equation T-1.3.

T-2.41 FOULING RESISTANCES FOR WATER

Temperature of Heating Medium	Up to 240°F.		240°F.-400°F.*	
Temperature of Water	125°F. or Less		Over 125°F.	
Types of Water	Water Velocity Ft./Sec.		Water Velocity Ft./Sec.	
	3 Ft. And Less	Over 3 Ft.	3 Ft. And Less	Over 3 Ft.
Sea Water	.0005	.0005	.001	.001
Brackish Water	.002	.001	.003	.002
Cooling Tower and Artificial Spray Pond:				
Treated Makeup	.001	.001	.002	.002
Untreated	.003	.003	.005	.004
City or Well Water (Such as Great Lakes)	.001	.001	.002	.002
Great Lakes	.001	.001	.002	.002
River Water:				
Minimum	.002	.001	.003	.002
Mississippi	.003	.002	.004	.003
Delaware, Schuylkill	.003	.002	.004	.003
East River and New York Bay	.003	.002	.004	.003
Chicago Sanitary Canal	.008	.006	.010	.008
Muddy or Silty	.003	.002	.004	.003
Hard (Over 15 grains/gal.)	.003	.003	.005	.005
Engine Jacket	.001	.001	.001	.001
Distilled	.0005	.0005	.0005	.0005
Treated Boiler Feedwater	.001	.0005	.001	.001
Boiler Blowdown	.002	.002	.002	.002

*Ratings in columns 3 and 4 are based on a temperature of the heating medium of 240°-400° F. If the heating medium temperature is over 400° F. and the cooling medium is known to scale, these ratings should be modified accordingly.

T-2 FOULING RESISTANCES—(Continued)

T-2.42 FOULING RESISTANCES FOR INDUSTRIAL FLUIDS

T-2.421 OILS

Fuel Oil	.005
Transformer Oil	.001
Engine Lube Oil	.001
Quench Oil	.004

T-2.422 GASES AND VAPORS

Manufactured Gas	.01
Engine Exhaust Gas	.01
Steam (nonoil bearing)	.0005
Exhaust Steam (oil bearing)	.001
Refrigerant Vapors (oil bearing)	.002
Compressed Air	.002
Industrial Organic Heat Transfer Media	.001

T-2.423 LIQUIDS

Refrigerant Liquids	.001
Hydraulic Fluid	.001
Industrial Organic Heat Transfer Media	.001
Molten Heat Transfer Salts	.0005

T-2.43 FOULING RESISTANCES FOR CHEMICAL PROCESSING STREAMS

T-2.431 GASES AND VAPORS

Acid Gas	.001
Solvent Vapors	.001
Stable Overhead Products	.001

T-2.432 LIQUIDS

MEA & DEA Solutions	.002
DEG & TEG Solutions	.002
Stable Side Draw and Bottom Product	.001
Caustic Solutions	.002
Vegetable Oils	.003

T-2.44 FOULING RESISTANCES FOR NATURAL GAS-GASOLINE PROCESSING STREAMS

T-2.441 GASES AND VAPORS

Natural Gas	.001
Overhead Products	.001

T-2.442 LIQUIDS

Lean Oil	.002
Rich Oil	.001
Natural Gasoline & Liquefied Petroleum Gases	.001

T-2.45 FOULING RESISTANCES FOR OIL REFINERY STREAMS

T-2.451 CRUDE & VACUUM UNIT GASES AND VAPORS

Atmospheric Tower Overhead Vapors	.001
Light Naphthas	.001
Vacuum Overhead Vapors	.002

T-2 FOULING RESISTANCES—(Continued)

T-2.452 CRUDE & VACUUM LIQUIDS

Crude Oil

	0-199°F. Velocity Ft./Sec.			200°-299°F. Velocity Ft./Sec.		
	Under 2 Ft.	2-4 Ft.	4 Ft. And Over	Under 2 Ft.	2-4 Ft.	4 Ft. And Over
Dry	.003	.002	.002	.003	.002	.002
Salt*	.003	.002	.002	.005	.004	.004

	300°-499°F. Velocity Ft./Sec.			500°F. and Over Velocity Ft./Sec.		
	Under 2 Ft.	2-4 Ft.	4 Ft. And Over	Under 2 Ft.	2-4 Ft.	4 Ft. And Over
Dry	.004	.003	.002	.005	.004	.003
Salt*	.006	.005	.004	.007	.006	.005

*Normally desalted below this temperature range. (Asterisk to apply to 200-299°F., 300-499°F., 500°F. and over.)

Gasoline	.001
Naphtha & Light Distillates	.001
Kerosene	.001
Light Gas Oil	.002
Heavy Gas Oil	.003
Heavy Fuel Oils	.005
Asphalt & Residuum	.010

T-2.453 CRACKING & COKING UNIT STREAMS

Overhead Vapors	.002
Light Cycle Oil	.002
Heavy Cycle Oil	.003
Light Coker Gas Oil	.003
Heavy Coker Gas Oil	.004
Bottoms Slurry Oil (4½ ft./sec. minimum)	.003
Light Liquid Products	.002

T-2.454 CATALYTIC REFORMING, HYDROCRACKING, & HYDRODESULFURIZATION STREAMS

Reformer Charge	.002
Reformer Effluent	.001
Hydrocracker Charge & Effluent**	.002
Recycle Gas	.001
Hydrodesulfurization Charge & Effluent**	.002
Overhead Vapors	.001
Liquid Product over 50° A.P.I.	.001
Liquid Product 30°-50° A.P.I.	.002

**Depending on charge characteristics and storage history, charge resistance may be many times this value.

T-2.455 LIGHT ENDS PROCESSING STREAMS

Overhead Vapors & Gases	.001
Liquid Products	.001
Absorption Oils	.002
Alkylation Trace Acid Streams	.002
Reboiler Streams	.003

T-2 FOULING RESISTANCES—(Continued)

T-2.456 LUBE OIL PROCESSING STREAMS

Feed Stock	.002
Solvent Feed Mix	.002
Solvent	.001
Extract*	.003
Raffinate	.001
Asphalt	.005
Wax Slurries*	.003
Refined Lube Oil	.001

*Precautions must be taken to prevent wax deposition on cold tube walls.

T-3 FLUID TEMPERATURE RELATIONS

T-3.1 LOGARITHMIC MEAN TEMPERATURE DIFFERENCE

When heat exchangers are of the true countercurrent or cocurrent flow types, and the heat capacities of the fluids and overall heat transfer coefficients are substantially constant, the logarithmic mean temperature difference may satisfactorily be applied. This may be obtained from Figure T-3.1, page 128. For the case of variable coefficient, this result may be used in conjunction with paragraph P-1, Average Fluid Temperature.

T-3.2 CORRECTION FOR MULTIPASS FLOW

In multipass heat exchangers, where there is a combination of cocurrent and countercurrent flow in alternate passes, the mean temperature difference is less than the logarithmic mean calculated for countercurrent flow and greater than that based on the cocurrent flow. The correct mean temperature difference may be evaluated as the product of the logarithmic mean for countercurrent flow and an MTD correction Factor, "F". Figures T-3.2A to T-3.2H, inclusive, pages 129 through 136, give values for "F" as a function of the heat capacity rate ratio "R" and the required heat exchanger effectiveness "P". T-3.2A to 3.2F apply for one, two, three, four, five, and six shell passes, with two or more tube passes per shell pass. T-3.2G applies for a divided flow shell pass with two tube passes. T-3.2H applies for a split flow shell pass with two tube passes. These charts are based on constant specific heats of the fluids and on constant overall heat transfer coefficients. "F" factors from these charts should not be used much below a value of 0.80.

T-3.3 HEAT EXCHANGER EFFECTIVENESS

The thermal effectiveness of a heat exchanger is customarily defined as the ratio of the temperature change of one stream to the difference between the two fluid inlet temperatures, thus:

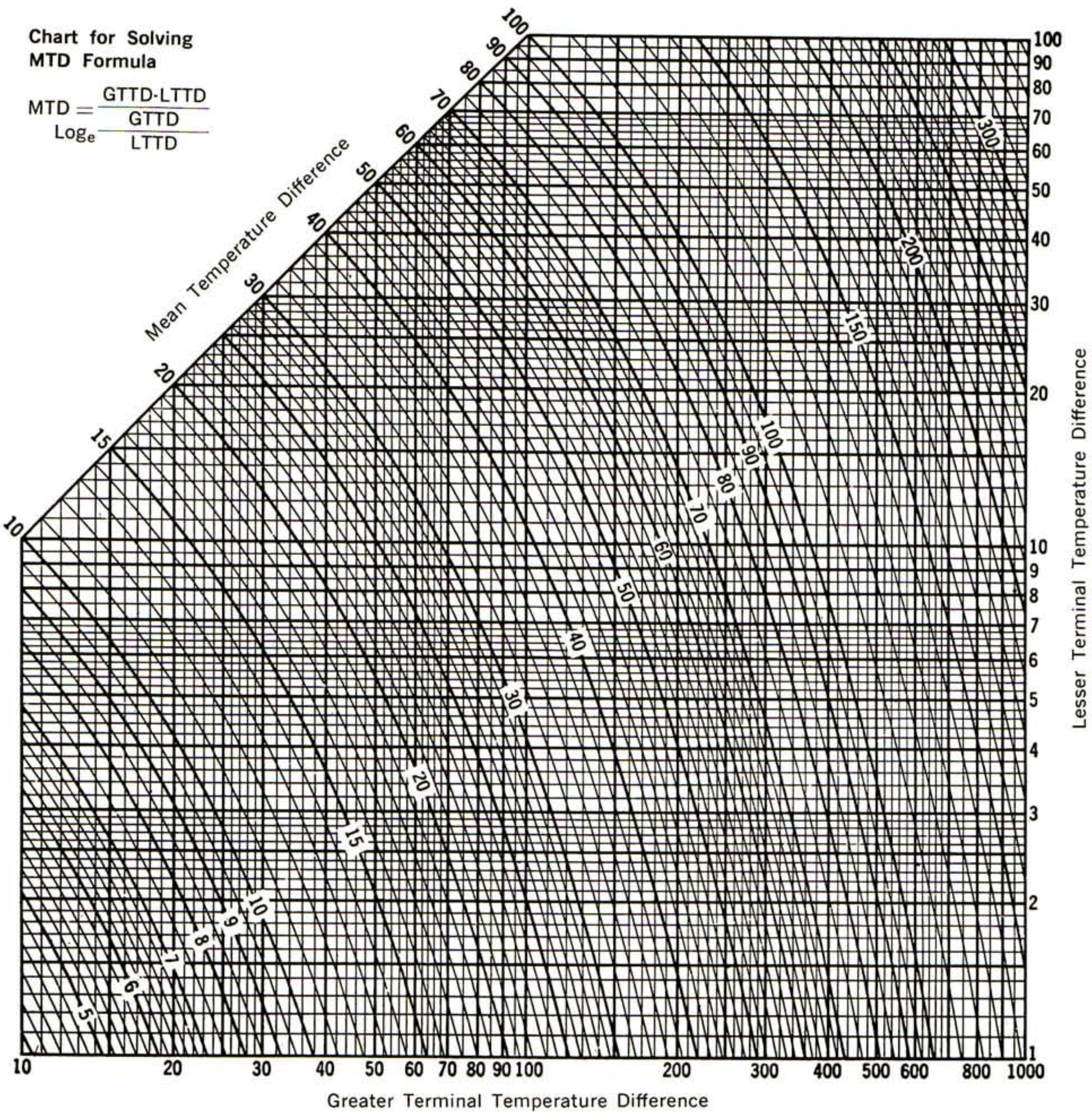
$$P = \frac{(t_2 - t_1)}{(T_1 - t_1)}$$

where "P" is the effectiveness. Figures T-3.3, T-3.3A, and T-3.3B, pages 137, 138, and 139, show the thermal effectiveness of counterflow, single-pass shell and two-pass tube, and two-pass shell and four-pass tube exchangers respectively, in terms of overall heat transfer coefficient, surface, fluid flow rates, and specific heats. In all cases the lower case symbols (t_1, t_2, w and c) refer to the tube side fluid, and upper case (T_1, W, and C) to the shell side fluid. (This distinction is not necessary in the case of counterflow exchangers, but confusion will be avoided if it is observed.) These charts are based on constant specific heats of the fluids and on constant overall heat transfer coefficient.

T-4 HEAT TRANSFER AND PRESSURE DROP DATA

In view of the many variations in constructional details of tubular heat transfer equipment, many of which significantly affect both heat transfer and pressure drop, it has been decided that this edition will not include specific recommendations for performance calculations for either shell or tube side. Those interested in the detailed calculation of heat exchanger performance may refer, as in the past, to various standard reference works on heat transfer as well as to the literature on the subject in engineering society journals and elsewhere. The University of Delaware Engineering Experiment Station, under the joint sponsorship of ASME, API, TEMA, and other interested organizations, has conducted research on flow outside of bare tubes which is summarized in their "Bulletin No. 5 (1963) Final Report of the Cooperative Research Program on Shell and Tube Heat Exchangers."

FIGURE T-3.1



NOTE—For points not included on this sheet multiply Greater Terminal Temperature Difference and Lesser Terminal Temperature Difference by any multiple of 10 and divide resulting value of curved lines by same multiple.

FIGURE T-3.2A

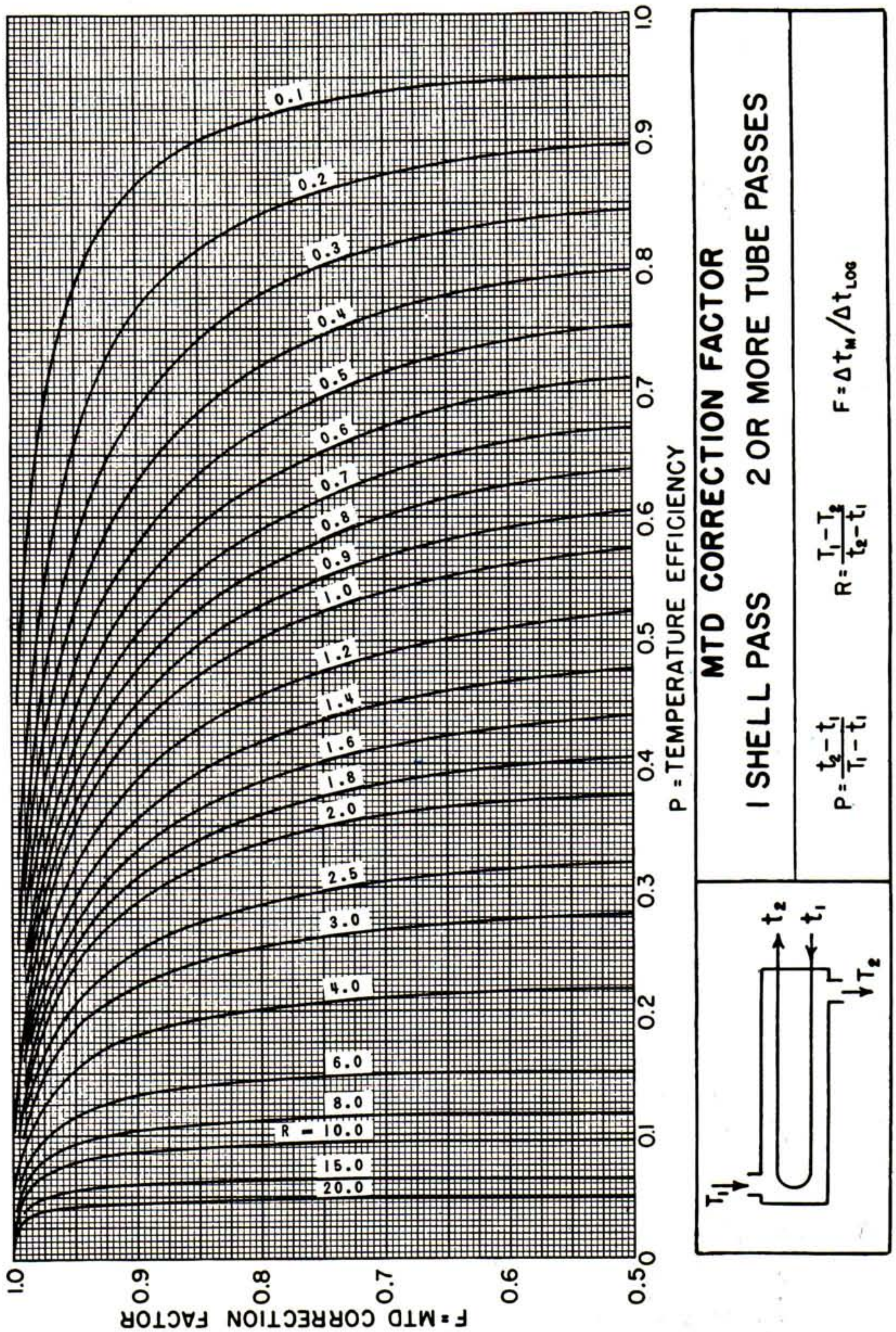

MTD CORRECTION FACTOR
1 SHELL PASS 2 OR MORE TUBE PASSES
$P = \frac{t_2 - t_1}{T_1 - t_1}$
$R = \frac{T_1 - T_2}{t_2 - t_1}$
$F = \Delta t_M / \Delta t_{LOG}$
P = TEMPERATURE EFFICIENCY
F = MTD CORRECTION FACTOR
R = 10.0
T_1
T_2
t_1
t_2

FIGURE T-3.2B

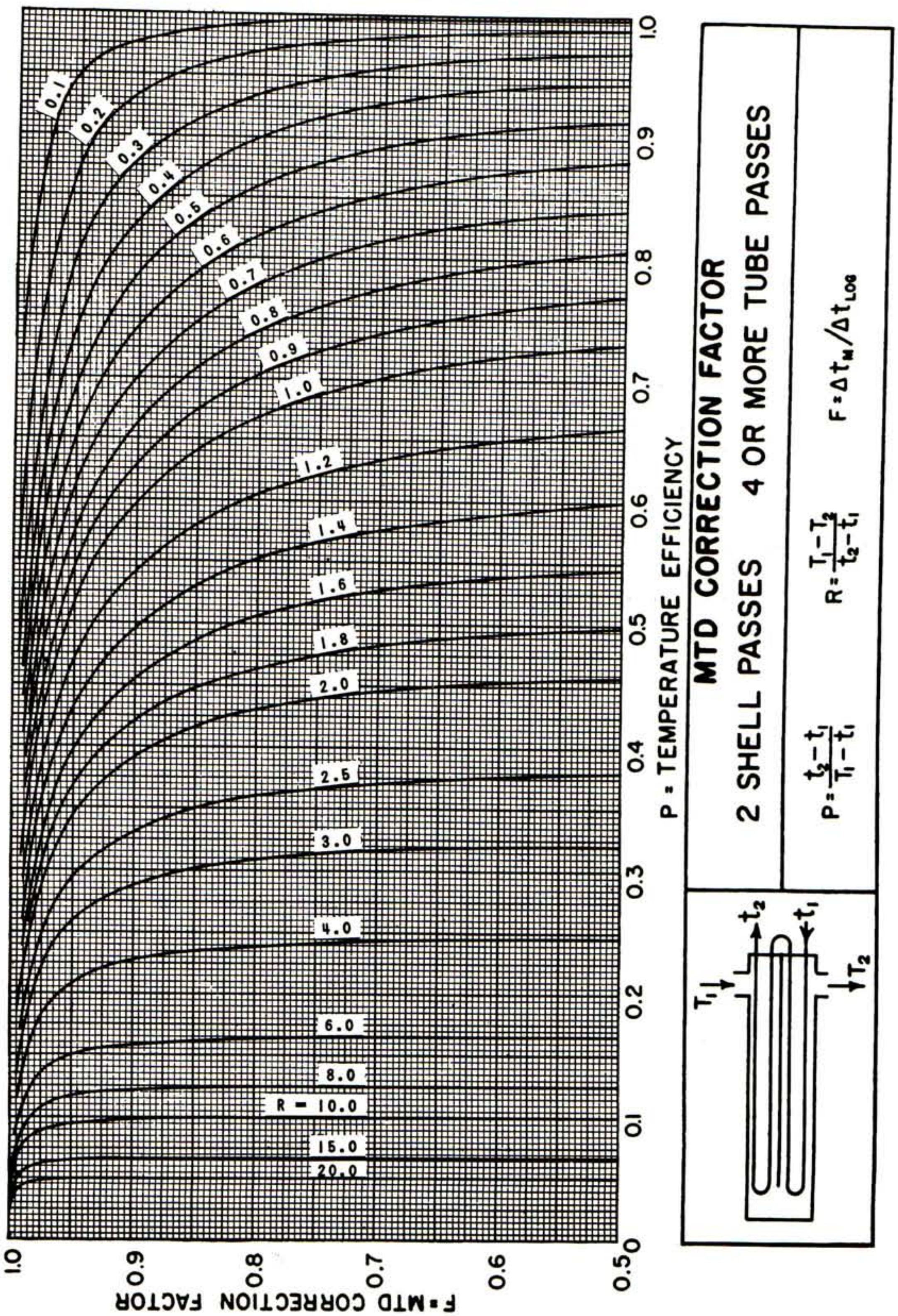

MTD CORRECTION FACTOR
2 SHELL PASSES 4 OR MORE TUBE PASSES
P = TEMPERATURE EFFICIENCY
F = MTD CORRECTION FACTOR
$P = \frac{t_2 - t_1}{T_1 - t_1}$
$R = \frac{T_1 - T_2}{t_2 - t_1}$
$F = \Delta t_M / \Delta t_{LOG}$
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
4.0
6.0
8.0
R = 10.0
15.0
20.0
T_1
T_2
t_1
t_2

FIGURE T-3.2C

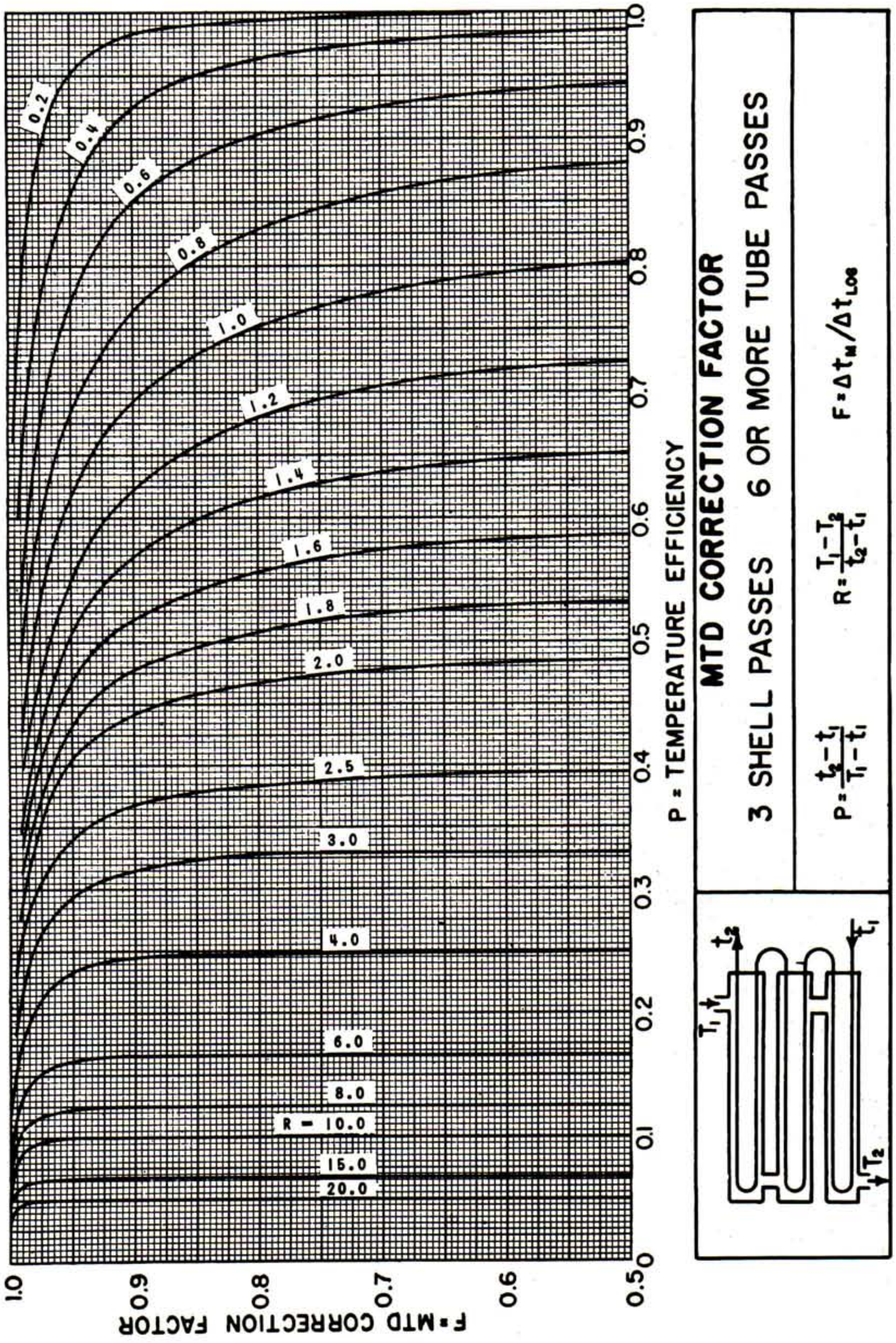
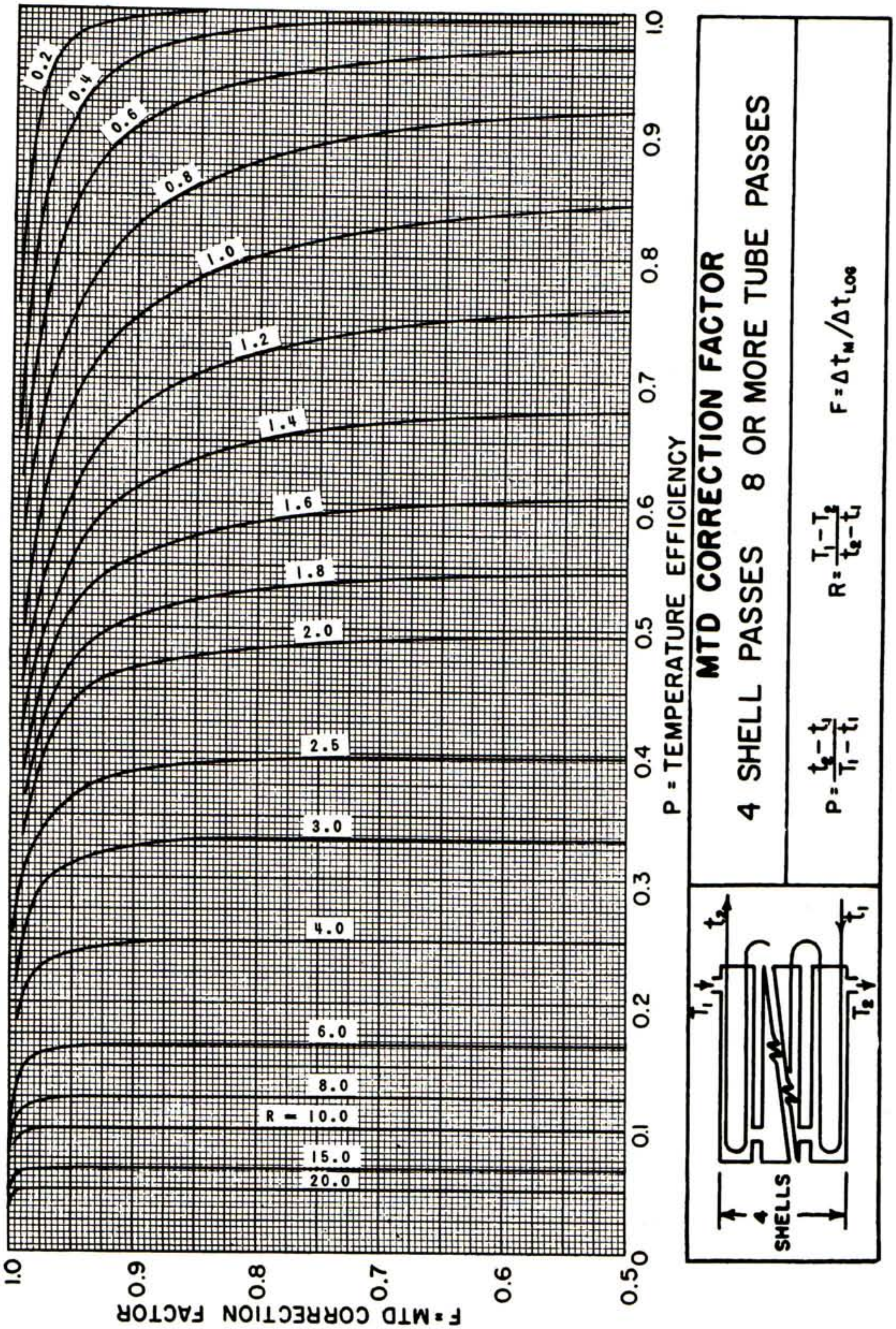

MTD CORRECTION FACTOR
3 SHELL PASSES 6 OR MORE TUBE PASSES
P = TEMPERATURE EFFICIENCY
F = MTD CORRECTION FACTOR
F = Δt_M/Δt_LOG
R = 10.0

FIGURE T-3.2D



$P = \frac{t_2 - t_1}{T_1 - t_1}$ $R = \frac{T_1 - T_2}{t_2 - t_1}$ $F = \Delta t_M / \Delta t_{LOG}$

FIGURE T-3.2E

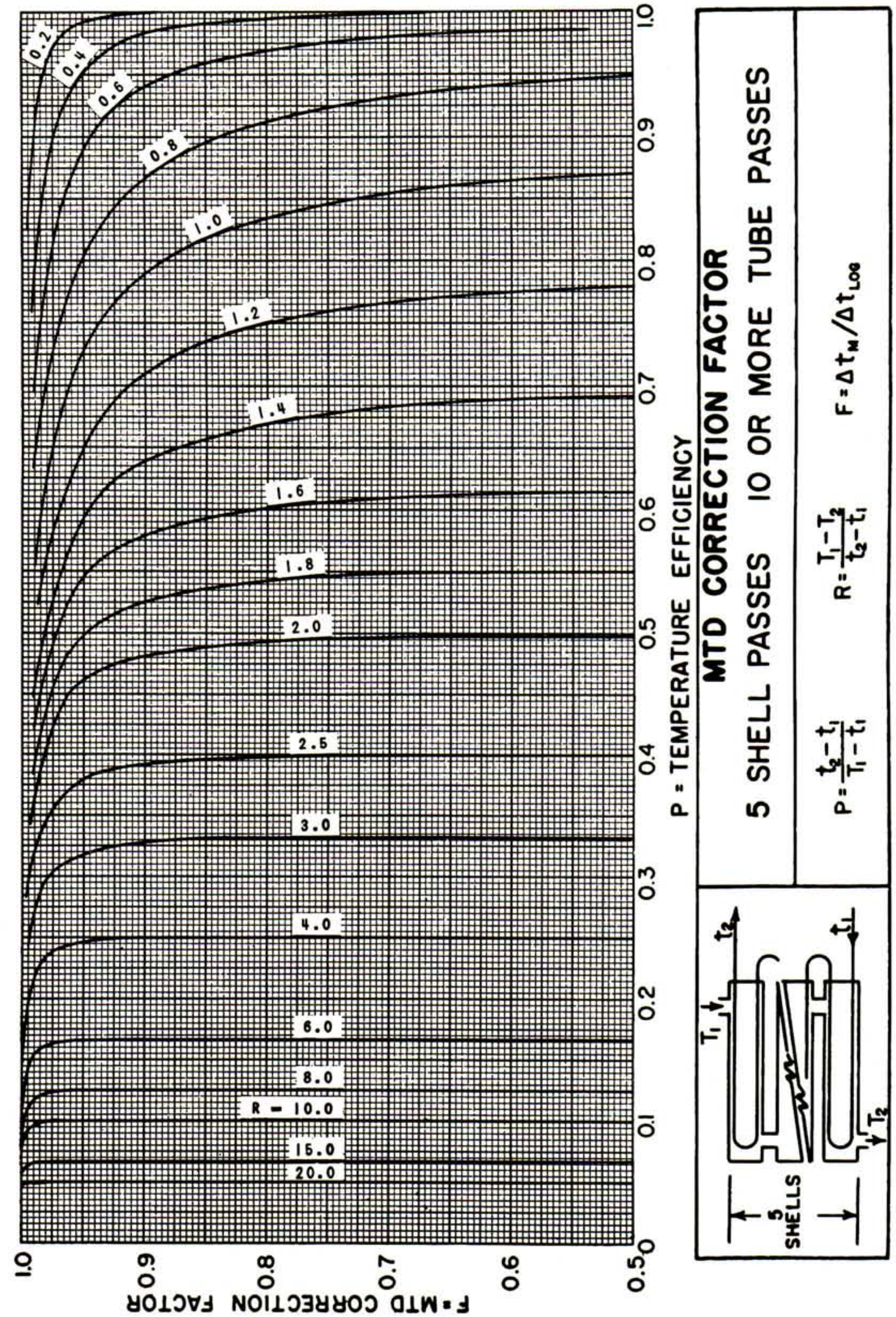

MTD CORRECTION FACTOR
5 SHELL PASSES 10 OR MORE TUBE PASSES
P = TEMPERATURE EFFICIENCY
F = MTD CORRECTION FACTOR
$P = \frac{t_2 - t_1}{T_1 - t_1}$
$R = \frac{T_1 - T_2}{t_2 - t_1}$
$F = \Delta t_M / \Delta t_{LOG}$
5 SHELLS
T_1
T_2
t_1
t_2
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
4.0
6.0
8.0
R = 10.0
15.0
20.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.5
0.6
0.7
0.8
0.9
1.0

FIGURE T-3.2F

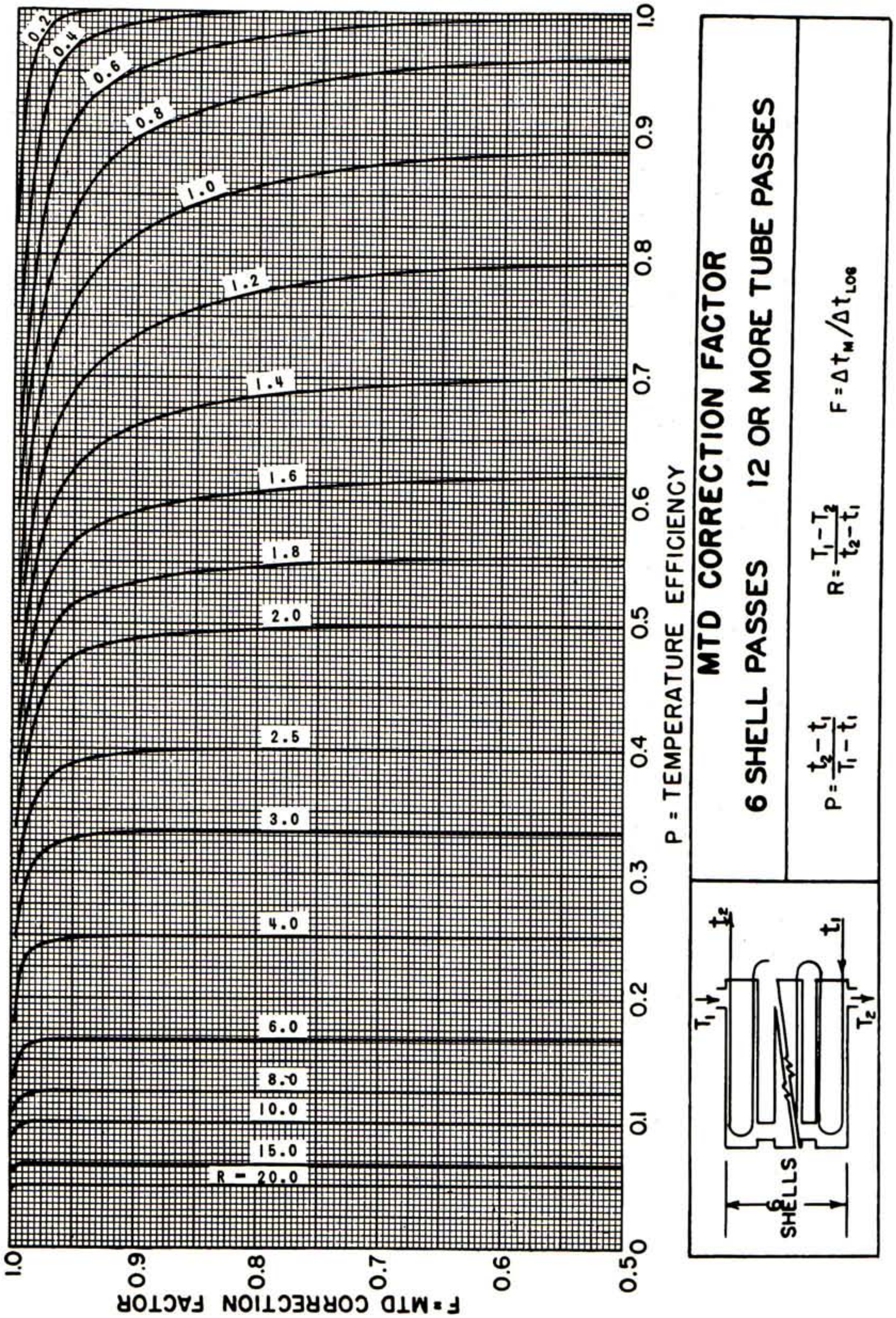

MTD CORRECTION FACTOR
6 SHELL PASSES 12 OR MORE TUBE PASSES
$P = \frac{t_2 - t_1}{T_1 - t_1}$
$R = \frac{T_1 - T_2}{t_2 - t_1}$
$F = \Delta t_M / \Delta t_{LOG}$
P = TEMPERATURE EFFICIENCY
F = MTD CORRECTION FACTOR
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
4.0
6.0
8.0
10.0
15.0
R = 20.0
6 SHELLS
T_1
T_2
t_1
t_2

FIGURE T-3.2G

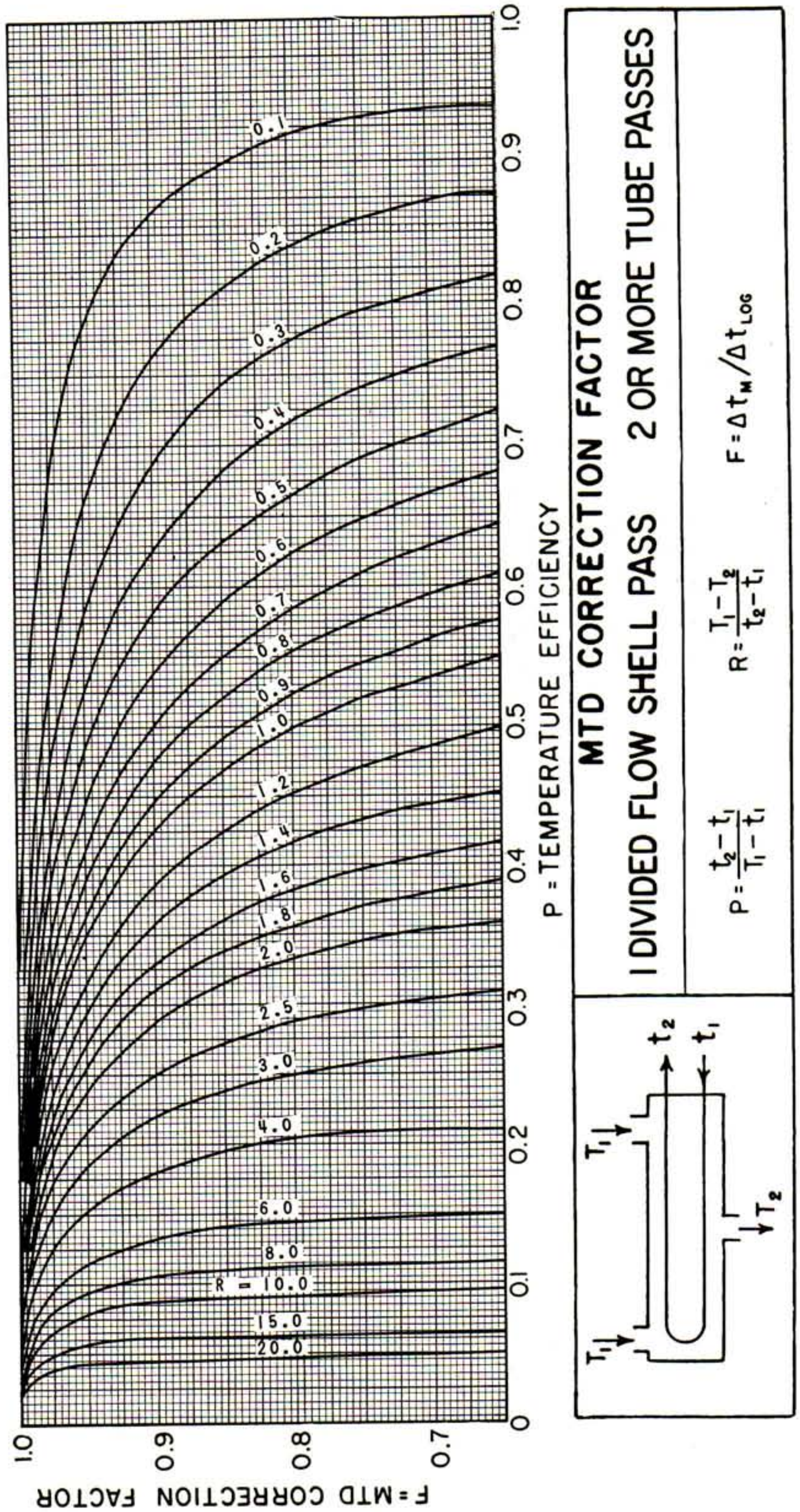

MTD CORRECTION FACTOR
1 DIVIDED FLOW SHELL PASS 2 OR MORE TUBE PASSES
$P = \frac{t_2 - t_1}{T_1 - t_1}$
$R = \frac{T_1 - T_2}{t_2 - t_1}$
$F = \Delta t_M / \Delta t_{LOG}$
P = TEMPERATURE EFFICIENCY
F = MTD CORRECTION FACTOR
R = 10.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
4.0
6.0
8.0
15.0
20.0
T_1
T_2
t_1
t_2

