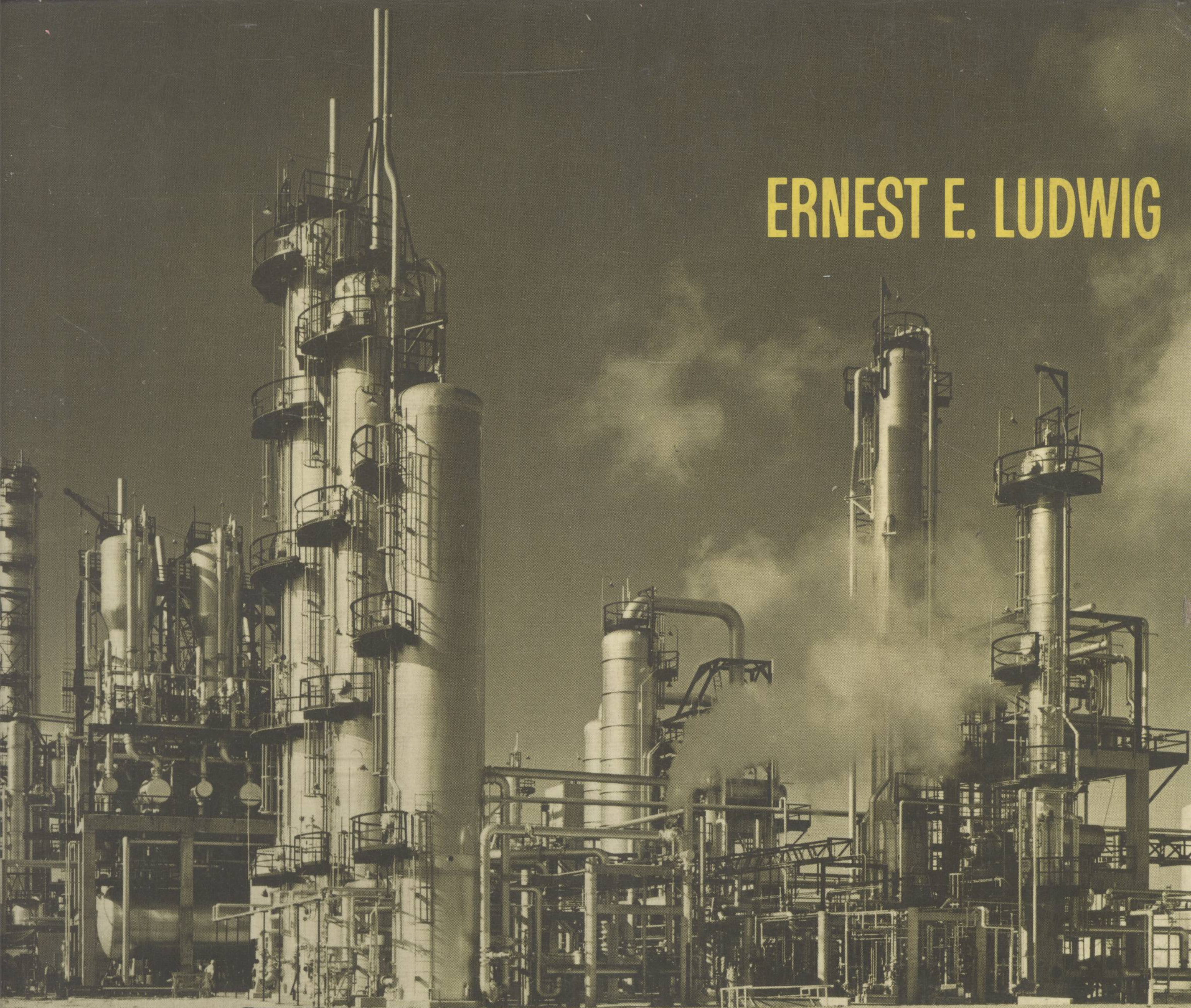

ERNEST E. LUDWIG

APPLIED PROCESS DESIGN FOR CHEMICAL AND PETROCHEMICAL PLANTS / VOLUME 3

SECOND EDITION

Third of a 3-volume set which emphasizes how to apply techniques of process control and interpret results into mechanical equipment details

Design for Chemical and Petrochemical Plants

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Baton Rouge, Louisiana

Gulf Publishing Company
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Houston, London, Paris, Tokyo

Dedication

To my wife, Sue, for her
patient encouragement and help

APPLIED PROCESS DESIGN FOR
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Foreword to the Second Edition

The techniques of process design continue to improve as the science of chemical engineering develops new and better interpretations of fundamentals. Accordingly, this second edition presents additional, reliable design methods based on proven techniques and supported by pertinent data. Since the first edition, much progress has been made in standardizing and improving the design techniques for the hardware components that are used in designing process equipment. This standardization has been incorporated in this latest edition, as much as practically possible.

The "heart" of proper process design is interpreting the process requirements into properly *arranged* and *sized* mechanical hardware expressed as (1) off-the-shelf mechanical equipment (with appropriate electric drives and instrumentation for control); (2) custom-designed vessels, controls, etc.; or (3) some combination of (1) and (2). The unique process conditions must be attainable in, by, and through the equipment. Therefore, it is essential that the process designer carefully visualize physically and mathematically just how the process will behave in the equipment and through the control schemes proposed.

Although most of the chapters have been expanded to include new material, some obsolete information has been removed.

Chapter 10, Heat Transfer, has been updated, and now includes several important design techniques for difficult condensing situations and for the application of thermosiphon reboilers.

Chapter 11, Refrigeration Systems, has been improved with additional data and new systems designs for light hydrocarbon refrigeration.

Chapter 12, Compression Equipment, has been generally updated.

Chapter 13, Compression Surge Drums, presents several new techniques, as well as additional detailed examples.