FIGURE T-3.2H

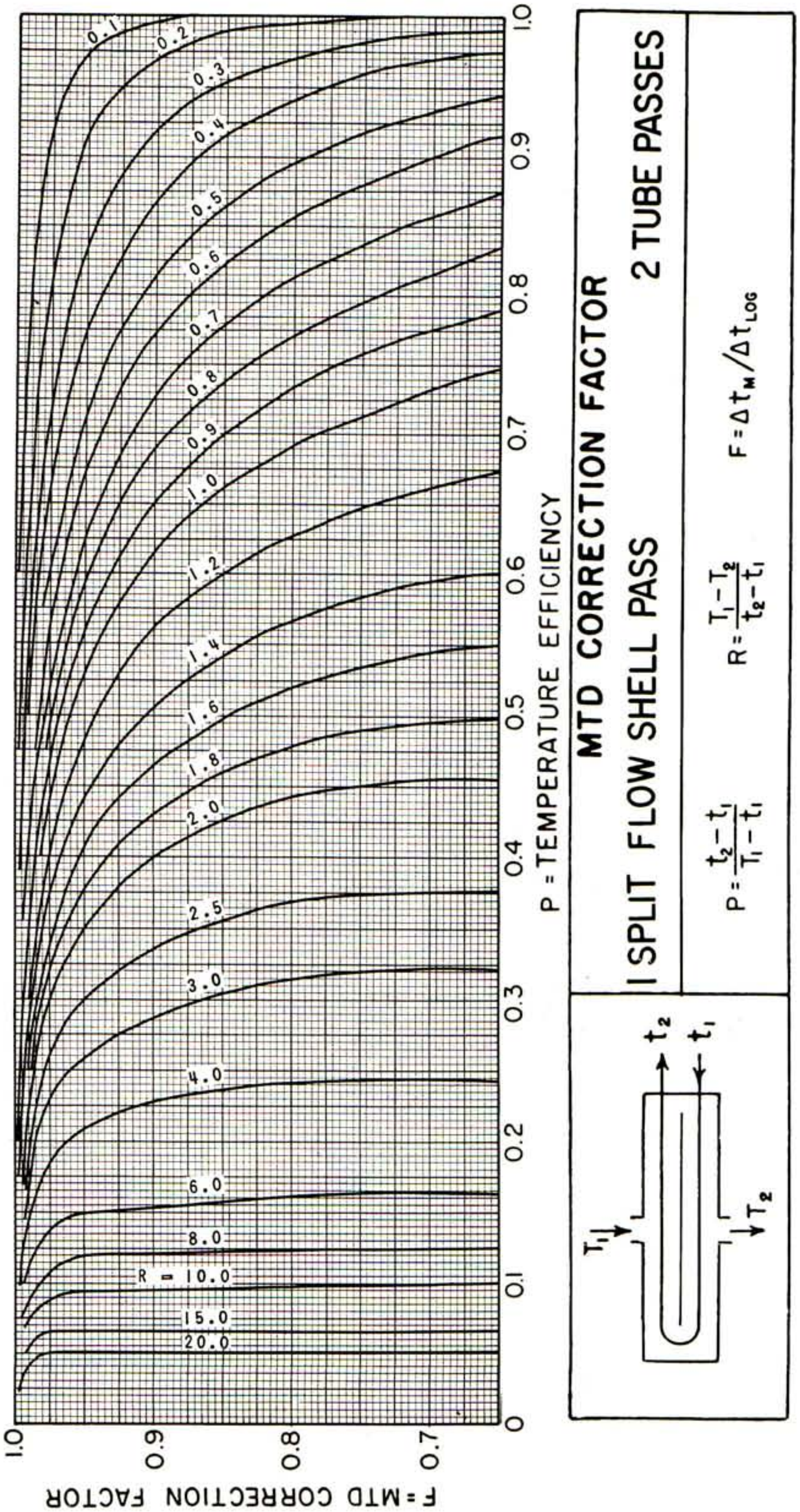
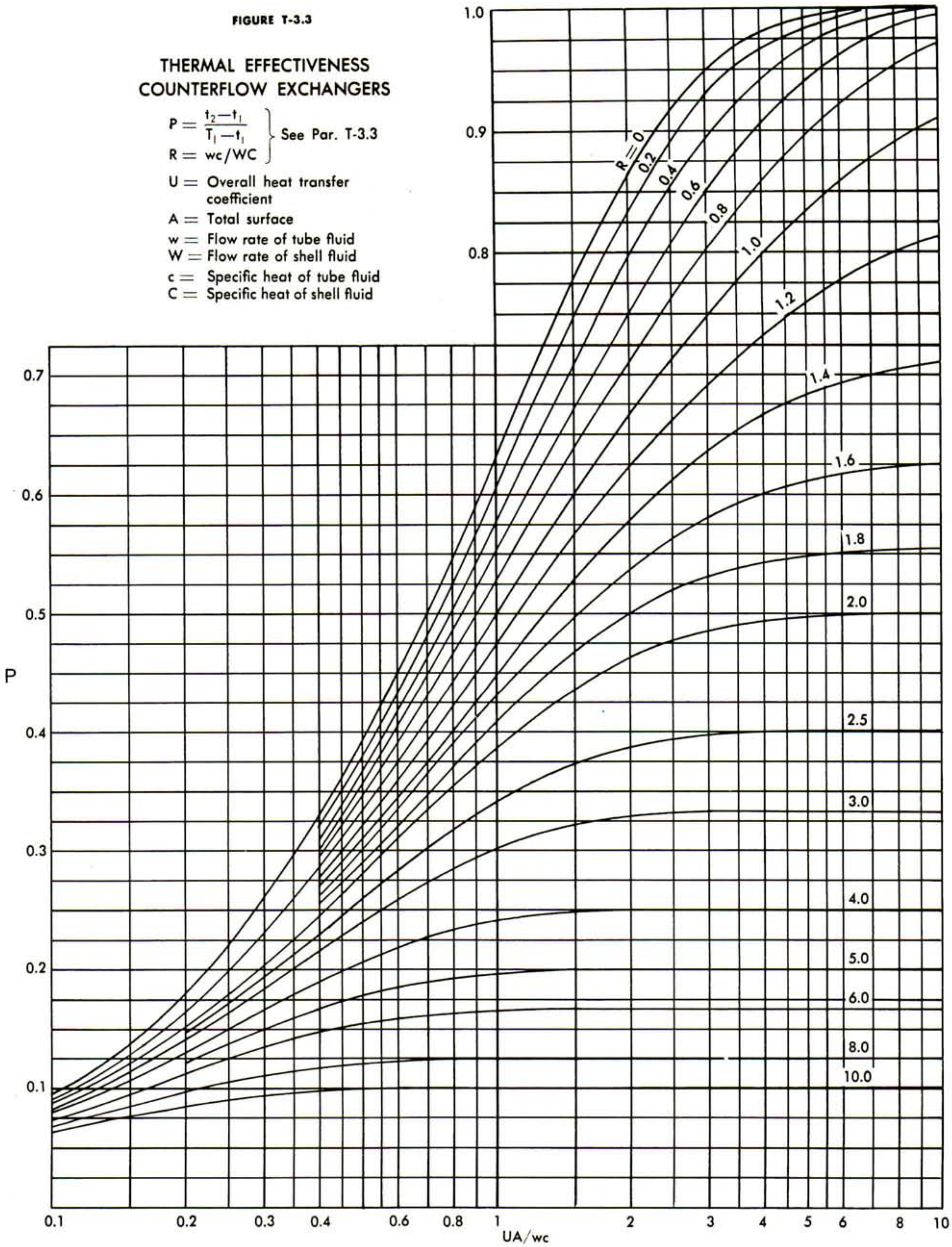

MTD CORRECTION FACTOR
1 SPLIT FLOW SHELL PASS
2 TUBE PASSES
$P = \frac{t_2 - t_1}{T_1 - t_1}$
$R = \frac{T_1 - T_2}{t_2 - t_1}$
$F = \Delta t_M / \Delta t_{LOG}$
P = TEMPERATURE EFFICIENCY
F = MTD CORRECTION FACTOR
R = 10.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
4.0
6.0
8.0
15.0
20.0
T_1
T_2
t_1
t_2

FIGURE T-3.3

THERMAL EFFECTIVENESS COUNTERFLOW EXCHANGERS

$P = \frac{t_2 - t_1}{T_1 - t_1}$, $R = wc/WC$ } See Par. T-3.3

U = Overall heat transfer coefficient
A = Total surface
w = Flow rate of tube fluid
W = Flow rate of shell fluid
c = Specific heat of tube fluid
C = Specific heat of shell fluid



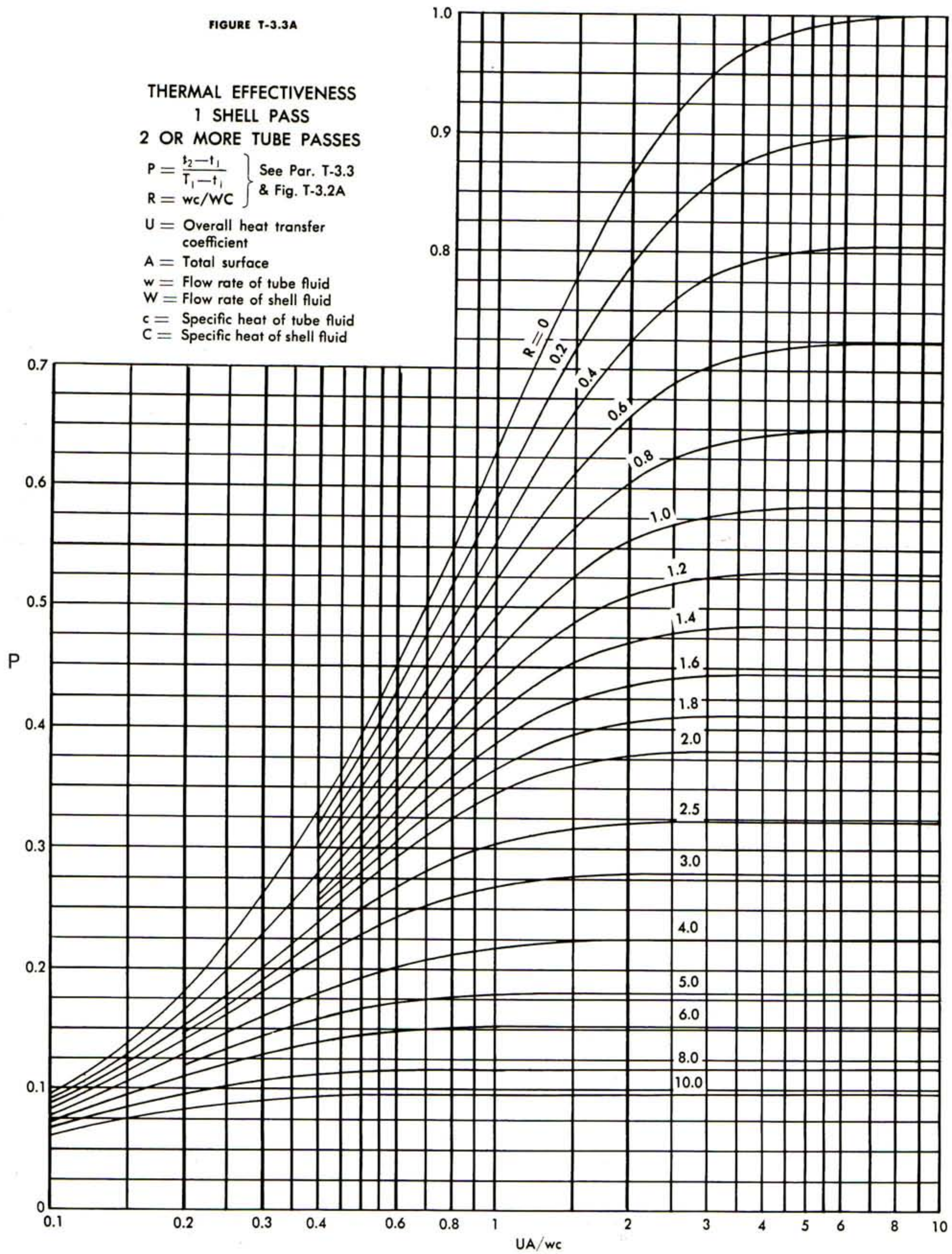


FIGURE T-3.3A
THERMAL EFFECTIVENESS
1 SHELL PASS
2 OR MORE TUBE PASSES
$P = \frac{t_2 - t_1}{T_1 - t_1}$ } See Par. T-3.3
$R = wc/WC$ } & Fig. T-3.2A
U = Overall heat transfer coefficient
A = Total surface
w = Flow rate of tube fluid
W = Flow rate of shell fluid
c = Specific heat of tube fluid
C = Specific heat of shell fluid
P
UA/wc
R = 0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
4.0
5.0
6.0
8.0
10.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.1
0.2
0.3
0.4
0.6
0.8
1
2
3
4
5
6
8
10

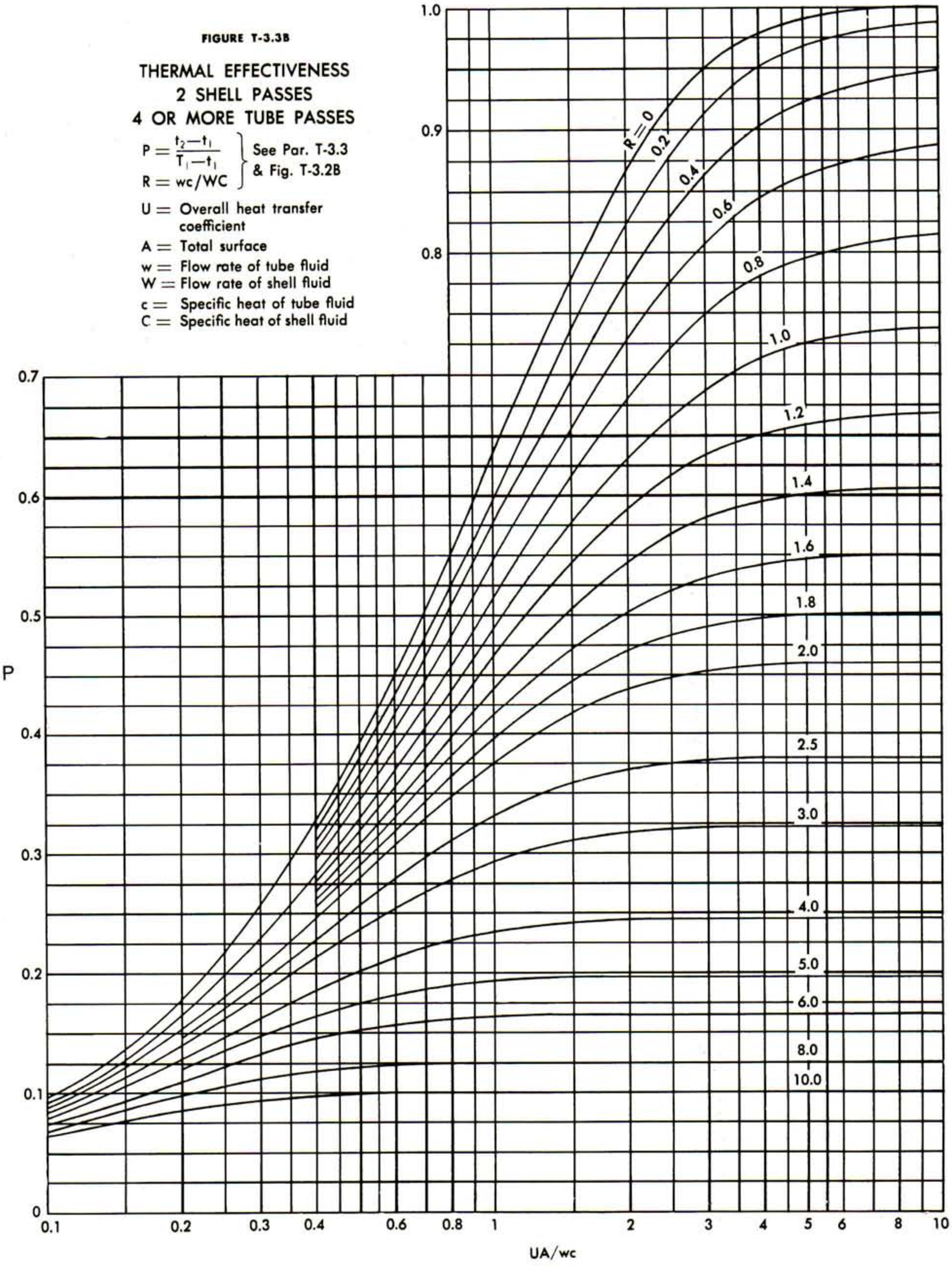


FIGURE T-3.3B
THERMAL EFFECTIVENESS
2 SHELL PASSES
4 OR MORE TUBE PASSES
$P = \frac{t_2 - t_1}{T_1 - t_1}$ } See Par. T-3.3 & Fig. T-3.2B
$R = wc/WC$
U = Overall heat transfer coefficient
A = Total surface
w = Flow rate of tube fluid
W = Flow rate of shell fluid
c = Specific heat of tube fluid
C = Specific heat of shell fluid
P
UA/wc
R = 0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
4.0
5.0
6.0
8.0
10.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.1
0.2
0.3
0.4
0.6
0.8
1
2
3
4
5
6
8
10

P-1 AVERAGE FLUID TEMPERATURE

When the overall coefficient of heat transfer varies from one end of the heat exchanger to the other, and when this variation may be assumed approximately linear, the appropriate physical properties of the fluids may be approximated by evaluating them at the average temperatures determined from Figure P-1, page 143. The temperature change of each fluid multiplied by the Factor F from the figure is added to its cold terminal temperature to obtain this average temperature. The Factor F is plotted against the ratio of the cold and hot terminal temperature differences, with the fractional change in the overall heat transfer coefficient C as a parameter. When the fluid under consideration is a mixture of hydrocarbons or a petroleum oil, the determination of the factor C may be simplified by use of the inset curve of C versus API gravity, with temperature change, ($T_1 - T_2$), as a parameter. While based on the viscosity-density-temperature relationships of only one related group of petroleum oils, the inset curve gives results which, when used with Figure P-1, are within the limits of accuracy of most heat transfer data. Its use should, however, be confined to problems where most of the resistance to heat flow is on the oil side; e.g., oil coolers using water as the cooling medium or oil heaters using steam as the heating medium. Figure P-1 is strictly applicable only to calculation of heat transfer coefficients for true countercurrent flow or true cocurrent flow, but may be used as a reasonable approximation for multipass heat exchangers.

P-2 FLUID DENSITY

P-2.1 SPECIFIC GRAVITY OF LIQUID PETROLEUM FRACTIONS

The specific gravities of liquid petroleum fractions and saturated light hydrocarbons are shown in Figure P-2.1, page 144.

P-2.2 DENSITY OF ORGANIC LIQUIDS

The general density nomograph Fig. P-2.2 permits the approximation of the density of organic liquids at temperatures between −150° F and +500° F, if densities at two temperatures are known. Table P-2.2 lists the coordinates on the center grid for locating the reference points for 54 compounds. The reference point for a substance may be determined, if the density is known for two different temperatures. The intersection point of the two straight lines joining the corresponding values of the known temperatures and densities, is the desired reference point of the substance. Figure P-2.2 and Table P-2.2 are shown on page 145.

P-2.3 COMPRESSIBILITY FACTORS FOR GASES AND VAPORS

The P-v-T relationships for gases and vapors may conveniently be expressed by the equation $Pv = ZRT$, where P is the absolute pressure, v is the specific volume, T is the absolute temperature, R is a constant which may be found by dividing the universal gas constant ***R*** by the molecular weight of the gas, and Z is the compressibility factor. Z has the value of unity for an ideal gas under all conditions and, therefore, is a measure of the extent of the deviation of a real gas or vapor from the ideal state. Figures P-2.3A, P-2.3B, P-2.3C, pages 146, 147, and 148, are generalized plots of compressibility factor as a function of reduced pressure, P/P_c, and reduced temperature, T/T_c. The dotted curves represent constant values of the pseudo-reduced volume $v_r' = v/(RT_c/P_c)$ where the subscript c refers to the critical value. These may be used to calculate pressure (or temperature) when the temperature (or pressure) and specific volume are known. If P is expressed in pounds per square inch, v in cubic feet per pound, and T in degrees Rankine, the numerical value of ***R*** is 10.73. For critical property data, see paragraph P-7.

P-3 SPECIFIC HEAT

P-3.1 LIQUID PETROLEUM FRACTIONS

The specific heats of liquid petroleum fractions of various API gravities are shown as functions of temperature in Figure P-3.1, page 149. The specific heat versus temperature lines shown apply to virgin mid-continent stock and must be corrected for other stocks. An inset curve of this correction factor versus characterization factor is provided.

P-3.2 PETROLEUM VAPORS

The specific heats of petroleum vapors of various characterization factors are shown as functions of temperature in Figure P-3.2, page 150.

P-3 SPECIFIC HEAT—(Continued)

P-3.3 PURE HYDROCARBON GASES

The low pressure specific heats of a number of pure hydrocarbons are shown as functions of temperature in Figures P-3.3A, P-3.3B, and P-3.3C, pages 151, 152, and 153.

P-3.4 MISCELLANEOUS LIQUIDS AND GASES

The specific heats of miscellaneous liquids and gases at various temperatures may be read from the alignment charts, Figures P-3.4A and P-3.4B, pages 154 and 155.

P-3.5 GASES AND VAPORS AT ELEVATED PRESSURES

Specific heat data in Figures P-3.2, P-3.3A, P-3.3B, P-3.3C, and P-3.4B apply only at pressures low enough so that the specific heats are not significantly affected by pressure changes. At higher pressures, the specific heats may be substantially higher than the low pressure values. Figure P-3.5 is a generalized chart which may be used to calculate the approximate correction to the low pressure specific heat for any gas at high pressure. The isothermal change in molal specific heat, $\Delta C_p - C_p - C_p^*$, is plotted against reduced pressure, P_r, with reduced temperature, T_r, as a parameter. Outside the range of the chart, the following empirical equations are accurate enough for most practical purposes. For $T_r > 1.2$ and $\Delta C_p < 2$, $\Delta C_p = 5.03\ P_r/T_r^3$, for $T_r < 1.2$ and $\Delta C_p < 2.5$, $\Delta C_p = 9\ P_r/T_r^6$. For critical property data, see Paragraph P-7.1, and P-7.2.

P-4 HEAT CONTENT OF PETROLEUM FRACTIONS

P-4.1 Heat content of petroleum fractions including the effect of pressure, are shown as functions of temperature and API gravity for UOP K=12 in Figure P-4.1.

P-4.2 The latent heats of vaporization of various liquids may be estimated by the use of Figure P-4.2. The recommended range of use is indicated for the compounds listed.

P-5 THERMAL CONDUCTIVITY

P-5.1 CONVERSION OF UNITS

Table P-5.1, page 159, gives factors for converting thermal conductivity values from one set of units to another.

P-5.2 LIQUID PETROLEUM FRACTIONS

The thermal conductivities of liquid petroleum fractions and hydrocarbon mixtures are shown in Figure P-5.2, page 159. The chart should not be used for pseudo-reduced temperatures exceeding 0.85.

P-5.3 PURE HYDROCARBON LIQUIDS

The thermal conductivities of liquid normal paraffinic hydrocarbons are shown in Figure P-5.3, page 160.

P-5.4 MISCELLANEOUS LIQUIDS AND GASES

Tables P-5.4A and P-5.4B, pages 161 and 162, give tabulated values of thermal conductivity for a number of liquids and gases.

P-5.5 GASES AND VAPORS AT ELEVATED PRESSURES

Thermal conductivity values in Table P-5.4B are for gases and vapors at low pressure, and will, in general, be low for pressures much in excess of one atmosphere. Published correlations for the effect of pressure appear to give scattered results for simple molecules.

P-6 VISCOSITY

P-6.1 VISCOSITY CONVERSION

A viscosity conversion plot, Figure P-6.1, page 163, provides a means of converting viscosity from Saybolt, Redwood, or Engler time to kinematic viscosity in centistokes. The absolute viscosity in centipoises may be determined by multiplying the kinematic viscosity in centistokes by the specific gravity. Table P-6.1, page 163, gives factors for converting viscosity values to various systems of units.

P-6.2 The viscosities of petroleum oils having Watson and Nelson (UOP) characterization factors of 10.0, 11.0, 11.8 and 12.5 are shown plotted against temperatures in Figures P-6.2A, B, C and D, pages 164 and 165.

P-6.3 LIQUID PETROLEUM FRACTIONS

Figures P-6.3A and P-6.3B, pages 166 and 167, give viscosity data for a number of typical petroleum fractions plotted as straight lines on ASTM viscosity charts. These charts are so constructed that for any given petroleum oil the viscosity-temperature points lie on a straight line. They are, therefore, a convenient means for determining the viscosity of a petroleum oil at any temperature, provided viscosities at two temperatures are known.

P-6.4 MISCELLANEOUS LIQUIDS AND GASES

The viscosity of certain liquids are shown as functions of temperature in Figure P-6.4A, page 168. The viscosities of certain gases and vapors at one atmosphere pressure are given by Figure P-6.4B, page 169.

P-6.5 EFFECT OF PRESSURE ON GAS VISCOSITY

Figure P-6.5, page 170, is a generalized chart which may be used to estimate the viscosities of gases and vapors at elevated pressure if the critical temperature and pressure and the viscosity at low pressure are known. The viscosity ratio, μ_p/μ_{atm}, is plotted against reduced pressure, P_r, with reduced temperature, T_r, as parameter. In this μ_{atm} and μ_p are respectively the viscosities at atmospheric pressure and at pressure P. For critical property data, see paragraph P.7.

P-7 CRITICAL PROPERTIES

P-7.1 PURE SUBSTANCES

Table P-7.1, page 170, gives values of the molecular weights, critical temperatures, and critical pressures for a variety of pure compounds. For the calculation of compressibility factor, it is recommended that the critical pressures and temperatures of hydrogen, helium, and neon be increased by 118 psi and 14.4°R. respectively.

P-7.2 GAS AND VAPOR MIXTURES

Figures P-2.3, P-3.5, and P-6.5 may be used to estimate the properties of gas mixtures as well as pure substances if pseudo-critical properties are used in place of the critical values. The pseudo-critical temperature and pressure are defined as follows:

$$T_{p.c.} = Y_1 T_{c1} + Y_2 T_{c2} + \ldots\ldots$$
$$P_{p.c.} = Y_1 P_{c1} + Y_2 P_{c2} + \ldots\ldots$$

where Y_1, Y_2, etc. are the mole fractions of the individual components and T_{c1}, T_{c2}, etc., and P_{c1}, P_{c2}, etc. are their critical temperatures and pressures.

P-8 SELECTED REFERENCES

P-8.1 Reid, R. C. and Sherwood, T. K., Properties of Gases and Liquids, 2nd Ed., McGraw Hill Book Company Inc., New York 1966.

P-8.2 Comings, E. W., High Pressure Technology, McGraw Hill Book Company, Inc. New York 1956.

P-8.3 Hougan, O. A., Watson, K. M., Ragatz, R. A., Chemical Process Principles Part I, 2nd Ed., John Wiley & Sons, Inc., New York. 1956.

P-8.4 Tsederberg, N. V., Thermal Conductivities of Gases and Liquids, The M.I.T. Press, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1965.

FIGURE P-1

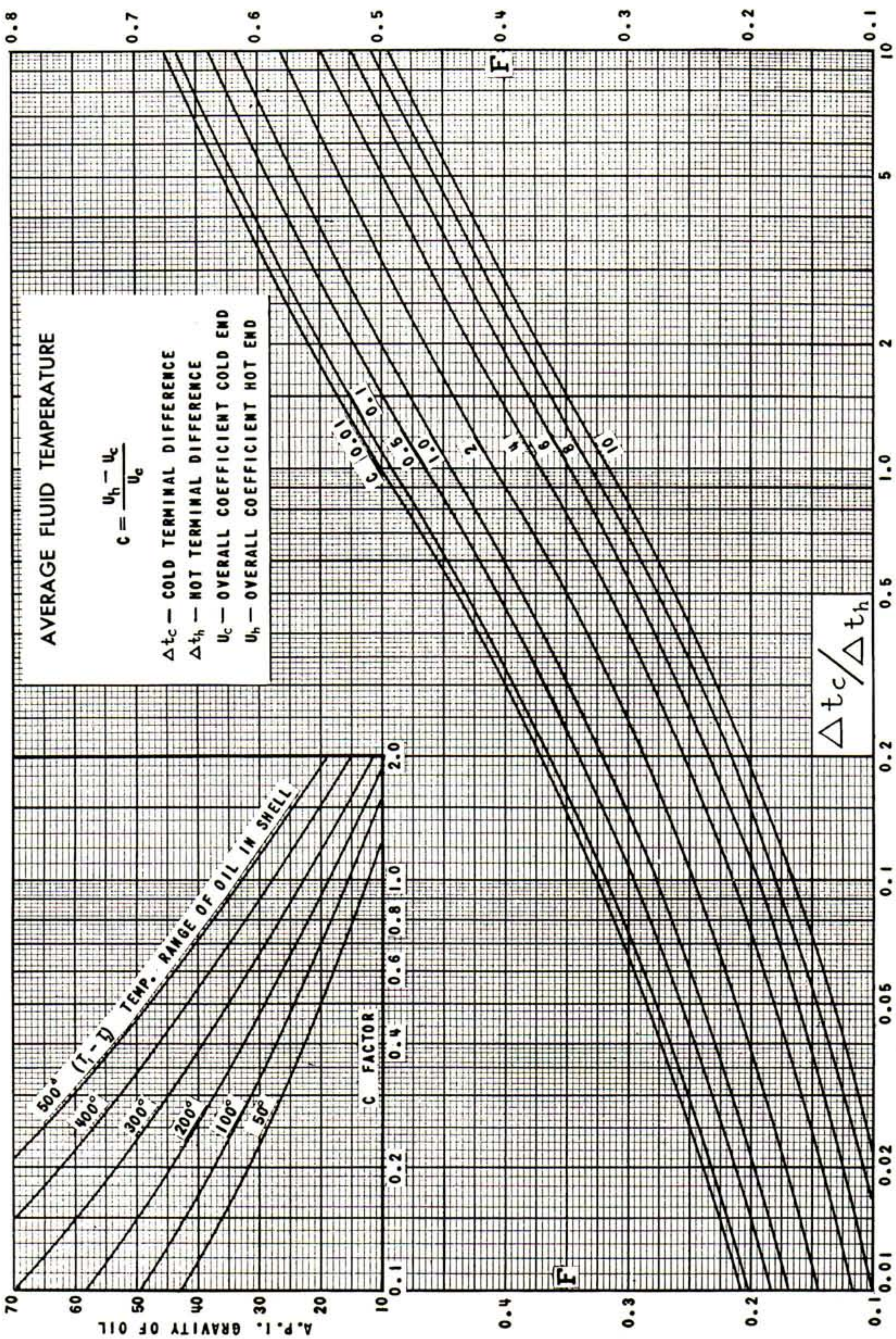

AVERAGE FLUID TEMPERATURE
C = (U_h − U_c) / U_c
Δt_c — COLD TERMINAL DIFFERENCE
Δt_h — HOT TERMINAL DIFFERENCE
U_c — OVERALL COEFFICIENT COLD END
U_h — OVERALL COEFFICIENT HOT END
F
Δt_c/Δt_h
C FACTOR
A.P.I. GRAVITY OF OIL
(T1 − T2) TEMP. RANGE OF OIL IN SHELL
500°
400°
300°
200°
100°
50°
C 0.0
0.1
0.5
1.0
2
4
6
8
10

FIGURE P-2.1

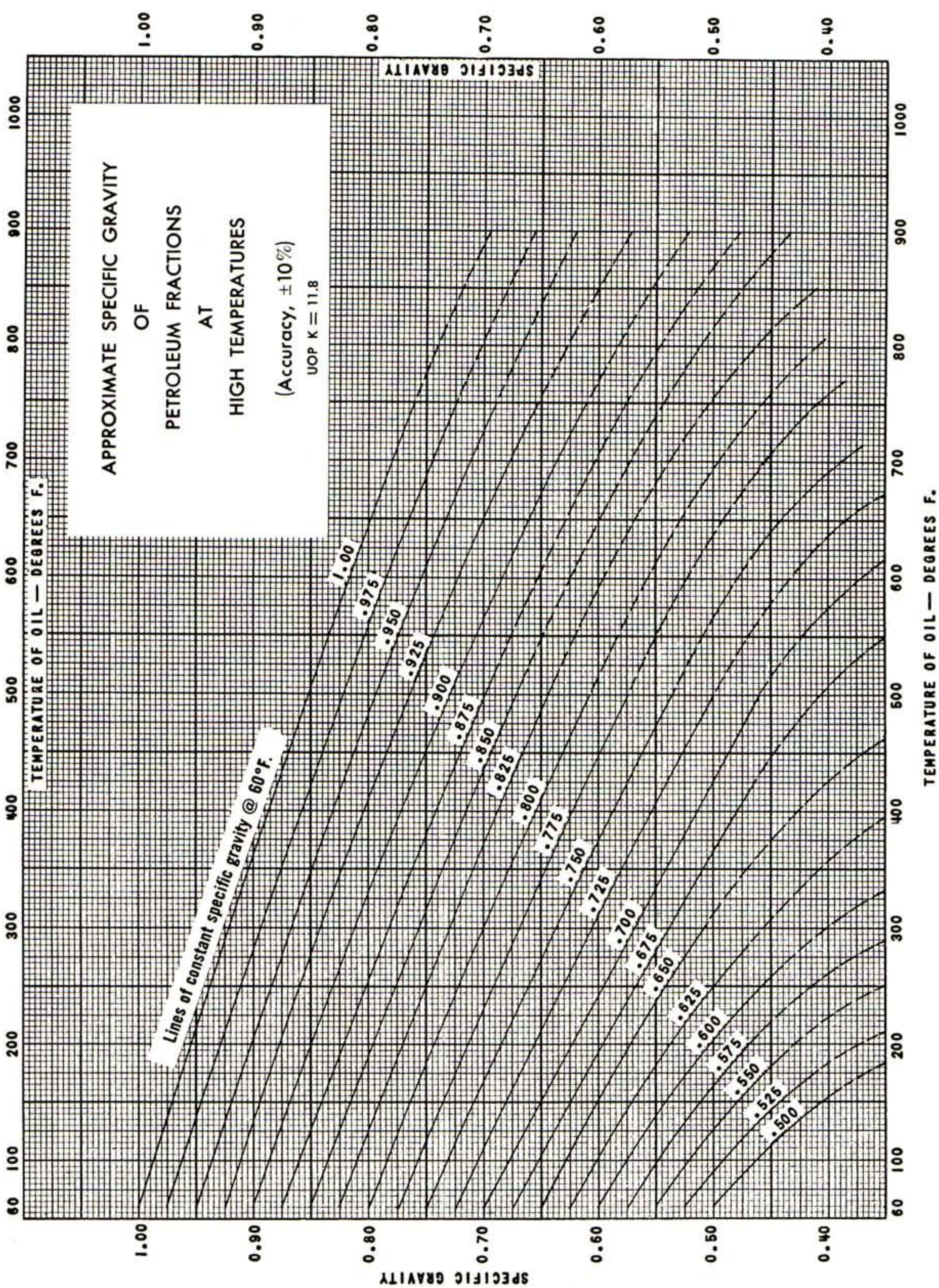

APPROXIMATE SPECIFIC GRAVITY
OF
PETROLEUM FRACTIONS
AT
HIGH TEMPERATURES
(Accuracy, ±10%)
UOP K = 11.8
Lines of constant specific gravity @ 60°F.
1.00
.975
.950
.925
.900
.875
.850
.825
.800
.775
.750
.725
.700
.675
.650
.625
.600
.575
.550
.525
.500
SPECIFIC GRAVITY
1.00
0.90
0.80
0.70
0.60
0.50
0.40
TEMPERATURE OF OIL — DEGREES F.
60
100
200
300
400
500
600
700
800
900
1000

FIGURE P-2.2

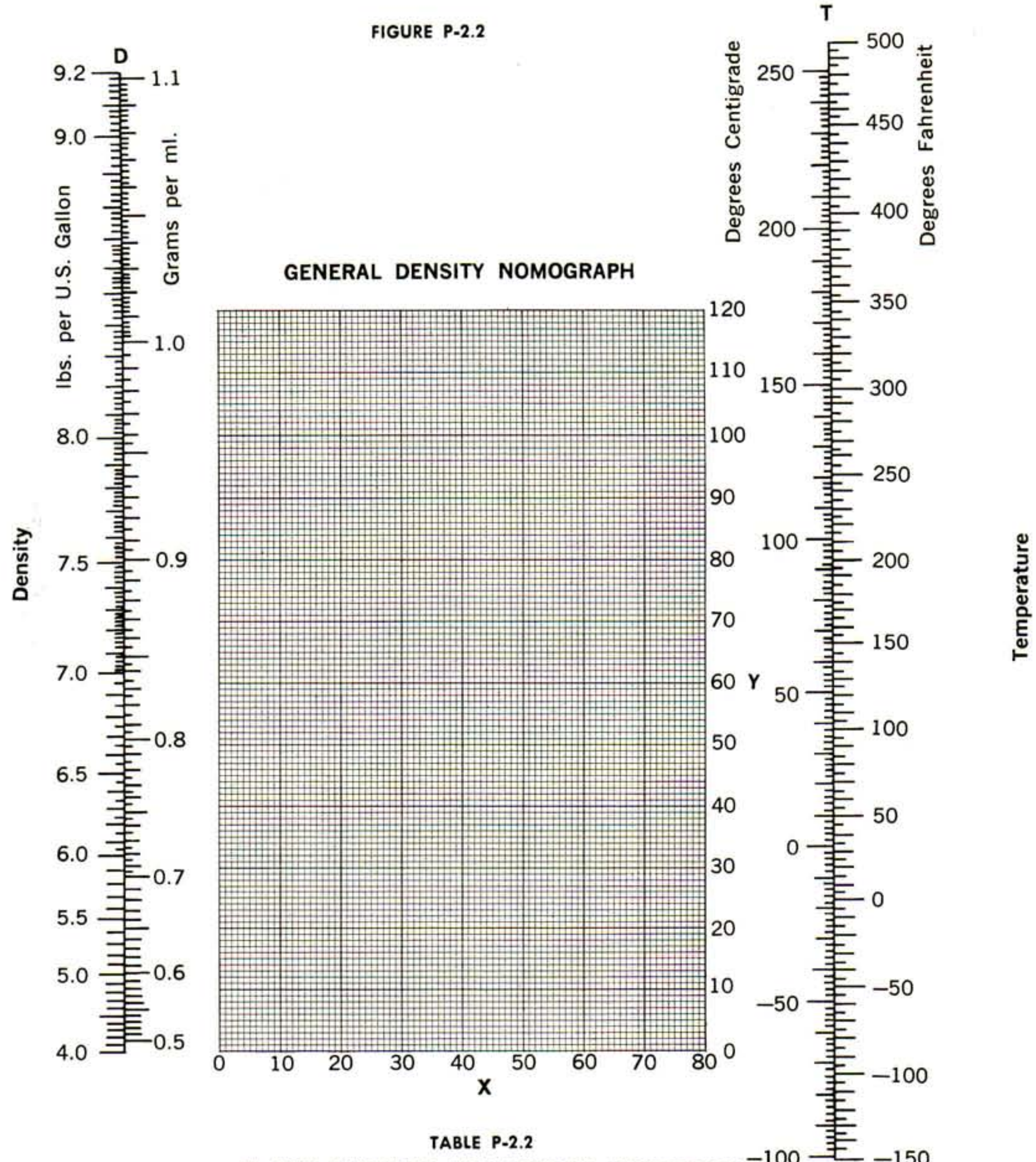


TABLE P-2.2

X AND Y VALUES FOR DENSITY NOMOGRAPH

Compound	X	Y	Compound	X	Y	Compound	X	Y
Acetic Acid	40.6	93.5	Ethyl chloride	42.7	62.4	Methyl sulfide	31.9	57.4
Acetone	26.1	47.8	Ethylene	17.0	3.5	n-Nonane	16.2	36.5
Acetonitrile	21.8	44.9	Ethyl ether	22.6	35.8	n-Octadecane	16.2	46.5
Acetylene	20.8	10.1	Ethyl formate	37.6	68.4	n-Octane	12.7	32.5
Ammonia	22.4	24.6	Ethyl propionate	32.1	63.9	n-Pentadecane	15.8	44.2
Isoamyl alcohol	20.5	52.0	Ethyl propyl ether	20.0	37.0	n-Pentane	12.6	22.6
Ammine	33.5	92.5	Ethyl auindo	25.7	55.3	n-Nonadecane	14.9	47.0
Benzene	32.7	63.0	Fluorobenzene	41.9	87.6	Isopentane	13.5	22.5
n-Butyric acid	31.3	78.7	n-Heptadecane	15.6	45.7	Phenol	36.7	103.8
Isobutane	13.7	16.5	n-Heptane	12.6	29.8	Phosphine	28.0	22.1
Isobutyric acid	31.5	75.9	n-Hexadecane	15.8	45.0	Propane	14.2	12.2
Carbon dioxide	78.6	45.4	n-Hexane	13.5	27.0	Propionic acid	35.0	83.5
Chlorobenzene	41.7	105.0	Methanethiol	37.3	59.5	Piperidene	27.5	60.0
Cyclohexane	19.6	44.0	Methyl acetate	40.1	70.3	Propionitrile	20.1	44.6
n-Decane	16.0	38.2	Methyl alcohol	25.8	49.1	Propyl acetate	33.0	65.5
n-Dedecane	14.3	41.4	Methyl n-butyrate	31.5	65.5	Propyl alcohol	23.8	50.8
Diethylamine	17.8	33.5	Methyl isobutyrate	33.0	64.1	Propyl formate	33.8	66.7
n-Elconane	14.8	47.5	Methyl chloride	52.3	62.9	n-Tetradecane	15.8	43.3
Ethane	10.8	4.4	Methyl ether	27.2	30.1	n-Tridecane	15.3	42.4
Ethanethiol	32.0	55.5	Methyl ethyl ether	25.0	34.4	Triethylamine	17.9	37.0
Ethyl acetate	35.0	95.0	Methyl formate	46.4	74.6	n-Undecane	14.4	39.2
Ethyl alcohol	24.2	48.6	Methyl propionate	36.5	68.3			

Ref: Othmer, Josefowitz & Schmutzler, Ind. Engr. Chem. Vol. 40,5,883-5

FIGURE P-2.3A

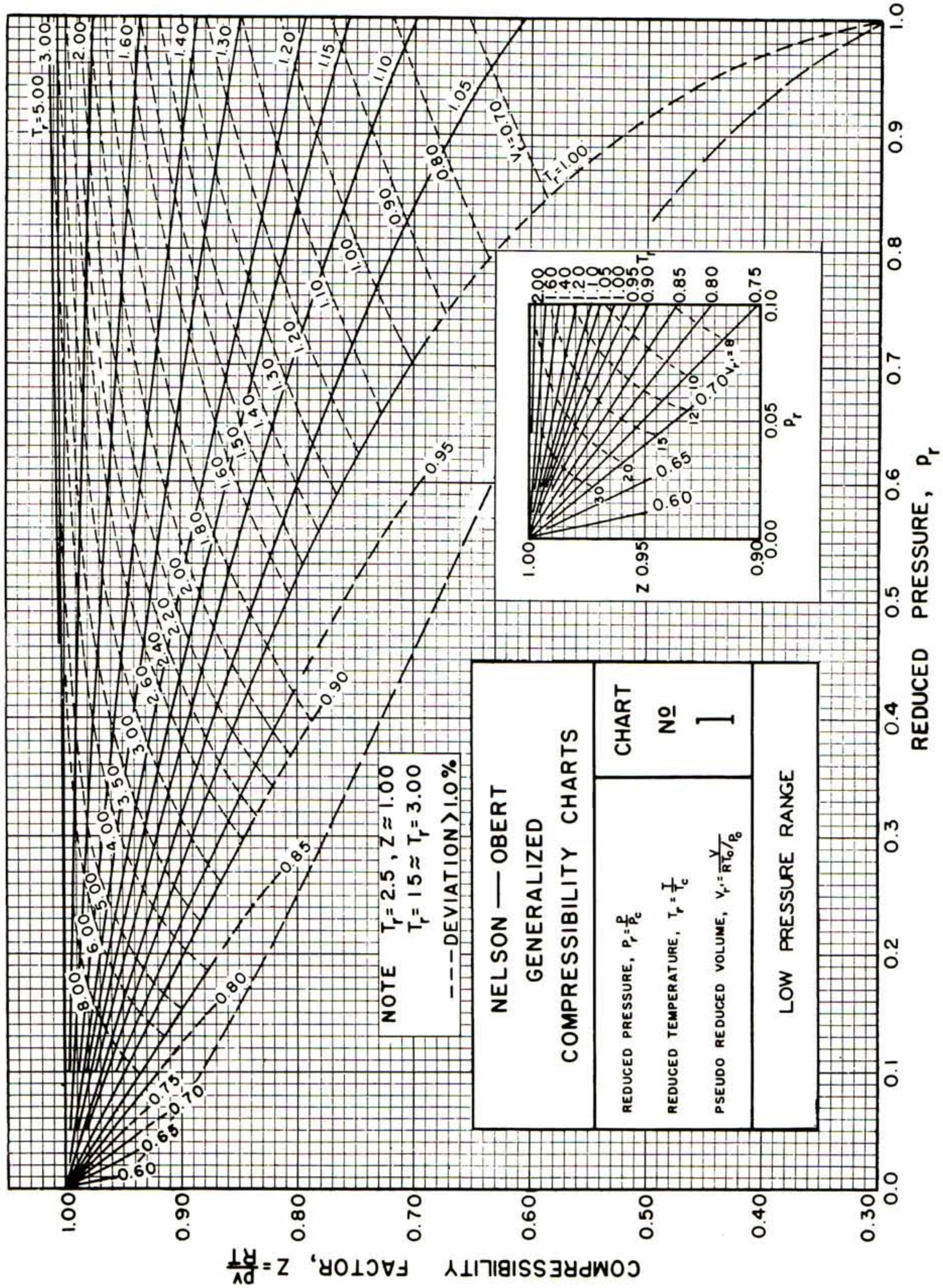

NELSON — OBERT
GENERALIZED
COMPRESSIBILITY CHARTS
CHART
No 1
REDUCED PRESSURE, $P_r = \frac{P}{P_c}$
REDUCED TEMPERATURE, $T_r = \frac{T}{T_c}$
PSEUDO REDUCED VOLUME, $V_r' = \frac{V}{RT_c/P_c}$
LOW PRESSURE RANGE
NOTE $T_r = 2.5$, $Z \simeq 1.00$
$T_r = 15 \simeq T_r = 3.00$
---DEVIATION > 1.0%
REDUCED PRESSURE, P_r
COMPRESSIBILITY FACTOR, $Z = \frac{PV}{RT}$

FIGURE P-2.3B

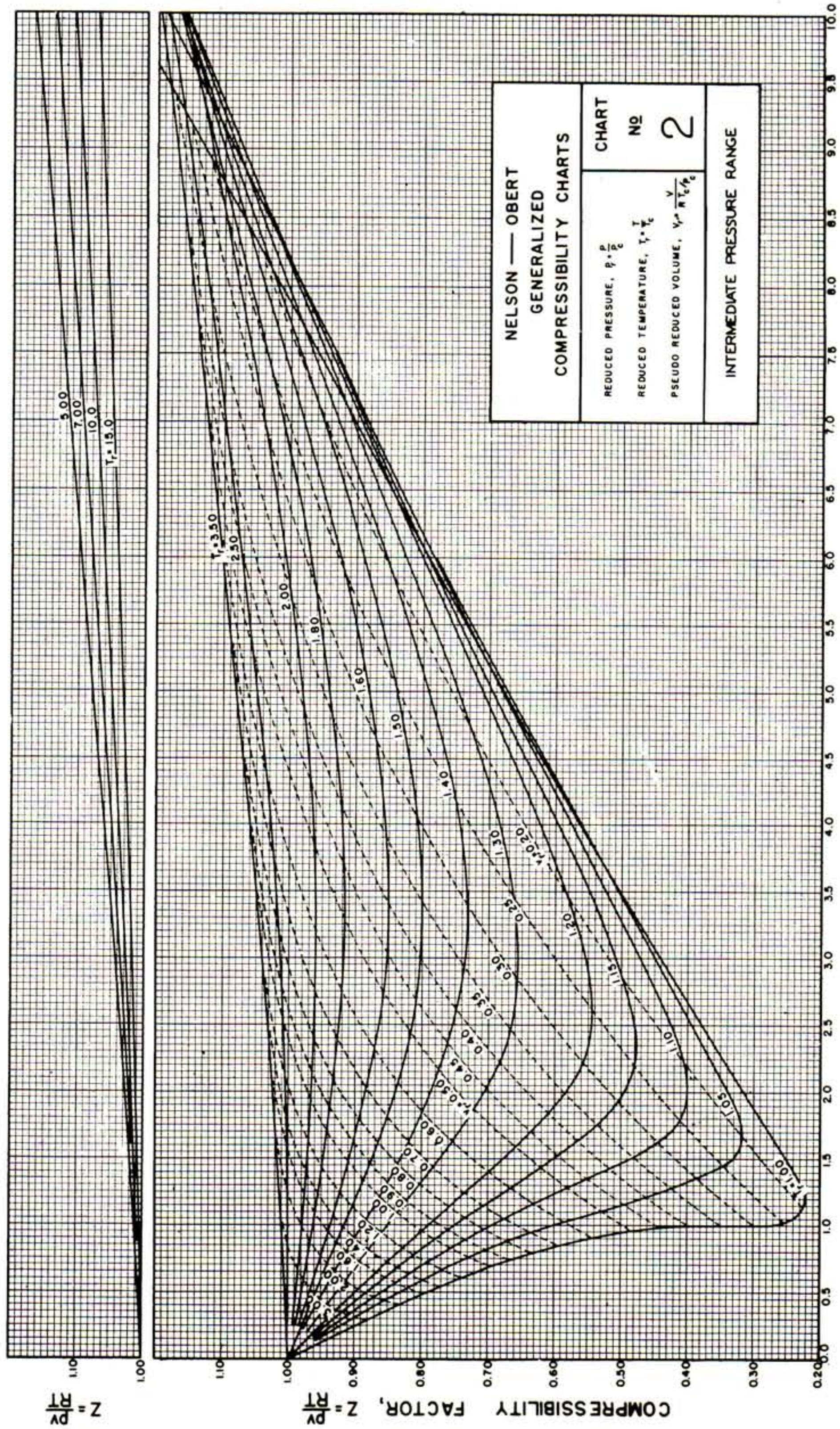

NELSON — OBERT
GENERALIZED
COMPRESSIBILITY CHARTS
CHART
No
2
INTERMEDIATE PRESSURE RANGE
REDUCED PRESSURE, P_r
COMPRESSIBILITY FACTOR, $Z = \frac{PV}{RT}$
$Z = \frac{PV}{RT}$

FIGURE P-2.3C

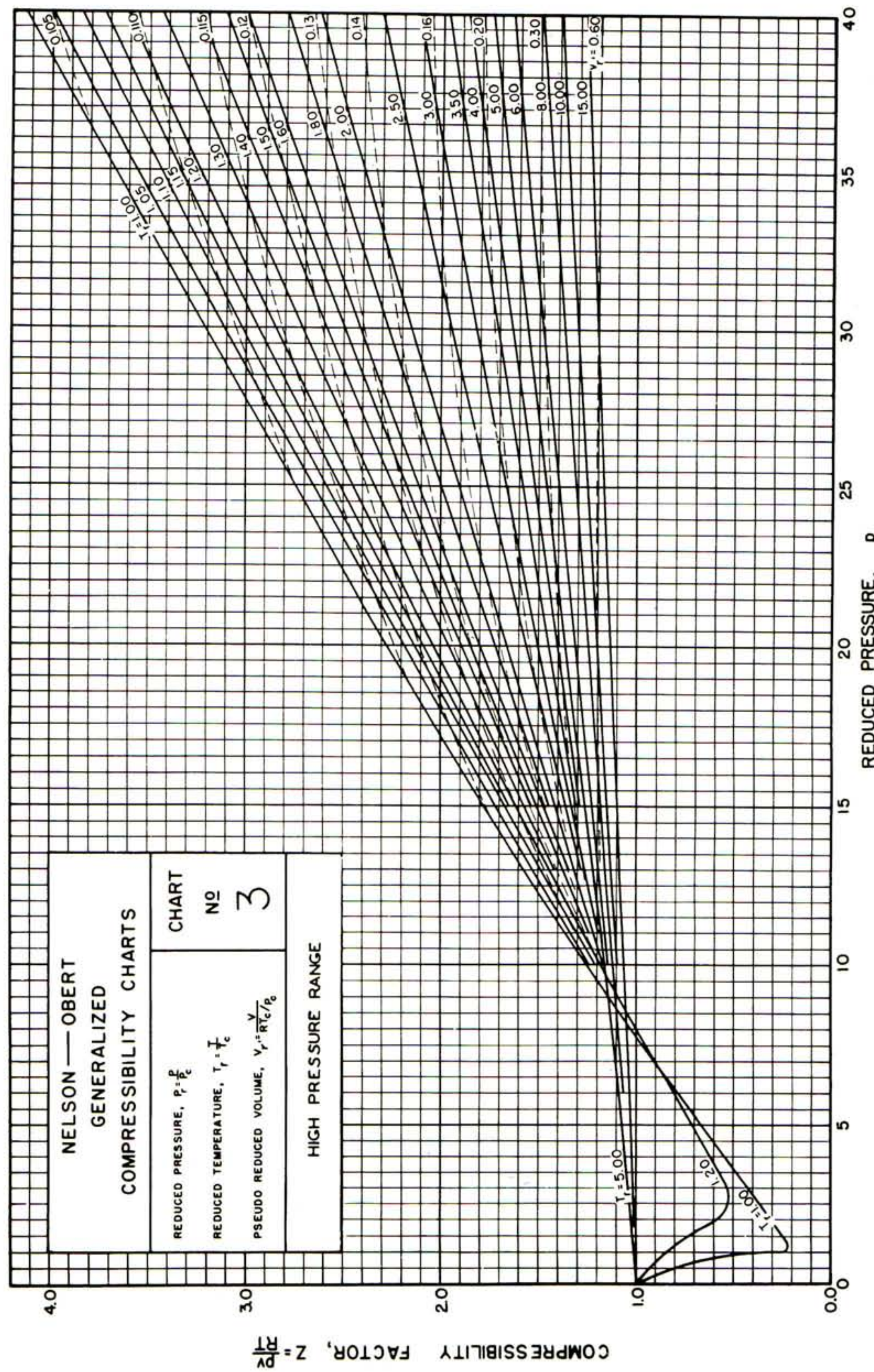

NELSON — OBERT
GENERALIZED
COMPRESSIBILITY CHARTS
REDUCED PRESSURE, $P_r = \frac{P}{P_c}$
REDUCED TEMPERATURE, $T_r = \frac{T}{T_c}$
PSEUDO REDUCED VOLUME, $V_r' = \frac{V}{RT_c/P_c}$
CHART
No
3
HIGH PRESSURE RANGE
REDUCED PRESSURE, P_r
COMPRESSIBILITY FACTOR, $Z = \frac{PV}{RT}$

FIGURE P-3.1

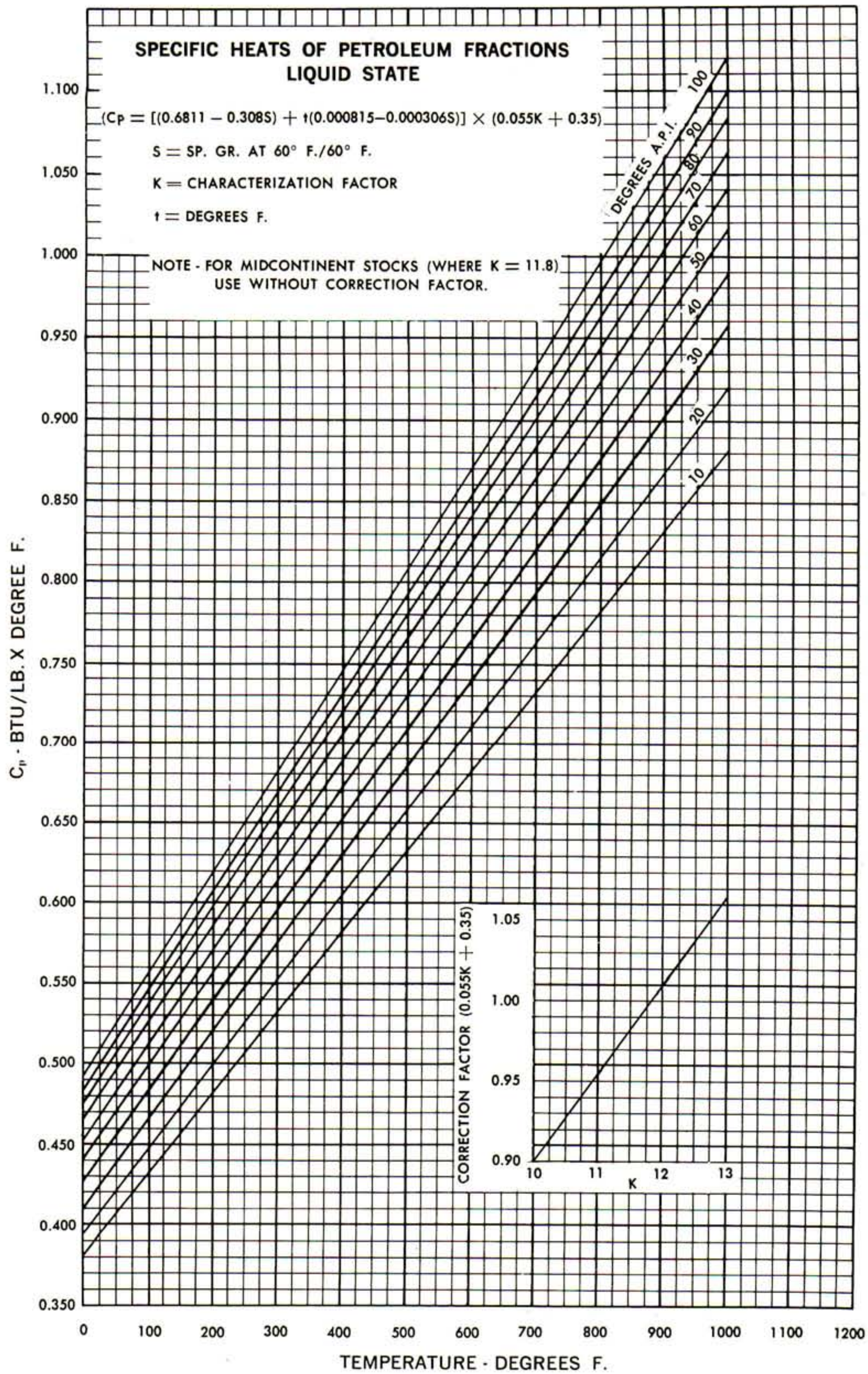

SPECIFIC HEATS OF PETROLEUM FRACTIONS
LIQUID STATE
(Cp = [(0.6811 − 0.308S) + t(0.000815−0.000306S)] × (0.055K + 0.35))
S = SP. GR. AT 60° F./60° F.
K = CHARACTERIZATION FACTOR
t = DEGREES F.
NOTE - FOR MIDCONTINENT STOCKS (WHERE K = 11.8)
USE WITHOUT CORRECTION FACTOR.
DEGREES A.P.I.
100
90
80
70
60
50
40
30
20
10
Cp - BTU/LB. X DEGREE F.
1.100
1.050
1.000
0.950
0.900
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
TEMPERATURE - DEGREES F.
CORRECTION FACTOR (0.055K + 0.35)
1.05
1.00
0.95
0.90
10
11
12
13
K

FIGURE P-3.2

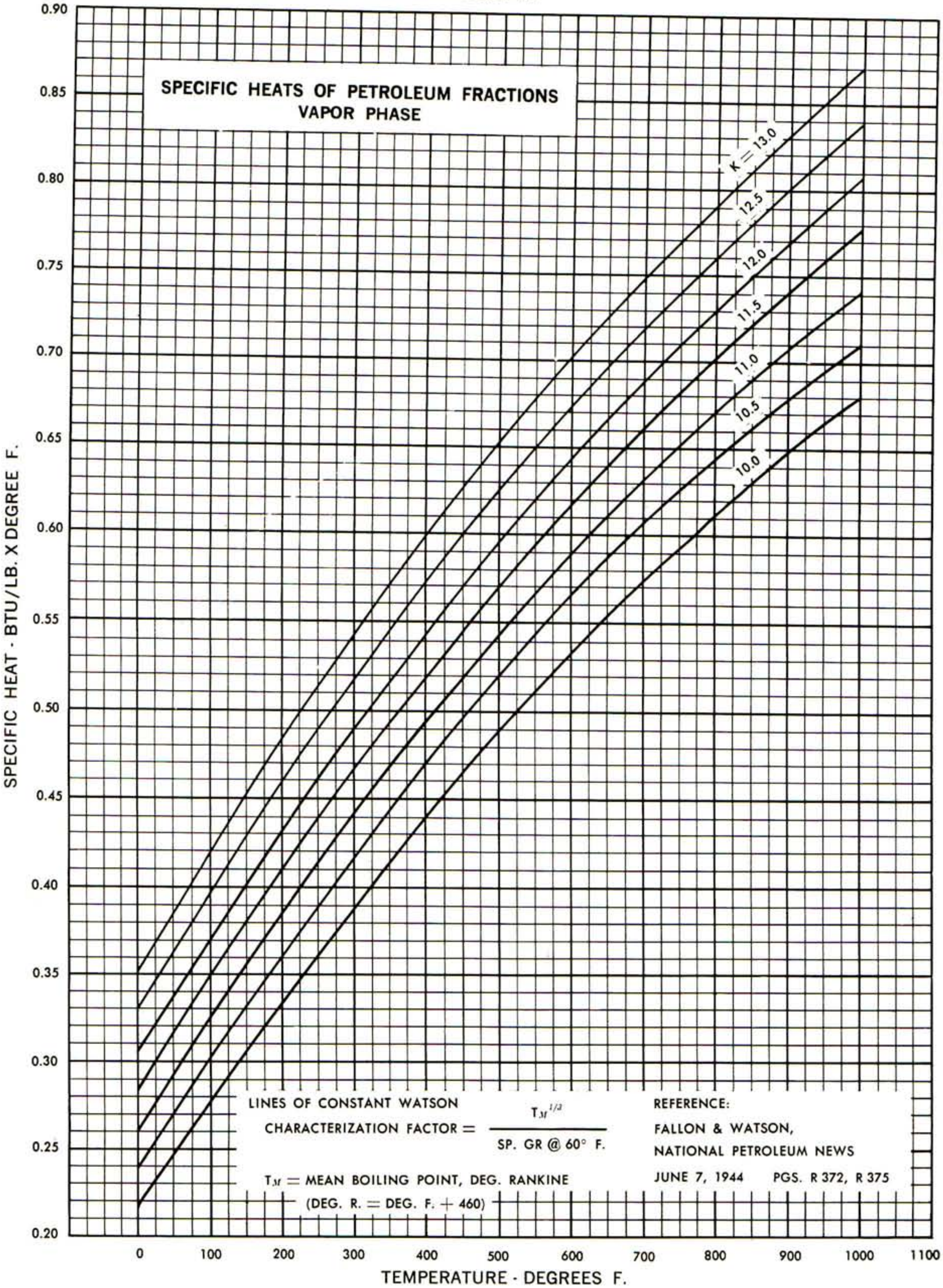

SPECIFIC HEATS OF PETROLEUM FRACTIONS
VAPOR PHASE
K = 13.0
12.5
12.0
11.5
11.0
10.5
10.0
SPECIFIC HEAT - BTU/LB. X DEGREE F.
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0
100
200
300
400
500
600
700
800
900
1000
1100
TEMPERATURE - DEGREES F.
LINES OF CONSTANT WATSON
CHARACTERIZATION FACTOR = $T_M^{1/3}$ / SP. GR @ 60° F.
T_M = MEAN BOILING POINT, DEG. RANKINE
(DEG. R. = DEG. F. + 460)
REFERENCE:
FALLON & WATSON,
NATIONAL PETROLEUM NEWS
JUNE 7, 1944 PGS. R 372, R 375

FIGURE P-3.3A

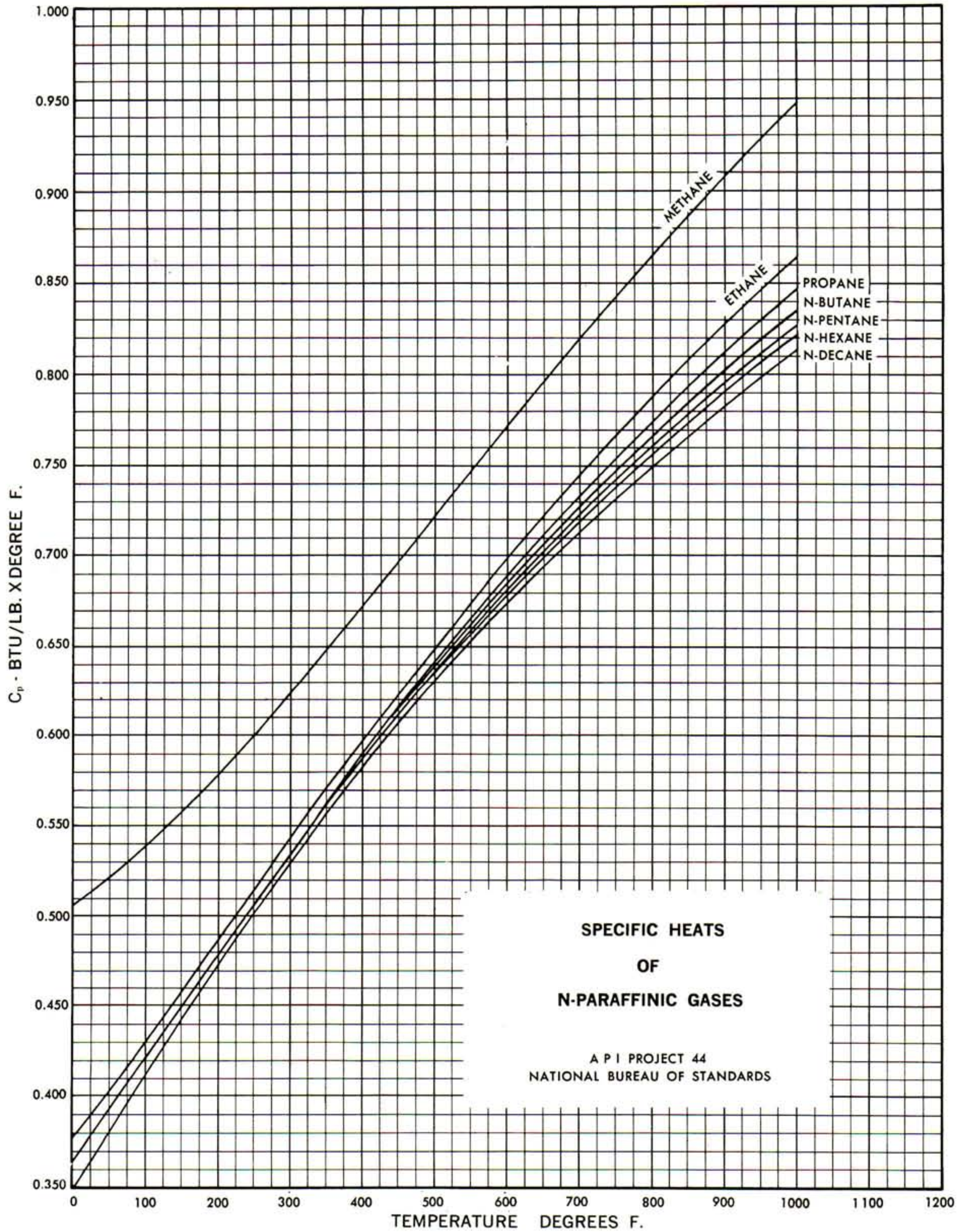

1.000
0.950
0.900
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
C_p - BTU/LB. X DEGREE F.
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
TEMPERATURE DEGREES F.
METHANE
ETHANE
PROPANE
N-BUTANE
N-PENTANE
N-HEXANE
N-DECANE
SPECIFIC HEATS
OF
N-PARAFFINIC GASES
A P I PROJECT 44
NATIONAL BUREAU OF STANDARDS

FIGURE P-3.3B

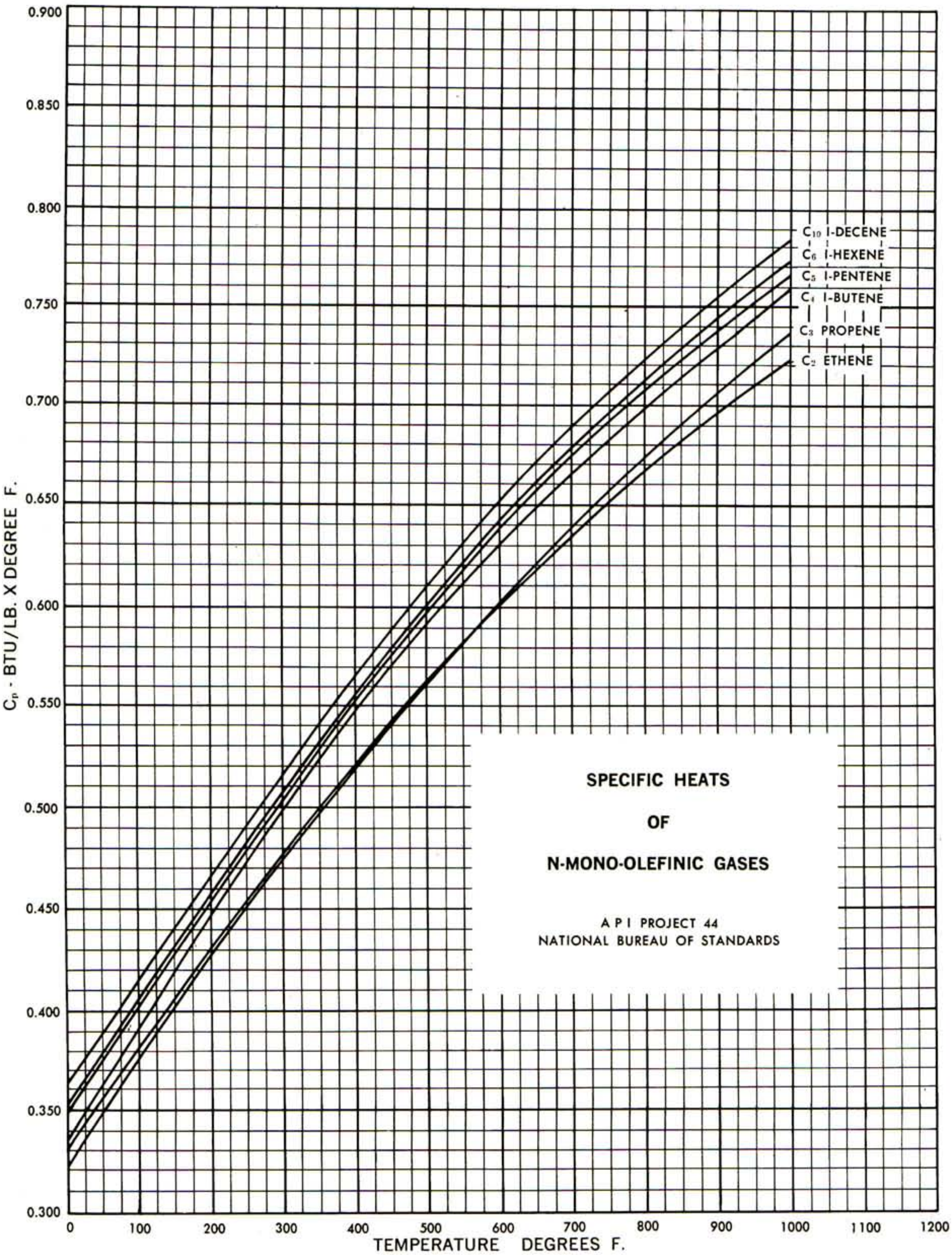

0.900
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
C_p - BTU/LB. X DEGREE F.
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
TEMPERATURE DEGREES F.
C_{10} 1-DECENE
C_6 1-HEXENE
C_5 1-PENTENE
C_4 1-BUTENE
C_3 PROPENE
C_2 ETHENE
SPECIFIC HEATS
OF
N-MONO-OLEFINIC GASES
A P I PROJECT 44
NATIONAL BUREAU OF STANDARDS

FIGURE P-3.3C

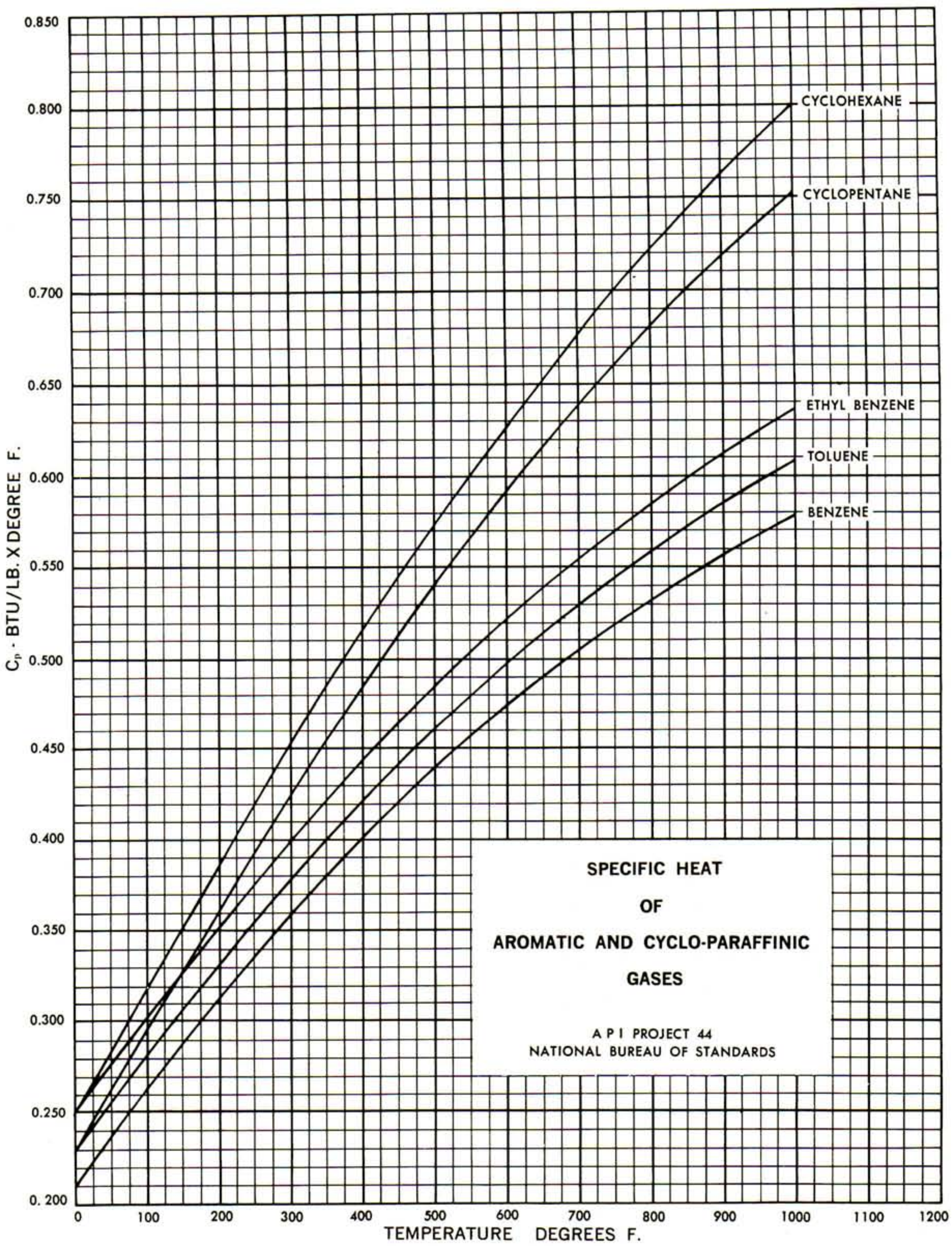
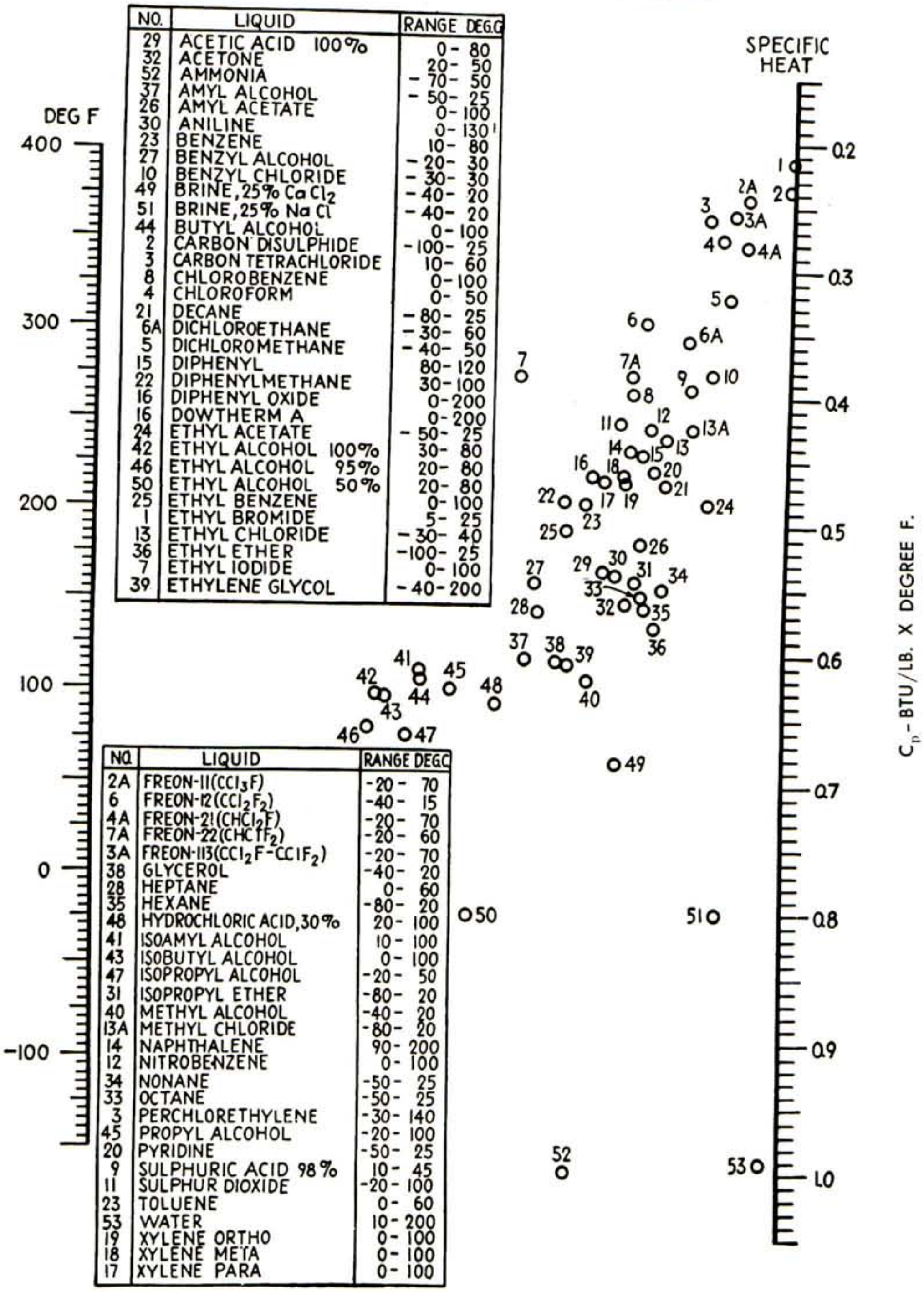

SPECIFIC HEAT
OF
AROMATIC AND CYCLO-PARAFFINIC
GASES
A P I PROJECT 44
NATIONAL BUREAU OF STANDARDS
CYCLOHEXANE
CYCLOPENTANE
ETHYL BENZENE
TOLUENE
BENZENE
C_p - BTU/LB. X DEGREE F.
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0. 200
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
TEMPERATURE DEGREES F.

FIGURE P-3.4A

SPECIFIC HEATS OF LIQUIDS



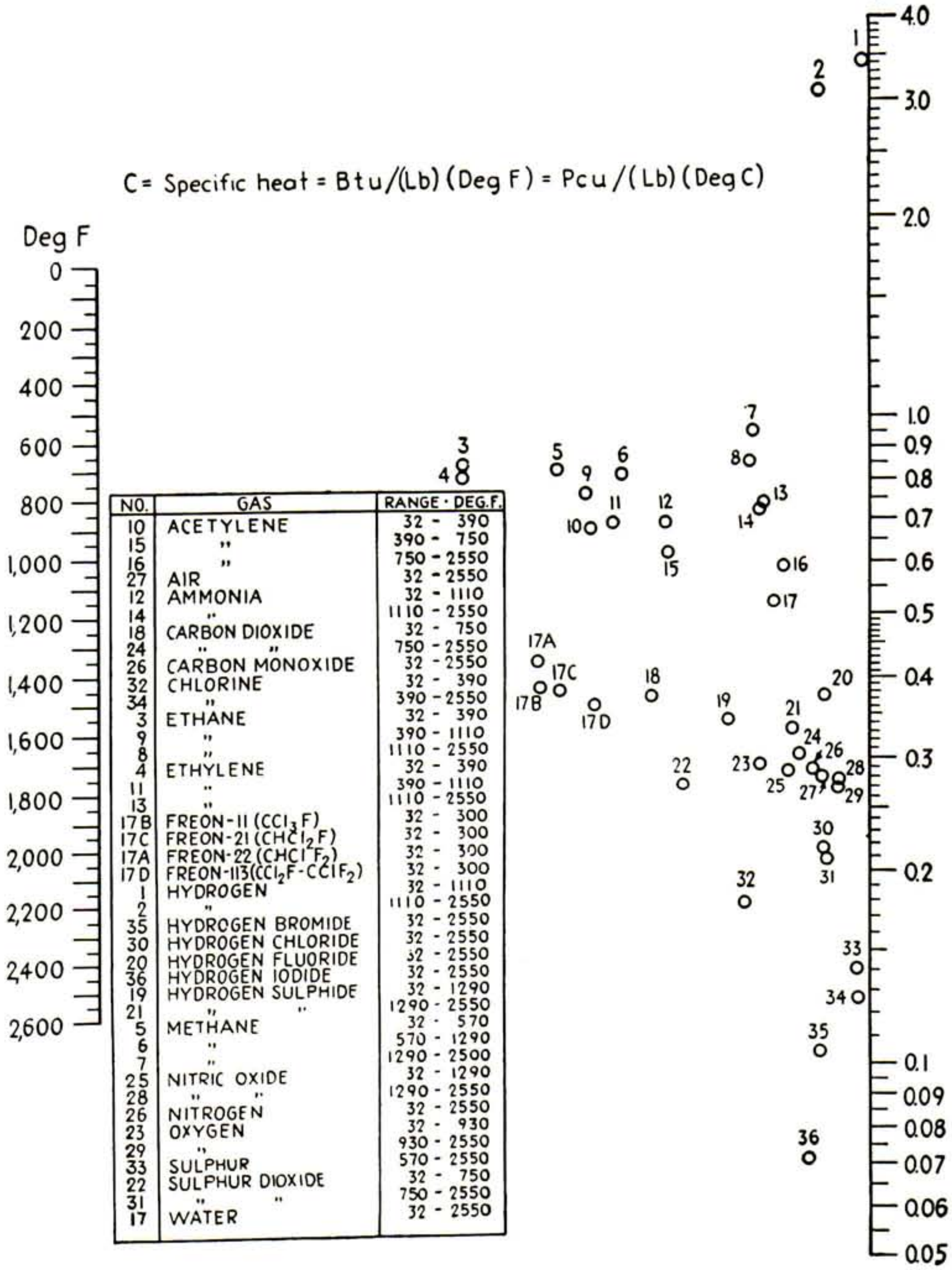
NO.	LIQUID	RANGE DEG.C
29	ACETIC ACID 100%	0 - 80
32	ACETONE	20 - 50
52	AMMONIA	-70 - 50
37	AMYL ALCOHOL	-50 - 25
26	AMYL ACETATE	0 - 100
30	ANILINE	0 - 130
23	BENZENE	10 - 80
27	BENZYL ALCOHOL	-20 - 30
10	BENZYL CHLORIDE	-30 - 30
49	BRINE, 25% $CaCl_2$	-40 - 20
51	BRINE, 25% NaCl	-40 - 20
44	BUTYL ALCOHOL	0 - 100
2	CARBON DISULPHIDE	-100 - 25
3	CARBON TETRACHLORIDE	10 - 60
8	CHLOROBENZENE	0 - 100
4	CHLOROFORM	0 - 50
21	DECANE	-80 - 25
6A	DICHLOROETHANE	-30 - 60
5	DICHLOROMETHANE	-40 - 50
15	DIPHENYL	80 - 120
22	DIPHENYLMETHANE	30 - 100
16	DIPHENYL OXIDE	0 - 200
16	DOWTHERM A	0 - 200
24	ETHYL ACETATE	-50 - 25
42	ETHYL ALCOHOL 100%	30 - 80
46	ETHYL ALCOHOL 95%	20 - 80
50	ETHYL ALCOHOL 50%	20 - 80
25	ETHYL BENZENE	0 - 100
1	ETHYL BROMIDE	5 - 25
13	ETHYL CHLORIDE	-30 - 40
36	ETHYL ETHER	-100 - 25
7	ETHYL IODIDE	0 - 100
39	ETHYLENE GLYCOL	-40 - 200

NO.	LIQUID	RANGE DEG.C
2A	FREON-11 (CCl_3F)	-20 - 70
6	FREON-12 (CCl_2F_2)	-40 - 15
4A	FREON-21 ($CHCl_2F$)	-20 - 70
7A	FREON-22 ($CHClF_2$)	-20 - 60
3A	FREON-113 (CCl_2F-$CClF_2$)	-20 - 70
38	GLYCEROL	-40 - 20
28	HEPTANE	0 - 60
35	HEXANE	-80 - 20
48	HYDROCHLORIC ACID, 30%	20 - 100
41	ISOAMYL ALCOHOL	10 - 100
43	ISOBUTYL ALCOHOL	0 - 100
47	ISOPROPYL ALCOHOL	-20 - 50
31	ISOPROPYL ETHER	-80 - 20
40	METHYL ALCOHOL	-40 - 20
13A	METHYL CHLORIDE	-80 - 20
14	NAPHTHALENE	90 - 200
12	NITROBENZENE	0 - 100
34	NONANE	-50 - 25
33	OCTANE	-50 - 25
3	PERCHLORETHYLENE	-30 - 140
45	PROPYL ALCOHOL	-20 - 100
20	PYRIDINE	-50 - 25
9	SULPHURIC ACID 98%	10 - 45
11	SULPHUR DIOXIDE	-20 - 100
23	TOLUENE	0 - 60
53	WATER	10 - 200
19	XYLENE ORTHO	0 - 100
18	XYLENE META	0 - 100
17	XYLENE PARA	0 - 100

FIGURE P-3.4B

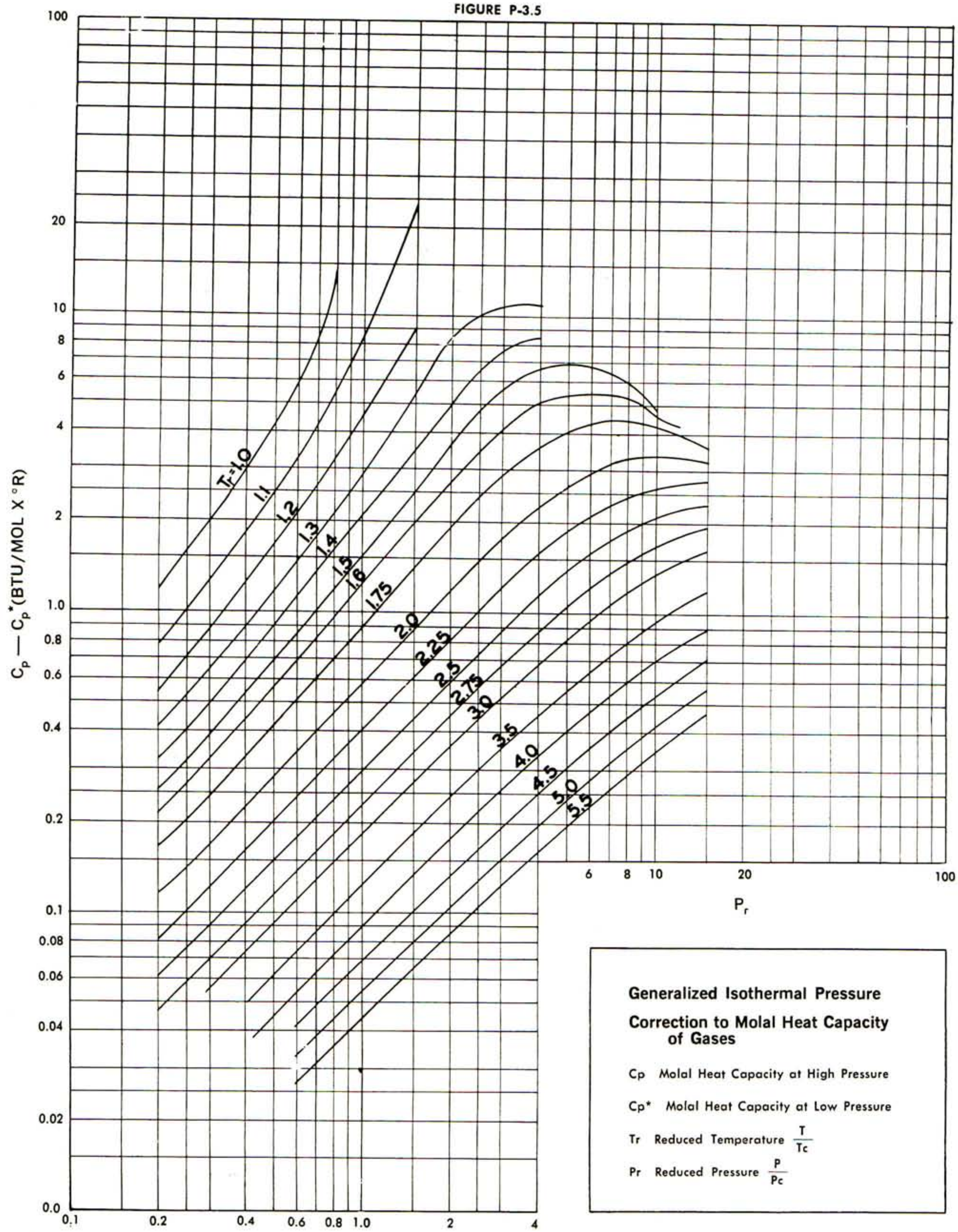
SPECIFIC HEATS-GASES 1 ATM.