Chapter 14, Mechanical Drivers, has been updated to the latest code and standards of the National Electrical Manufacturer's Association, in addition to including information on the new energy efficient motors.

Also, the new Appendix provides an array of basic reference and conversion data.

Although computers are now an increasingly valuable tool for the process design engineer, it is beyond the scope of these 3 volumes to incorporate the programming and mathematical techniques required to convert the basic process design methods presented into computer programs. There are now many useful computer programs for process design, as well as optimization, and the process designer is encouraged to develop his/her own or become familiar with available commercial programs through several of the recognized firms specializing in design and simulation computer software.

The many aspects of process design are essential to the proper performance of the work of chemical engineers and other engineers engaged in the process engineering design details for chemical and petrochemical plants. Process design has developed by necessity into a unique section of the scope of work for the broad spectrum of chemical engineering.

The purpose of these 3 volumes is to present techniques of process design and to interpret the results into mechanical equipment details. There is no attempt to present theoretical developments of the design equations. The equations recommended have practically all been used in actual plant equipment design, and are considered to be the most reasonable available to the author, and still capable of being handled by both the inexperienced as well as the experienced engineer. A conscious effort has been made to offer guidelines to judgment, decisions and selections, and some of this will be found in the illustrative problems.

The text material assumes that the reader is a graduate or equivalent chemical or related engineer having a sound knowledge of the fundamentals of the profession. From this background the reader is led into the techniques of design required to actually design as well as mechanically detail and specify. It is the author's philosophy that the process engineer has not adequately performed his function unless the results of a process calculation for equipment are specified in terms of something that can be economically built, and which can by visual or mental techniques be *mechanically interpreted* to actually perform the process function for which it is being designed. This concept is stressed to a reasonable degree in the various chapters.

As part of the objective the chapters are developed by the *design function* of the designing engineer and not in accordance with previously suggested standards for unit operations. In fact, some chapters utilize the same principles, but require different interpretations when recognized in relation to the *process* and the function the equipment performs in this process.

Due to the magnitude of the task of preparing such material in proper detail, it has been necessary to drop several important topics with which every designing engineer must be acquainted, such as corrosion, cost estimating, economics and several others. These are now left to the more specialized works of several fine authors. Recognizing this reduction in content, it is still the hope of the author that in many petrochemical and chemical processes the designer will find design techniques adaptable to 75-80 percent of his requirements. Thus, an effort has been made to place this book in a position of utilization somewhere between a handbook and a fundamentals teaching text. The present work is considered suitable for graduate courses in detailed process design, and particularly if a general course in plant design is available to fill in the broader factors associated with overall plant layout and planning.

The author is indebted to the many industrial firms which have so generously made available certain valuable design data and information. This credit is acknowledged at the appropriate locations in the text, except for the few cases where a specific request was made to omit this credit.

The author was encouraged to undertake this work by Dr. James Villbrandt together with Dr. W.A. Cunningham and Dr. J. J. McKetta. The latter two together with the late Dr. K.A. Kobe offered many suggestions to help establish the usefulness of the material to the broadest group of engineers.

In addition, the author is deeply appreciative of the courtesy of The Dow Chemical Co. for use of certain noncredited materials, and their release for publication. In this regard particular thanks are given to Mr. N.D. Griswold and Mr. J.E. Ross. The valuable contribution of associates in checking material and making suggestions is gratefully acknowledged to H.F. Hasenbeck, L.T. McBeth, E.R. Ketchum, J.D. Hajek, W.J. Evers, D.A. Gibson.

The courtesy of the Rexall Chemical Co. to encourage continuation of this work is also gratefully appreciated.

Ernest E. Ludwig
Baton Rouge, Louisiana

Contents

Chapter 10

Heat Transfer

Heat transfer is perhaps the most important as well as most applied process in chemical and petrochemical plants. Economics of plant operation often are controlled by the effectiveness of the utilization and recovery of heat or cold (refrigeration). The service functions of steam, power, refrigeration supply and the like are dictated by how these services or utilities are used within the process to produce an efficient conversion and recovery of heat.

Although there are many good references[5,22,36,37,40,61,70,74,82] and the technical literature is well represented by important details of good heat transfer design principles and good aproaches to equipment design, there still remains an unknown factor which enters into every design. This is the scale or fouling from the fluids being processed, and is wholly dependent on the fluids, their temperature, velocity, and to a certain extent the nature of the heat transfer tube surface and its chemical composition. Due to the unknown nature of the assumptions, these fouling factors can markedly affect the design of heat transfer equipment. Keep this in mind as this chapter develops. Conventional practice is presented here; however, Kern[71] has proposed new thermal concepts which may offer new approaches.

Before presenting design details, a summary of the usual equipment found in process plants will be reviewed.

Types of Heat Transfer Equipment

Terminology

It is important for the process engineer to understand the terminology of the heat transfer equipment manufacturers in order to properly design, specify, evaluate bids, and check drawings for this equipment.

Figures 10-1A–G from the Standards of Tubular Exchanger Manufacturers Association[107] give the nomenclature of the basic types of units. Many exchangers can be designed without all parts, specifically the performance design may not require (a) floating head and its associated parts, or (b) impingement baffle, but may require a longitudinal shell side baffle (not shown). It is important to recognize that the components in Figures 10-1A–K are associated with the basic terminology regardless of type of unit. An application and selection guide is shown in Table 10-1.

Details of Exchange Equipment Assembly and Arrangement

The process design of heat exchange equipment depends to a certain extent upon the basic type of unit considered for the process and how it will be arranged together with certain details of assembly as they pertain to that particular type. It is important to recognize that certain basic types of exchangers as given in Table 10-1 are less expensive than others, and also that inherently there are problems related to the fabrication in materials of construction to resist the fluids, cleaning, future reassignment to other services, etc. The following presentation will alert the designer to the various features that should be considered.