C = Specific heat = Btu/(Lb) (Deg F) = Pcu/(Lb) (Deg C)



NO.	GAS	RANGE - DEG.F.
10	ACETYLENE	32 - 390
15	"	390 - 750
16	"	750 - 2550
27	AIR	32 - 2550
12	AMMONIA	32 - 1110
14	"	1110 - 2550
18	CARBON DIOXIDE	32 - 750
24	" "	750 - 2550
26	CARBON MONOXIDE	32 - 2550
32	CHLORINE	32 - 390
34	"	390 - 2550
3	ETHANE	32 - 390
9	"	390 - 1110
8	"	1110 - 2550
4	ETHYLENE	32 - 390
11	"	390 - 1110
13	"	1110 - 2550
17B	FREON-11 (CCl_3F)	32 - 300
17C	FREON-21 ($CHCl_2F$)	32 - 300
17A	FREON-22 ($CHClF_2$)	32 - 300
17D	FREON-113 (CCl_2F-$CClF_2$)	32 - 300
1	HYDROGEN	32 - 1110
2	"	1110 - 2550
35	HYDROGEN BROMIDE	32 - 2550
30	HYDROGEN CHLORIDE	32 - 2550
20	HYDROGEN FLUORIDE	32 - 2550
36	HYDROGEN IODIDE	32 - 2550
19	HYDROGEN SULPHIDE	32 - 1290
21	" "	1290 - 2550
5	METHANE	32 - 570
6	"	570 - 1290
7	"	1290 - 2500
25	NITRIC OXIDE	32 - 1290
28	" "	1290 - 2550
26	NITROGEN	32 - 2550
23	OXYGEN	32 - 930
29	"	930 - 2550
33	SULPHUR	570 - 2550
22	SULPHUR DIOXIDE	32 - 750
31	" "	750 - 2550
17	WATER	32 - 2550

FIGURE P-3.5



Generalized Isothermal Pressure Correction to Molal Heat Capacity of Gases

Cp Molal Heat Capacity at High Pressure

Cp* Molal Heat Capacity at Low Pressure

Tr Reduced Temperature $\frac{T}{Tc}$

Pr Reduced Pressure $\frac{P}{Pc}$

Reprinted by permission from Industrial and Engineering Chemistry, vol. 49, p. 121, 1957. A. H. Weiss and J. Joffe.

FIGURE 4.1

HEAT CONTENT OF PETROLEUM FRACTIONS INCLUDING THE EFFECT OF PRESSURE

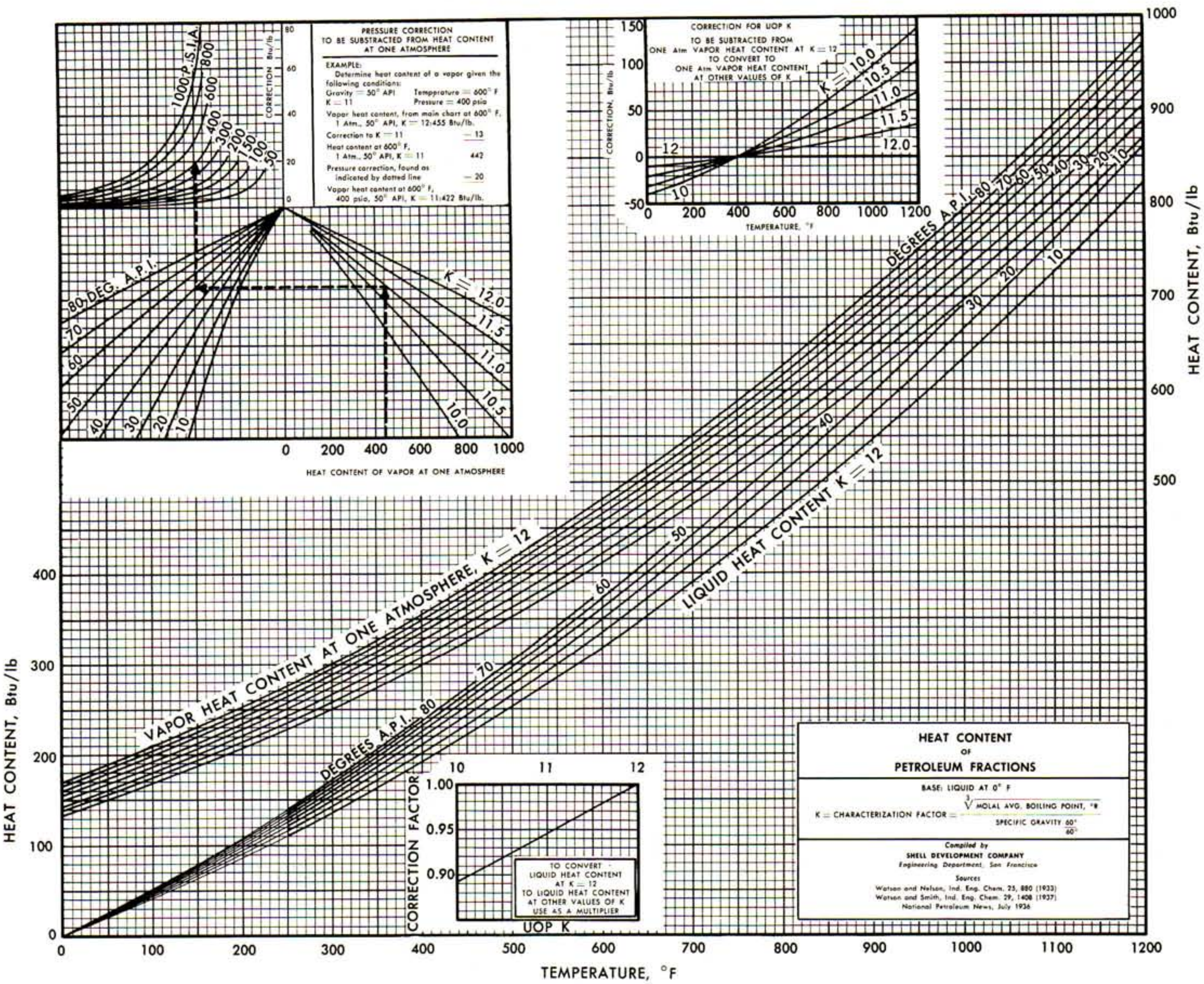
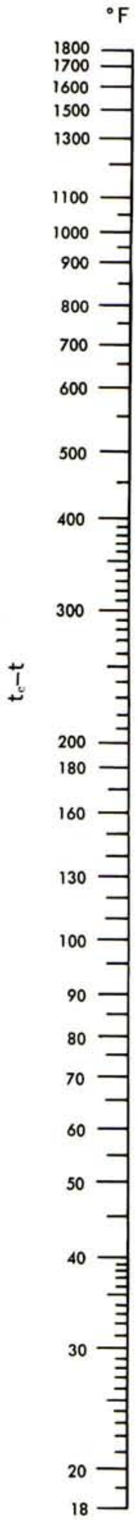
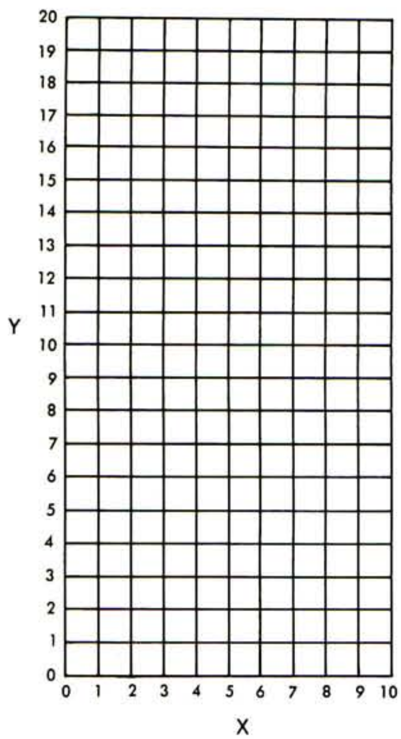


FIGURE 4.2

LATENT HEATS OF VAPORIZATION OF VARIOUS LIQUIDS



LIQUID	t_c °F	Range t_c–t °F	X	Y
Acetic Acid	609	212-392	5.6	11.9
Acetone	455	284-464	4.0	10.3
Ammonia	272	176-392	3.2	3.8
Amyl alcohol (-iso)	585	392-572	6.0	9.4
Benzene	552	50-572	3.6	12.5
Butane (-n)	307	104-158	2.6	11.6
Butane		158-392	3.6	11.7
Butane (-iso)	273	167-345	3.4	12.1
Butyl alcohol (-n)	548	337-572	2.0	9.8
Butyl alcohol (-iso)	508	302-392	1.7	9.7
Butyl alcohol		392-517	6.9	7.7
Butyl alcohol (-sec)	508	337-517	5.6	8.8
Butyl alcohol (-tert)	455	302-392	3.9	9.5
Carbon dioxide	91	50-212	3.3	11.1
Carbon disulfide	522	284-527	3.5	13.7
Carbon tetrachloride	542	50-572	3.6	17.3
Chlorine	291	212-392	1.5	14.5
Chloroform	506	345-508	3.7	15.7
Dichloroethylene (-cie)	468	392-572	9.4	13.3
Dimethyl amine	329	256-392	4.8	8.8
Diphenyl	982	50- 90	2.2	15.2
Diphenyl		90-302	3.8	15.2
Diphenyl		302-752	0.8	12.8
Diphenyl oxide	952	176-643	3.1	15.5
Diphenyl oxide		643-932	6.2	14.5
Ethane	895	50-266	4.0	9.8
Ethyl alcohol	470	50-284	3.1	7.0
Ethyl alcohol		285-482	4.7	6.3
Ethyl amine	362	266-446	3.9	9.0
Ethyl chloride	369	302-446	4.1	12.2
Ethylene	50	50-122	3.0	9.3
Ethylene		122-256	4.0	0.6
Ethyl ether	382	59-266	3.1	12.7
Ethyl ether		266-464	1.8	12.7
Freon-11 (CCl_3F)	388	158-482	3.6	17.3
Freon-12 (CCl_2F_2)	232	140-302	3.9	17.2
Freon-21 ($CHCl_2F$)	325	176-427	3.3	15.4
Freon-22 ($CHClF_2$)	205	122-320	4.0	15.1
Freon-113 (CCl_2FCClF_2)	417	194-482	3.5	18.7
Freon-114 ($CClF_2CClF_2$)	293	113-392	3.5	18.7
Heptane (-n)	512	50-517	3.4	13.5
Hexane (-n)	456	131-464	3.4	13.2
Methane	116	50-194	5.2	8.3
Methyl alcohol	464	68-285	3.3	5.3
Methyl alcohol		283-464	3.6	4.7
Methyl amine	315	212-392	4.1	6.5
Methyl chloride	289	61-230	2.6	11.1
Methyl chloride		230-247	5.2	11.2
Methyl formate	417	302-482	1.9	11.3
Methylene chloride	421	302-482	1.0	13.7
Nitrous oxide	97	43- 77	1.2	9.2
Nitrous oxide		77-256	5.6	12.3
Octane (-n)	565	61-572	3.6	13.8
Pentane (-n)	386	59-482	3.3	12.7
Pentane (-iso)	370	50-392	3.2	12.7
Propane	205	59-482	4.3	11.0
Propyl alcohol (-n)	507	77-517	2.1	8.8
Propyl alcohol (-iso)	456	302-482	3.5	8.3
Pyridine	652	446-661	2.3	12.5
Sulfur dioxide	314	212-392	2.0	12.3
Toluene	611	212-572	1.5	13.7
Trichloroethylene	520	355-582	6.0	15.9
Water	707	50-675	3.0	1.0



Example:—For water at 212°F, $t_c - t = 707\text{-}212 = 495$ and the latent heat per lb is 970 Btu

(Latent heat accurate within ± 10 per cent)

From "Process Heat Transfer," 1st Ed., Donald Q. Kern; McGraw-Hill Book Company, reprinted by permission.

TABLE P-5.1

THERMAL CONDUCTIVITY CONVERSION FACTORS

BTU / hr-ft² x °F/ft	g-cal / sec-cm² x °C/cm	watts / cm² x °C/cm	kg-cal / hr-m² x °C/m	BTU / hr-ft² x °F/in
1	.004134	.01731	1.488	12
241.8	1	4.183	360	2901
57.8	.239	1	86.1	694
.672	.002778	.01162	1	8.06
.0833	.0003447	.001441	.1241	1

FIGURE P-5.2

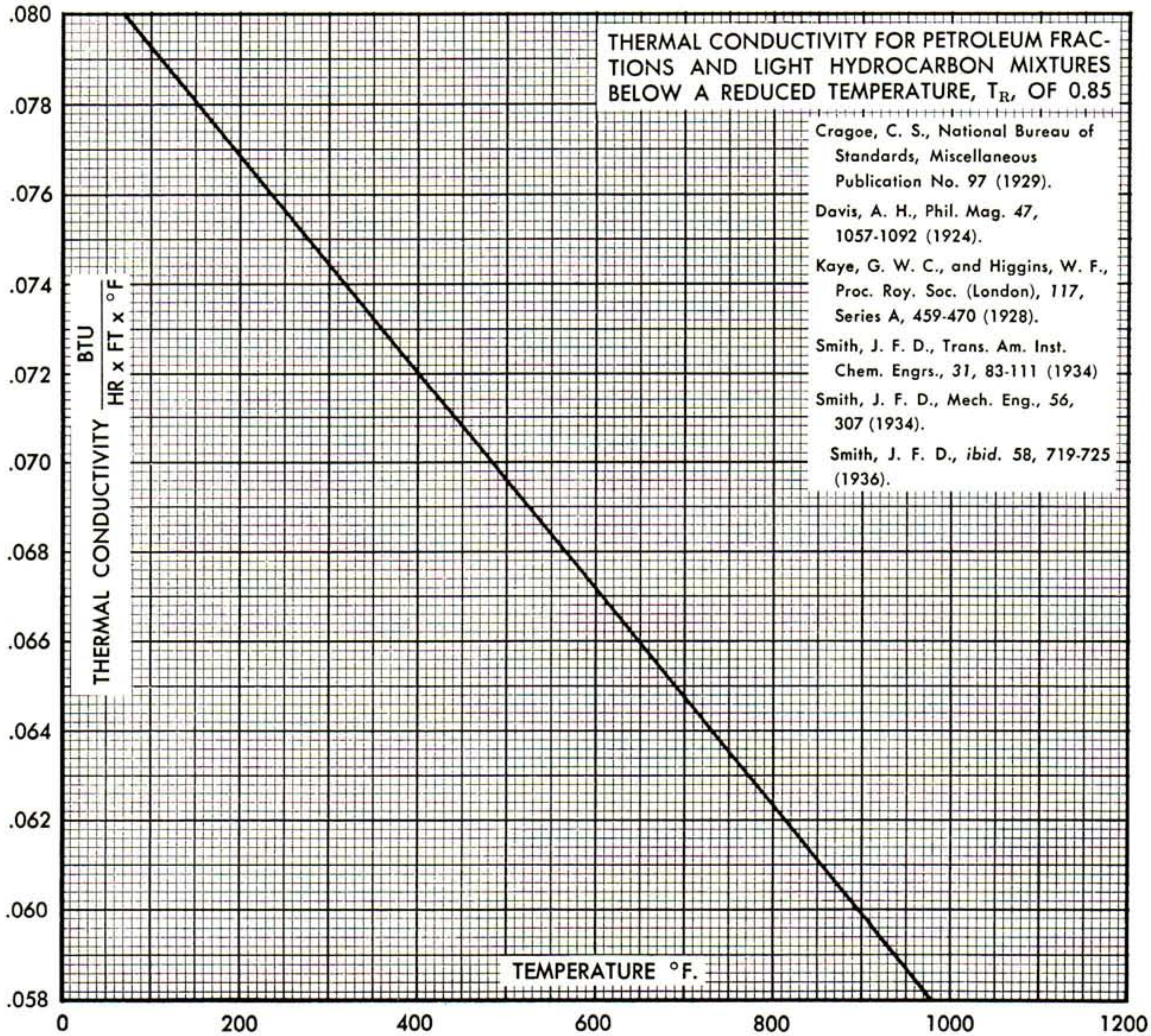


FIGURE P-5.3

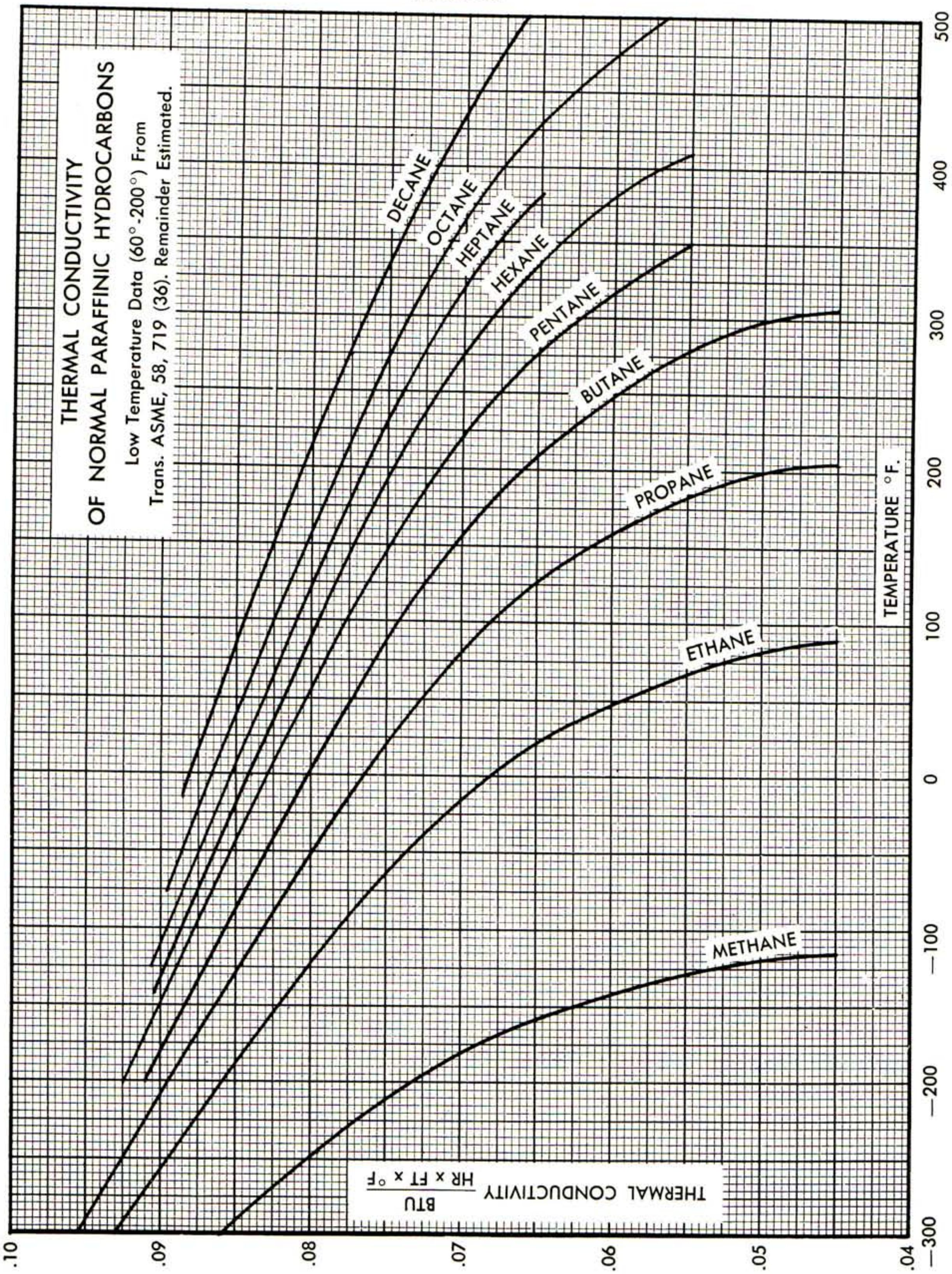

THERMAL CONDUCTIVITY
OF NORMAL PARAFFINIC HYDROCARBONS
Low Temperature Data (60°-200°) From
Trans. ASME, 58, 719 (36). Remainder Estimated.
DECANE
OCTANE
HEPTANE
HEXANE
PENTANE
BUTANE
PROPANE
ETHANE
METHANE
TEMPERATURE °F.
500
400
300
200
100
0
—100
—200
—300
THERMAL CONDUCTIVITY BTU / HR × FT × °F
.10
.09
.08
.07
.06
.05
.04

TABLE P-5.4A

THERMAL CONDUCTIVITY OF LIQUIDS

k = B.t.u./(hr.)(sq. ft.)(°F./ft.)

A linear variation with temperature may be assumed. The extreme values given constitute also the temperature limits over which the data are recommended.

Liquid	t, °F.	k
Acetic acid 100%	68	0.099
50%	68	.20
Acetone	86	.102
	167	.095
Allyl alcohol	77-86	.104
Ammonia	5-86	.29
Ammonia, aqueous 26%	68	.261
	140	.29
Amyl acetate	50	.083
alcohol (n-)	86	.094
	212	.089
(iso-)	86	.088
	167	.087
Aniline	32-68	.100
Benzene	86	.092
	140	.087
Bromobenzene	86	.074
	212	.070
Butyl acetate (n-)	77-86	.085
alcohol (n-)	86	.097
	167	.095
(iso-)	50	.091
Calcium chloride brine 30%	86	.32
15%	86	.34
Carbon disulfide	86	.093
	167	.088
tetrachloride	32	.107
	154	.094
Chlorobenzene	50	.083
Chloroform	86	.080
Cymene (para-)	86	.078
	140	.079
Decane (n-)	86	.085
	140	.083
Dichlorodifluoromethane	20	.057
	60	.053
	100	.048
	140	.043
	180	.038
Dichloroethane	122	.082
Dichloromethane	5	.111
	86	.096
Ethyl acetate	68	.101
alcohol 100%	68	.105
80%	68	.137
60%	68	.176
40%	68	.224
20%	68	.281
100%	122	.087
benzene	86	.086
	140	.082
bromide	68	.070
ether	86	.080
	167	.078
iodide	104	.064
	167	.063
Ethylene glycol	32	.153
Gasoline	86	.078
Glycerol 100%	68	.164
80%	68	.189
60%	68	.220
40%	68	.259
20%	68	.278
100%	212	.164
Heptane (n-)	86	.081
	140	.079

Liquid	t, °F.	k
Hexane (n-)	86	0.080
	140	.078
Heptyl alcohol (n-)	86	.094
	167	.091
Hexyl alcohol (n-)	86	.093
	167	.090
Kerosene	68	.086
	167	.081
Mercury	82	4.83
Methyl alcohol 100%	68	0.124
80%	68	.154
60%	68	.190
40%	68	.234
20%	68	.284
100%	122	.114
chloride	5	.111
	86	.089
Nitrobenzene	86	.095
	212	.088
Nitromethane	86	.125
	140	.120
Nonane (n-)	86	.084
	140	.082
Octane	86	.083
	140	.081
Oils*	86	.079
castor	68	.104
	212	.100
olive	68	.097
	212	.095
Paraldehyde	86	.084
	212	.078
Pentane (n-)	86	.078
	167	.074
Perchloroethylene	122	.092
Petroleum ether	86	.075
	167	.073
Propyl alcohol (n-)	86	.099
	167	.095
alcohol (iso-)	86	.091
	140	.090
Sodium	212	49
	410	46
Sodium chloride brine 25.0%	86	0.33
12.5%	86	.34
Sulfuric acid 90%	86	.21
60%	86	.25
30%	86	.30
Sulfur dioxide	5	.128
	86	.111
Toluene	86	.086
	167	.084
β-Trichloroethane	122	.077
Trichloroethylene	122	.080
Turpentine	59	.074
Vaseline	59	.106
Water	32	.343
	100	.363
	200	.393
	300	.395
	420	.376
	620	.275
Xylene (ortho-)	68	.090
(meta-)	68	.090

*Suggested value where more specific data are lacking.

TABLE P-5.4B

THERMAL CONDUCTIVITIES OF GASES AND VAPORS

[k = BTU/(hr)(sq ft)(deg. F per ft)]

Substance	TEMPERATURE °F.							
	−328	−148	32	122	212	392	572	752
Acetone			.0057	.0076	.0099	.0157		
Acetylene		.0056	.0108	.0140	.0172			
Air	.0040	.0091	.0140		.0184	.0224	.0260	
Ammonia		.0097*	.0126		.0192	.0280	.0385	.0509
Argon		.0063	.0095		.0123	.0148	.0171	
Benzene			.0052	.0075	.0103	.0166		
Butane (n-)			.0078		.0135			
Butane (iso-)			.0080		.0139			
Carbon dioxide		.0064*	.0084		.0128	.0177	.0229	
Carbon disulfide			.0040					
Carbon monoxide	.0037	.0088	.0134		.0176			
Carbon tetrachloride				.0042	.0052	.0068		
Chlorine			.0043					
Chloroform			.0038	.0047	.0058	.0081		
Cyclohexane					.0094			
Dichlorodifluoromethane			.0048	.0064	.0080	.0115		
Ethane		.0055	.0106		.0175			
Ethyl acetate				.0074	.0096	.0150		
Ethyl alcohol			.0081		.0124			
Ethyl chloride			.0055		.0095	.0145		
Ethyl ether			.0077	.0101	.0131	.0200		
Ethylene		.0051	.0101	.0131	.0161			
Helium	.0338	.0612	.0818		.0988			
Heptane (n-)					.0103	.0112		
Hexane (n-)			.0072	.0080†				
Hexene			.0061		.0109			
Hydrogen	.0293	.0652	.0966		.1240	.1484	.1705	
Hydrogen sulfide			.0076					
Mercury						.0197		
Methane	.0045	.0109	.0176		.0255	.0358	.0490	
Methyl acetate			.0059	.0068†				
Methyl alcohol			.0083		.0128			
Methyl chloride			.0053	.0074	.0094	.0140		
Methylene chloride			.0039	.0050	.0063	.0091		
Neon			.0026					
Nitric oxide		.0089	.0138	.0161				
Nitrogen	.0040	.0091	.0139		.0181	.0220	.0255	.0287
Nitrous oxide		.0047	.0088		.0138			
Oxygen	.0038	.0091	.0142	.0166	.0188			
Pentane (n-)			.0074	.0083†				
Pentane (iso-)			.0072		.0127			
Propane			.0087		.0151			
Sulfur dioxide			.0050		.0069			
Water vapor, zero pressure					.0136	.0182	.0230	.0279

* Value at — 58° F.
† Value at 68° F.

Adapted from Heat Transmission, by W. H. McAdams. Copyrighted 1954. McGraw-Hill Book Company, Incorporated.

TABLE P-6.1

VISCOSITY CONVERSION FACTORS

centipoises	poises $= \frac{gm}{cm\text{-}sec}$	$\frac{lb}{ft\text{-}sec}$	$\frac{lb\text{-}sec}{ft^2}$	$\frac{lb}{ft\text{-}hr}$	$\frac{kg\text{-}sec}{m^2}$
1	.01	.000672	.0000209	2.42	.000102
100	1	.0672	.00209	242	.0102
1488	14.88	1	.0311	3600	.1517
47900	479	32.2	1	116000	4.88
.413	.00413	.000278	.00000864	1	.0000421
9810	98.1	6.59	.2048	23730	1

FIGURE P-6.1

VISCOSITY CONVERSION PLOT

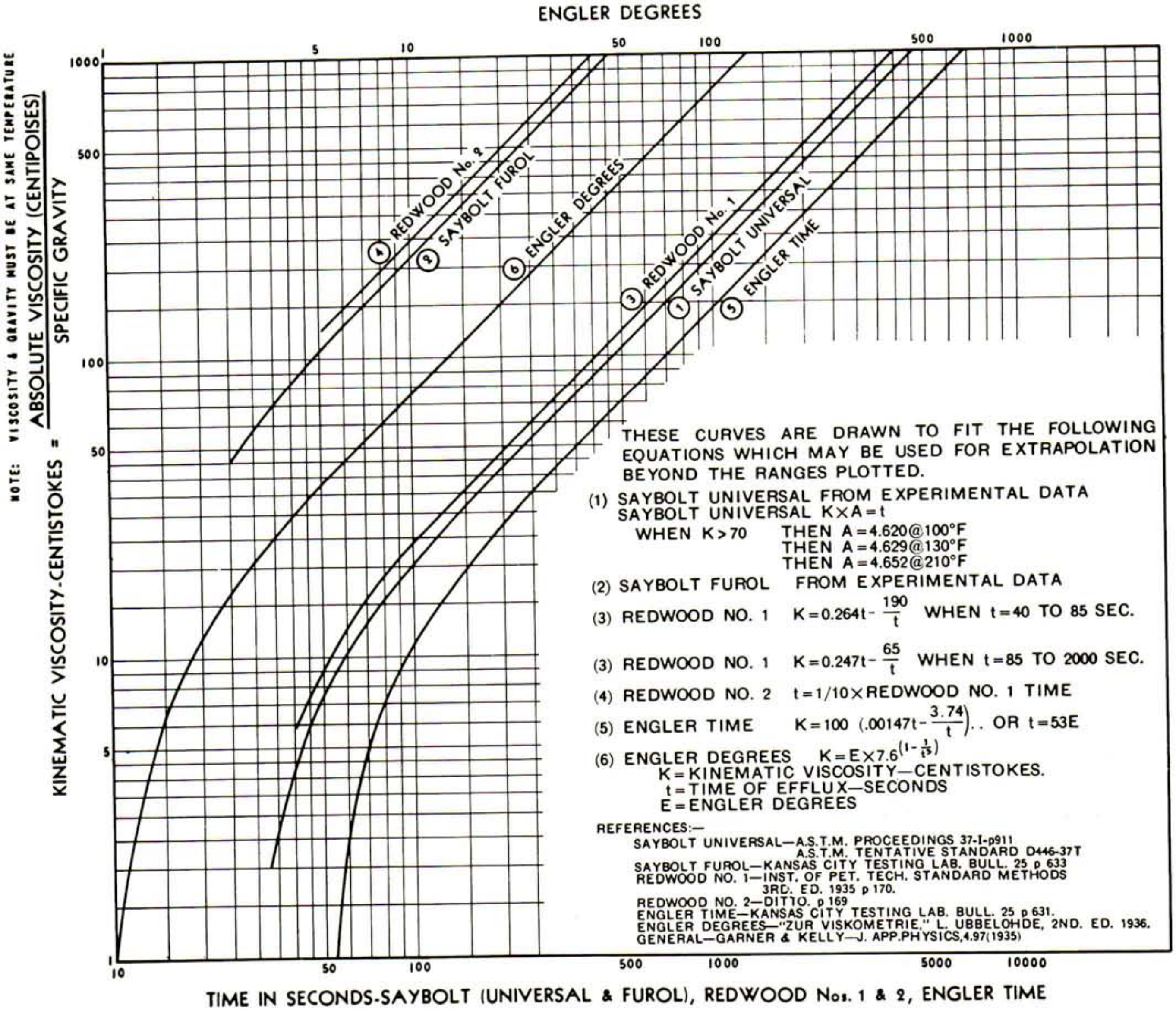


FIGURE P-6.2A

VISCOSITY — TEMPERATURE RELATIONSHIP FOR PETROLEUM OILS

LINES OF CONSTANT DEGREES A.P.I.

CHARACTERIZATION FACTOR, K = 10.0

Ref: Watson, Wien & Murphy, Industrial & Engineering Chemistry 28,605-9 (1936)

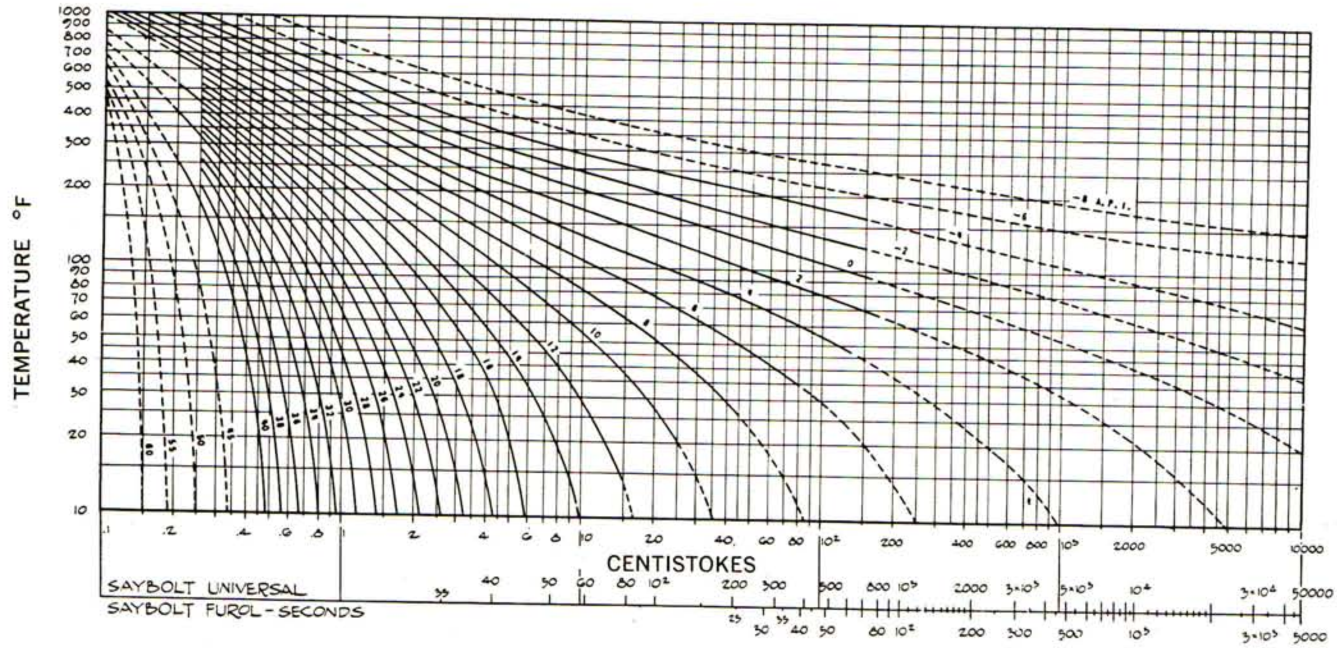


FIGURE P-6.2B

VISCOSITY — TEMPERATURE RELATIONSHIP FOR PETROLEUM OILS

LINES OF CONSTANT DEGREES A.P.I.

CHARACTERIZATION FACTOR, K = 11.0

Ref: Watson, Wien & Murphy, Industrial & Engineering Chemistry 28,605-9 (1936)

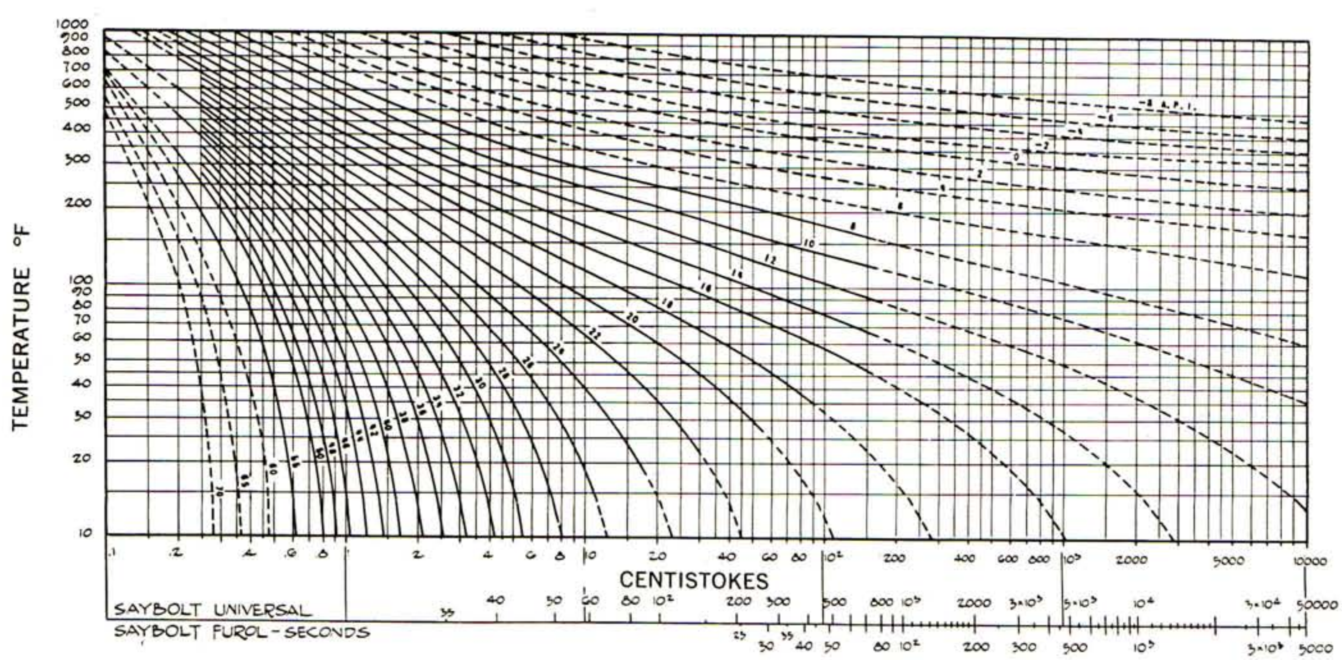


FIGURE P-6.2C

VISCOSITY — TEMPERATURE RELATIONSHIP FOR PETROLEUM OILS

LINES OF CONSTANT DEGREES A.P.I. CHARACTERIZATION FACTOR, K = 11.8

Ref: Watson, Wien & Murphy, Industrial & Engineering Chemistry 28,605-9 (1936)

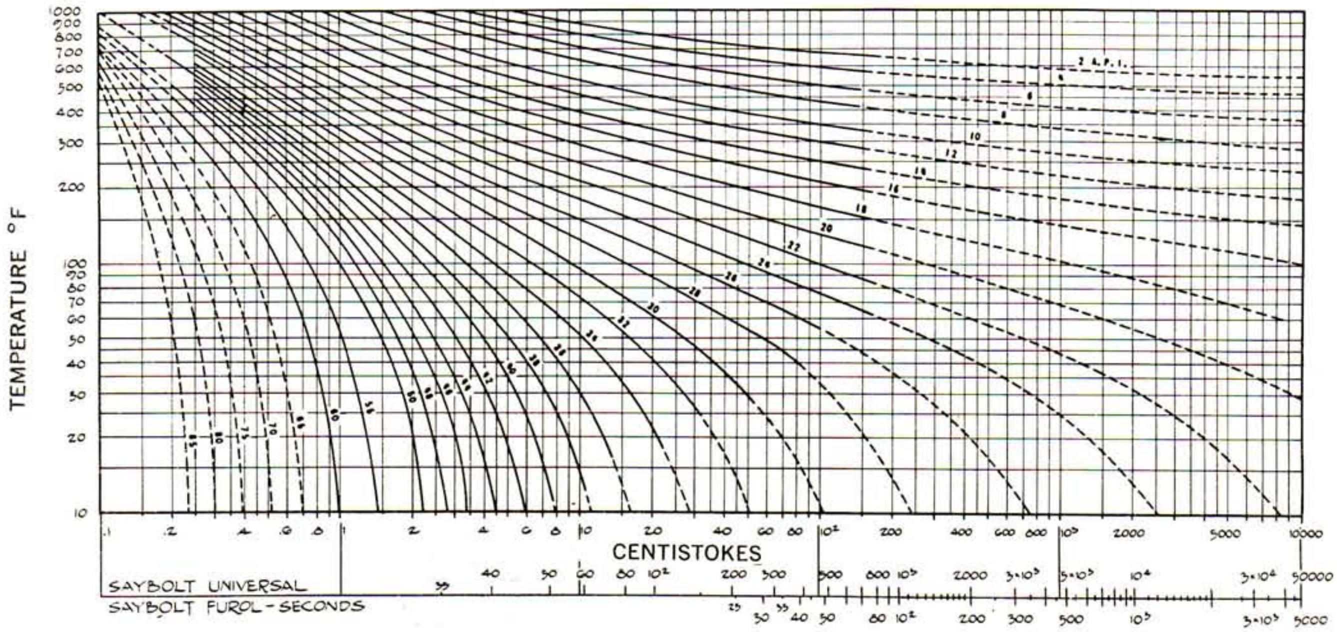


FIGURE P-6.2D

VISCOSITY — TEMPERATURE RELATIONSHIP FOR PETROLEUM OILS

LINES OF CONSTANT DEGREES A.P.I. CHARACTERIZATION FACTOR, K = 12.5

Ref: Watson, Wien & Murphy, Industrial & Engineering Chemistry 28,605-9 (1936)

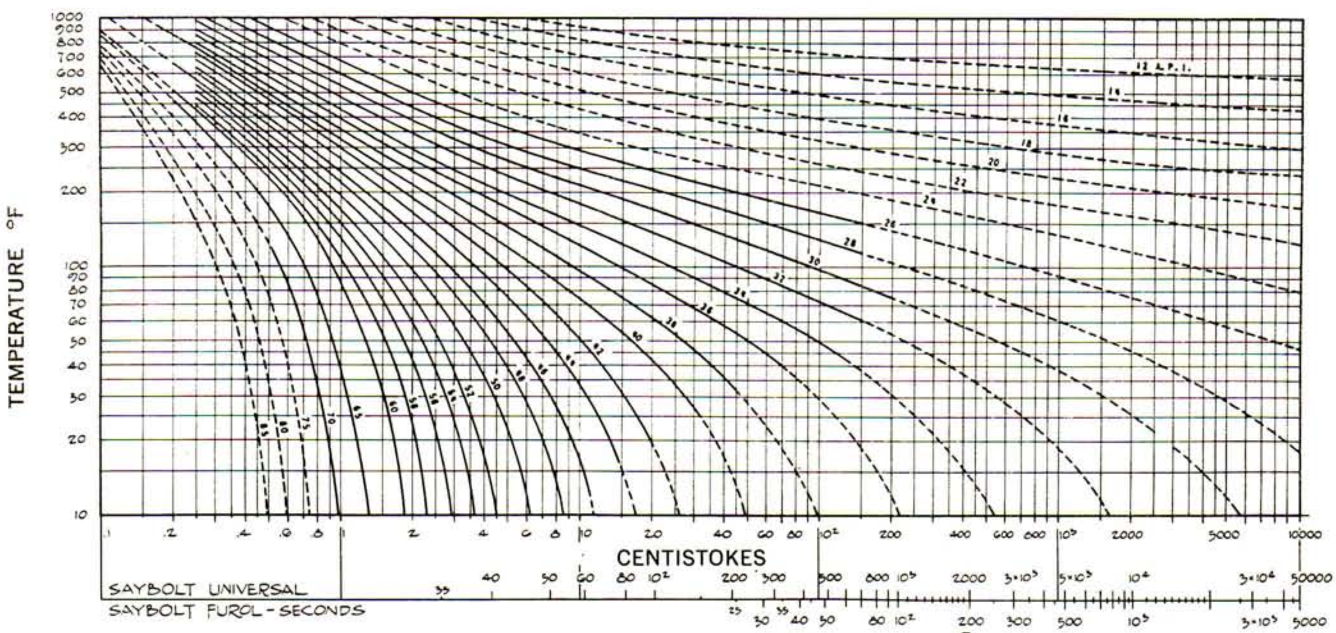


FIGURE P-6.3A

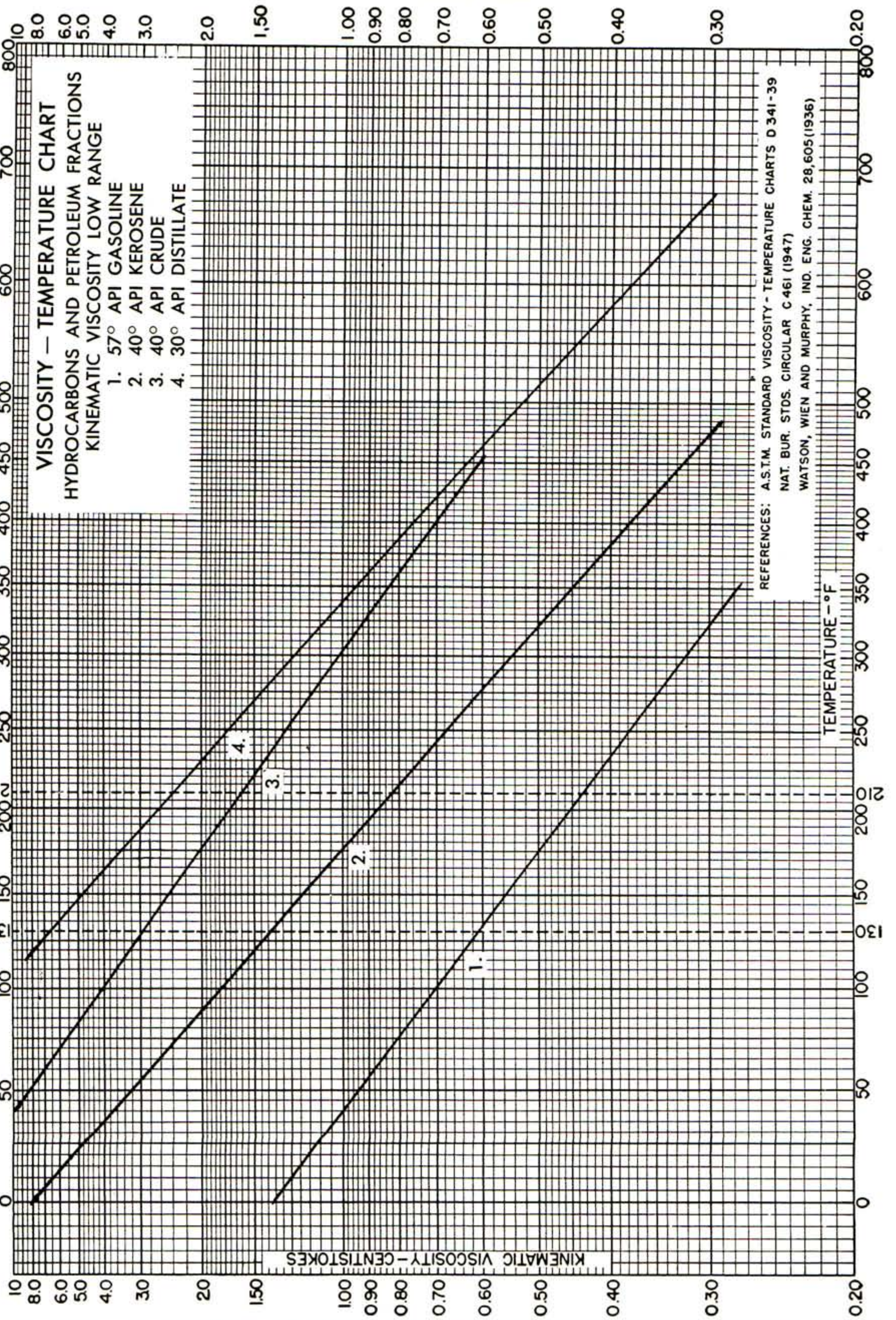


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FIGURE P-6.3B

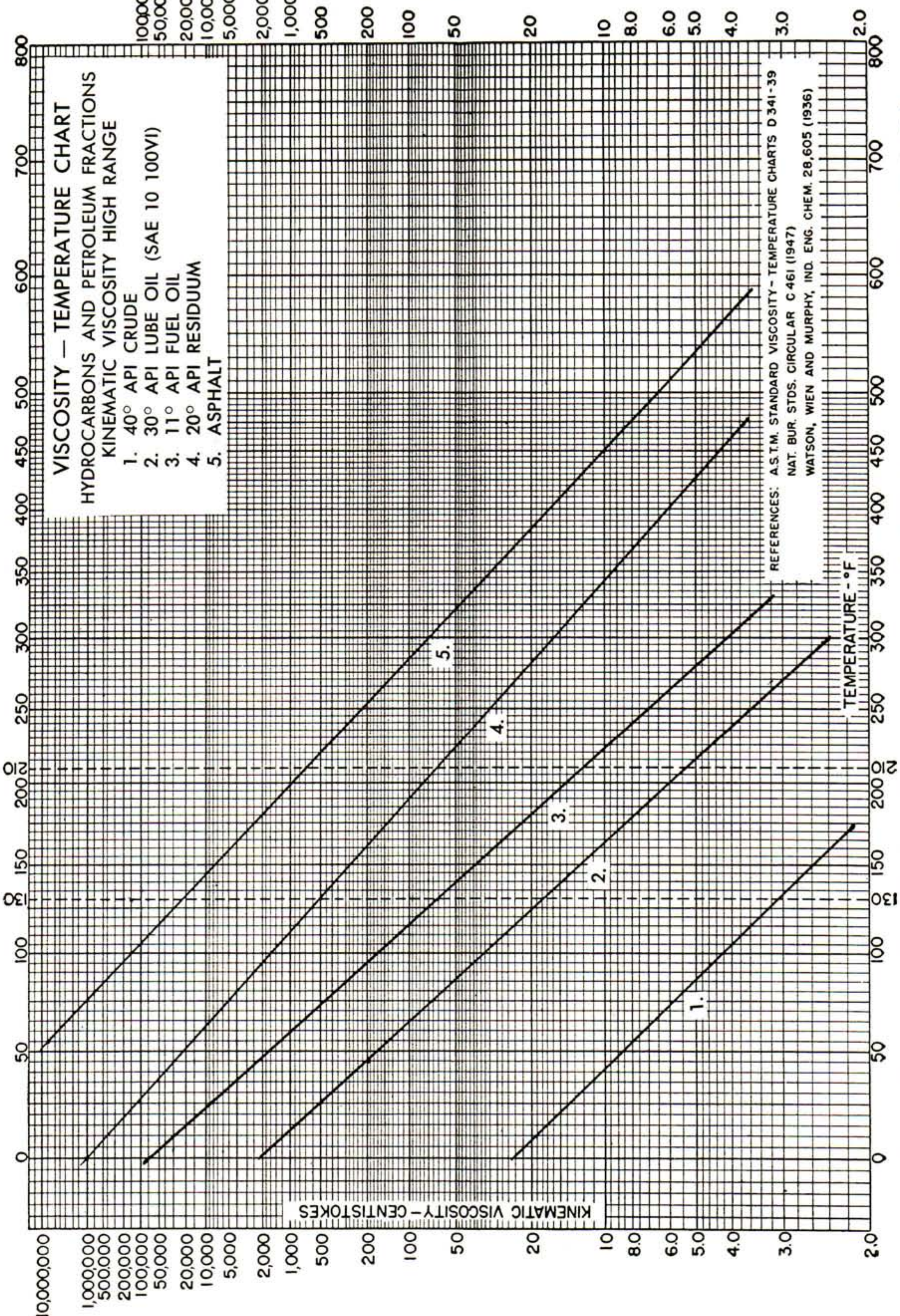

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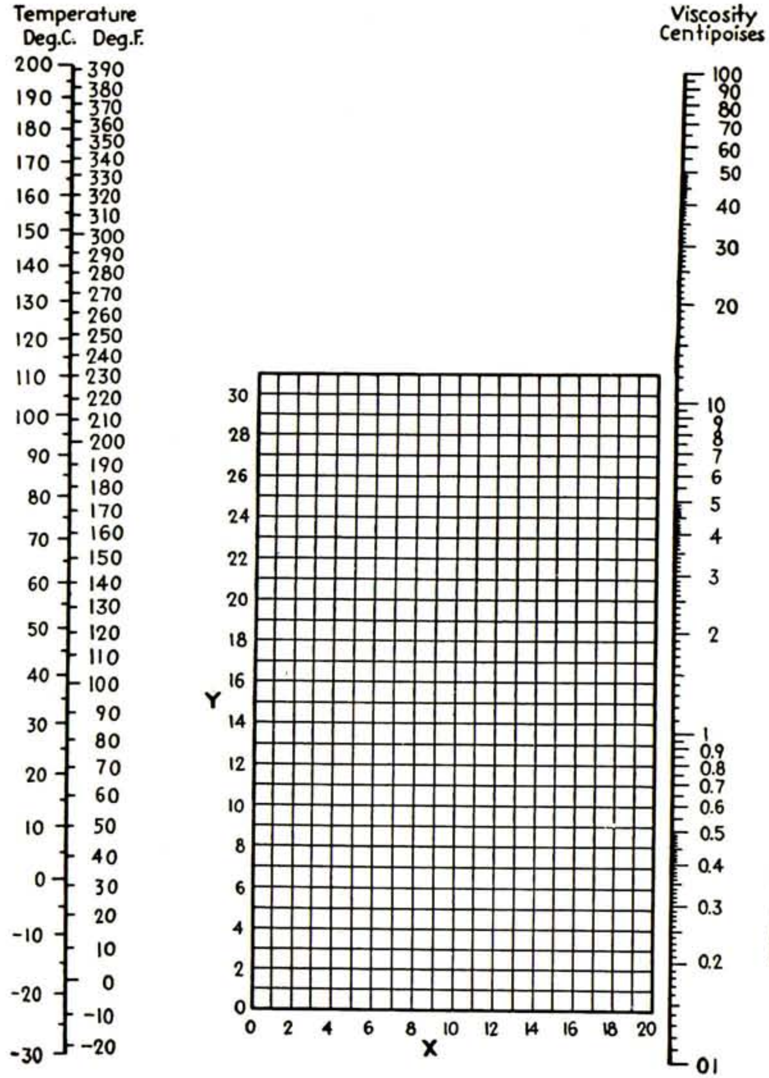
FIGURE P-6.4A

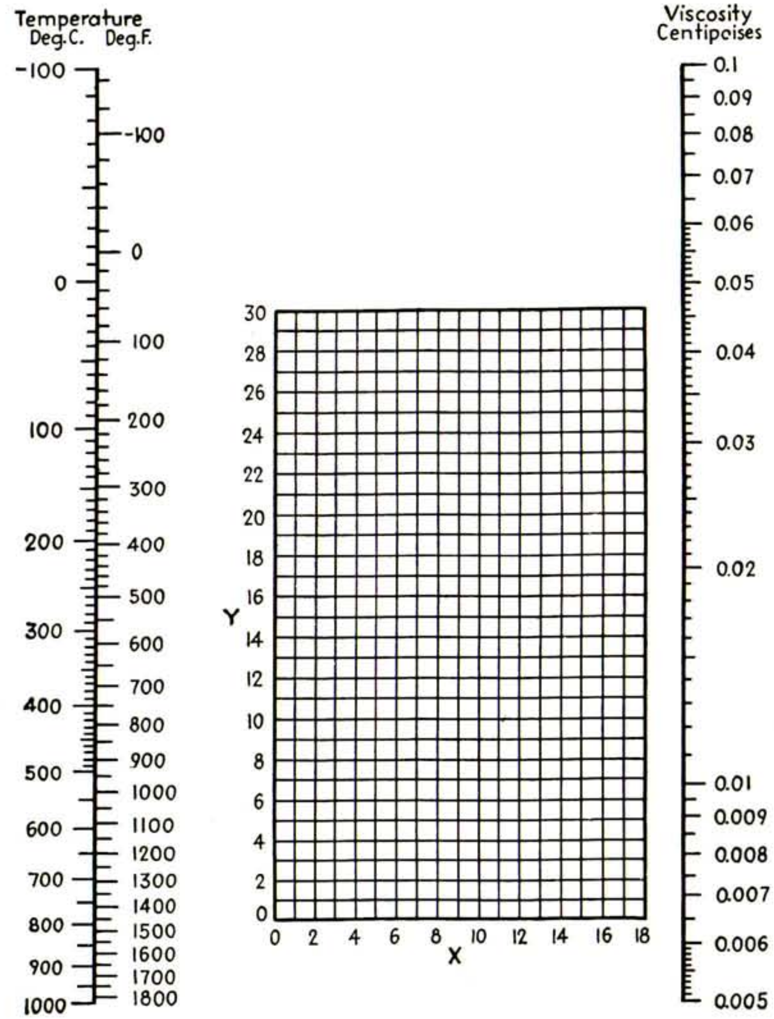
VISCOSITIES OF LIQUIDS AT 1 ATM.



No.	Liquid	X	Y	No.	Liquid	X	Y
1	Acetaldehyde	15.2	4.8	56	Freon-22	17.2	4.7
2	Acetic acid, 100 %	12.1	14.2	57	Freon-113	12.5	11.4
3	Acetic acid, 70 %	9.5	17.0	58	Glycerol, 100 %	2.0	30.0
4	Acetic anhydride	12.7	12.8	59	Glycerol, 50 %	6.9	19.6
5	Acetone, 100 %	14.5	7.2	60	Heptene	14.1	8.4
6	Acetone, 35 %	7.9	15.0	61	Hexane	14.7	7.0
7	Allyl alcohol	10.2	14.3	62	Hydrochloric acid, 31.5 %	13.0	16.6
8	Ammonia, 100 %	12.6	2.0	63	Isobutyl alcohol	7.1	18.0
9	Ammonia, 26 %	10.1	13.9	64	Isobutyric acid	12.2	14.4
10	Amyl acetate	11.8	12.5	65	Isopropyl alcohol	8.2	16.0
11	Amyl alcohol	7.5	18.4	66	Kerosene	10.2	16.9
12	Aniline	8.1	18.7	67	Linseed oil, raw	7.5	27.2
13	Anisole	12.3	13.5	68	Mercury	18.4	16.4
14	Arsenic trichloride	13.9	14.5	69	Methanol, 100 %	12.4	10.5
15	Benzene	12.5	10.9	70	Methanol, 90 %	12.3	11.8
16	Brine, $CaCl_2$, 25 %	6.6	15.9	71	Methanol, 40 %	7.8	15.5
17	Brine, NaCl, 25 %	10.2	16.6	72	Methyl acetate	14.2	8.2
18	Bromine	14.2	13.2	73	Methyl chloride	15.0	3.8
19	Bromotoluene	20.0	15.9	74	Methyl ethyl ketone	13.9	8.6
20	Butyl acetate	12.3	11.0	75	Naphthalene	7.9	18.1
21	Butyl alcohol	8.6	17.2	76	Nitric acid, 95 %	12.8	13.8
22	Butyric acid	12.1	15.3	77	Nitric acid, 60 %	10.8	17.0
23	Carbon dioxide	11.6	0.3	78	Nitrobenzene	10.6	16.2
24	Carbon disulphide	16.1	7.5	79	Nitrotoluene	11.0	17.0
25	Carbon tetrachloride	12.7	13.1	80	Octane	13.7	10.0
26	Chlorobenzene	12.3	12.4	81	Octyl alcohol	6.6	21.1
27	Chloroform	14.4	10.2	82	Pentachloroethane	10.9	17.3
28	Chlorosulfonic acid	11.2	18.1	83	Pentane	14.9	5.2
29	Chlorotoluene, ortho	13.0	13.3	84	Phenol	6.9	20.8
30	Chlorotoluene, meta	13.3	12.5	85	Phosphorus tribromide	13.8	16.7
31	Chlorotoluene para	13.3	12.5	86	Phosphorus trichloride	16.2	10.9
32	Cresol, meta	2.5	20.8	87	Propionic acid	12.8	13.8
33	Cyclohexanol	2.9	24.3	88	Propyl alcohol	9.1	16.5
34	Dibromoethane	12.7	15.8	89	Propyl bromide	14.5	9.6
35	Dichloroethane	13.2	12.2	90	Propyl chloride	14.4	7.5
36	Dichloromethane	14.6	8.9	91	Propyl iodide	14.1	11.6
37	Diethyl oxalate	11.0	16.4	92	Sodium	16.4	13.9
38	Dimethyl oxalate	12.3	15.8	93	Sodium hydroxide, 50 %	3.2	25.8
39	Diphenyl	12.0	18.3	94	Stannic chloride	13.5	12.8
40	Dipropyl oxalate	10.3	17.7	95	Sulphur dioxide	15.2	7.1
41	Ethyl acetate	13.7	9.1	96	Sulphuric acid, 110 %	7.2	27.4
42	Ethyl alcohol, 100 %	10.5	13.8	97	Sulphuric acid, 98 %	7.0	24.8
43	Ethyl alcohol, 95 %	9.8	14.3	98	Sulphuric acid, 60 %	10.2	21.3
44	Ethyl alcohol, 40 %	6.5	16.6	99	Sulphuryl chloride	15.2	12.4
45	Ethyl benzene	13.2	11.5	100	Tetrachloroethane	11.9	15.7
46	Ethyl bromide	14.5	8.1	101	Tetrachloroethylene	14.2	12.7
47	Ethyl chloride	14.8	6.0	102	Titanium tetrachloride	14.4	12.3
48	Ethyl ether	14.5	5.3	103	Toluene	13.7	10.4
49	Ethyl formate	14.2	8.4	104	Trichloroethylene	14.8	10.5
50	Ethyl iodide	14.7	10.3	105	Turpentine	11.5	14.9
51	Ethylene glycol	6.0	23.6	106	Vinyl acetate	14.0	8.8
52	Formic acid	10.7	15.8	107	Water	10.2	13.0
53	Freon-11	14.4	9.0	108	Xylene, ortho	13.5	12.1
54	Freon-12	16.8	5.6	109	Xylene, meta	13.9	10.6
55	Freon-21	15.7	7.5	110	Xylene, para	13.9	10.9

FIGURE P-6.4B

VISCOSITIES OF GASES AND VAPORS AT 1 ATM.



By permission from HEAT TRANSMISSION, by W. H. McAdams.

No.	Gas	X	Y	No.	Gas	X	Y
1	Acetic acid	7.7	14.3	29	Freon-113	11.3	14.0
2	Acetone	8.9	13.0	30	Helium	10.9	20.5
3	Acetylene	9.8	14.9	31	Hexane	8.6	11.8
4	Air	11.0	20.0	32	Hydrogen	11.2	12.4
5	Ammonia	8.4	16.0	33	$3H_2 + 1N_2$	11.2	17.2
6	Argon	10.5	22.4	34	Hydrogen bromide	8.8	20.9
7	Benzene	8.5	13.2	35	Hydrogen chloride	8.8	18.7
8	Bromine	8.9	19.2	36	Hydrogen cyanide	9.8	14.9
9	Butene	9.2	13.7	37	Hydrogen iodide	9.0	21.3
10	Butylene	8.9	13.0	38	Hydrogen sulphide	8.6	18.0
11	Carbon dioxide	9.5	18.7	39	Iodine	9.0	18.4
12	Carbon disulphide	8.0	16.0	40	Mercury	5.3	22.9
13	Carbon monoxide	11.0	20.0	41	Methane	9.9	15.5
14	Chlorine	9.0	18.4	42	Methyl alcohol	8.5	15.6
15	Chloroform	8.9	15.7	43	Nitric oxide	10.9	20.5
16	Cyanogen	9.2	15.2	44	Nitrogen	10.6	20.0
17	Cyclohexane	9.2	12.0	45	Nitrosyl chloride	8.0	17.6
18	Ethane	9.1	14.5	46	Nitrous oxide	8.8	19.0
19	Ethyl acetate	8.5	13.2	47	Oxygen	11.0	21.3
20	Ethyl alcohol	9.2	14.2	48	Pentane	7.0	12.8
21	Ethyl chloride	8.5	15.6	49	Propane	9.7	12.9
22	Ethyl ether	8.9	13.0	50	Propyl alcohol	8.4	13.4
23	Ethylene	9.5	15.1	51	Propylene	9.0	13.8
24	Fluorine	7.3	23.8	52	Sulphur dioxide	9.6	17.0
25	Freon-11	10.6	15.1	53	Toluene	8.6	12.4
26	Freon-12	11.1	16.0	54	2, 3, 3-trimethylbutane	9.5	10.5
27	Freon-21	10.8	15.3	55	Water	8.0	16.0
28	Freon-22	10.1	17.0	56	Xenon	9.3	23.0

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FIGURE P-6.5

HIGH PRESSURE GAS VISCOSITY

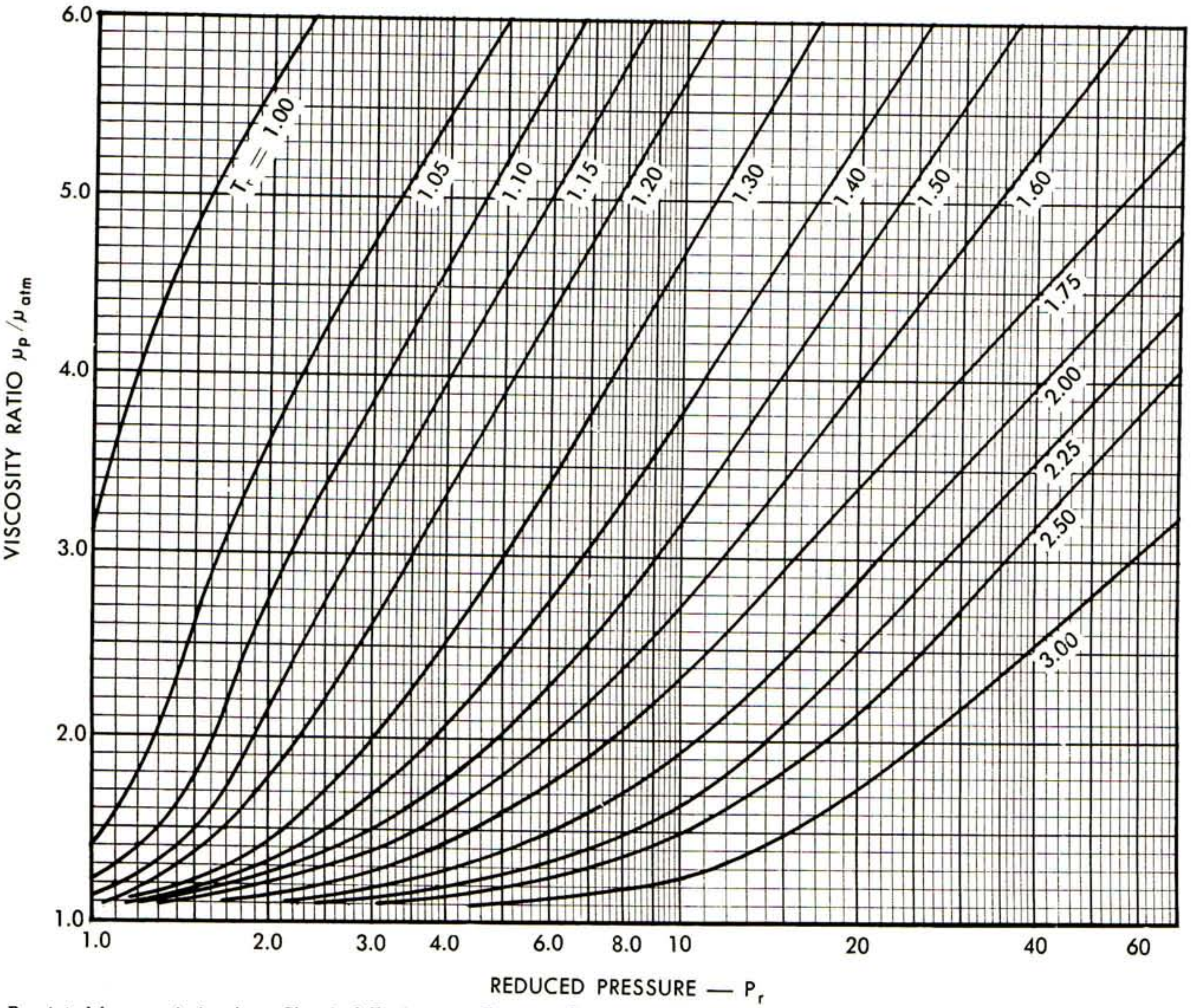

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TABLE P-7.1

CRITICAL PROPERTY DATA

Substance	Molecular Weight	Critical Temperature Degrees Rankine	Critical Pressure PSIA	Substance	Molecular Weight	Critical Temperature Degrees Rankine	Critical Pressure PSIA
Acetylene	26.04	557	905	Hydrogen Chloride	36.46	584	1199
Ammonia	17.03	730	1639	Hydrogen Sulfide	34.08	672	1307
Benzene	78.1	1013	714	Isobutane	58.1	735	529
1, 3-Butadiene	54.1	765	628	Isobutene	56.1	752	580
n-Butane	58.1	765	551	Isopentane	72.1	830	483
Butene-1	56.1	755	583	Methane	16.04	343	673
Carbon Dioxide	44.0	547	1070	Nitrogen	28.02	227	492
Carbon Monoxide	28.01	239	510	n-Octane	114.2	1025	362
Chlorine	70.9	751	1119	Oxygen	32.00	278	731
Cyclohexane	84.2	998	588	n-Pentane	72.1	846	490
Ethane	30.07	550	708	Propane	44.1	666	617
Ethene	28.05	510	742	Propene	42.1	657	667
n-Heptane	100.2	972	397	Sulfur Dioxide	64.1	775	1142
n-Hexane	86.2	914	440	Toluene	92.1	1069	590
Hydrogen	2.016	60	188	Water	18.02	1165	3206

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TABLE D-1

DIMENSIONS OF WELDED AND SEAMLESS PIPE

NOMINAL PIPE SIZE	OUT-SIDE DIAM.	NOMINAL WALL THICKNESS FOR														
		SCHED. 5S*	SCHED. 10S*	SCHED. 10	SCHED. 20	SCHED. 30	STAND-ARD †	SCHED. 40	SCHED. 60	EXTRA STRONG §	SCHED. 80	SCHED. 100	SCHED. 120	SCHED. 140	SCHED. 160	XX STRONG
1/8	0.405	.....	0.049	.....	.....	.....	*0.068*	0.068	.....	*0.095*	0.095	.....	.....	.....	.....	.....
1/4	0.540	.....	0.065	.....	.....	.....	*0.088*	0.088	.....	*0.119*	0.119	.....	.....	.....	.....	.....
3/8	0.675	.....	0.065	.....	.....	.....	*0.091*	0.091	.....	*0.126*	0.126	.....	.....	.....	.....	.....
1/2	0.840	0.065	0.083	.....	.....	.....	*0.109*	0.109	.....	*0.147*	0.147	.....	.....	.....	0.188	0.294
3/4	1.050	0.065	0.083	.....	.....	.....	*0.113*	0.113	.....	*0.154*	0.154	.....	.....	.....	0.219	0.308
1	1.315	0.065	0.109	.....	.....	.....	*0.133*	0.133	.....	*0.179*	0.179	.....	.....	.....	0.250	0.358
1 1/4	1.660	0.065	0.109	.....	.....	.....	*0.140*	0.140	.....	*0.191*	0.191	.....	.....	.....	0.250	0.382
1 1/2	1.900	0.065	0.109	.....	.....	.....	*0.145*	0.145	.....	*0.200*	0.200	.....	.....	.....	0.281	0.400
2	2.375	0.065	0.109	.....	.....	.....	*0.154*	0.154	.....	*0.218*	0.218	.....	.....	.....	0.344	0.436
2 1/2	2.875	0.083	0.120	.....	.....	.....	*0.203*	0.203	.....	*0.276*	0.276	.....	.....	.....	0.375	0.552
3	3.5	0.083	0.120	.....	.....	.....	*0.216*	0.216	.....	*0.300*	0.300	.....	.....	.....	0.438	0.600
3 1/2	4.0	0.083	0.120	.....	.....	.....	*0.226*	0.226	.....	*0.318*	0.318	.....	.....	.....	.....	.....
4	4.5	0.083	0.120	.....	.....	.....	*0.237*	0.237	.....	*0.337*	0.337	.....	0.438	.....	0.531	0.674
5	5.563	0.109	0.134	.....	.....	.....	*0.258*	0.258	.....	*0.375*	0.375	.....	0.500	.....	0.625	0.750
6	6.625	0.109	0.134	.....	.....	.....	*0.280*	0.280	.....	*0.432*	0.432	.....	0.562	.....	0.719	0.864
8	8.625	0.109	0.148	.....	0.250	0.277	*0.322*	0.322	0.406	*0.500*	0.500	0.594	0.719	0.812	0.906	0.875
10	10.75	0.134	0.165	.....	0.250	0.307	*0.365*	0.365	0.500	0.500	0.594	0.719	0.844	1.000	1.125	1.000
12	12.75	0.156	0.180	.....	0.250	0.330	*0.375*	0.406	0.562	0.500	0.688	0.844	1.000	1.125	1.312	1.000
14 O.D.	14.0	0.156	0.188	0.250	0.312	0.375	0.375	0.438	0.594	0.500	0.750	0.938	1.094	1.250	1.406	.....
16 O.D.	16.0	0.165	0.188	0.250	0.312	0.375	0.375	0.500	0.656	0.500	0.844	1.031	1.219	1.438	1.594	.....
18 O.D.	18.0	0.165	0.188	0.250	0.312	0.438	0.375	0.562	0.750	0.500	0.938	1.156	1.375	1.562	1.781	.....
20 O.D.	20.0	0.188	0.218	0.250	0.375	0.500	0.375	0.594	0.812	0.500	1.031	1.281	1.500	1.750	1.969	.....
22 O.D.	22.0	0.188	0.218	0.250	0.375	0.500	0.375	.....	0.875	0.500	1.125	1.375	1.625	1.875	2.125	.....
24 O.D.	24.0	0.218	0.250	0.250	0.375	0.562	0.375	0.688	0.969	0.500	1.218	1.531	1.812	2.062	2.344	.....
26 O.D.	26.0	.....	.....	0.312	0.500	.....	0.375	.....	.....	0.500	.....	.....	.....	.....	.....	.....
28 O.D.	28.0	.....	.....	0.312	0.500	0.625	0.375	.....	.....	0.500	.....	.....	.....	.....	.....	.....
30 O.D.	30.0	0.250	0.312	0.312	0.500	0.625	0.375	.....	.....	0.500	.....	.....	.....	.....	.....	.....
32 O.D.	32.0	.....	.....	0.312	0.500	0.625	0.375	0.688	.....	0.500	.....	.....	.....	.....	.....	.....
34 O.D.	34.0	.....	.....	0.312	0.500	0.625	0.375	0.688	.....	0.500	.....	.....	.....	.....	.....	.....
36 O.D.	36.0	.....	.....	0.312	0.500	0.625	0.375	0.750	.....	0.500	.....	.....	.....	.....	.....	.....
42 O.D.	42.0	.....	.....	.....	.....	.....	0.375	.....	.....	0.500	.....	.....	.....	.....	.....	.....

All dimensions are given in inches.

Decimal equivalents for certain fractional dimensions are 0.001" more than previously published data and wall thicknesses in this table because of a change in Pipe Standards Committee procedure for round-off.

The decimal thicknesses listed for the respective pipe sizes represent their nominal or average wall dimensions. The actual thicknesses may be as much as 12.5% under the nominal thickness because of mill tolerance. Thicknesses shown in light face for Schedule 60 and heavier pipe are not currently supplied by the mills, unless a certain minimum tonnage is ordered.

* Schedules 5S and 10S are available in corrosion resistant materials and Schedule 10S is also available in carbon steel.

† Thicknesses shown in **italics** are available also in stainless steel, under the designation Schedule 40S.

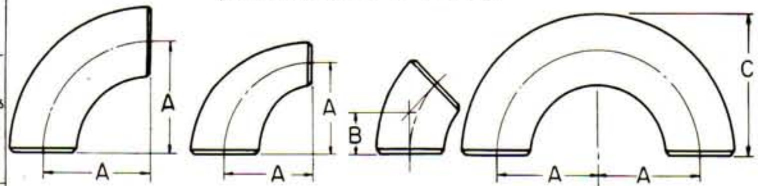
§ Thicknesses shown in **italics** are available also in stainless steel, under the designation Schedule 80S.

TABLE D-2

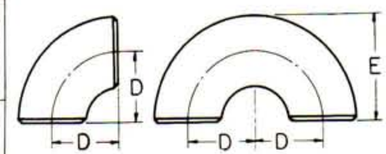
DIMENSIONS OF WELDING FITTINGS

(All Dimensions in Inches)

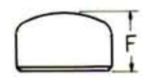
Nom. Pipe Size	A	B	C	D	E	F	L USA	L Short	G
1/2	1 1/2	5/8	1 7/8	......	......	1	3	......	1 3/8
3/4	1 1/8	7/16	1 11/16	......	......	1 1/2	3	2	1 11/16
1	1 1/2	7/8	2 3/16	1	1 5/8	1 1/2	4	2	2
1 1/4	1 7/8	1	2 3/4	1 1/4	2 1/16	1 1/2	4	2	2 1/2
1 1/2	2 1/4	1 1/8	3 1/4	1 1/2	2 7/16	1 1/2	4	2	2 7/8
2	3	1 3/8	4 3/16	2	3 3/16	1 1/2	6	2 1/2	3 5/8
2 1/2	3 3/4	1 3/4	5 3/16	2 1/2	3 15/16	1 1/2	6	2 1/2	4 1/8
3	4 1/2	2	6 1/4	3	4 3/4	2	6	2 1/2	5
3 1/2	5 1/4	2 1/4	7 1/4	3 1/2	5 1/2	2 1/2	6	3	5 1/2
4	6	2 1/2	8 1/4	4	6 1/4	2 1/2	6	3	6 3/16
5	7 1/2	3 1/8	10 5/16	5	7 3/4	3	8	3	7 5/16
6	9	3 3/4	12 5/16	6	9 5/16	3 1/2	8	3 1/2	8 1/2
8	12	5	16 5/16	8	12 5/16	4	8	4	10 5/8
10	15	6 1/4	20 3/8	10	15 3/8	5	10	5	12 3/4
12	18	7 1/2	24 3/8	12	18 3/8	6	10	6	15
14	21	8 3/4	28	14	21	6 1/2	12	......	16 1/4
16	24	10	32	16	24	7	12	......	18 1/2
18	27	11 1/4	36	18	27	8	12	......	21
20	30	12 1/2	40	20	30	9	12	......	23
24	36	15	48	24	36	10 1/2	12	......	27 1/4
30	45	18 1/2	60	30	45	10 1/2	....	......	......