1. Construction Codes

The American Society of Mechanical Engineers (ASME) *Unfired Pressure Vessel Code*[119] is accepted by all states and by most industrial insurance underwriters as a basic guide for fabrication of pressure vessel equipment.

Key to Figures 10-1A to 10-1F

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
24. Packing
25. Packing Gland
26. Lantern Ring
27. Tierods and Spacers
28. Transverse Baffles or Support Plates
29. Impingement Plate
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

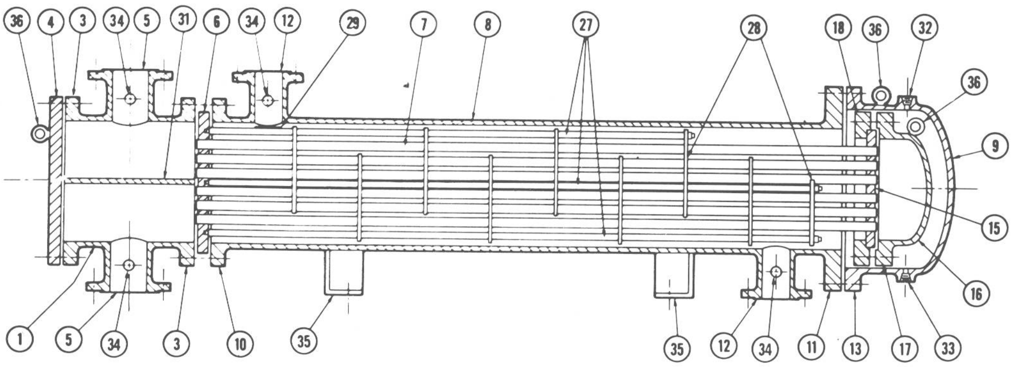


Figure 10-1A. Floating head. (© 1978 by Tubular Exchanger Manufacturers Association.)

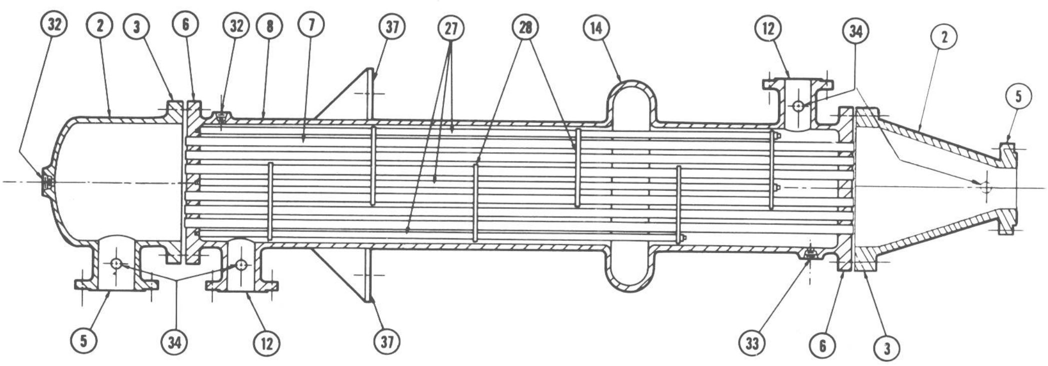


Figure 10-1B. Fixed tubesheet. (© 1978 by Tubular Exchanger Manufacturers Association.)

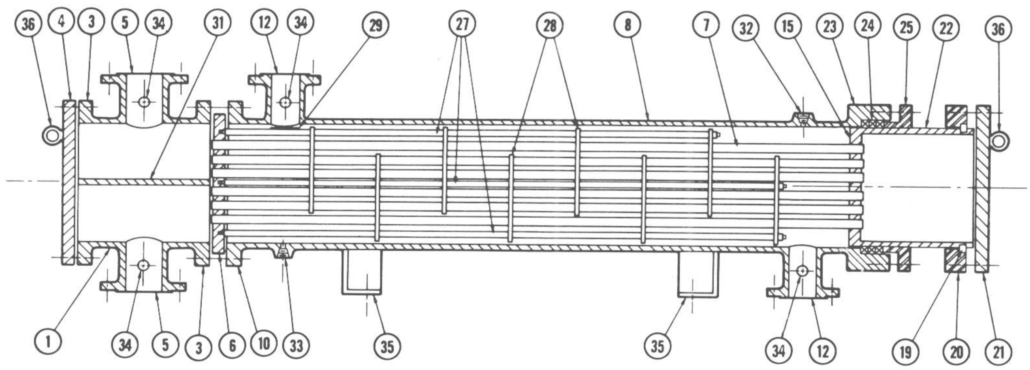


Figure 10-1C. Floating head—outside packed. (© 1978 by Tubular Exchanger Manufacturers Association.)

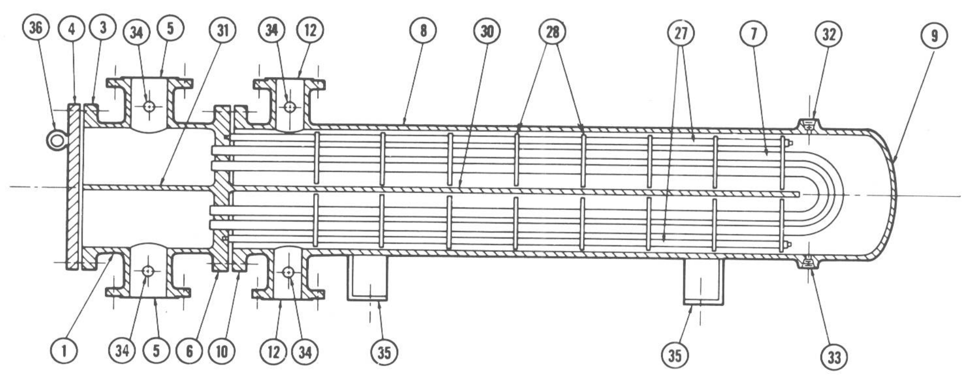


Figure 10-1D. Removable U-bundle. (© 1978 by Tubular Exchanger Manufacturers Association.)