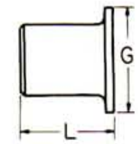
Long Radius Weld Ells



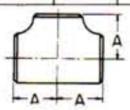
Short Radius Weld Ells



Caps

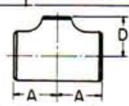


Stub Ends



Straight Tees

Nom. Pipe Size	Outlet	A	D	L
1	1	1 1/2	......	......
1	3/4	1 1/2	1 1/2	2
1	1/2	1 1/2	1 1/2	2
1 1/4	1 1/4	1 7/8	......	......
1 1/4	1	1 7/8	1 7/8	2
1 1/4	3/4	1 7/8	1 7/8	2
1 1/4	1/2	1 7/8	1 7/8	2
1 1/2	1 1/2	2 1/4	......	......
1 1/2	1 1/4	2 1/4	2 1/4	2 1/2
1 1/2	1	2 1/4	2 1/4	2 1/2
1 1/2	3/4	2 1/4	2 1/4	2 1/2
1 1/2	1/2	2 1/4	2 1/4	2 1/2
2	2	2 1/2	......	......
2	1 1/2	2 1/2	2 3/8	3
2	1 1/4	2 1/2	2 1/4	3
2	1	2 1/2	2	3
2	3/4	2 1/2	1 3/4	3
2 1/2	2 1/2	3	......	......
2 1/2	2	3	2 3/4	3 1/2
2 1/2	1 1/2	3	2 5/8	3 1/2
2 1/2	1 1/4	3	2 1/2	3 1/2
2 1/2	1	3	2 1/4	3 1/2
3	3	3 3/8	......	......
3	2 1/2	3 3/8	3 1/4	3 1/2
3	2	3 3/8	3	3 1/2
3	1 1/2	3 3/8	2 7/8	3 1/2
3	1 1/4	3 3/8	2 3/4	3 1/2
3 1/2	3 1/2	3 3/4	......	......
3 1/2	3	3 3/4	3 5/8	4
3 1/2	2 1/2	3 3/4	3 1/2	4
3 1/2	2	3 3/4	3 1/4	4
3 1/2	1 1/2	3 3/4	3 1/8	4



Reducing Tees

Nom. Pipe Size	Outlet	A	D	L
4	4	4 1/8	......	......
4	3 1/2	4 1/8	4	4
4	3	4 1/8	3 7/8	4
4	2 1/2	4 1/8	3 3/4	4
4	2	4 1/8	3 1/2	4
4	1 1/2	4 1/8	3 3/8	4
5	5	4 7/8	......	......
5	4	4 7/8	4 5/8	5
5	3 1/2	4 7/8	4 1/2	5
5	3	4 7/8	4 3/8	5
5	2 1/2	4 7/8	4 1/4	5
5	2	4 7/8	4 1/8	5
6	6	5 5/8	......	......
6	5	5 5/8	5 3/8	5 1/2
6	4	5 5/8	5 1/8	5 1/2
6	3 1/2	5 5/8	5	5 1/2
6	3	5 5/8	4 7/8	5 1/2
6	2 1/2	5 5/8	4 3/4	5 1/2
8	8	7	......	......
8	6	7	6 5/8	6
8	5	7	6 3/8	6
8	4	7	6 1/8	6
8	3 1/2	7	6	6
10	10	8 1/2	......	......
10	8	8 1/2	8	7
10	6	8 1/2	7 5/8	7
10	5	8 1/2	7 1/2	7
10	4	8 1/2	7 1/4	7
12	12	10	......	......
12	10	10	9 1/2	8
12	8	10	9	8
12	6	10	8 5/8	8
12	5	10	8 1/2	8

Con. & Ecc. Reducers

Nom. Pipe Size	Outlet	A	D	L
14	14	11	......	......
14	12	11	10 5/8	13
14	10	11	10 1/8	13
14	8	11	9 3/4	13
14	6	11	9 3/8	13
16	16	12	......	......
16	14	12	12	14
16	12	12	11 5/8	14
16	10	12	11 1/8	14
16	8	12	10 3/4	14
16	6	12	10 3/8	14
18	18	13 1/2	......	......
18	16	13 1/2	13	15
18	14	13 1/2	13	15
18	12	13 1/2	12 5/8	15
18	10	13 1/2	12 1/8	15
18	8	13 1/2	11 3/4	15
20	20	15	......	......
20	18	15	14 1/2	20
20	16	15	14	20
20	14	15	14	20
20	12	15	13 5/8	20
20	10	15	13 1/8	20
20	8	15	12 3/4	20
24	24	17	......	......
24	20	17	17	20
24	18	17	16 1/2	20
24	16	17	16	20
24	14	17	16	20
24	12	17	15 5/8	20
24	10	17	15 1/8	20

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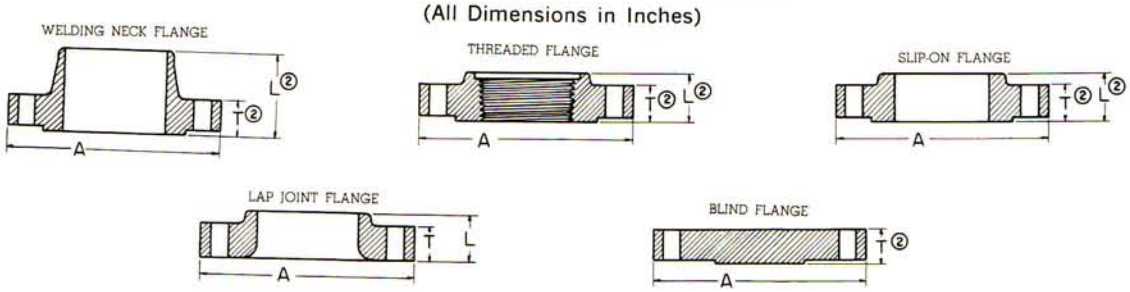
TABLE D-3

DIMENSIONS OF USA STANDARD FLANGES

(All Dimensions in Inches)



150 LB. FLANGES

Nom. Pipe Size	A	T②	L② Weld Neck	L② Thrd. Slip on	L② Lap Joint	Bolt Circle	No. and Sizes of Holes
1/2	3 1/2	7/16	1 7/8	5/8	5/8	2 3/8	4-5/8
3/4	3 7/8	1/2	2 1/16	5/8	5/8	2 3/4	4-5/8
1	4 1/4	9/16	2 3/16	11/16	11/16	3 1/8	4-5/8
1 1/4	4 5/8	5/8	2 1/4	13/16	13/16	3 1/2	4-5/8
1 1/2	5	11/16	2 7/16	7/8	7/8	3 7/8	4-5/8
2	6	3/4	2 1/2	1	1	4 3/4	4-3/4
2 1/2	7	7/8	2 3/4	1 1/8	1 1/8	5 1/2	4-3/4
3	7 1/2	15/16	2 3/4	1 3/16	1 3/16	6	4-3/4
3 1/2	8 1/2	15/16	2 13/16	1 1/4	1 1/4	7	8-3/4
4	9	15/16	3	1 5/16	1 5/16	7 1/2	8-3/4
5	10	15/16	3 1/2	1 7/16	1 7/16	8 1/2	8-7/8
6	11	1	3 1/2	1 9/16	1 9/16	9 1/2	8-7/8
8	13 1/2	1 1/8	4	1 3/4	1 3/4	11 3/4	8-7/8
10	16	1 3/16	4	1 15/16	1 15/16	14 1/4	12-1
12	19	1 1/4	4 1/2	2 3/16	2 3/16	17	12-1
14	21	1 3/8	5	2 1/4	3 1/8	18 3/4	12-1 1/8
16	23 1/2	1 7/16	5	2 1/2	3 7/16	21 1/4	16-1 1/8
18	25	1 9/16	5 1/2	2 11/16	3 13/16	22 3/4	16-1 1/4
20	27 1/2	1 11/16	5 11/16	2 7/8	4 1/16	25	20-1 1/4
24	32	1 7/8	6	3 1/4	4 3/8	29 1/2	20-1 3/8

300 LB. FLANGES

A	T②	L② Weld Neck	L② Thrd. Slip on	L② Lap Joint	Bolt Circle	No. and Size of Holes	Nom. Pipe Size
3 3/4	9/16	2 1/16	7/8	7/8	2 5/8	4-5/8	1/2
4 5/8	5/8	2 1/4	1	1	3 1/4	4-3/4	3/4
4 7/8	11/16	2 7/16	1 1/16	1 1/16	3 1/2	4-3/4	1
5 1/4	3/4	2 9/16	1 1/16	1 1/16	3 7/8	4-3/4	1 1/4
6 1/8	13/16	2 11/16	1 3/16	1 3/16	4 1/2	4-7/8	1 1/2
6 1/2	7/8	2 3/4	1 5/16	1 5/16	5	8-3/4	2
7 1/2	1	3	1 1/2	1 1/2	5 7/8	8-7/8	2 1/2
8 1/4	1 1/8	3 1/8	1 11/16	1 11/16	6 5/8	8-7/8	3
9	1 3/16	3 3/16	1 3/4	1 3/4	7 1/4	8-7/8	3 1/2
10	1 1/4	3 3/8	1 7/8	1 7/8	7 7/8	8-7/8	4
11	1 3/8	3 7/8	2	2	9 1/4	8-7/8	5
12 1/2	1 7/16	3 7/8	2 1/16	2 1/16	10 5/8	12-7/8	6
15	1 5/8	4 3/8	2 7/16	2 7/16	13	12-1	8
17 1/2	1 7/8	4 5/8	2 5/8	3 3/4	15 1/4	16-1 1/8	10
20 1/2	2	5 1/8	2 7/8	4	17 3/4	16-1 1/4	12
23	2 1/8	5 5/8	3	4 3/8	20 1/4	20-1 1/4	14
25 1/2	2 1/4	5 3/4	3 1/4	4 3/4	22 1/2	20-1 3/8	16
28	2 3/8	6 1/4	3 1/2	5 1/8	24 3/4	24-1 3/8	18
30 1/2	2 1/2	6 3/8	3 3/4	5 1/2	27	24-1 3/8	20
36	2 3/4	6 5/8	4 3/16	6	32	24-1 5/8	24

400 LB. FLANGES

Nom. Pipe Size	A	T②	L② Weld Neck	L② Thrd. Slip on	L② Lap Joint	Bolt Circle	No. and Size of Holes
1/2	3 3/4	9/16	2 1/16	7/8	7/8	2 5/8	4-5/8
3/4	4 5/8	5/8	2 1/4	1	1	3 1/4	4-3/4
1	4 7/8	11/16	2 7/16	1 1/16	1 1/16	3 1/2	4-3/4
1 1/4	5 1/4	13/16	2 5/8	1 1/8	1 1/8	3 7/8	4-3/4
1 1/2	6 1/8	7/8	2 3/4	1 1/4	1 1/4	4 1/2	4-7/8
2	6 1/2	1	2 7/8	1 7/16	1 7/16	5	8-3/4
2 1/2	7 1/2	1 1/8	3 1/8	1 5/8	1 5/8	5 7/8	8-7/8
3	8 1/4	1 1/4	3 1/4	1 13/16	1 13/16	6 5/8	8-7/8
3 1/2	9	1 3/8	3 3/8	1 15/16	1 15/16	7 1/4	8-1
4	10	1 3/8	3 1/2	2	2	7 7/8	8-1
5	11	1 1/2	4	2 1/8	2 1/8	9 1/4	8-1
6	12 1/2	1 5/8	4 1/16	2 1/4	2 1/4	10 5/8	12-1
8	15	1 7/8	4 5/8	2 11/16	2 11/16	13	12-1 1/8
10	17 1/2	2 1/8	4 7/8	2 7/8	4	15 1/4	16-1 1/4
12	20 1/2	2 1/4	5 3/8	3 1/8	4 1/4	17 3/4	16-1 3/8
14	23	2 3/8	5 7/8	3 5/16	4 5/8	20 1/4	20-1 3/8
16	25 1/2	2 1/2	6	3 11/16	5	22 1/2	20-1 1/2
18	28	2 5/8	6 1/2	3 7/8	5 3/8	24 3/4	24-1 1/2
20	30 1/2	2 3/4	6 5/8	4	5 3/4	27	24-1 5/8
24	36	3	6 7/8	4 1/2	6 1/4	32	24-1 7/8

600 LB. FLANGES

A	T②	L② Weld Neck	L② Thrd. Slip on	L② Lap Joint	Bolt Circle	No. and Size of Holes	Nom. Pipe Size
3 3/4	9/16	2 1/16	7/8	7/8	2 5/8	4-5/8	1/2
4 5/8	5/8	2 1/4	1	1	3 1/4	4-3/4	3/4
4 7/8	11/16	2 7/16	1 1/16	1 1/16	3 1/2	4-3/4	1
5 1/4	13/16	2 5/8	1 1/8	1 1/8	3 7/8	4-3/4	1 1/4
6 1/8	7/8	2 3/4	1 1/4	1 1/4	4 1/2	4-7/8	1 1/2
6 1/2	1	2 7/8	1 7/16	1 7/16	5	8-3/4	2
7 1/2	1 1/8	3 1/8	1 5/8	1 5/8	5 7/8	8-7/8	2 1/2
8 1/4	1 1/4	3 1/4	1 13/16	1 13/16	6 5/8	8-7/8	3
9	1 3/8	3 3/8	1 15/16	1 15/16	7 1/4	8-1	3 1/2
10 3/4	1 1/2	4	2 1/8	2 1/8	8 1/2	8-1	4
13	1 3/4	4 1/2	2 3/8	2 3/8	10 1/2	8-1 1/8	5
14	1 7/8	4 5/8	2 5/8	2 5/8	11 1/2	12 1 1/8	6
16 1/2	2 3/16	5 1/4	3	3	13 3/4	12-1 1/4	8
20	2 1/2	6	3 3/8	4 3/8	17	16-1 3/8	10
22	2 5/8	6 1/8	3 5/8	4 5/8	19 1/4	20-1 3/8	12
23 3/4	2 3/4	6 1/2	3 11/16	5	20 3/4	20-1 1/2	14
27	3	7	4 3/16	5 1/2	23 3/4	20-1 5/8	16
29 1/4	3 1/4	7 1/4	4 5/8	6	25 3/4	20-1 3/4	18
32	3 1/2	7 1/2	5	6 1/2	28 1/2	24-1 3/4	20
37	4	8	5 1/2	7 1/4	33	24-2	24

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TABLE D-3—(Continued)

DIMENSIONS OF USA STANDARD FLANGES

900 LB. FLANGES

Nom. Pipe Size	A	T (2)	L (1) Weld Neck	L (1) Thrd. Slip on	L (1) Lap Joint	Bolt Circle	No. and Size of Holes
1/2	4 3/4	7/8	2 3/8	1 1/4	1 1/4	3 1/4	4-7/8
3/4	5 1/8	1	2 3/4	1 3/8	1 3/8	3 1/2	4-7/8
1	5 7/8	1 1/8	2 7/8	1 5/8	1 5/8	4	4-1
1 1/4	6 1/4	1 1/8	2 7/8	1 5/8	1 5/8	4 3/8	4-1
1 1/2	7	1 1/4	3 1/4	1 3/4	1 3/4	4 7/8	4-1 1/8
2	8 1/2	1 1/2	4	2 1/4	2 1/4	6 1/2	8-1
2 1/2	9 5/8	1 5/8	4 1/8	2 1/2	2 1/2	7 1/2	8-1 1/8
3	9 1/2	1 1/2	4	2 1/8	2 1/8	7 1/2	8-1
3 1/2	......	......	......	......	......	......	......
4	11 1/2	1 3/4	4 1/2	2 3/4	2 3/4	9 1/4	8-1 1/4
5	13 3/4	2	5	3 1/8	3 1/8	11	8-1 3/8
6	15	2 3/16	5 1/2	3 3/8	3 3/8	12 1/2	12-1 1/4
8	18 1/2	2 1/2	6 3/8	4	4 1/2	15 1/2	12-1 1/2
10	21 1/2	2 3/4	7 1/4	4 1/4	5	18 1/2	16-1 1/2
12	24	3 1/8	7 7/8	4 5/8	5 5/8	21	20-1 1/2
14	25 1/4	3 3/8	8 3/8	5 1/8	6 1/8	22	20-1 5/8
16	27 3/4	3 1/2	8 1/2	5 1/4	6 1/2	24 1/4	20-1 3/4
18	31	4	9	6	7 1/2	27	20-2
20	33 3/4	4 1/4	9 3/4	6 1/4	8 1/4	29 1/2	20-2 1/8
24	41	5 1/2	11 1/2	8	10 1/2	35 1/2	20-2 5/8

1500 LB. FLANGES

A	T (2)	L (1) Weld Neck	L (1) Thrd. Slip on	L (1) Lap Joint	Bolt Circle	No. and Size of Holes	Nom. Pipe Size
4 3/4	7/8	2 3/8	1 1/4	1 1/4	3 1/4	4-7/8	1/2
5 1/8	1	2 3/4	1 3/8	1 3/8	3 1/2	4-7/8	3/4
5 7/8	1 1/8	2 7/8	1 5/8	1 5/8	4	4-1	1
6 1/4	1 1/8	2 7/8	1 5/8	1 5/8	4 3/8	4-1	1 1/4
7	1 1/4	3 1/4	1 3/4	1 3/4	4 7/8	4-1 1/8	1 1/2
8 1/2	1 1/2	4	2 1/4	2 1/4	6 1/2	8-1	2
9 5/8	1 5/8	4 1/8	2 1/2	2 1/2	7 1/2	8-1 1/8	2 1/2
10 1/2	1 7/8	4 5/8	2 7/8	2 7/8	8	8-1 1/4	3
......	......	......	......	......	......	......	3 1/2
12 1/4	2 1/8	4 7/8	3 9/16	3 9/16	9 1/2	8-1 3/8	4
14 3/4	2 7/8	6 1/8	4 1/8	4 1/8	11 1/2	8 1 5/8	5
15 1/2	3 1/4	6 3/4	4 11/16	4 11/16	12 1/2	12-1 1/2	6
19	3 5/8	8 3/8	5 5/8	5 5/8	15 1/2	12-1 3/4	8
23	4 1/4	10	6 1/4	7	19	12-2	10
26 1/2	4 7/8	11 1/8	7 1/8	8 5/8	22 1/2	16-2 1/8	12
29 1/2	5 1/4	11 3/4	......	9 1/2	25	16-2 3/8	14
32 1/2	5 3/4	12 1/4	......	10 1/4	27 3/4	16-2 5/8	16
36	6 3/8	12 7/8	......	10 7/8	30 1/2	16-2 7/8	18
38 3/4	7	14	......	11 1/2	32 3/4	16-3 1/8	20
46	8	16	......	13	39	16-3 5/8	24

2500 LB. FLANGES

Nom. Pipe Size	A	T (2)	L (1) Weld Neck	L (1) Thrd.	L (1) Lap Joint	Bolt Circle	No. and Size of Holes
1/2	5 1/4	1 3/16	2 7/8	1 9/16	1 9/16	3 1/2	4-7/8
3/4	5 1/2	1 1/4	3 1/8	1 11/16	1 11/16	3 3/4	4-7/8
1	6 1/4	1 3/8	3 1/2	1 7/8	1 7/8	4 1/4	4-1
1 1/4	7 1/4	1 1/2	3 3/4	2 1/16	2 1/16	5 1/8	4-1 1/8
1 1/2	8	1 3/4	4 3/8	2 3/8	2 3/8	5 3/4	4-1 1/4
2	9 1/4	2	5	2 3/4	2 3/4	6 3/4	8-1 1/8
2 1/2	10 1/2	2 1/4	5 5/8	3 1/8	3 1/8	7 3/4	8-1 1/4
3	12	2 5/8	6 5/8	3 5/8	3 5/8	9	8-1 3/8
4	14	3	7 1/2	4 1/4	4 1/4	10 3/4	8-1 5/8
5	16 1/2	3 5/8	9	5 1/8	5 1/8	12 3/4	8-1 7/8
6	19	4 1/4	10 3/4	6	6	14 1/2	8-2 1/8
8	21 3/4	5	12 1/2	7	7	17 1/4	12-2 1/8
10	26 1/2	6 1/2	16 1/2	9	9	21 1/4	12-2 5/8
12	30	7 1/4	18 1/4	10	10	24 3/8	12-2 7/8

(1) Bore to match schedule of attached pipe.

(2) Includes 1/16" raised face in 150 pound and 300 pound standard. Does *not* include raised face in 400, 600, 900, 1500 and 2500 pound standard.

(3) Inside pipe diameters are also provided by this table.

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WELDING NECK FLANGE BORES (1)(3)

Nom. Pipe Size	Outside Diameter	Sched. 10	Sched. 20	Sched. 30	Standard Wall	Sched. 40	Sched. 60	Extra Strong	Sched. 80	Sched. 100	Sched. 120	Sched. 140	Sched. 160	Double Extra Strong	Nom. Pipe Size
1/2	0.840	....	....	....	0.622	0.622	....	0.546	0.546	....	....	....	0.466	0.252	1/2
3/4	1.050	....	....	....	0.824	0.824	....	0.742	0.742	....	....	....	0.614	0.434	3/4
1	1.315	....	....	....	1.049	1.049	....	0.957	0.957	....	....	....	0.815	0.599	1
1 1/4	1.660	....	....	....	1.380	1.380	....	1.278	1.278	....	....	....	1.160	0.896	1 1/4
1 1/2	1.900	....	....	....	1.610	1.610	....	1.500	1.500	....	....	....	1.338	1.100	1 1/2
2	2.375	....	....	....	2.067	2.067	....	1.939	1.939	....	....	....	1.689	1.503	2
2 1/2	2.875	....	....	....	2.469	2.469	....	2.323	2.323	....	....	....	2.125	1.771	2 1/2
3	3.500	....	....	....	3.068	3.068	....	2.900	2.900	....	....	....	2.624	2.300	3
3 1/2	4.000	....	....	....	3.548	3.548	....	3.364	3.364	....	....	....	....	....	3 1/2
4	4.500	....	....	....	4.026	4.026	....	3.826	3.826	....	3.624	....	3.438	3.152	4
5	5.563	....	....	....	5.047	5.047	....	4.813	4.813	....	4.563	....	4.313	4.063	5
6	6.625	....	....	....	6.065	6.065	....	5.761	5.761	....	5.501	....	5.189	4.897	6
8	8.625	....	8.125	8.071	7.981	7.981	7.813	7.625	7.625	7.439	7.189	7.001	6.813	6.875	8
10	10.750	....	10.250	10.136	10.020	10.020	9.750	9.750	9.564	9.314	9.064	8.750	8.500	....	10
12	12.750	....	12.250	12.090	12.000	11.938	11.626	11.750	11.376	11.064	10.750	10.500	10.126	....	12
14	14.000	13.500	13.375	13.250	13.250	13.124	12.814	13.000	12.500	12.126	11.814	11.500	11.188	....	14
16	16.000	15.500	15.375	15.250	15.250	15.000	14.688	15.000	14.314	13.938	13.564	13.124	12.814	....	16
18	18.000	17.500	17.375	17.124	17.250	16.876	16.500	17.000	16.126	15.688	15.250	14.876	14.438	....	18
20	20.000	19.500	19.250	19.000	19.250	18.814	18.376	19.000	17.938	17.438	17.000	16.500	16.064	....	20
24	24.000	23.500	23.250	22.876	23.250	22.626	22.064	23.000	21.564	20.938	20.376	19.876	19.314	....	24
30	30.000	29.376	29.000	28.750	29.250	....	....	29.000	....	....	....	....	....	....	30

TABLE D-4

LENGTH OF ALLOY STEEL STUD BOLTS

(All Dimensions in Inches)

FOR 150 LB. USA STANDARD FLANGES

Nominal Pipe Size	Drilling		Length of Stud Bolts	
	Number of Bolts	Diameter of Bolts	1/16-inch Raised Face	Ring Joint
½	4	½	2¼	. . .
¾	4	½	2¼	. . .
1	4	½	2½	3
1¼	4	½	2½	3
1½	4	½	2¾	3¼
2	4	⅝	3	3½
2½	4	⅝	3¼	3¾
3	4	⅝	3½	4
3½	8	⅝	3½	4
4	8	⅝	3½	4
5	8	¾	3¾	4¼
6	8	¾	3¾	4¼
8	8	¾	4	4½
10	12	⅞	4½	5
12	12	⅞	4½	5
14	12	1	5	5½
16	16	1	5¼	5¾
18	16	1⅛	5¾	6¼
20	20	1⅛	6	6½
24	20	1¼	6¾	7¼

FOR 300 LB. USA STANDARD FLANGES

Nominal Pipe Size	Drilling		Length of Stud Bolts	
	Number of Bolts	Diameter of Bolts	1/16-inch Raised Face	Ring Joint
½	4	½	2½	3
¾	4	⅝	2¾	3¼
1	4	⅝	3	3½
1¼	4	⅝	3	3½
1½	4	¾	3½	4
2	8	⅝	3¼	4
2½	8	¾	3¾	4½
3	8	¾	4	4¾
3½	8	¾	4¼	5
4	8	¾	4¼	5
5	8	¾	4½	5¼
6	12	¾	4¾	5½
8	12	⅞	5¼	6
10	16	1	6	6¾
12	16	1⅛	6½	7¼
14	20	1⅛	6¾	7½
16	20	1¼	7¼	8
18	24	1¼	7½	8¼
20	24	1¼	8	8¾
24	24	1½	9	10

FOR 400 LB. USA STANDARD FLANGES

Nominal Pipe Size	Drilling		Length of Stud Bolts		
	Number of Bolts	Diameter of Bolts	¼-inch Raised Face	Male & Female also Tongue & Groove	Ring Joint
½	4	½	3	2¾	3
¾	4	⅝	3¼	3	3¼
1	4	⅝	3½	3¼	3½
1¼	4	⅝	3¾	3½	3¾
1½	4	¾	4	3¾	4
2	8	⅝	4	3¾	4¼
2½	8	¾	4½	4¼	4¾
3	8	¾	4¾	4½	5
3½	8	⅞	5¼	5	5½
4	8	⅞	5¼	5	5½
5	8	⅞	5½	5¼	5¾
6	12	⅞	5¾	5½	6
8	12	1	6½	6¼	6¾
10	16	1⅛	7¼	7	7½
12	16	1¼	7¾	7½	8
14	20	1¼	8	7¾	8¼
16	20	1⅜	8½	8¼	8¾
18	24	1⅜	8¾	8½	9
20	24	1½	9½	9¼	9¾
24	24	1¾	10½	10¼	11

FOR 600 LB. USA STANDARD FLANGES

Nominal Pipe Size	Drilling		Length of Stud Bolts		
	Number of Bolts	Diameter of Bolts	¼-inch Raised Face	Male & Female also Tongue & Groove	Ring Joint
½	4	½	3	2¾	3
¾	4	⅝	3¼	3	3¼
1	4	⅝	3½	3¼	3½
1¼	4	⅝	3¾	3½	3¾
1½	4	¾	4	3¾	4
2	8	⅝	4	3¾	4¼
2½	8	¾	4½	4¼	4¾
3	8	¾	4¾	4½	5
3½	8	⅞	5¼	5	5½
4	8	⅞	5½	5¼	5¾
5	8	1	6¼	6	6½
6	12	1	6½	6¼	6¾
8	12	1⅛	7½	7¼	7¾
10	16	1¼	8¼	8	8½
12	20	1¼	8½	8¼	8¾
14	20	1⅜	9	8¾	9¼
16	20	1½	9¾	9½	10
18	20	1⅝	10½	10¼	10¾
20	24	1⅝	11¼	11	11½
24	24	1⅞	12¾	12½	13¼

TABLE D-4—(Continued)

LENGTH OF ALLOY STEEL STUD BOLTS

(All Dimensions in Inches)

FOR 900 LB. USA STANDARD FLANGES

Nominal Pipe Size	Drilling: Number of Bolts	Drilling: Diameter of Bolts	Length of Stud Bolts: 1/4-inch Raised Face	Length of Stud Bolts: Male & Female also Tongue & Groove	Length of Stud Bolts: Ring Joint
1/2	4	3/4	4	3 3/4	4
3/4	4	3/4	4 1/4	4	4 1/4
1	4	7/8	4 3/4	4 1/2	4 3/4
1 1/4	4	7/8	4 3/4	4 1/2	4 3/4
1 1/2	4	1	5 1/4	5	5 1/4
2	8	7/8	5 1/2	5 1/4	5 3/4
2 1/2	8	1	6	5 3/4	6 1/4
3	8	7/8	5 1/2	5 1/4	5 3/4
4	8	1 1/8	6 1/2	6 1/4	6 3/4
5	8	1 1/4	7 1/4	7	7 1/2
6	12	1 1/8	7 1/2	7 1/4	7 1/2
8	12	1 3/8	8 1/2	8 1/4	8 3/4
10	16	1 3/8	9	8 3/4	9 1/4
12	20	1 3/8	9 3/4	9 1/2	10
14	20	1 1/2	10 1/2	10 1/4	11
16	20	1 5/8	11	10 3/4	11 1/2
18	20	1 7/8	12 3/4	12 1/2	13 1/4
20	20	2	13 1/2	13 1/4	14
24	20	2 1/2	17	16 3/4	17 3/4

FOR 1500 LB. USA STANDARD FLANGES

Nominal Pipe Size	Drilling: Number of Bolts	Drilling: Diameter of Bolts	Length of Stud Bolts: 1/4-inch Raised Face	Length of Stud Bolts: Male & Female also Tongue & Groove	Length of Stud Bolts: Ring Joint
1/2	4	3/4	4	3 3/4	4
3/4	4	3/4	4 1/4	4	4 1/4
1	4	7/8	4 3/4	4 1/2	4 3/4
1 1/4	4	7/8	4 3/4	4 1/2	4 3/4
1 1/2	4	1	5 1/4	5	5 1/4
2	8	7/8	5 1/2	5 1/4	5 3/4
2 1/2	8	1	6	5 3/4	6 1/4
3	8	1 1/8	6 3/4	6 1/2	7
4	8	1 1/4	7 1/2	7 1/4	7 3/4
5	8	1 1/2	9 1/2	9 1/4	9 3/4
6	12	1 3/8	10	9 3/4	10 1/4
8	12	1 5/8	11 1/4	11	11 3/4
10	12	1 7/8	13 1/4	13	13 1/2
12	16	2	14 3/4	14 1/2	15 1/4
14	16	2 1/4	16	15 3/4	16 3/4
16	16	2 1/2	17 1/2	17 1/4	18 1/2
18	16	2 3/4	19 1/4	19	20 1/4
20	16	3	21	20 3/4	22 1/4
24	16	3 1/2	24	23 3/4	25 1/2

FOR 2500 LB. USA STANDARD FLANGES

Nominal Pipe Size	Drilling: Number of Bolts	Drilling: Diameter of Bolts	Length of Stud Bolts: 1/4-inch Raised Face	Length of Stud Bolts: Male & Female also Tongue & Groove	Length of Stud Bolts: Ring Joint
1/2	4	3/4	4 3/4	4 1/2	4 3/4
3/4	4	3/4	4 3/4	4 1/2	4 3/4
1	4	7/8	5 1/4	5	5 1/4
1 1/4	4	1	5 3/4	5 1/2	6
1 1/2	4	1 1/8	6 1/2	6 1/4	6 3/4
2	8	1	6 3/4	6 1/2	7
2 1/2	8	1 1/8	7 1/2	7 1/4	7 3/4
3	8	1 1/4	8 1/2	8 1/4	8 3/4
4	8	1 1/2	9 3/4	9 1/2	10 1/4
5	8	1 3/4	11 1/2	11 1/4	12 1/4
6	8	2	13 1/2	13 1/4	14
8	12	2	15	14 3/4	15 1/2
10	12	2 1/2	19	18 3/4	20
12	12	2 3/4	21	20 3/4	22

The ends of all stud bolts shall be rounded or crowned.

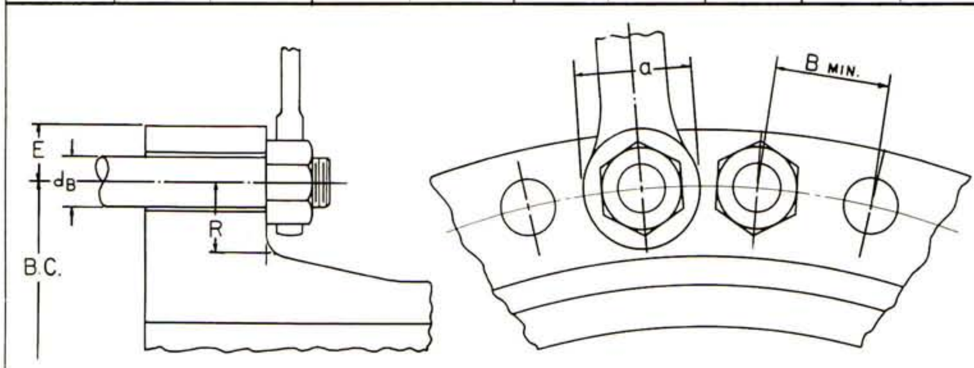
The lengths given in the tables do not include the height of this crown. These lengths include the thickness of two nuts.

(Extracted from American Standard Steel Pipe Flanges and Flanged Fittings (USA Standard B16.5-1961) with the permission of the publisher, The American Society of Mechanical Engineers, United Engineering Center, 345 E. 47th Street, New York 17, N. Y.)

TABLE D-5

BOLTING DATA

BOLT SIZE d_B	THREADS: NO. OF THREADS	THREADS: ROOT AREA □"	NUT DIMENSIONS: ACROSS FLATS	NUT DIMENSIONS: ACROSS CORNERS	MINIMUM BOLT SPACING B_{min}	MINIMUM RADIAL DISTANCE R	EDGE DISTANCE E	WRENCH DIAMETER a	BOLT SIZE d_B
1/2"	13	.126	7/8"	0.969"	1 1/4"	13/16"	5/8"	1 1/2"	1/2"
5/8	11	.202	1 1/16	1.175	1 1/2	15/16	3/4	1 3/4	5/8
3/4	10	.302	1 1/4	1.383	1 3/4	1 1/8	13/16	2 1/16	3/4
7/8	9	.419	1 7/16	1.589	2 1/16	1 1/4	15/16	2 3/8	7/8
1	8	.551	1 5/8	1.796	2 1/4	1 3/8	1 1/16	2 5/8	1
1 1/8	8	.728	1 13/16	2.002	2 1/2	1 1/2	1 1/8	2 7/8	1 1/8
1 1/4	8	.929	2	2.209	2 13/16	1 3/4	1 1/4	3 1/4	1 1/4
1 3/8	8	1.155	2 3/16	2.416	3 1/16	1 7/8	1 3/8	3 1/2	1 3/8
1 1/2	8	1.405	2 3/8	2.622	3 1/4	2	1 1/2	3 3/4	1 1/2
1 5/8	8	1.680	2 9/16	2.828	3 1/2	2 1/8	1 5/8	4	1 5/8
1 3/4	8	1.980	2 3/4	3.035	3 3/4	2 1/4	1 3/4	4 1/4	1 3/4
1 7/8	8	2.304	2 15/16	3.242	4	2 3/8	1 7/8	4 1/2	1 7/8
2	8	2.652	3 1/8	3.449	4 1/4	2 1/2	2	4 3/4	2
2 1/4	8	3.423	3 1/2	3.862	4 3/4	2 3/4	2 1/4	5 1/4	2 1/4
2 1/2	8	4.292	3 7/8	4.275	5 1/4	3 1/16	2 3/8	5 7/8	2 1/2
2 3/4	8	5.259	4 1/4	4.688	5 3/4	3 3/8	2 5/8	6 1/2	2 3/4
3	8	6.324	4 5/8	5.102	6 1/4	3 5/8	2 7/8	7	3



Nut dimensions are U.S.A. heavy series hexagon.

Threads are National Coarse series below 1" and eight-pitch thread series 1" and above.

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PRESSURE-TEMPERATURE RATINGS FOR VALVES, FITTINGS, AND FLANGES(1)

TABLES D-6—D-6.6

INTRODUCTORY NOTES

1. Products used within the jurisdiction of the ASME Boiler and Pressure Vessel Code and the USA Standard Code for pressure piping are subject to the maximum temperature and stress limitations upon the material and piping stated therein.

2. The ratings at −20°F to 100°F given for the materials covered on pages 180 to 186 inclusive, shall also apply at lower temperatures. The ratings for low temperature service of the cast and forged materials listed in ASTM A352 and A350 shall be taken the same as the −20°F to 100°F ratings for carbon steel on pages 180 to 186 inclusive.

Some of the materials listed in the rating tables undergo a decrease in impact resistance at temperatures lower than −20°F to such an extent as to be unable to safely resist shock loadings, sudden changes of stress or high stress concentrations. Therefore, products that are to operate at temperatures below —20°F shall conform to the rules of the applicable Codes under which they are to be used.

3. The pressure-temperature ratings in the tables apply to all products covered by this standard. Valves conforming to the requirements of this standard must, in other respects, merit these ratings.

All ratings are the maximum allowable nonshock pressures (psig) at the tabulated temperatures (degree F) and may be interpolated between the temperatures shown. The primary service pressure ratings (150, 300, 400, 600, 900, 1500, 2500 lb.) are those at the head of the tables and shown in boldface type in the body of the tables.

Temperatures (degree F) shown in the tables, used in determining these rating tables, were temperatures on the inside of the pressure retaining structure.

The use of these ratings require gaskets conforming to the requirements of Introductory Note 6.10 of USA Standard Specification B16.5-1961. The user is responsible for selecting gaskets of dimensions and materials to withstand the required bolt loading without injurious crushing, and suitable for the service conditions in all other respects.

(1) Extracted from American Standard Steel Pipe Flanges and Flanged Fittings (USA B16.5-1961) with the permission of the publisher, The American Society of Mechanical Engineers, United Engineering Center, 345 E. 47th Street, New York 17, New York.

TABLE D-6

150 Pound Pressure-Temperature Ratings

NOTE: These ratings are all subject to stipulations in Introductory Note 3 which form a part of this table. All pressures are in pounds per square inch gage (psig).

Service Temperature Deg F	Material																	Service Temperature Deg F
	Carbon Steel	Carbon Moly	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	TYPES						
			½-½	1-½	1¼-½	2-½	2¼-1	3-1	5-½	5-½-Si	9-1	304	347 & 321	316	310	304L	316L	
−20 to 100[2]								275										−20 to 100[2]
150								255										150
200								240										200
250								225										250
300								210										300
350								195										350
400								180										400
450								165										450
500								**150**										500
550								140										550
600								130										600
650								120										650
700								110										700
750								100										750
800								92										800
850	82[1]							82								---	82	850
875	75[1]	75[1]						75								---	---	875
900	70[1]	70[1]						70								---	---	900
925	60[1]	60[1]						60								---	---	925
950	55[1]	55[1]						55								---	---	950
975	50[1]	50[1]						50								---	---	975
1000	40[1]	40[1]						40								---	---	1000
Hydrostatic Shell Test Pressure								425										

[1] See Introductory Note 1 on Boiler Code and Pressure Piping Code limitations.

[2] See Introductory Note 2 for low temperature-pressure ratings including other materials.

TABLE D-6.1

300 Pound Pressure-Temperature Ratings

NOTE: These ratings are all subject to stipulations in Introductory Note 3 which form a part of this table. All pressures are in pounds per square inch gage (psig).

Service Temperature Deg F	Material																	Service Temperature Deg F
	Carbon Steel	Carbon Moly	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	Cr-Mo	TYPES						
			½-½	1-½	1¼-½	2-½	2¼-1	3-1	5-½	5-½-Si	9-1	304	347 & 321	316	310	304L	316L	
−20 to 100[2]						720						615		720		515	515	−20 to 100[2]
150						710						585		710		510	515	150
200						700						550		700		505	515	200
250						690						520		690		465	495	250
300						680						495		680		430	475	300
350						675						470		675		395	435	350
400						665						450		665		360	395	400
450						650						430		650		340	380	450
500						625						410		625		320	360	500
550						590						395		590		310	350	550
600						555						380		555		**300**	335	600
650						515						370		515		290	325	650
700	470	480	480	485	485	480	485	480	485	480	485	355	495		490	280	310	700
750	425	445	445	450	450	445	450	445	450	445	450	340	470		465	275	**300**	750
800	365	410	410	415	415	410	415	410	415	410	415	330	450		440	265	290	800
850	**300**[1]	370	370	385	385	370	385	370	385	370	385	320	425		415		280	850
875	260[1]	355[1]	355	365	365	355	365	355	365	355	365	315	415		400			875
900	225[1]	335[1]	335	350	350	335	350	335	350	335	350	310	400		390			900
925	190[1]	320[1]	320	335	335	320	335	320	335	320	335	305	390		375			925
950	155[1]	**300**[1]	**300**	315	315	**300**	315	**300**	315	**300**	315	305	380		365			950
975	120[1]	280[1]	280	**300**	**300**	280	**300**	275	**300**	250	**300**	**300**	370		350			975
1000	85[1]	215[1]	215	255	265	215	265	240	250	190	290	**300**	355		340			1000
1025				215	230[1]	180	235	215	215	155	240	295	345		325			1025
1050				170	190[1]	145	200	190	180	120	190	290	335		315			1050
1075				135	165[1]	120	170[1]	165	145	105	150	275	325		**300**			1075
1100				95	135[1]	95	145[1]	135	115	85	115	255	310		290			1100
1125				75[1]	110[1]	75	125[1]	115	95	75	95	225	**300**		270			1125
1150				55[1]	85[1]	60	105[1]	95	75	60	75	195	260	290	250			1150
1175				45[1]	65[1]	50	85[1]	70	65	50	65	175	215	260	225			1175
1200				35[1]	40[1]	40	70[1]	50	50	40	50	155	170	235	205			1200
1225												135	140	205	185			1225
1250												110	115	180	165			1250
1275												100	95	160	140			1275
1300												85	75	135	120			1300
1325												75	65	115	100			1325
1350												60	50	95	80			1350
1375												55	45	80	70			1375
1400												50	40	70	55			1400
1425												40	35	60	45			1425
1450												35	30	50	40			1450
1475												30	30	45	30			1475
1500												25	25	35	25			1500
Hydrostatic Shell Test Pressure							1100					925		1100		775		

[1] See Introductory Note 1 on Boiler Code and Pressure Piping Code limitations.

[2] See Introductory Note 2 for low temperature-pressure ratings including other materials.

TABLE D-6.2

400 Pound Pressure-Temperature Ratings

NOTE: These ratings are all subject to stipulations in Introductory Note 3 which form a part of this table. All pressures are in pounds per square inch gage (psig).

Service Temperature Deg F	Material: Carbon Steel	Carbon Moly	Cr-Mo ½-½	Cr-Mo 1-½	Cr-Mo 1¼-½	Cr-Mo 2-½	Cr-Mo 2¼-1	Cr-Mo 3-1	Cr-Mo 5-½	Cr-Mo 5-½-Si	Cr-Mo 9-1	TYPES 304	347 & 321	316	310	304L	316L	Service Temperature Deg F
-20 to 100[2]	←					960					→	825	←	960	→	685	685	-20 to 100[2]
150						945						775		945		680	685	150
200						930						730		930		670	685	200
250						920						695		920		625	660	250
300						910						660		910		575	635	300
350						900						630		900		530	580	350
400						890						600		890		485	525	400
450						870						575		870		455	505	450
500						835						550		835		425	485	500
550						790						530		790		410	465	550
600						740						510		740		**400**	445	600
650						690						490		690		385	430	650
700	635	640	640	645	645	640	645	640	645	640	645	475	660		655	375	415	700
750	575	590	590	600	600	590	600	590	600	590	600	455	625		620	365	**400**	750
800	490	545	545	555	555	545	555	545	555	545	555	440	595		585	355	385	800
850	**400**[1]	495[1]	495	510	510	495	510	495	510	495	510	425	565		550		375	850
875	350[1]	470[1]	470	490	490	470	490	470	490	470	490	420	550		535			875
900	295[1]	450[1]	450	465	465	450	465	450	465	450	465	415	535		520			900
925	250[1]	425[1]	425	445	445	425	445	425	445	425	445	410	520		500			925
950	205[1]	**400**[1]	**400**	420	420	**400**	420	**400**	420	**400**	420	405	505		485			950
975	160[1]	370[1]	370	**400**	**400**	370	**400**	365	**400**	330	**400**	405	490		470			975
1000	115[1]	285[1]	285	345	355	285	355	320	335	250	390	**400**	475		450			1000
1025				285	305[1]	240	310	285	285	205	320	395	460		435			1025
1050				230	250[1]	190	265	250	240	160	250	390	445		415			1050
1075				180	215[1]	160	230[1]	215	195	135	200	365	430		**400**			1075
1100				130	185[1]	125	190[1]	185	150	115	150	345	415		390			1100
1125				100[1]	150[1]	105	165[1]	155	125	100	125	305	**400**		360			1125
1150				70[1]	115[1]	80	135[1]	125	100	80	100	265	345	390	330			1150
1175				60[1]	85[1]	65	115[1]	95	85	70	85	235	290	350	305			1175
1200				45[1]	55[1]	55	90[1]	70	70	55	70	205	230	310	275			1200
1225												175	190	275	245			1225
1250												150	150	240	215			1250
1275												130	125	215	190			1275
1300												110	100	185	160			1300
1325												95	85	155	135			1325
1350												80	70	125	105			1350
1375												75	60	105	90			1375
1400												65	55	90	75			1400
1425												55	50	80	60			1425
1450												45	40	70	50			1450
1475												40	40	55	40			1475
1500												35	35	45	35			1500
Hydrostatic Shell Test Pressure						1450						1250		1450		1025		

[1] See Introductory Note 1 on Boiler Code and Pressure Piping Code limitations.

[2] See Introductory Note 2 for low temperature-pressure ratings including other materials.

TABLE D-6.3

600 Pound Pressure-Temperature Ratings

NOTE: These ratings are all subject to stipulations in Introductory Note 3 which form a part of this table. All pressures are in pounds per square inch gage (psig).

Service Temperature Deg F	Carbon Steel	Carbon Moly	Cr-Mo ½-½	Cr-Mo 1-½	Cr-Mo 1¼-½	Cr-Mo 2-½	Cr-Mo 2¼-1	Cr-Mo 3-1	Cr-Mo 5-½	Cr-Mo 5-½-Si	Cr-Mo 9-1	TYPES 304	TYPES 347 & 321	TYPES 316	TYPES 310	TYPES 304L	TYPES 316L	Service Temperature Deg F
-20 to 100[2]						1440						1235		1440		1030	1030	-20 to 100[2]
150						1420						1165		1420		1020	1030	150
200						1400						1095		1400		1005	1030	200
250						1380						1040		1380		935	990	250
300						1365						985		1365		860	955	300
350						1350						945		1350		795	870	350
400						1330						900		1330		725	790	400
450						1305						860		1305		680	755	450
500						1250						825		1250		640	725	500
550						1180						795		1180		615	695	550
600						1110						765		1110		**600**	670	600
650						1030						735		1030		575	645	650
700	940	960	960	965	965	960	965	960	965	960	965	710	985		980	560	620	700
750	850	890	890	900	900	890	900	890	900	890	900	685	940		930	545	**600**	750
800	730	815	815	835	835	815	835	815	835	815	835	660	895		880	535	580	800
850	**600**[1]	745	745	765	765	745	765	745	765	745	765	640	850		830		560	850
875	525[1]	710[1]	710	735	735	710	735	710	735	710	735	630	825		805			875
900	445[1]	670[1]	670	700	700	670	700	670	700	670	700	620	805		780			900
925	375[1]	635[1]	635	665	665	635	665	635	665	635	665	615	780		755			925
950	310[1]	**600**[1]	**600**	635	635	**600**	635	**600**	635	**600**	635	610	760		725			950
975	240[1]	555[1]	555	**600**	**600**	555	**600**	550	**600**	495	**600**	605	735		700			975
1000	170[1]	430[1]	430	515	535	425	535	480	500	375	585	**600**	715		675			1000
1025				430	455[1]	355	465	430	430	310	480	595	690		650			1025
1050				345	375[1]	290	400	375	355	240	375	585	670		625			1050
1075				265	325[1]	240	345[1]	325	290	205	300	550	645		**600**			1075
1100				190	275[1]	190	290[1]	275	225	170	225	515	625		585			1100
1125				150[1]	225[1]	155	245[1]	230	190	145	190	455	**600**		540			1125
1150				105[1]	170[1]	120	205[1]	185	150	125	150	395	520	585	495			1150
1175				85[1]	125[1]	100	170[1]	145	125	105	125	350	430	525	455			1175
1200				70[1]	80[1]	80	135[1]	105	105	80	105	310	345	465	410			1200
1225												265	285	415	370			1225
1250												225	225	365	325			1250
1275												195	190	320	285			1275
1300												170	150	275	240			1300
1325												145	125	230	200			1325
1350												125	105	185	160			1350
1375												110	95	160	135			1375
1400												95	80	135	110			1400
1425												80	70	120	95			1425
1450												70	60	105	75			1450
1475												60	55	85	65			1475
1500												50	50	70	50			1500
Hydrostatic Shell Test Pressure	2175											1875	2175			1550		

1 See Introductory Note 1 on Boiler Code and Pressure Piping Code limitations.
2 See Introductory Note 2 for low temperature-pressure ratings including other materials.

TABLE D-6.4

900 Pound Pressure-Temperature Ratings

NOTE: These ratings are all subject to stipulations in Introductory Note 3 which form a part of this table. All pressures are in pounds per square inch gage (psig).

Service Temperature Deg F	Material: Carbon Steel	Carbon Moly	Cr-Mo ½-½	Cr-Mo 1-½	Cr-Mo 1¼-½	Cr-Mo 2-½	Cr-Mo 2¼-1	Cr-Mo 3-1	Cr-Mo 5-½	Cr-Mo 5-½-Si	Cr-Mo 9-1	TYPES: 304	347 & 321	316	310	304L	316L	Service Temperature Deg F
-20 to 100[2]						2160						1850		2160		1545	1545	-20 to 100[2]
150						2130						1750		2130		1525	1545	150
200						2100						1645		2100		1510	1545	200
250						2070						1565		2070		1400	1490	250
300						2050						1480		2050		1295	1430	300
350						2025						1415		2025		1190	1310	350
400						2000						1350		2000		1085	1185	400
450						1955						1290		1955		1020	1135	450
500						1875						1235		1875		960	1085	500
550						1775						1190		1775		925	1045	550
600						1660						1145		1660		**900**	1005	600
650						1550						1105		1550		865	970	650
700	1410	1440	1440	1450	1450	1440	1450	1440	1450	1440	1450	1065	1480		1470	840	935	700
750	1275	1330	1330	1350	1350	1330	1350	1330	1350	1330	1350	1025	1410		1395	820	**900**	750
800	1100	1225	1225	1250	1250	1225	1250	1225	1250	1225	1250	985	1345		1320	800	870	800
850	**900**[1]	1115[1]	1115	1150	1150	1115	1150	1115	1150	1115	1150	960	1275		1245		840	850
875	785[1]	1060[1]	1060	1100	1100	1060	1100	1060	1100	1060	1100	945	1240		1205			875
900	670[1]	1010[1]	1010	1050	1050	1010	1050	1010	1050	1010	1050	930	1205		1165			900
925	565[1]	955[1]	955	1000	1000	955	1000	955	1000	955	1000	920	1175		1130			925
950	465[1]	**900**[1]	**900**	950	950	**900**	950	**900**	950	**900**	950	915	1140		1090			950
975	360[1]	835[1]	835	**900**	**900**	835	**900**	825	**900**	745	**900**	905	1105		1050			975
1000	255[1]	645[1]	645	770	800	635	800	720	750	565	875	**900**	1070		1015			1000
1025				645	685[1]	535	700	645	645	465	720	890	1035		975			1025
1050				515	565[1]	430	595	565	535	360	565	875	1000		940			1050
1075				400	490[1]	355	515[1]	490	435	310	455	825	970		**900**			1075
1100				290	410[1]	285	430[1]	410	340	255	340	770	935		875			1100
1125				225[1]	335[1]	230	370[1]	345	285	220	285	680	**900**		810			1125
1150				160[1]	255[1]	180	310[1]	280	225	185	225	590	780	875	745			1150
1175				130[1]	190[1]	150	255[1]	215	190	155	190	525	650	785	680			1175
1200				105[1]	125[1]	125	205[1]	155	155	125	155	465	515	700	615			1200
1225												400	425	620	555			1225
1250												335	340	545	490			1250
1275												295	285	480	425			1275
1300												250	225	410	360			1300
1325												220	190	345	300			1325
1350												185	155	280	240			1350
1375												165	140	240	205			1375
1400												145	125	205	165			1400
1425												125	110	180	140			1425
1450												105	95	155	115			1450
1475												90	85	130	95			1475
1500												75	75	105	75			1500
Hydrostatic Shell Test Pressure						3250						2775		3250		2325		

[1] See Introductory Note 1 on Boiler Code and Pressure Piping Code limitations.
[2] See Introductory Note 2 for low temperature-pressure ratings including other materials.

TABLE D-6.5

1500 Pound Pressure-Temperature Ratings

NOTE: These ratings are all subject to stipulations in Introductory Note 3 which form a part of this table. All pressures are in pounds per square inch gage (psig).

Service Temperature Deg F	Material: Carbon Steel	Carbon Moly	Cr-Mo ½-½	Cr-Mo 1-½	Cr-Mo 1¼-½	Cr-Mo 2-½	Cr-Mo 2¼-1	Cr-Mo 3-1	Cr-Mo 5-½	Cr-Mo 5-½-Si	Cr-Mo 9-1	TYPES 304	347 & 321	316	310	304L	316L	Service Temperature Deg F
–20 to 100[2]						3600						3085		3600		2570	2570	–20 to 100[2]
150						3550						2915		3550		2545	2570	150
200						3500						2740		3500		2520	2570	200
250						3450						2605		3450		2335	2480	250
300						3415						2470		3415		2155	2385	300
350						3375						2360		3375		1985	2180	350
400						3330						2245		3330		1810	1975	400
450						3255						2150		3255		1705	1895	450
500						3125						2055		3125		1600	1810	500
550						2955						1985		2955		1540	1740	550
600						2770						1910		2770		**1500**	1670	600
650						2580						1845		2580		1440	1615	650
700	2350	2400	2400	2415	2415	2400	2415	2400	2415	2400	2415	1775	2465		2455	1400	1555	700
750	2125	2220	2220	2250	2250	2220	2250	2220	2250	2220	2250	1710	2355		2325	1365	**1500**	750
800	1830	2040	2040	2080	2080	2040	2080	2040	2080	2040	2080	1645	2240		2200	1335	1450	800
850	**1500**[1]	1860[1]	1860	1915	1915	1860	1915	1860	1915	1860	1915	1595	2125		2070		1400	850
875	1305[1]	1770[1]	1770	1830	1830	1770	1830	1770	1830	1770	1830	1570	2070		2010			875
900	1115[1]	1680[1]	1680	1750	1750	1680	1750	1680	1750	1680	1750	1545	2010		1945			900
925	945[1]	1590[1]	1590	1665	1665	1590	1665	1590	1665	1590	1665	1535	1955		1880			925
950	770[1]	**1500**[1]	**1500**	1585	1585	**1500**	1585	**1500**	1585	**1500**	1585	1525	1900		1820			950
975	600[1]	1395[1]	1395	**1500**	**1500**	1390	**1500**	1370	**1500**	1245	**1500**	1510	1840		1755			975
1000	430[1]	1070[1]	1070	1285	1335	1065	1335	1200	1250	945	1455	**1500**	1785		1690			1000
1025				1070	1140[1]	890	1165	1070	1070	770	1200	1485	1725		1625			1025
1050				855	945[1]	720	995	945	890	600	945	1455	1670		1565			1050
1075				670	815[1]	595	855[1]	815	730	515	755	1370	1615		**1500**			1075
1100				480	685[1]	470	720[1]	685	565	430	565	1285	1555		1455			1100
1125				375[1]	555[1]	385	615[1]	575	470	370	470	1135	**1500**		1350			1125
1150				265[1]	430[1]	300	515[1]	465	375	310	375	985	1305	1455	1245			1150
1175				220[1]	315[1]	255	430[1]	360	315	255	315	880	1080	1310	1135			1175
1200				170[1]	205[1]	205	345[1]	255	255	205	255	770	855	1165	1030			1200
1225												665	710	1035	920			1225
1250												555	565	910	815			1250
1275												490	470	795	705			1275
1300												420	375	685	600			1300
1325												365	315	575	500			1325
1350												310	255	465	405			1350
1375												275	230	405	340			1375
1400												240	205	345	275			1400
1425												205	180	300	230			1425
1450												170	155	255	190			1450
1475												150	140	215	160			1475
1500												130	130	170	130			1500
Hydrostatic Shell Test Pressure							5400					4650		5400		3850		

1 See Introductory Note 1 on Boiler Code and Pressure Piping Code limitations.

2 See Introductory Note 2 for low temperature-pressure ratings including other materials.

TABLE D-6.6

2500 Pound Pressure-Temperature Ratings

NOTE: These ratings are all subject to stipulations in Introductory Note 3 which form a part of this table. All pressures are in pounds per square inch gage (psig).

Service Temperature Deg F	Material: Carbon Steel	Carbon Moly	Cr-Mo ½-½	Cr-Mo 1-½	Cr-Mo 1¼-½	Cr-Mo 2-½	Cr-Mo 2¼-1	Cr-Mo 3-1	Cr-Mo 5-½	Cr-Mo 5-½-Si	Cr-Mo 9-1	TYPES 304	347 & 321	316	310	304L	316L	Service Temperature Deg F
-20 to 100[2]						6000						5145		6000		4285	4285	-20 to 100[2]
150						5915						4855		5915		4240	4285	150
200						5830						4565		5830		4200	4285	200
250						5750						4340		5750		3895	4135	250
300						5690						4115		5690		3595	3980	300
350						5625						3930		5625		3305	3635	350
400						5550						3745		5550		3020	3295	400
450						5430						3585		5430		2840	3155	450
500						5210						3430		5210		2660	3020	500
550						4925						3305		4925		2565	2900	550
600						4620						3180		4620		**2500**	2785	600
650						4300						3070		4300		2400	2690	650
700	3920	4000	4000	4025	4025	4000	4025	4000	4025	4000	4025	2960		4110	4090	2340	2595	700
750	3550	3700	3700	3745	3745	3700	3745	3700	3745	3700	3745	2850		3920	3875	2280	**2500**	750
800	3050	3400	3400	3470	3470	3400	3470	3400	3470	3400	3470	2745		3730	3665	2225	2415	800
850	**2500**[1]	3100	3100	3190	3190	3100	3190	3100	3190	3100	3190	2660		3540	3455		2335	850
875	2180[1]	2950[1]	2950	3055	3055	2950	3055	2950	3055	2950	3055	2620		3445	3345			875
900	1855[1]	2800[1]	2800	2915	2915	2800	2915	2800	2915	2800	2915	2580		3350	3240			900
925	1570[1]	2650[1]	2650	2775	2775	2650	2775	2650	2775	2650	2775	2560		3260	3135			925
950	1285[1]	**2500**[1]	**2500**	2640	2640	**2500**	2640	**2500**	2640	**2500**	2640	2540		3165	3030			950
975	1000[1]	2320[1]	2320	**2500**	**2500**	2315	**2500**	2285	**2500**	2070	**2500**	2520		3070	2925			975
1000	715[1]	1785[1]	1785	2145	2230	1770	2230	2000	2085	1570	2430	**2500**		2975	2820			1000
1025				1785	1900[1]	1485	1945	1785	1785	1285	2000	2470		2880	2710			1025
1050				1430	1570[1]	1200	1655	1570	1485	1000	1570	2430		2785	2605			1050
1075				1115	1355[1]	995	1430[1]	1355	1215	855	1255	2285		2690	**2500**			1075
1100				800	1145[1]	785	1200[1]	1145	945	715	945	2145		2595	2430			1100
1125				620[1]	930[1]	645	1030[1]	955	785	615	785	1895		**2500**	2250			1125
1150				445[1]	715[1]	500	855[1]	770	630	515	630	1645	2170	2430	2070			1150
1175				365[1]	530[1]	420	715[1]	600	530	430	530	1465	1800	2185	1895			1175
1200				285[1]	345[1]	345	570[1]	430	430	345	430	1285	1430	1945	1715			1200
1225												1105	1185	1730	1535			1225
1250												930	945	1515	1355			1250
1275												815	785	1330	1180			1275
1300												700	630	1145	1000			1300
1325												605	530	955	835			1325
1350												515	430	770	670			1350
1375												455	385	670	565			1375
1400												400	345	570	455			1400
1425												345	300	500	385			1425
1450												285	255	430	315			1450
1475												250	235	355	265			1475
1500												215	215	285	215			1500
Hydrostatic Shell Test Pressure	9000											7725	9000			6425		

1 See Introductory Note 1 on Boiler Code and Pressure Piping Code limitations.
2 See Introductory Note 2 for low temperature-pressure ratings including other materials.

TABLE D-7

CHARACTERISTICS OF TUBING

O.D. of Tubing	B.W.G. Gauge	Thick-ness Inches	Internal Area Sq. Inch	Sq. Ft. External Surface Per Foot Length	Sq. Ft. Internal Surface Per Foot Length	Weight Per Ft. Length Steel Lbs.*	I. D. Tubing Inches	Moment of Inertia Inches^4	Section Modulus Inches^3	Radius of Gyration Inches	Constant C**	O. D. / I. D.	Metal Area (Transverse Metal Area) Sq. Inch
1/4	22	.028	.0295	.0655	.0508	.066	.194	.00012	.00098	.0792	46	1.289	.0195
1/4	24	.022	.0333	.0655	.0539	.054	.206	.00011	.00083	.0810	52	1.214	.0159
1/4	26	.018	.0360	.0655	.0560	.045	.214	.00009	.00071	.0824	56	1.168	.0131
3/8	18	.049	.0603	.0982	.0725	.171	.277	.00068	.0036	.1164	94	1.354	.0502
3/8	20	.035	.0731	.0982	.0798	.127	.305	.00055	.0029	.1213	114	1.233	.0374
3/8	22	.028	.0799	.0982	.0835	.104	.319	.00046	.0025	.1227	125	1.176	.0305
3/8	24	.022	.0860	.0982	.0867	.083	.331	.00038	.0020	.1248	134	1.133	.0244
1/2	16	.065	.1075	.1309	.0969	.302	.370	.0022	.0086	.1556	168	1.351	.0888
1/2	18	.049	.1269	.1309	.1052	.236	.402	.0018	.0072	.1606	198	1.244	.0694
1/2	20	.035	.1452	.1309	.1126	.174	.430	.0014	.0056	.1649	227	1.163	.0511
1/2	22	.028	.1548	.1309	.1162	.141	.444	.0012	.0046	.1671	241	1.126	.0415
5/8	12	.109	.1301	.1636	.1066	.602	.407	.0061	.0197	.1864	203	1.536	.177
5/8	13	.095	.1486	.1636	.1139	.537	.435	.0057	.0183	.1903	232	1.437	.158
5/8	14	.083	.1655	.1636	.1202	.479	.459	.0053	.0170	.1938	258	1.362	.141
5/8	15	.072	.1817	.1636	.1259	.425	.481	.0049	.0156	.1971	283	1.299	.125
5/8	16	.065	.1924	.1636	.1296	.388	.495	.0045	.0145	.1993	300	1.263	.114
5/8	17	.058	.2035	.1636	.1333	.350	.509	.0042	.0134	.2016	317	1.228	.103
5/8	18	.049	.2181	.1636	.1380	.303	.527	.0037	.0118	.2043	340	1.186	.089
5/8	19	.042	.2298	.1636	.1416	.262	.541	.0033	.0105	.2068	358	1.155	.077
5/8	20	.035	.2419	.1636	.1453	.221	.555	.0028	.0091	.2089	377	1.126	.065
3/4	10	.134	.1825	.1963	.1262	.884	.482	.0129	.0344	.2229	285	1.556	.260
3/4	11	.120	.2043	.1963	.1335	.809	.510	.0122	.0326	.2267	319	1.471	.238
3/4	12	.109	.2223	.1963	.1393	.748	.532	.0116	.0309	.2299	347	1.410	.220
3/4	13	.095	.2463	.1963	.1466	.666	.560	.0107	.0285	.2340	384	1.339	.196
3/4	14	.083	.2679	.1963	.1529	.592	.584	.0098	.0262	.2376	418	1.284	.174
3/4	15	.072	.2884	.1963	.1587	.520	.606	.0089	.0238	.2410	450	1.238	.153
3/4	16	.065	.3019	.1963	.1623	.476	.620	.0083	.0221	.2433	471	1.210	.140
3/4	17	.058	.3157	.1963	.1660	.428	.634	.0076	.0203	.2455	492	1.183	.126
3/4	18	.049	.3339	.1963	.1707	.367	.652	.0067	.0178	.2484	521	1.150	.108
3/4	20	.035	.3632	.1963	.1780	.269	.680	.0050	.0134	.2532	567	1.103	.079
7/8	10	.134	.2892	.2291	.1589	1.061	.607	.0221	.0505	.2662	451	1.441	.312
7/8	11	.120	.3166	.2291	.1662	.969	.635	.0208	.0475	.2703	494	1.378	.285
7/8	12	.109	.3390	.2291	.1720	.891	.657	.0196	.0449	.2736	529	1.332	.262
7/8	13	.095	.3685	.2291	.1793	.792	.685	.0180	.0411	.2778	575	1.277	.233
7/8	14	.083	.3948	.2291	.1856	.704	.709	.0164	.0374	.2815	616	1.234	.207
7/8	16	.065	.4359	.2291	.1950	.561	.745	.0137	.0312	.2873	680	1.174	.165
7/8	18	.049	.4742	.2291	.2034	.432	.777	.0109	.0249	.2925	740	1.126	.127
7/8	20	.035	.5090	.2291	.2107	.313	.805	.0082	.0187	.2992	794	1.087	.092
1	8	.165	.3526	.2618	.1754	1.462	.670	.0392	.0784	.3009	550	1.493	.430
1	10	.134	.4208	.2618	.1916	1.237	.732	.0350	.0700	.3098	656	1.366	.364
1	11	.120	.4536	.2618	.1990	1.129	.760	.0327	.0654	.3140	708	1.316	.332
1	12	.109	.4803	.2618	.2047	1.037	.782	.0307	.0615	.3174	749	1.279	.305
1	13	.095	.5153	.2618	.2121	.918	.810	.0280	.0559	.3217	804	1.235	.270
1	14	.083	.5463	.2618	.2183	.813	.834	.0253	.0507	.3255	852	1.199	.239
1	15	.072	.5755	.2618	.2241	.714	.856	.0227	.0455	.3291	898	1.167	.210
1	16	.065	.5945	.2618	.2278	.649	.870	.0210	.0419	.3314	927	1.149	.191
1	18	.049	.6390	.2618	.2361	.496	.902	.0166	.0332	.3366	997	1.109	.146
1	20	.035	.6793	.2618	.2435	.360	.930	.0124	.0247	.3414	1060	1.075	.106
1-1/4	7	.180	.6221	.3272	.2330	2.057	.890	.0890	.1425	.3836	970	1.404	.605
1-1/4	8	.165	.6648	.3272	.2409	1.921	.920	.0847	.1355	.3880	1037	1.359	.565
1-1/4	10	.134	.7574	.3272	.2571	1.598	.982	.0741	.1186	.3974	1182	1.273	.470
1-1/4	11	.120	.8012	.3272	.2644	1.448	1.010	.0688	.1100	.4018	1250	1.238	.426
1-1/4	12	.109	.8365	.3272	.2702	1.329	1.032	.0642	.1027	.4052	1305	1.211	.391
1-1/4	13	.095	.8825	.3272	.2775	1.173	1.060	.0579	.0926	.4097	1377	1.179	.345
1-1/4	14	.083	.9229	.3272	.2838	1.033	1.084	.0521	.0833	.4136	1440	1.153	.304
1-1/4	16	.065	.9852	.3272	.2932	.823	1.120	.0426	.0682	.4196	1537	1.116	.242
1-1/4	18	.049	1.042	.3272	.3016	.629	1.152	.0334	.0534	.4250	1626	1.085	.185
1-1/4	20	.035	1.094	.3272	.3089	.456	1.180	.0247	.0395	.4297	1707	1.059	.134
1-1/2	10	.134	1.192	.3927	.3225	1.955	1.232	.1354	.1806	4853	1860	1.218	.575
1-1/2	12	.109	1.291	.3927	.3356	1.618	1.282	.1159	.1546	.4933	2014	1.170	.476
1-1/2	14	.083	1.398	.3927	.3492	1.258	1.334	.0931	.1241	.5018	2181	1.124	.370
1-1/2	16	.065	1.474	.3927	.3587	.996	1.370	.0756	.1008	.5079	2299	1.095	.293
2	11	.120	2.433	.5236	.4608	2.410	1.760	.3144	.3144	.6660	3795	1.136	.709
2	13	.095	2.573	.5236	.4739	1.934	1.810	.2586	.2586	.6744	4014	1.105	.569
2-1/2	9	.148	3.815	.6540	.5770	3.719	2.204	.7592	.6074	.8332	5951	1.134	1.094

*Weights are based on low carbon steel with a density of 0.2833#/inch^3. For other metals multiply by the following factors:

Aluminum	0.35
A.I.S.I. 400 Series Stainless Steels	0.99
A.I.S.I. 300 Series Stainless Steels	1.02
Aluminum Bronze	1.04
Aluminum Brass	1.06
Nickel-Chrome-Iron	1.07
Admiralty	1.09
Nickel and Nickel-Copper	1.13
Copper and Cupro-Nickels	1.14

**Liquid Velocity $= \dfrac{\text{Lbs. Per Tube Per Hour}}{\text{C x SP. GR. of Liquid}}$ in feet per sec. (Sp. Gr. of Water at 60°F. = 1.0)

TABLE D-8

HARDNESS CONVERSION TABLE

APPROXIMATE RELATION BETWEEN VARIOUS HARDNESS TESTING SYSTEMS AND TENSILE STRENGTH OF CARBON AND ALLOY STEELS

Tensile Strength 1000 Lbs. psi	Brinell Hardness Number 3000-Kg. Load	Brinell Indentation Diameter mm.	ROCKWELL HARDNESS NUMBER					Diamond Pyramid Hardness Number	Sclero-scope Hardness Number	Tensile Strength 1000 Lbs. psi
			A-Scale, 60-Kg. Load, Brale Penetrator	B-Scale, 100-Kg. Load, 1/16" Dia. Ball	C-Scale, 150-Kg. Load, Brale Penetrator	D-Scale, 100-Kg. Load, Brale Penetrator	15N-Scale, 15-Kg. Load, Superficial Brale Penetrator			
384	780	2.20	....	....	....	....	....	....	....	384
368	745	2.25	....	....	65	....	....	840	91	368
352	712	2.30	....	....	64	....	....	785	87	352
337	682	2.35	82	....	62	72	91	737	84	337
324	653	2.40	81	....	60	71	90	697	81	324
323	627	2.45	81	....	59	70	90	667	79	323
318	601	2.50	81	....	59	70	90	677	77	318
309	578	2.55	80	....	57	69	89	640	75	309
293	555	2.60	79	....	56	67	88	607	73	293
279	534	2.65	78	....	54	66	88	579	71	279
266	514	2.70	77	....	53	65	87	553	70	266
259	495	2.75	77	....	52	64	86	539	68	259
247	477	2.80	76	....	50	63	86	516	66	247
237	461	2.85	75	....	49	62	85	495	65	237
226	444	2.90	74	....	47	61	84	474	63	226
217	429	2.95	73	....	46	60	83	455	61	217
210	415	3.00	73	....	45	59	83	440	59	210
202	401	3.05	72	....	43	58	82	425	58	202
195	388	3.10	71	....	42	57	81	410	56	195
188	375	3.15	71	....	40	56	81	396	54	188
182	363	3.20	70	....	39	55	80	383	52	182
176	352	3.25	69	....	38	54	79	372	51	176
170	341	3.30	69	....	37	53	79	360	50	170
166	331	3.35	68	....	36	52	78	350	48	166
160	321	3.40	68	....	34	51	77	339	47	160
155	311	3.45	67	....	33	50	77	328	46	155
150	302	3.50	66	....	32	49	76	319	45	150
145	293	3.55	66	....	31	48	76	309	43	145
141	285	3.60	65	....	30	48	75	301	42	141
137	277	3.65	65	....	29	47	74	292	41	137
133	269	3.70	64	....	28	46	74	284	40	133
129	262	3.75	64	....	27	45	73	276	39	129
126	255	3.80	63	....	25	44	73	269	38	126
122	248	3.85	63	....	24	43	72	261	37	122
118	241	3.90	62	100	23	42	71	253	36	118
115	235	3.95	61	99	22	41	70	247	35	115
111	229	4.00	60	98	21	41	70	241	34	111
110	223	4.05	60	97	20	....	....	223	32	110
107	217	4.10	59	96	....	....	....	217	31	107
104	212	4.15	59	96	....	....	....	212	31	104
101	207	4.20	58	95	....	....	....	207	30	101
99	202	4.25	58	94	....	....	....	202	30	99
97	197	4.30	57	93	....	....	....	197	29	97
95	192	4.35	57	92	....	....	....	192	28	95
93	187	4.40	56	91	....	....	....	187	28	93
91	183	4.45	56	90	....	....	....	183	27	91
89	179	4.50	55	89	....	....	....	179	27	89
87	174	4.55	54	88	....	....	....	174	26	87
85	170	4.60	54	87	....	....	....	170	26	85
83	166	4.65	53	86	....	....	....	166	25	83
82	163	4.70	53	85	....	....	....	163	25	82
80	159	4.75	52	84	....	....	....	159	24	80
78	156	4.80	51	83	....	....	....	156	24	78
76	153	4.85	51	82	....	....	....	153	23	76
75	149	4.90	50	81	....	....	....	149	23	75
74	146	4.95	50	80	....	....	....	146	22	74
72	143	5.00	49	79	....	....	....	143	22	72
71	140	5.05	49	78	....	....	....	140	21	71
70	137	5.10	48	77	....	....	....	137	21	70
68	134	5.15	47	76	....	....	....	134	21	68
66	131	5.20	46	74	....	....	....	131	20	66
65	128	5.25	46	73	....	....	....	128	20	65

NOTE: Brinell 128 to 495 with Standard Ball. Brinell 514 to 601 with Hultgren Ball. Brinell 627 to 682 with Carbide Ball.
References: ASTM E48-43T, ASM Metals Handbook 1948, Union Drawn Handbook No. 47 and Peter A. Frasse & Co., Inc.

TABLE D-9

INTERNAL AND (EXTERNAL) WORKING PRESSURES (PSI) OF TUBES AT VARIOUS VALUES OF ALLOWABLE STRESS

Tube O.D.	Tube Gage	PRESSURE									
		2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000
1/4″	24	379 (184)	757 (356)	1136 (524)	1515 (689)	1893 (853)	2272 (1014)	2651 (1175)	3029 (1334)	3408 (1493)	3787 (1650)
	23	435 (212)	870 (413)	1304 611)	1739 (807)	2174 (1001)	2609 (1194)	3044 (1385)	3478 (1575)	3913 (1765)	4348 (1954)
	22	492 (238)	984 (468)	1476 (694)	1968 (918)	2461 (1140)	2953 (1362)	3445 (1582)	3937 (1801)	4429 (2020)	4921 (2238)
	21	570 (276)	1141 (544)	1711 (809)	2282 (1071)	2852 (1332)	3423 (1592)	3993 (1851)	4563 (2109)	5134 (2366)	5704 (2623)
	20	631 (307)	1261 (604)	1892 (897)	2523 (1187)	3153 (1476)	3784 (1764)	4414 (2050)	5045 (2335)	5676 (2620)	6306 (2904)
	19	776 (387)	1552 (756)	2328 (1118)	3104 (1476)	3880 (1832)	4656 (2185)	5432 (2535)	6208 (2885)	6985 (3232)	7761 (3579)
	18	920 (481)	1841 (942)	2761 (1396)	3682 (1844)	4602 (2289)	5523 (2732)	6443 (3172)	7363 (3610)	8284 (4046)	9204 (4481)
3/8″	22	318 (153)	635 (294)	953 (431)	1271 (565)	1588 (697)	1906 (828)	2224 (957)	2541 (1085)	2859 (1213)	3176 (1339)
	21	366 (178)	733 (344)	1099 (505)	1465 (664)	1832 (821)	2198 (976)	2564 (1130)	2931 (1283)	3297 (1435)	3663 (1586)
	20	404 (196)	807 (381)	1210 (562)	1614 (741)	2017 (918)	2421 (1093)	2824 (1267)	3228 (1440)	3631 (1612)	4035 (1783)
	19	492 (238)	984 (468)	1476 (694)	1968 (918)	2461 (1140)	2953 (1362)	3445 (1582)	3937 (1801)	4429 (2020)	4921 (2238)
	18	584 (283)	1167 (557)	1751 (828)	2335 (1097)	2918 (1364)	3502 (1630)	4086 (1895)	4669 (2159)	5253 (2423)	5837 (2685)
	17	706 (349)	1412 (684)	2118 (1014)	2824 (1340)	3530 (1665)	4236 (1987)	4942 (2308)	5648 (2627)	6354 (2945)	7060 (3262)
	16	803 (402)	1606 (784)	2410 (1159)	3214 (1530)	4017 (1898)	4820 (2262)	5624 (2625)	6427 (2986)	7231 (3345)	8034 (3702)
	15	900 (466)	1799 (911)	2699 (1349)	3599 (1782)	4499 (2211)	5398 (2637)	6298 (3061)	7198 (3483)	8097 (3904)	8997 (4322)
	14	1052 (582)	2104 (1147)	3156 (1705)	4208 (2260)	5260 (2812)	6312 (3361)	7364 (3909)	8416 (4455)	9468 (4999)	10520 (5542)
1/2″	20	297 (142)	593 (272)	890 (399)	1186 (523)	1483 (645)	1780 (765)	2076 (884)	2373 (1003)	2670 (1120)	2966 (1237)
	19	360 (175)	720 (337)	1081 (496)	1441 (651)	1801 (805)	2162 (957)	2521 (1107)	2882 (1257)	3242 (1406)	3602 (1554)
	18	425 (207)	851 (404)	1276 (597)	1701 (787)	2127 (976)	2552 (1163)	2977 (1349)	3403 (1534)	3828 (1719)	4254 (1902)
	17	512 (247)	1023 (486)	1534 (722)	2046 (955)	2557 (1188)	3069 (1419)	3580 (1649)	4092 (1879)	4603 (2107)	5115 (2335)
	16	580 (281)	1161 (554)	1741 (823)	2321 (1091)	2902 (1356)	3482 (1621)	4063 (1884)	4643 (2147)	5223 (2408)	5804 (2670)
	15	651 (318)	1302 (626)	1953 (929)	2604 (1229)	3255 (1528)	3906 (1825)	4557 (2121)	5208 (2416)	5859 (2710)	6510 (3003)
	14	766 (381)	1531 (745)	2297 (1103)	3063 (1456)	3828 (1807)	4594 (2155)	5360 (2502)	6126 (2846)	6891 (3190)	7657 (3532)
	13	889 (459)	1779 (896)	2668 (1326)	3557 (1751)	4447 (2172)	5336 (2590)	6225 (3006)	7115 (3420)	8004 (3833)	8893 (4244)
	12	1035 (566)	2069 (1115)	3104 (1657)	4139 (2196)	5173 (2732)	6208 (3265)	7243 (3796)	8277 (4326)	9312 (4854)	10347 (5381)
5/8″	20	235 (112)	469 (210)	704 (303)	938 (394)	1173 (483)	1407 (571)	1642 (657)	1876 (742)	2111 (826)	2345 (909)
	19	284 (136)	568 (260)	852 (380)	1136 (496)	1420 (611)	1704 (725)	1989 (837)	2273 (948)	2557 (1058)	2841 (1167)
	18	335 (162)	669 (311)	1004 (456)	1338 (599)	1673 (739)	2008 (878)	2342 (1016)	2677 (1152)	3011 (1288)	3346 (1423)
	17	401 (195)	802 (379)	1203 (559)	1604 (736)	2005 (911)	2406 (1085)	2807 (1257)	3208 (1429)	3609 (1600)	4010 (1770)
	16	454 (221)	908 (431)	1361 (639)	1815 (844)	2269 (1047)	2723 (1249)	3176 (1450)	3630 (1650)	4084 (1849)	4538 (2047)
	15	508 (245)	1015 (482)	1523 (716)	2030 (948)	2538 (1178)	3046 (1407)	3553 (1636)	4061 (1863)	4568 (2090)	5076 (2316)
	14	594 (289)	1189 (568)	1783 (844)	2377 (1118)	2972 (1390)	3566 (1661)	4160 (1931)	4755 (2200)	5349 (2468)	5943 (2735)
	13	692 (341)	1384 (669)	2077 (993)	2769 (1313)	3461 (1631)	4153 (1947)	4845 (2261)	5537 (2575)	6230 (2887)	6922 (3198)
	12	809 (405)	1618 (790)	2427 (1168)	3236 (1541)	4044 (1911)	4853 (2278)	5662 (2643)	6471 (3006)	7280 (3367)	8089 (3727)
	11	900 (466)	1799 (911)	2699 (1349)	3599 (1782)	4499 (2211)	5398 (2637)	6298 (3061)	7198 (3483)	8097 (3904)	8997 (4322)
	10	1016 (552)	2032 (1086)	3048 (1614)	4064 (2138)	5080 (2658)	6096 (3176)	7112 (3692)	8128 (4206)	9144 (4719)	10160 (5231)

TABLE D-9—(Continued)

INTERNAL AND (EXTERNAL) WORKING PRESSURES (PSI) OF TUBES AT VARIOUS VALUES OF ALLOWABLE STRESS

Tube O.D.	Tube Gage	PRESSURE 2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000
3/4"	18	276 (132)	552 (252)	827 (367)	1103 (479)	1379 (590)	1655 (698)	1930 (806)	2206 (912)	2482 (1018)	2758 (1123)
	17	330 (159)	660 (306)	989 (449)	1319 (589)	1649 (727)	1978 (864)	2308 (999)	2638 (1133)	2968 (1266)	3297 (1399)
	16	373 (181)	745 (350)	1118 (514)	1490 (676)	1863 (837)	2235 (995)	2607 (1152)	2980 (1308)	3352 (1464)	3725 (1618)
	15	416 (202)	832 (394)	1248 (582)	1664 (767)	2080 (951)	2496 (1133)	2912 (1314)	3328 (1493)	3744 (1672)	4159 (1851)
	14	486 (235)	971 (462)	1457 (684)	1943 (905)	2428 (1125)	2914 (1343)	3400 (1560)	3885 (1776)	4371 (1991)	4857 (2206)
	13	564 (273)	1128 (538)	1691 (799)	2255 (1058)	2819 (1316)	3383 (1573)	3947 (1829)	4510 (2084)	5074 (2338)	5638 (2591)
	12	658 (322)	1316 (633)	1973 (939)	2631 (1243)	3289 (1545)	3947 (1845)	4605 (2144)	5263 (2442)	5920 (2739)	6578 (3035)
	11	734 (364)	1468 (713)	2202 (1056)	2936 (1395)	3670 (1732)	4404 (2067)	5138 (2399)	5872 (2731)	6606 (3061)	7339 (3390)
	10	831 (417)	1662 (813)	2492 (1200)	3323 (1583)	4154 (1963)	4985 (2339)	5816 (2713)	6647 (3086)	7477 (3456)	8308 (3825)
	9	927 (487)	1855 (953)	2782 (1411)	3709 (1865)	4637 (2316)	5564 (2763)	6491 (3209)	7419 (3652)	8346 (4094)	9273 (4534)
	8	1045 (574)	2090 (1131)	3135 (1682)	4180 (2229)	5225 (2773)	6270 (3314)	7316 (3854)	8361 (4393)	9406 (4930)	10451 (5465)
1"	18	204 (94)	408 (176)	612 (254)	816 (329)	1020 (402)	1224 (473)	1428 (544)	1632 (613)	1836 (682)	2040 (749)
	17	243 (116)	487 (219)	730 (318)	973 (413)	1216 (507)	1460 (598)	1703 (689)	1946 (778)	2190 (867)	2433 (954)
	16	274 (132)	549 (250)	823 (365)	1097 (476)	1371 (586)	1646 (694)	1920 (801)	2194 (906)	2468 (1011)	2743 (1115)
	15	306 (147)	611 (282)	917 (412)	1222 (541)	1528 (667)	1834 (792)	2139 (915)	2445 (1038)	2750 (1160)	3056 (1280)
	14	356 (172)	711 (333)	1067 (489)	1423 (642)	1778 (793)	2134 (942)	2489 (1091)	2845 (1238)	3201 (1384)	3556 (1530)
	13	411 (200)	823 (389)	1234 (575)	1645 (757)	2056 (938)	2468 (1118)	2879 (1296)	3290 (1473)	3701 (1650)	4113 (1825)
	12	478 (232)	955 (454)	1433 (673)	1911 (890)	2388 (1105)	2866 (1319)	3344 (1532)	3821 (1744)	4299 (1955)	4777 (2166)
	11	531 (256)	1062 (504)	1593 (750)	2124 (993)	2655 (1236)	3186 (1477)	3717 (1717)	4248 (1957)	4779 (2196)	5310 (2434)
	10	600 (292)	1201 (574)	1801 (853)	2401 (1129)	3002 (1404)	3602 (1678)	4203 (1951)	4803 (2222)	5403 (2493)	6004 (2763)
	9	672 (330)	1343 (647)	2015 (961)	2686 (1271)	3358 (1579)	4029 (1886)	4701 (2191)	5372 (2496)	6044 (2799)	6715 (3101)
	8	760 (378)	1521 (740)	2281 (1095)	3042 (1446)	3802 (1794)	4562 (2141)	5323 (2485)	6083 (2827)	6843 (3168)	7604 (3508)
1-1/4"	16	217 (102)	434 (191)	651 (275)	868 (358)	1085 (438)	1302 (516)	1519 (594)	1736 (670)	1953 (746)	2170 (820)
	15	242 (115)	483 (217)	725 (315)	966 (409)	1208 (502)	1449 (593)	1691 (682)	1932 (771)	2174 (858)	2415 (945)
	14	281 (134)	561 (256)	842 (374)	1122 (489)	1403 (602)	1683 (713)	1964 (824)	2244 (933)	2525 (1041)	2805 (1148)
	13	324 (156)	647 (300)	971 (440)	1295 (577)	1618 (712)	1942 (846)	2266 (978)	2589 (1109)	2913 (1240)	3237 (1369)
	12	375 (182)	750 (352)	1125 (518)	1500 (682)	1875 (843)	2250 (1003)	2625 (1161)	3000 (1319)	3375 (1475)	3750 (1631)
	11	416 (202)	832 (394)	1248 (582)	1664 (767)	2080 (951)	2496 (1133)	2912 (1314)	3328 (1493)	3744 (1672)	4159 (1851)
	10	469 (228)	938 (446)	1407 (661)	1876 (873)	2345 (1084)	2814 (1294)	3283 (1502)	3752 (1710)	4221 (1917)	4690 (2123)
	9	523 (252)	1046 (497)	1570 (739)	2093 (978)	2616 (1217)	3139 (1454)	3662 (1690)	4185 (1925)	4708 (2160)	5232 (2394)
	8	590 (287)	1181 (564)	1771 (838)	2361 (1110)	2952 (1380)	3542 (1649)	4132 (1917)	4723 (2184)	5313 (2451)	5903 (2716)
1-1/2"	12	309 (148)	617 (285)	926 (417)	1234 (547)	1543 (674)	1852 (801)	2160 (926)	2469 (1050)	2778 (1173)	3086 (1295)
	11	342 (166)	684 (319)	1026 (468)	1368 (614)	1709 (758)	2051 (900)	2393 (1041)	2735 (1181)	3077 (1320)	3419 (1459)
	10	385 (187)	770 (362)	1155 (534)	1539 (702)	1924 (869)	2309 (1034)	2694 (1198)	3079 (1360)	3464 (1522)	3848 (1683)
	9	429 (209)	857 (407)	1286 (602)	1714 (794)	2142 (984)	2571 (1173)	2999 (1361)	3428 (1548)	3856 (1734)	4285 (1919)
	8	483 (234)	965 (459)	1447 (680)	1930 (899)	2412 (1117)	2895 (1333)	3377 (1549)	3860 (1763)	4342 (1977)	4825 (2190)

TABLE D-10

MODULUS OF ELASTICITY (a)

MATERIAL \ TEMP. °F	LBS./SQ. IN. x 10⁻⁶												
	70	100	200	300	400	500	600	700	800	900	1000	1100	1200
CARBON STEEL	29.0		28.7	28.2	27.6	26.8	25.9	24.5	23.0	21.0	18.1		
AUST. STAINLESS STL.	28.0		27.3	26.6	25.9	25.2	24.5	23.8	23.0	22.4	21.6		
CARBON-MO & LOW CHROME STEELS (thru 3% Chrome)	29.9		29.5	29.0	28.6	28.0	27.4	26.6	25.7	24.5	23.0	20.4	15.6
INTERMEDIATE CR- (b) MO STEELS (5-9% CR)	27.4		27.1	26.8	26.4	26.0	25.4	24.9	24.2	23.5	22.8	21.9	20.8
STRAIGHT CHROME STEELS—12, 17, 27% CR	29.2		28.7	28.3	27.7	27.0	26.0	24.8	23.1	21.1	18.6	15.6	12.2
GREY CAST IRON	13.4		13.2	12.9	12.6	12.2	11.7	11.0	10.2				
NICKEL-COPPER (66Ni 31.5 Cu)	26.0		26,0	25.8	25.6	25.4	24.7	23.1	21.0	18.6	16.0	14.3	13.0
CUPRO NICKELS 80-20, 70-30	18.9		18.4	18.0	17.6	17.2	16.7	16.2	15.3				
ALUMINUM	10.6		10.6	10.4	10.2	9.5	8.5						
NICKEL-CHROME-IRON 72 Ni 14-17 Cr 6-10 Fe	31.7		30.9	30.5	30.0	29.6	29.2	28.6	27.9		25		20
NICKEL (g)	30.0		29.6	29.1	28.6	28.0	27.4	26.9	26.2	25.6	25.0	24.3	23.7
COPPER (99.98%)	16.0	15.8	15.6	15.4	15.1	14.7	14.2	13.7					
COMMERCIAL BRASS (c)	14.0	13.9	13.7	13.5	13.0	12.7	12.2	11.8					
LEADED TIN (d) BRONZE	13.0	12.9	12.7	12.4	12.0	11.7	11.3	10.9					
PHOSPHOR BRONZE (e)	14.9	14.8	14.5	14.0	13.5	12.8	11.8	10.5	8.7				
MUNTZ (f)	15.3	15.0	14.0	12.9	11.8	10.8							
ADMIRALTY (h)	16.0		15.6	14.7	13.5	12.4	11.0	9.5	7.5				
TITANIUM (Grade 2)	16.0		15.0		13.8	13.2	12.5	11.8					

(a) From Transactions of A.S.M.E., Feb., 1965.
(b) Value @ 1300°F. = 19.5 @ 1400°F. = 18.1
(c) 66 Cu. 34 Zn
(d) 88 Cu. 6 Sn. 1.5 Pb. 4.5 Zn
(e) 85.38 Cu. 12.55 Sn, 1.01 Zn, 0.24 P. 0.02 Fe, 0.61 Pb: 0.11 Ni.
(f) 58.96 Cu. 38.77 Zn, 0.56 Sn. 0.67 Pb
(g) From International Nickel Co. Values 700°F. and above applicable only to Low-Carbon Nickel.
(h) From ASTM Special Technical Publication No. 181.