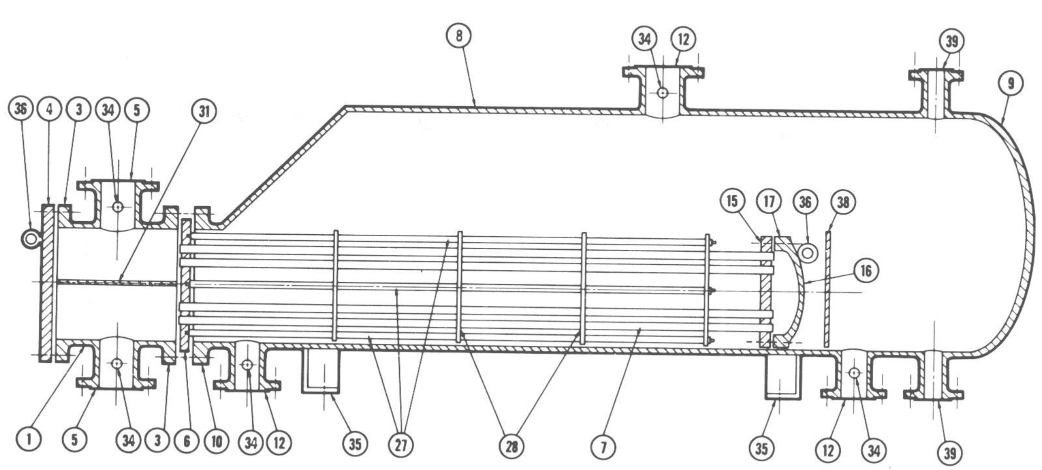


Figure 10-1E. Kettle reboiler. (© 1978 by Tubular Exchanger Manufacturers Association.)

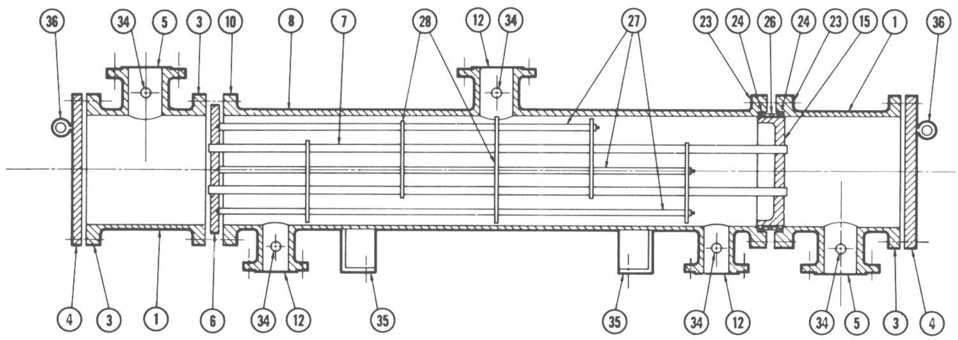


Figure 10-1F. Divided flow—packed tubesheet. (© 1978 by Tubular Exchanger Manufacturers Association.)

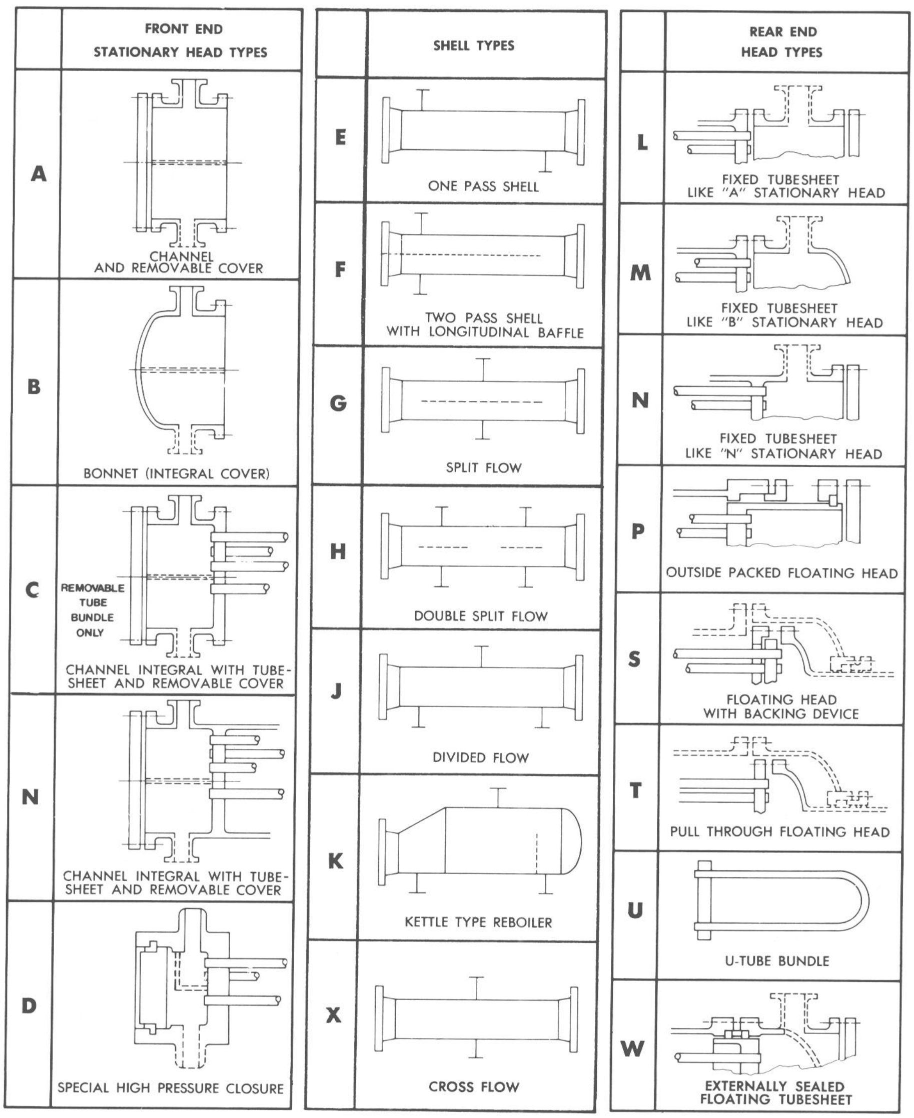


Figure 10-1G. Nomenclature of heat exchanger components. (© 1978 by Tubular Exchanger Manufacturers Association.)

Figure 10-1H. (Right) Fixed tubesheet, single-tube pass vertical heater or reboiler. (By permission, Engineers & Fabricators, Inc.)

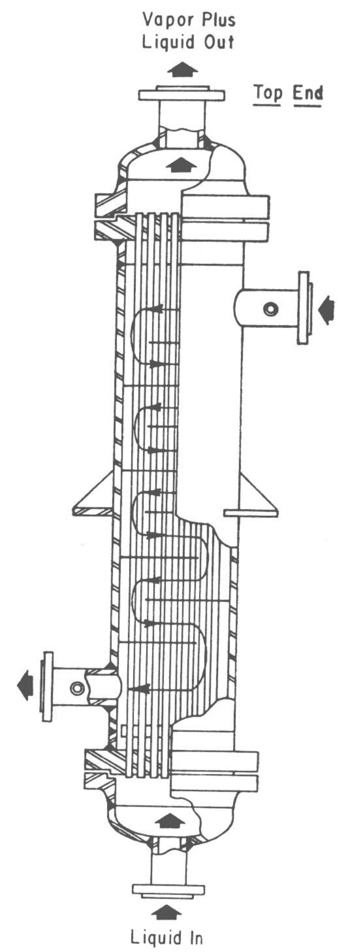
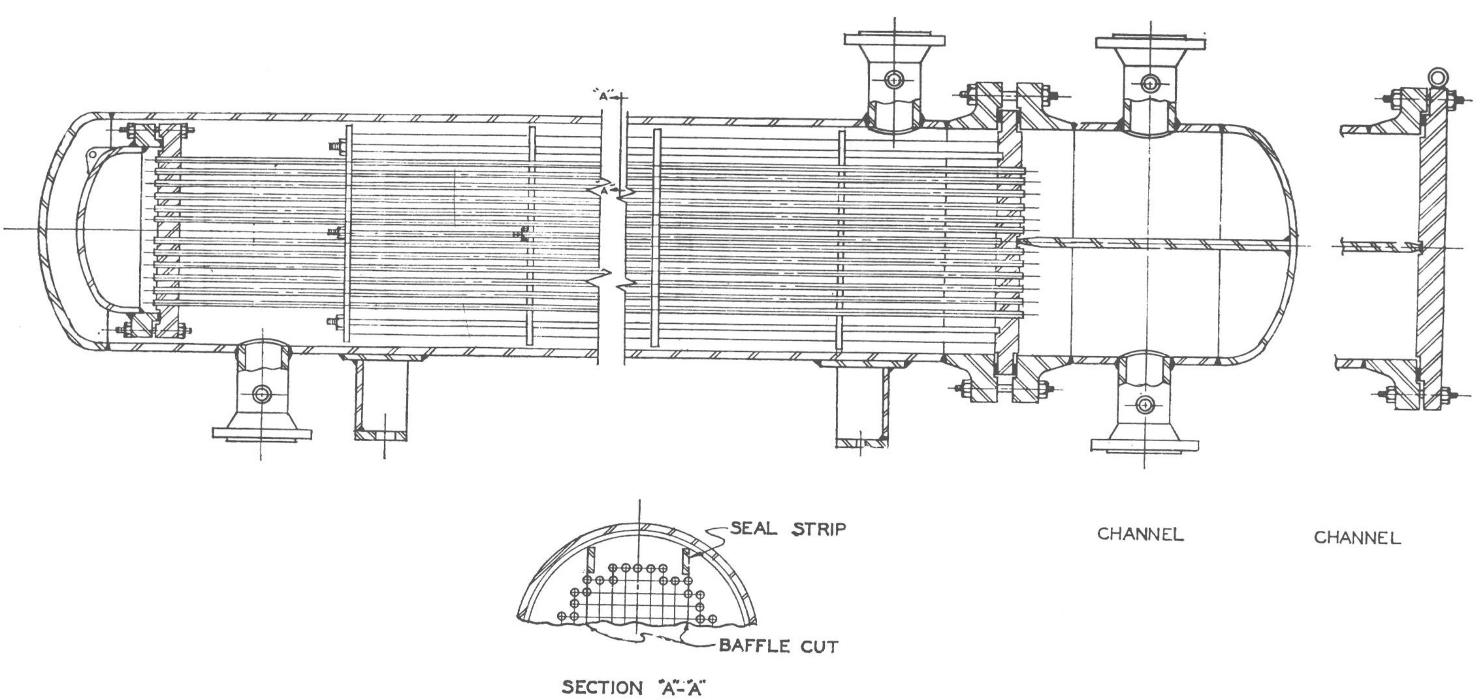


Figure 10-1I. (Below) Floating head, removable type. (By permission, Coynco Products, Inc.)