TABLE D-11

MEAN COEFFICIENTS OF THERMAL EXPANSION (1)

MATERIAL \ TEMP. °F	Inches per Inch per °F. x 10⁶ Between 70°F. and:															
	-200	-100	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
CARBON & CARBON-MO. STLS., LOW CR. STLS. THRU 3% CR.	5.6	5.8	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.7	7.9	8.0	8.1	8.2	8.3	8.4
INTERMED. ALLOY STLS.-5 CR.-MO. THRU 9 CR.-MO.	5.6	5.7	5.9	6.0	6.2	6.3	6.5	6.7	6.8	7.0	7.1	7.2	7.3	7.4	7.5	7.6
STRAIGHT CR. STLS.-12, 17, 27% CR.	5.1	5.3	5.4	5.5	5.7	5.8	6.0	6.1	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.9
AUSTENITIC STAINLESS STL.	8.8	8.9	9.2	9.3	9.5	9.6	9.7	9.8	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.6
25-20 CR.-Ni.				7.8	7.9	8.1	8.2	8.4	8.5	8.7	8.8	8.9	9.0	9.1	9.1	9.2
GRAY CAST IRON			5.6	5.8	6.0	6.1	6.3	6.5	6.7	6.8	7.0	7.2				
CUPRO-NICKEL 70 Cu. 30 Ni.				8.5	8.7	8.9										
COPPER	8.6	9.0	9.4	9.6	9.7	9.8	9.9	10.1	10.2	10.3	10.4	10.5				
BRASS (66 Cu.-34 Zn.)	9.1	9.3	9.6	9.7	10.0	10.2	10.5	10.7	10.9	11.2	11.4	11.6	11.9	12.1		
NICKEL-COPPER (Monel)	5.9	6.5	7.2	7.4	7.6	7.8	8.0	8.1	8.3	8.4	8.5	8.6	8.7			
ALUMINUM	11.8	12.1	12.7	13.0	13.3	13.6	13.9	14.2								
NICKEL-CR.-IRON (Inconel)	5.9	6.1	6.4	6.6	6.8	7.0	7.3	7.5	7.7	7.9	8.1	8.3	8.5	8.6	8.7	8.9
NICKEL	6.2	6.5	7.1	7.2	7.5	7.7	7.8	8.0	8.2	8.3	8.5	8.6	8.7	8.8	8.9	8.9
ADMIRALTY								11.2								
TITANIUM (Grade 2)				4.8		5.2		5.3								

(1) REF.:

Rudolph Michel, Transactions of A.S.M.E., Feb., 1955.
P. Hidnert, Metals Handbook of American Society for Metals, 1948.
National Bureau of Standards Circular C447, 1943.
Sabin Crocker, Piping Handbook, 4th Edition, McGraw-Hill, 1945.
International Nickel Co., Technical Bulletins T-5 (1958), T-7 (1956), T-15 (1957).
Bridgeport Brass Co., G. G. Menzies, personal communication, 1958.
Aluminum Co. of America, Aluminum Handbook, 1956.

TABLE D-12

THERMAL CONDUCTIVITY OF METALS

MATERIAL / TEMP. °F	BTU/HR. X SQ. FT./(°F/FT.)													
	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500
ALUMINUM (ANNEALED)														
Type 1100-0	126	124	123	122	121	120	118							
Type 3003-0	111	111	111	111	111	111	111							
Type 3004-0	97	98	99	100	102	103	104							
Type 6061-0	102	103	104	105	106	106	106							
ALUMINUM (TEMPERED)														
Type 1100 (All Tempers)	123	122	121	120	118	118	118							
Type 3003 (All Tempers)	96	97	98	99	100	102	104							
Type 3004 (All Tempers)	97	98	99	100	102	103	104							
Type 6061-T4 & T6	95	96	97	98	99	100	102							
Type 6063-T5 & T6	116	116	116	116	116	115	114							
Type 6063-T42	111	111	111	111	111	111	111							
CAST IRON	31	31	30	29	28	27	26	25						
CARBON STEEL	30	29	28	27	26	25	24	23						
CARBON MOLY (1/2%) STEEL	29	28	27	26	25	25	24	23						
CHROME MOLY STEELS														
1% Cr, 1/2% Mo	27	27	26	25	24	24	23	21	21					
2-1/4% Cr, 1% Mo	25	24	23	23	22	22	21	21	20	20				
5% Cr, 1/2% Mo	21	21	21	20	20	20	20	19	19	19				
12% Cr	14	15	15	15	16	16	16	16	17	17	17	18		
AUSTENITIC STAINLESS STEELS														
18% Cr, 8% Ni	9.3	9.8	10	11	11	12	12	13	13	14	14	14	15	15
25% Cr, 20% Ni	7.8	8.4	8.9	9.5	10	11	11	12	12	13	14	14	15	15
ADMIRALTY METAL	70	75	79	84	89									
NAVAL BRASS	71	74	77	80	83									
COPPER (ELECTROLYTIC)	225	225	224	224	223									
COPPER & NICKEL ALLOYS														
90% Cu, 10% Ni	30	31	34	37	42	47	49	51	53					
80% Cu, 20% Ni	22	23	25	27	29	31	34	37	40					
70% Cu, 30% Ni	18	19	21	23	25	27	30	33	37					
30% Cu, 70% Ni (Monel)	15	15	16	16	17	18	18	19	20	20				
NICKEL	38	36	33	31	29	28	28	29	31	33				
NICKEL-CHROME-IRON	9.4	9.7	9.9	10	10	11	11	11	12	12	12	13	13	13
TITANIUM (Grade 3)	10.9		10.4		10.5									

REF.:

Babcock & Wilcox Co., Technical Bulletin 6-G, 1955.

American Brass Company Tables, Central Technical Department.

A.I.M.E. Technical Publications No. 291 (1930), No. 360 (1930), No. 648 (1935).

International Nickel Co., Technical Bulletins T-5 (1958), T-7 (1956), T-15 (1957).

Trans. A.S.S.T. Vol. 21 (1933) Pages 1061-1078 by S. M. Shelton and W. H. Swanger.

Aluminum Company of America - Alcoa Research Laboratories.

TABLE D-13

WEIGHTS OF CIRCULAR RINGS AND DISCS (1)

Example:
Required: Weight of a Ring 48" O.D. x 36½" I.D. x 2½" Thick.

48" diameter disc, 1" thick, weighs 512.66 lbs.
36½" diameter disc, 1" thick, weighs 296.42 lbs.
Ring 48 x 36½ x 1" weighs 216.24 lbs.
Ring 48 x 36½ x 2½" weighs 540.60 lbs.

Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness
Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds
¾	.12	5	5.56	9	18.02	13	37.60	17	64.30	21	98.13	25	139.07
⅞	.17	⅛	5.84	⅛	18.53	⅛	38.33	⅛	65.25	⅛	99.30	⅛	140.46
1	.22												
⅛	.28	¼	6.13	¼	19.04	¼	39.06	¼	66.21	¼	100.48	¼	141.86
¼	.35	⅜	6.43	⅜	19.56	⅜	39.80	⅜	67.17	⅜	101.66	⅜	143.27
⅜	.42	½	6.73	½	20.08	½	40.55	½	68.14	½	102.85	½	144.68
½	.50	⅝	7.04	⅝	20.61	⅝	41.31	⅝	69.12	⅝	104.05	⅝	146.11
⅝	.59												
¾	.69	¾	7.36	¾	21.15	¾	42.07	¾	70.10	¾	105.26	¾	147.54
⅞	.78	⅞	7.68	⅞	21.70	⅞	42.84	⅞	71.09	⅞	106.47	⅞	148.97
2	.89	6	8.01	10	22.25	14	43.62	18	72.09	22	107.69	26	150.41
⅛	1.00	⅛	8.35	⅛	22.81	⅛	44.39	⅛	73.10	⅛	108.92	⅛	151.86
¼	1.12	¼	8.69	¼	23.38	¼	45.18	¼	74.11	¼	110.15	¼	153.32
⅜	1.25	⅜	9.04	⅜	23.95	⅜	45.98	⅜	75.13	⅜	111.40	⅜	154.78
½	1.39	½	9.40	½	24.53	½	46.78	½	76.15	½	112.64	½	156.25
⅝	1.53	⅝	9.77	⅝	25.12	⅝	47.59	⅝	77.19	⅝	113.90	⅝	157.73
¾	1.68	¾	10.14	¾	25.71	¾	48.41	¾	78.22	¾	115.16	¾	159.22
⅞	1.84	⅞	10.52	⅞	26.32	⅞	49.23	⅞	79.27	⅞	116.43	⅞	160.71
3	2.00	7	10.90	11	26.92	15	50.06	19	80.32	23	117.71	27	162.21
⅛	2.17	⅛	11.30	⅛	27.54	⅛	50.90	⅛	81.39	⅛	118.99	⅛	163.71
¼	2.35	¼	11.70	¼	28.16	¼	51.75	¼	82.45	¼	120.28	¼	165.22
⅜	2.53	⅜	12.10	⅜	28.79	⅜	52.60	⅜	83.53	⅜	121.58	⅜	166.74
½	2.75	½	12.52	½	29.43	½	53.46	½	84.61	½	122.88	½	168.27
⅝	2.92	⅝	12.94	⅝	30.07	⅝	54.32	⅝	85.70	⅝	124.19	⅝	169.80
¾	3.13	¾	13.36	¾	30.72	¾	55.20	¾	86.79	¾	125.51	¾	171.34
⅞	3.34	⅞	13.80	⅞	31.38	⅞	56.08	⅞	87.89	⅞	126.83	⅞	172.89
4	3.56	8	14.24	12	32.04	16	56.96	20	89.00	24	128.16	28	174.44
⅛	3.78	⅛	14.69	⅛	32.71	⅛	57.86	⅛	90.12	⅛	129.50	⅛	176.01
¼	4.02	¼	15.14	¼	33.39	¼	58.76	¼	91.24	¼	130.85	¼	177.57
⅜	4.26	⅜	15.61	⅜	34.08	⅜	59.66	⅜	92.37	⅜	132.20	⅜	179.15
½	4.50	½	16.08	½	34.77	½	60.58	½	93.51	½	133.57	½	180.73
⅝	4.76	⅝	16.55	⅝	35.47	⅝	61.50	⅝	94.65	⅝	134.93	⅝	182.32
¾	5.02	¾	17.04	¾	36.17	¾	62.43	¾	95.80	¾	136.30	¾	183.91
⅞	5.29	⅞	17.53	⅞	36.88	⅞	63.36	⅞	96.96	⅞	137.68	⅞	185.52

(1) Weights are based on low carbon steel with a density of 0.2833 # / inch³. For other metals multiply by the following factors:

Aluminum	0.35
A.I.S.I. 400 Series Stainless Steels	0.99
A.I.S.I. 300 Series Stainless Steels	1.02
Aluminum Bronze	1.04
Naval Rolled Brass	1.07
Muntz Metal	1.07
Nickel-Chrome-Iron	1.07
Admiralty	1.09
Nickel-Copper & Nickel	1.13
Copper & Cupro-Nickels	1.14

TABLE D-13—(Continued)

WEIGHTS OF CIRCULAR RINGS AND DISCS

Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness
Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds
29	187.13	35	272.57	41	374.04	47	491.50	53	625.02	59	774.54	65	940.07
1/8	188.74	1/8	274.52	1/8	376.31	1/8	494.13	1/8	627.96	1/8	777.83	1/8	943.70
1/4	190.37	1/4	276.48	1/4	378.60	1/4	496.76	1/4	630.91	1/4	781.11	1/4	947.33
3/8	192.00	3/8	278.44	3/8	380.90	3/8	499.37	3/8	633.88	3/8	784.40	3/8	950.95
1/2	193.64	1/2	280.41	1/2	383.22	1/2	502.04	1/2	636.86	1/2	787.72	1/2	954.61
5/8	195.28	5/8	282.39	5/8	385.51	5/8	504.67	5/8	639.83	5/8	791.03	5/8	958.23
3/4	196.93	3/4	284.38	3/4	387.84	3/4	507.33	3/4	642.84	3/4	794.34	3/4	961.89
7/8	198.59	7/8	286.37	7/8	390.16	7/8	509.97	7/8	645.81	7/8	797.69	7/8	965.54
30	200.25	36	288.37	42	392.48	48	512.66	54	648.81	60	801.00	66	969.23
1/8	201.93	1/8	290.38	1/8	394.84	1/8	515.32	1/8	651.82	1/8	804.35	1/8	972.91
1/4	203.61	1/4	292.39	1/4	397.19	1/4	518.01	1/4	654.85	1/4	807.69	1/4	976.59
3/8	205.29	3/8	294.41	3/8	399.54	3/8	520.68	3/8	657.85	3/8	811.06	3/8	980.27
1/2	206.99	1/2	296.42	1/2	401.89	1/2	523.40	1/2	660.88	1/2	814.43	1/2	983.96
5/8	208.69	5/8	298.46	5/8	404.27	5/8	526.09	5/8	663.91	5/8	817.77	5/8	987.67
3/4	210.39	3/4	300.50	3/4	406.65	3/4	528.78	3/4	666.97	3/4	821.17	3/4	991.38
7/8	212.11	7/8	302.56	7/8	409.03	7/8	531.50	7/8	670.00	7/8	824.54	7/8	995.09
31	213.83	37	304.60	43	411.41	49	534.22	55	673.06	61	827.94	67	998.83
1/8	215.56	1/8	306.67	1/8	413.82	1/8	536.97	1/8	676.12	1/8	831.34	1/8	1002.54
1/4	217.29	1/4	308.74	1/4	416.20	1/4	539.69	1/4	679.21	1/4	834.74	1/4	1006.28
3/8	219.03	3/8	310.81	3/8	418.60	3/8	542.43	3/8	682.27	3/8	838.14	3/8	1010.02
1/2	220.78	1/2	312.90	1/2	421.04	1/2	545.18	1/2	685.36	1/2	841.57	1/2	1013.79
5/8	222.54	5/8	314.97	5/8	423.45	5/8	547.96	5/8	688.45	5/8	845.00	5/8	1017.53
3/4	224.30	3/4	317.07	3/4	425.88	3/4	550.71	3/4	691.56	3/4	848.43	3/4	1021.30
7/8	226.07	7/8	319.19	7/8	428.32	7/8	553.48	7/8	694.65	7/8	851.85	7/8	1025.06
32	227.85	38	321.29	44	430.76	50	556.26	56	697.77	62	855.31	68	1028.86
1/8	229.63	1/8	323.42	1/8	433.22	1/8	559.04	1/8	700.88	1/8	858.77	1/8	1032.63
1/4	231.42	1/4	325.54	1/4	435.69	1/4	561.84	1/4	704.00	1/4	862.22	1/4	1036.42
3/8	233.22	3/8	327.66	3/8	438.15	3/8	564.65	3/8	707.15	3/8	865.68	3/8	1040.22
1/2	235.02	1/2	329.82	1/2	440.62	1/2	567.45	1/2	710.29	1/2	869.16	1/2	1044.05
5/8	236.83	5/8	331.94	5/8	443.08	5/8	570.25	5/8	713.43	5/8	872.65	5/8	1047.84
3/4	238.65	3/4	334.10	3/4	445.57	3/4	573.06	3/4	716.58	3/4	876.13	3/4	1051.67
7/8	240.48	7/8	336.25	7/8	448.07	7/8	575.89	7/8	719.75	7/8	879.62	7/8	1055.49
33	242.31	39	338.43	45	450.56	51	578.73	57	722.92	63	883.10	69	1059.34
1/8	244.15	1/8	340.61	1/8	453.08	1/8	581.56	1/8	726.10	1/8	886.62	1/8	1063.17
1/4	245.99	1/4	342.79	1/4	455.60	1/4	584.42	1/4	729.27	1/4	890.13	1/4	1067.02
3/8	247.85	3/8	344.97	3/8	458.10	3/8	587.28	3/8	732.44	3/8	893.67	3/8	1070.87
1/2	249.71	1/2	347.16	1/2	460.65	1/2	590.14	1/2	735.65	1/2	897.18	1/2	1074.75
5/8	251.57	5/8	349.37	5/8	463.17	5/8	593.00	5/8	738.85	5/8	900.72	5/8	1078.61
3/4	253.45	3/4	351.58	3/4	465.72	3/4	595.86	3/4	742.08	3/4	904.27	3/4	1082.49
7/8	255.33	7/8	353.79	7/8	468.27	7/8	598.75	7/8	745.28	7/8	907.81	7/8	1086.37
34	257.22	40	355.99	46	470.82	52	601.64	58	748.51	64	911.38	70	1090.28
1/8	259.11	1/8	358.23	1/8	473.37	1/8	604.53	1/8	751.74	1/8	914.95	1/8	1094.16
1/4	261.01	1/4	360.47	1/4	475.94	1/4	607.45	1/4	754.97	1/4	918.52	1/4	1098.07
3/8	262.92	3/8	362.71	3/8	478.52	3/8	610.37	3/8	758.22	3/8	922.08	3/8	1101.98
1/2	264.84	1/2	364.95	1/2	481.10	1/2	613.29	1/2	761.45	1/2	925.68	1/2	1105.89
5/8	266.76	5/8	367.21	5/8	483.71	5/8	616.21	5/8	764.71	5/8	929.25	5/8	1109.83
3/4	268.69	3/4	369.48	3/4	486.28	3/4	619.12	3/4	768.00	3/4	932.85	3/4	1113.77
7/8	270.63	7/8	371.75	7/8	488.89	7/8	622.07	7/8	771.26	7/8	936.48	7/8	1117.70

TABLE D-13—(Continued)

WEIGHTS OF CIRCULAR RINGS AND DISCS

Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness	Diameter	Weight per Inch of Thickness
Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds	Inches	Pounds
71	1121.64	77	1319.21	83	1532.82	89	1762.44	95	2008.09	101	2270.01	107	2547.71
⅛	1125.58	⅛	1323.52	⅛	1537.44	⅛	1767.40	⅛	2013.38	⅛	2275.61	⅛	2553.67
¼	1129.55	¼	1327.80	¼	1542.09	¼	1772.35	¼	2018.68	¼	2281.25	¼	2559.64
⅜	1133.51	⅜	1332.10	⅜	1546.70	⅜	1777.34	⅜	2023.98	⅜	2286.89	⅜	2565.61
½	1137.51	½	1336.41	½	1551.35	½	1782.30	½	2029.28	½	2292.54	½	2571.58
⅝	1141.47	⅝	1340.72	⅝	1556.00	⅝	1787.28	⅝	2034.60	⅝	2298.18	⅝	2577.57
¾	1145.47	¾	1345.05	¾	1560.64	¾	1792.27	¾	2039.93	¾	2303.84	¾	2583.56
⅞	1149.46	⅞	1349.39	⅞	1565.32	⅞	1797.28	⅞	2045.26	⅞	2309.50	⅞	2589.56
72	1153.46	78	1353.72	84	1569.99	90	1802.27	96	2050.58	102	2315.18	108	2595.56
⅛	1157.48	⅛	1358.06	⅛	1574.67	⅛	1807.28	⅛	2055.94	⅛	2320.86	⅛	2601.57
¼	1161.47	¼	1362.39	¼	1579.34	¼	1812.30	¼	2061.29	¼	2326.54	¼	2607.59
⅜	1165.50	⅜	1366.75	⅜	1584.04	⅜	1817.34	⅜	2066.65	⅜	2332.23	⅜	2613.62
½	1169.52	½	1371.12	½	1588.72	½	1822.36	½	2072.00	½	2337.93	½	2619.65
⅝	1173.57	⅝	1375.48	⅝	1593.42	⅝	1827.40	⅝	2077.38	⅝	2343.63	⅝	2625.69
¾	1177.62	¾	1379.87	¾	1598.15	¾	1832.44	¾	2082.76	¾	2349.35	¾	2631.74
⅞	1181.67	⅞	1384.26	⅞	1602.85	⅞	1837.48	⅞	2088.15	⅞	2355.07	⅞	2637.79
73	1185.72	79	1388.65	85	1607.59	91	1842.55	97	2093.53	103	2360.80	109	2643.84
⅛	1189.78	⅛	1393.04	⅛	1612.32	⅛	1847.63	⅛	2098.94	⅛	2366.53	⅛	2649.91
¼	1193.85	¼	1397.43	¼	1617.05	¼	1852.70	¼	2104.35	¼	2372.27	¼	2655.99
⅜	1197.93	⅜	1401.85	⅜	1621.81	⅜	1857.77	⅜	2109.76	⅜	2378.02	⅜	2662.07
½	1202.01	½	1406.27	½	1626.57	½	1862.84	½	2115.17	½	2383.77	½	2668.16
⅝	1206.12	⅝	1410.69	⅝	1631.33	⅝	1867.94	⅝	2120.59	⅝	2389.53	⅝	2674.26
¾	1210.20	¾	1415.14	¾	1636.09	¾	1873.04	¾	2126.02	¾	2395.29	¾	2680.36
⅞	1214.31	⅞	1419.59	⅞	1640.85	⅞	1878.17	⅞	2131.46	⅞	2401.07	⅞	2686.47
74	1218.42	80	1424.01	86	1645.63	92	1883.27	98	2136.93	104	2406.85	110	2692.58
⅛	1222.55	⅛	1428.48	⅛	1650.42	⅛	1888.39	⅛	2142.37	⅛	2412.63	⅛	2698.41
¼	1226.66	¼	1432.93	¼	1655.21	¼	1893.52	¼	2147.84	¼	2418.44	¼	2704.03
⅜	1230.80	⅜	1437.41	⅜	1660.02	⅜	1898.65	⅜	2153.31	⅜	2424.24	⅜	2710.68
½	1234.96	½	1441.88	½	1664.81	½	1903.80	½	2158.77	½	2430.05	½	2716.82
⅝	1239.10	⅝	1446.36	⅝	1669.63	⅝	1908.93	⅝	2164.27	⅝	2435.87	⅝	2722.97
¾	1243.26	¾	1450.84	¾	1674.47	¾	1914.09	¾	2169.77	¾	2441.69	¾	2729.13
⅞	1247.40	⅞	1455.34	⅞	1679.29	⅞	1919.27	⅞	2175.26	⅞	2447.53	⅞	2735.29
75	1251.59	81	1459.84	87	1684.13	93	1924.43	99	2180.76	105	2453.37	111	2741.44
⅛	1255.76	⅛	1464.35	⅛	1688.98	⅛	1929.61	⅛	2186.25	⅛	2459.21	⅛	2747.62
¼	1259.95	¼	1468.88	¼	1693.82	¼	1934.80	¼	2191.78	¼	2465.06	¼	2753.80
⅜	1264.14	⅜	1473.39	⅜	1698.67	⅜	1939.98	⅜	2197.30	⅜	2470.92	⅜	2760.02
½	1268.33	½	1477.92	½	1703.54	½	1945.17	½	2202.83	½	2476.78	½	2766.24
⅝	1272.53	⅝	1482.45	⅝	1708.41	⅝	1950.38	⅝	2208.38	⅝	2482.65	⅝	2772.42
¾	1276.75	¾	1487.01	¾	1713.29	¾	1955.59	¾	2213.93	¾	2488.53	¾	2778.60
⅞	1280.94	⅞	1491.55	⅞	1718.19	⅞	1960.80	⅞	2219.49	⅞	2494.42	⅞	2784.84
76	1285.19	82	1496.11	88	1723.06	94	1966.05	100	2225.04	106	2500.32	112	2791.08
⅛	1289.41	⅛	1500.67	⅛	1727.96	⅛	1971.26	⅛	2230.84	⅛	2506.22	⅛	2797.30
¼	1293.66	¼	1505.26	¼	1732.86	¼	1976.50	¼	2236.41	¼	2512.13	¼	2803.52
⅜	1297.88	⅜	1509.82	⅜	1737.79	⅜	1981.77	⅜	2242.00	⅜	2518.04	⅜	2809.76
½	1302.13	½	1514.41	½	1742.69	½	1987.01	½	2247.58	½	2523.96	½	2816.00
⅝	1306.41	⅝	1519.00	⅝	1747.62	⅝	1992.28	⅝	2253.18	⅝	2529.89	⅝	2822.30
¾	1310.66	¾	1523.62	¾	1752.55	¾	1997.55	¾	2258.77	¾	2535.83	¾	2828.60
⅞	1314.94	⅞	1528.21	⅞	1757.51	⅞	2002.82	⅞	2264.38	⅞	2541.77	⅞	2834.88

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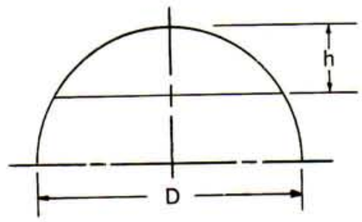
TABLE D-14

AREAS OF CIRCULAR SEGMENTS



AREA = D^2 X C
D = DIAMETER
h = HEIGHT

h/D	C	h/D	C	h/D	C	h/D	C	h/D	C	h/D	C	h/D	C	h/D	C	h/D	C
		0.050	0.01468	0.100	0.04087	0.150	0.07387	0.200	0.11182	0.250	0.15355	0.300	0.19817	0.350	0.24498	0.400	0.29337	0.450	0.34278
0.001	0.00004	.051	.01512	.101	.04148	.151	.07459	.201	.11262	.251	.15441	.301	.19908	.351	.24593	.401	.29435	.451	.34378
.002	.00012	.052	.01556	.102	.04208	.152	.07531	.202	.11343	.252	.15528	.302	.20000	.352	.24689	.402	.29533	.452	.34477
.003	.00022	.053	.01601	.103	.04269	.153	.07603	.203	.11423	.253	.15615	.303	.20092	.353	.24784	.403	.29631	.453	.34577
.004	.00034	.054	.01646	.104	.04330	.154	.07675	.204	.11504	.254	.15702	.304	.20184	.354	.24880	.404	.29729	.454	.34676
.005	.00047	.055	.01691	.105	.04391	.155	.07747	.205	.11584	.255	.15789	.305	.20276	.355	.24976	.405	.29827	.455	.34776
.006	.00062	.056	.01737	.106	.04452	.156	.07819	.206	.11665	.256	.15876	.306	.20368	.356	.25071	.406	.29926	.456	.34876
.007	.00078	.057	.01783	.107	.04514	.157	.07892	.207	.11746	.257	.15964	.307	.20460	.357	.25167	.407	.30024	.457	.34975
.008	.00095	.058	.01830	.108	.04576	.158	.07965	.208	.11827	.258	.16051	.308	.20553	.358	.25263	.408	.30122	.458	.35075
.009	.00113	.059	.01877	.109	.04638	.159	.08038	.209	.11908	.259	.16139	.309	.20645	.359	.25359	.409	.30220	.459	.35175
.010	.00133	.060	.01924	.110	.04701	.160	.08111	.210	.11990	.260	.16226	.310	.20738	.360	.25455	.410	.30319	.460	.35274
.011	.00153	.061	.01972	.111	.04763	.161	.08185	.211	.12071	.261	.16314	.311	.20830	.361	.25551	.411	.30417	.461	.35374
.012	.00175	.062	.02020	.112	.04826	.162	.08258	.212	.12153	.262	.16402	.312	.20923	.362	.25647	.412	.30516	.462	.35474
.013	.00197	.063	.02068	.113	.04889	.163	.08332	.213	.12235	.263	.16490	.313	.21015	.363	.25743	.413	.30614	.463	.35573
.014	.00220	.064	.02117	.114	.04953	.164	.08406	.214	.12317	.264	.16578	.314	.21108	.364	.25839	.414	.30712	.464	.35673
.015	.00244	.065	.02166	.115	.05016	.165	.08480	.215	.12399	.265	.16666	.315	.21201	.365	.25936	.415	.30811	.465	.35773
.016	.00268	.066	.02215	.116	.05080	.166	.08554	.216	.12481	.266	.16755	.316	.21294	.366	.26032	.416	.30910	.466	.35873
.017	.00294	.067	.02265	.117	.05145	.167	.08629	.217	.12563	.267	.16843	.317	.21387	.367	.26128	.417	.31008	.467	.35972
.018	.00320	.068	.02315	.118	.05209	.168	.08704	.218	.12646	.268	.16932	.318	.21480	.368	.26225	.418	.31107	.468	.36072
.019	.00347	.069	.02366	.119	.05274	.169	.08779	.219	.12729	.269	.17020	.319	.21573	.369	.26321	.419	.31205	.469	.36172
.020	.00375	.070	.02417	.120	.05338	.170	.08854	.220	.12811	.270	.17109	.320	.21667	.370	.26418	.420	.31304	.470	.36272
.021	.00403	.071	.02468	.121	.05404	.171	.08929	.221	.12894	.271	.17198	.321	.21760	.371	.26514	.421	.31403	.471	.36372
.022	.00432	.072	.02520	.122	.05469	.172	.09004	.222	.12977	.272	.17287	.322	.21853	.372	.26611	.422	.31502	.472	.36471
.023	.00462	.073	.02571	.123	.05535	.173	.09080	.223	.13060	.273	.17376	.323	.21947	.373	.26708	.423	.31600	.473	.36571
.024	.00492	.074	.02624	.124	.05600	.174	.09155	.224	.13144	.274	.17465	.324	.22040	.374	.26805	.424	.31699	.474	.36671
.025	.00523	.075	.02676	.125	.05666	.175	.09231	.225	.13227	.275	.17554	.325	.22134	.375	.26901	.425	.31798	.475	.36771
.026	.00555	.076	.02729	.126	.05733	.176	.09307	.226	.13311	.276	.17644	.326	.22228	.376	.26998	.426	.31897	.476	.36871
.027	.00587	.077	.02782	.127	.05799	.177	.09384	.227	.13395	.277	.17733	.327	.22322	.377	.27095	.427	.31996	.477	.36971
.028	.00619	.078	.02836	.128	.05866	.178	.09460	.228	.13478	.278	.17823	.328	.22415	.378	.27192	.428	.32095	.478	.37071
.029	.00653	.079	.02889	.129	.05933	.179	.09537	.229	.13562	.279	.17912	.329	.22509	.379	.27289	.429	.32194	.479	.37171
.030	.00687	.080	.02943	:130	.06000	.180	.09613	.230	.13646	.280	.18002	.330	.22603	.380	.27386	.430	.32293	.480	.37270
.031	.00721	.081	.02998	.131	.06067	.181	.09690	.231	.13731	.281	.18092	.331	.22697	.381	.27483	.431	.32392	.481	.37370
.032	.00756	.082	.03053	.132	.06135	.182	.09767	.232	.13815	.282	.18182	.332	.22792	.382	.27580	.432	.32491	.482	.37470
.033	.00791	.083	.03108	.133	.06203	.183	.09845	.233	.13900	.283	.18272	.333	.22886	.383	.27678	.433	.32590	.483	.37570
.034	.00827	.084	.03163	.134	.06271	.184	.09922	.234	.13984	.284	.18362	.334	.22980	.384	.27775	.434	.32689	.484	.37670
.035	.00864	.085	.03219	.135	.06339	.185	.10000	.235	.14069	.285	.19452	.335	.23074	.385	.27872	.435	.32788	.485	.37770
.036	.00901	.086	.03275	.136	.06407	.186	.10077	.236	.14154	.286	.18542	.336	.23169	.386	.27969	.436	.32887	.486	.37870
.037	.00938	.087	.03331	.137	.06476	.187	.10155	.237	.14239	.287	.18633	.337	.23263	.387	.28067	.437	.32987	.487	.37970
.038	.00976	.088	.03387	.138	.06545	.188	.10233	.238	.14324	.288	.18723	.338	.23358	.388	.28164	.438	.33086	.488	.38070
.039	.01015	.089	.03444	.139	.06614	.189	.10312	.239	.14409	.289	.18814	.339	.23453	.389	.28262	.439	.33185	.489	.38170
.040	.01054	.090	.03501	.140	.06683	.190	.10390	.240	.14494	.290	.18905	.340	.23547	.390	.28359	.440	.33284	.490	.38270
.041	.01093	.091	.03559	.141	.06753	.191	.10469	.241	.14580	.291	.18996	.341	.23642	.391	.28457	.441	.33384	.491	.38370
.042	.01133	.092	.03616	.142	.06822	.192	.10547	.242	.14666	.292	.19086	.342	.23737	.392	.28554	.442	.33483	.492	.38470
.043	.01173	.093	.03674	.143	.06892	.193	.10626	.243	.14751	.293	.19177	.343	.23832	.393	.28652	.443	.33582	.493	.38570
.044	.01214	.094	.03732	.144	.06963	.194	.10705	.244	.14837	.294	.19268	.344	.23927	.394	.28750	.444	.33682	.494	.38670
.045	.01255	.095	.03791	.145	.07033	.195	.10784	.245	.14923	.295	.19360	.345	.24022	.395	.28848	.445	.33781	.495	.38770
.046	.01297	.096	.03850	.146	.07103	.196	.10864	.246	.15009	.296	.19451	.346	.24117	.396	.28945	.446	.33880	.496	.38870
.047	.01339	.097	.03909	.147	.07174	.197	.10943	.247	.15095	.297	.19542	.347	.24212	.397	.29043	.447	.33980	.497	.38970
.048	.01382	.098	.03968	.148	.07245	.198	.11023	.248	.15182	.298	.19634	.348	.24307	.398	.29141	.448	.34079	.498	.39070
.049	.01425	.099	.04028	.149	.07316	.199	.11102	.249	.15268	.299	.19725	.349	.24403	.399	.29239	.449	.34179	.499	.39170
																		.500	.39270

TABLE D-15

CONVERSION FACTORS AND DEFINITIONS

Acre	=	43560	square feet
Acre	=	4047	square meters
Acre	=	160	square rods
Acre	=	5645	square varas (Texas)
Acre	=	0.4047	hectares
Acre foot	=	7758	barrels
Atmosphere (Standard)	=	33.93	ft of water at 60 F
Atmosphere (Standard)	=	29.92	inches of mercury at 32 F
Atmosphere (Standard)	=	760	mm of mercury at 0 C
Atmosphere (Standard)	=	14.70	pounds per square inch
Barrel	=	5.615	cubic feet
Barrel	=	42	gallons
Barrel of water at 60 F	=	0.1588	metric tons
Barrell (36 deg A.P.I.)	=	0.1342	metric tons
Barrel per hour	=	0.0936	cubic feet per minute
Barrel per hour	=	0.700	gallons per minute
Barrel per hour	=	2.695	cubic inches per second
Barrel per day	=	0.02917	gallons per minute
British thermal unit	=	0.2520	kilocalories, International
British thermal unit	=	0.2930	International watt-hours
British thermal unit	=	778	foot-pounds
Btu per minute	=	.02358	horsepower
Centimeter	=	0.3937	inches
Centimeter of mercury at 32 F	=	0.1934	pounds per square inch
Chain (Gunther's)	=	66	feet
Chain (Gunther's)	=	4	rods
Cubic centimeter	=	0.06102	cubic inches
Cubic foot	=	0.1781	barrels
Cubic foot	=	7.481	gallons
Cubic foot	=	0.02832	cubic meters
Cubic foot per minute	=	10.684	barrels per hour
Cubic foot per minute	=	28.8	cubic inches per second
Cubic inch	=	16.39	cubic centimeters
Cubic meter	=	6.290	barrels
Cubic meter	=	35.31	cubic feet
Cubic meter	=	1.308	cubic yards
Cubic yard	=	4.809	barrels
Cubic yard	=	46656	cubic inches
Cubic yard	=	0.7646	cubic meters
Foot	=	30.48	centimeters
Foot	=	0.3048	meters
Foot	=	0.3600	varas (Texas)
Foot of water at 60 F	=	0.4331	pounds per square inch
Foot per second	=	0.6818	miles per hour
Foot-pound	=	0.001285	British thermal units
Foot-pound per second	=	0.001818	horsepower
Gallon (U.S.)	=	0.02381	barrels
Gallon (U.S.)	=	0.1337	cubic feet
Gallon (U.S.)	=	231	cubic inches
Gallon (U.S.)	=	3.785	liters
Gallon (U.S.)	=	0.8327	gallons (Imperial)
Gallon (Imperial)	=	1.201	gallons (U.S.)
Gallon (Imperial)	=	277.4	cubic inches
Gallon per minute	=	1.429	barrels per hour
Gallon per minute	=	0.1337	cubic feet per minute
Gallon per minute	=	34.29	barrels per day
Grain (Avoirdupois)	=	0.06480	grams
Grain per gallon	=	17.12	parts per million
Grain per gallon	=	142.9	pounds per million gallons
Grain per gallon	=	0.01712	grams per liter
Gram	=	15.43	grains
Gram	=	0.03527	ounces
Gram per liter	=	58.41	grains per gallon
Horsepower	=	42.41	British thermal units per minute
Horsepower	=	33000	foot-pounds per minute
Horsepower	=	550	foot-pounds per second
Horsepower	=	1.014	horsepower (metric)
Horsepower	=	.7456	kilowatts (International)
Horsepower hour	=	2544	British thermal units
Inch	=	2.540	centimeters
Inch of mercury at 32 F	=	1.133	feet of water at 39.1 F
Inch of mercury at 32 F	=	0.4912	pounds per square inch
Inch of water at 60 F	=	0.0361	pounds per square inch
Kilogram	=	2.2046	pounds
Kilogram-calorie	=	3.966	British thermal units
Kilogram per square cm	=	14.22	pounds per square inch
Kilogram per square mm	=	1422	pounds per square inch
Kilometer	=	3281	feet
Kilometer	=	0.6214	miles
Kilowatts (International)	=	1.3413	horsepower
Link (Surveyor's)	=	7.92	inches
Liter	=	0.2642	gallons (U.S.)
Liter	=	1.057	quarts (U.S.)
Meter	=	3.281	feet
Meter	=	39.37	inches
Mile	=	5280	feet
Mile	=	1.609	kilometers
Mile	=	1900.8	varas (Texas)
Mile per hour	=	1.467	feet per second
Ounce (Avoirdupois)	=	437.5	grains
Ounce (Avoirdupois)	=	28.35	grams
Part per million	=	0.05841	grains per gallon
Part per million	=	8.345	pounds per million gallons
Pound (Avoirdupois)	=	7000	grains
Pound (Avoirdupois)	=	0.4536	kilograms
Pound per cubic inch	=	27.680	grams per cu cm
Pound per square inch	=	2.309	feet of water at 60 F
Pound per square inch	=	2.0360	inches of mercury at 32 F
Pound per square inch	=	51.72	millimeters of mercury at 32 F
Pound per square inch	=	0.0703	kilogram per sq cm
Pound per million gal	=	0.00700	grains per gallon
Pound per million gal	=	0.1198	parts per million
Quart (Liquid)	=	0.946	liters
Rod	=	16.5	feet
Rod	=	25	links
Square centimeter	=	0.1550	square inches
Square foot	=	0.0929	square meters
Square foot	=	0.1296	square varas (Texas)
Square inch	=	6.452	square centimeters
Square kilometer	=	0.3861	square miles
Square meter	=	10.76	square feet
Square mile	=	2.590	square kilometers
Temp Centigrade	=	5/9 (Temp F —32)	
Temp Fahrenheit	=	9/5 Temp C +32	
Temp Kelvin	=	Temp C +273.1	
Temp Rankine	=	Temp F +460	
Ton (Long)	=	2240	pounds
Ton (Metric)	=	2205	pounds
Ton (Short or Net)	=	2000	pounds
Ton (Metric)	=	1.102	tons (short or net)
Ton (Metric)	=	1000	kilograms
Ton (Metric)	=	6.297	barrels of water at 60 F
Ton (Metric)	=	7.452	barrels (36 deg A.P.I.)
Ton (Short or Net)	=	0.907	tons (metric)
Vara (Texas)	=	33.333	inches
Watt-hour (International)	=	3.413	British thermal units
Yard	=	0.9144	meters

Barrel, above, always means oil barrel = 42 gallons.
Gallon, unless otherwise noted, means U.S. gallon.

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