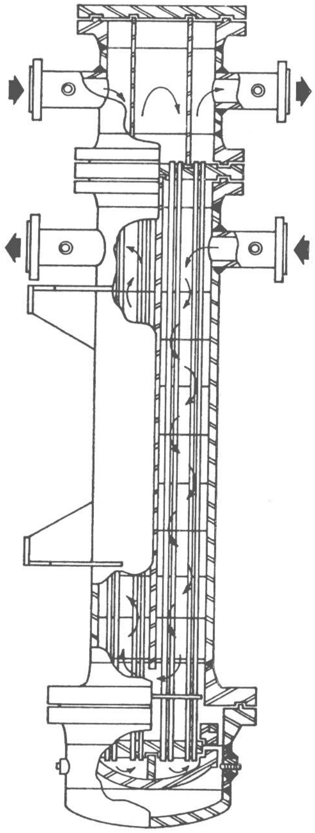


Figure 10-1J. Split-ring removable floating head, four-pass tube-side and two-pass shell-side. (By permission, Engineers & Fabricators, Inc.)

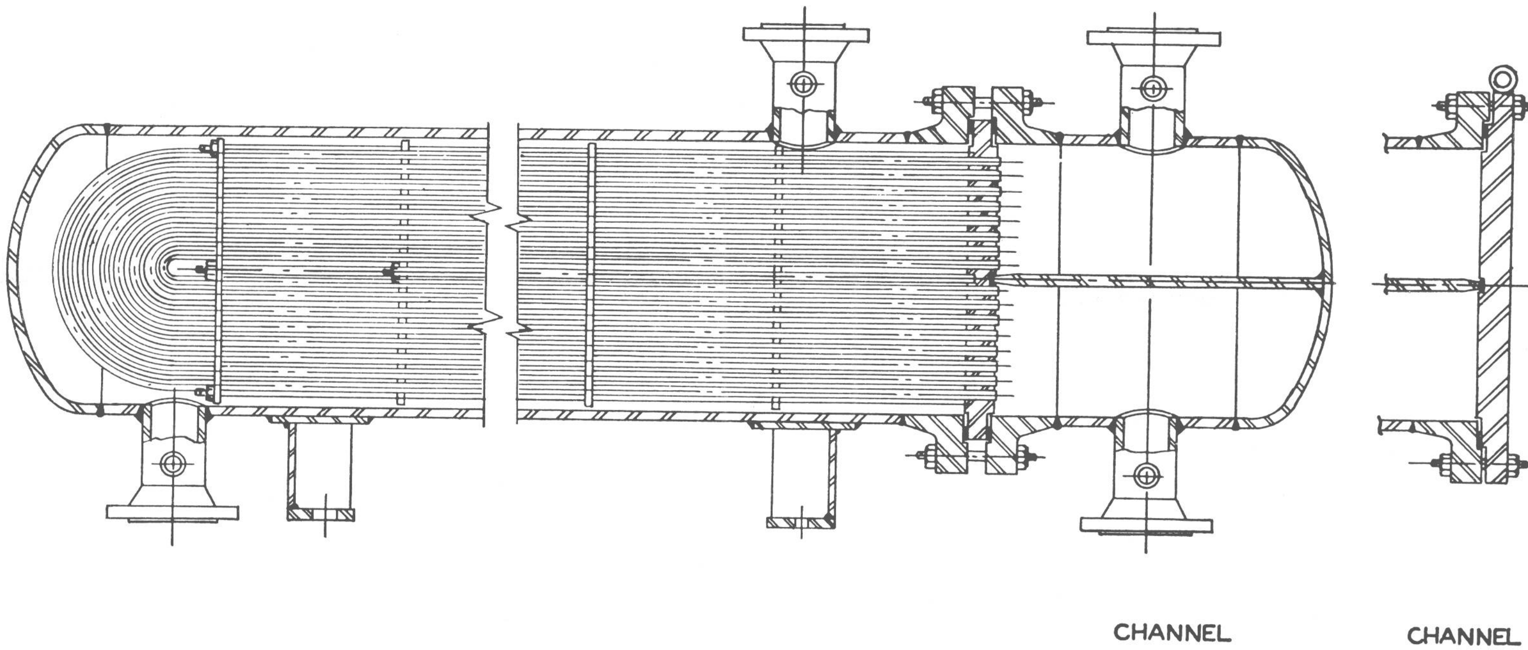


Figure 10-1K. U-tube exchanger. (By permission, Coynco Products, Inc.)

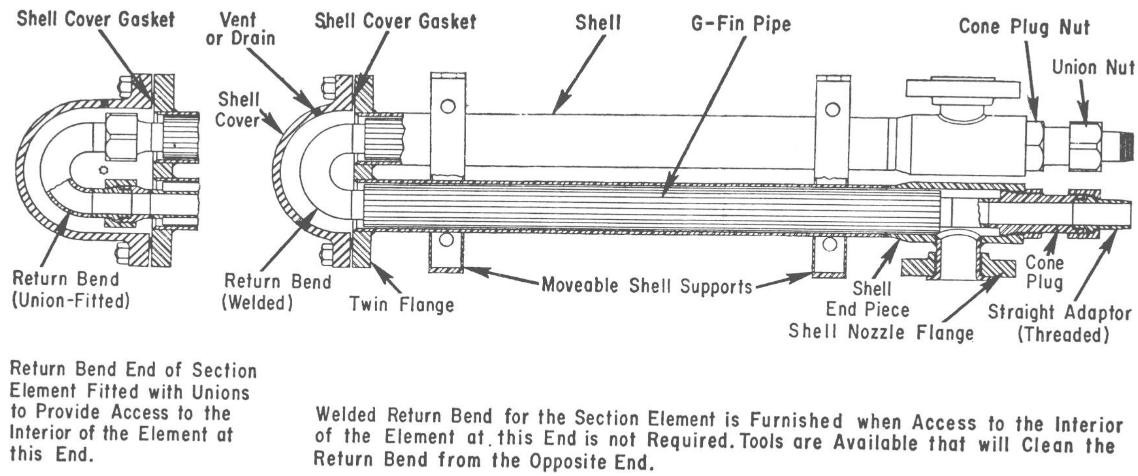
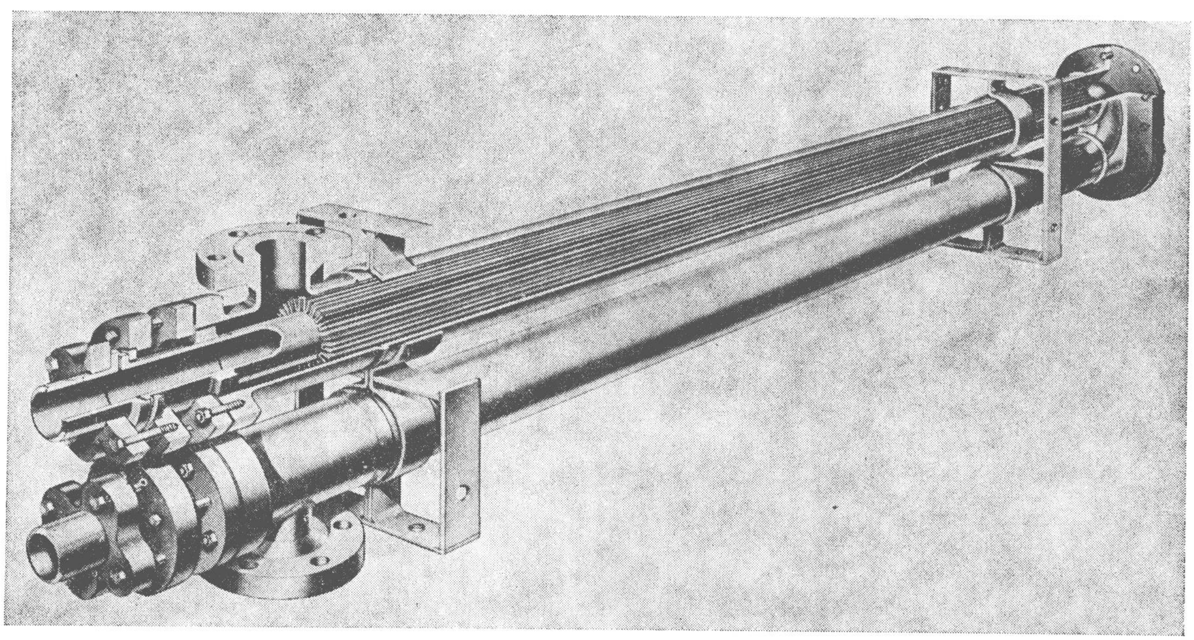


Figure 10-2A. Double-pipe longitudinal finned exchanger. (By permission, The Griscom-Russell Co., Massillon, Ohio, Bull., 1401R, 1956.)



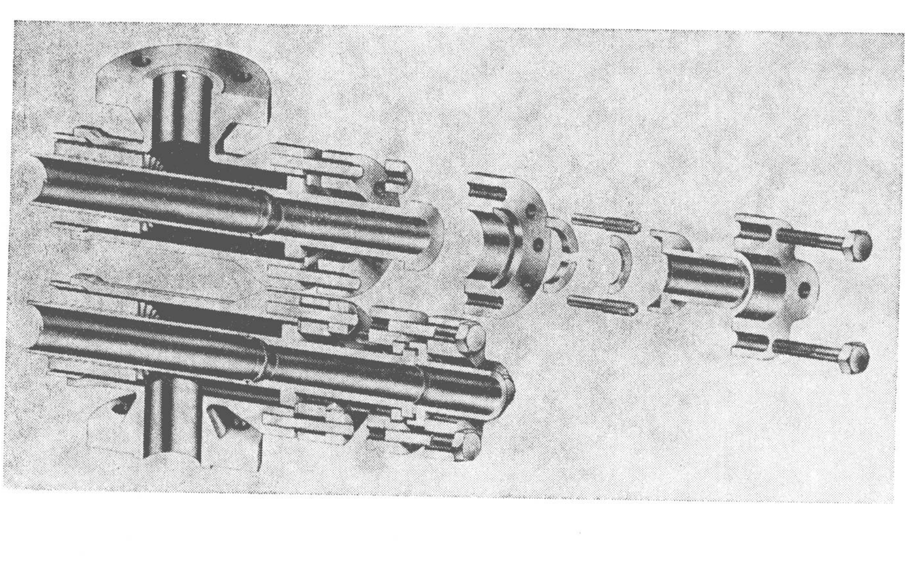


Figure 10-2B. Cut-away view of finned double-pipe exchanger. (Courtesy ALCO Products, Inc.)

Figure 10-2C. (Left) Standard fixed-end closure, exploded view. (Courtesy ALCO Products, Inc.)

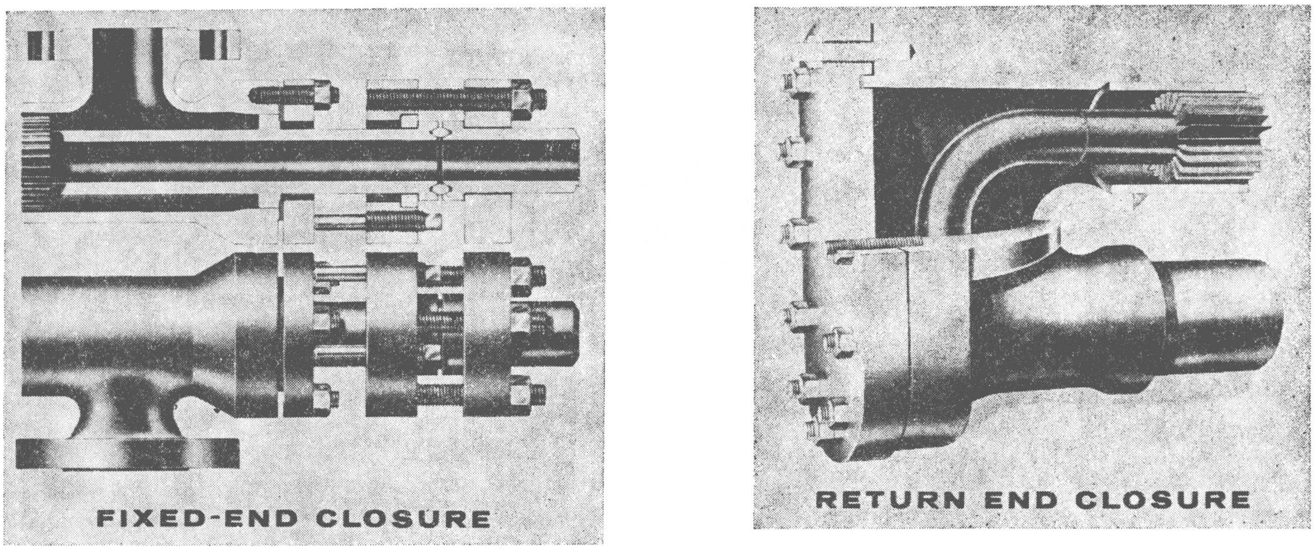


Figure 10-2D. High-pressure fixed-end closure and return-end closure. (Courtesy ALCO Products, Inc.)

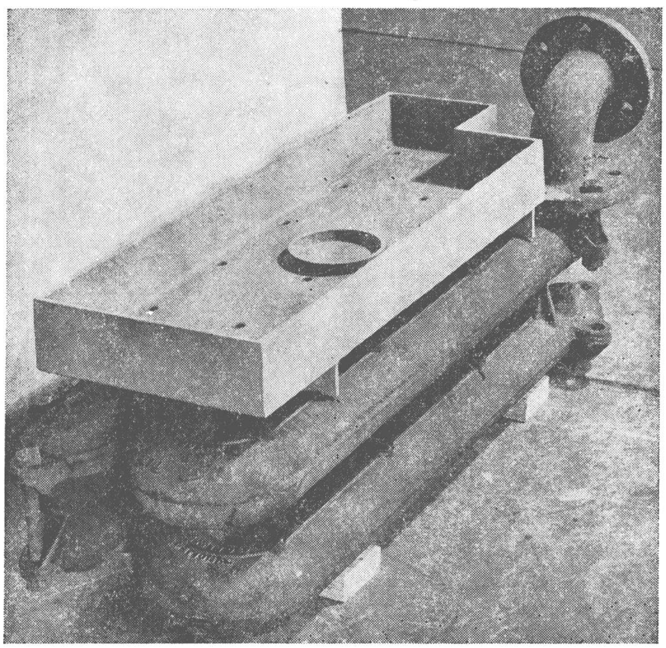


Figure 10-3A. Cast iron sections; opened coil cooler—coil and distribution pan. (By permission, Crane Co., Process Equipment Div.)

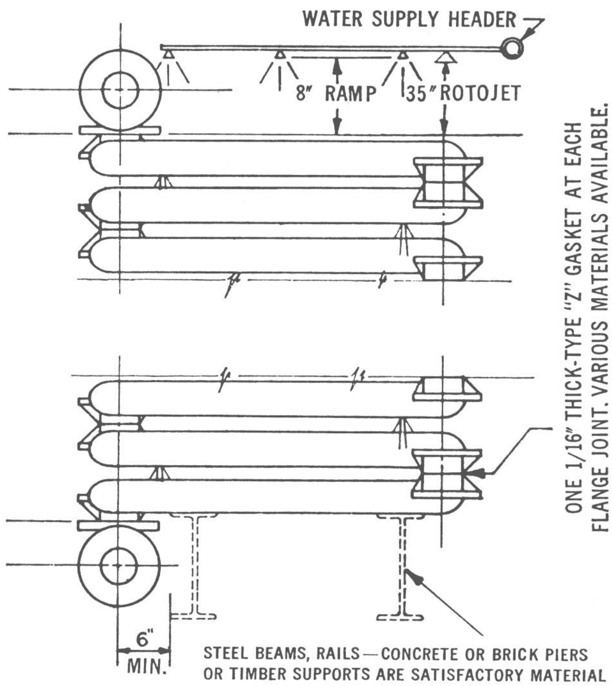


Figure 10-3B. Elevation assembly. (By permission, Crane Co., Process Equipment Div.)

Table 10-1

Selection Guide Heat Exchanger Types

Type Designation	Figure No.	Significant Feature	Applications Best Suited	Limitations	Relative Cost in Carbon Steel Construction
Fixed Tube Sheet	10-1B 10-1H	Both tube sheets fixed to shell	Condensers; liquid-liquid; gas-gas; gas-liquid; cooling and heating, horizontal or vertical, reboiling	Temperature difference at extremes of about 200° F. due to differential expansion	1.0
Floating Head or Tube Sheet (Removable and non-removable bundles)	10-1A 10-1C 10-1F 10-1I 10-1J	One tube sheet "floats" in shell or with shell, tube bundle may or may not be removable from shell, but back cover can be removed to expose tube ends.	High temperature differentials, above about 200° F. extremes; dirty fluids requiring cleaning of inside as well as outside of shell, horizontal or vertical.	Internal gaskets offer danger of leaking. Corrosiveness of fluids on shell side floating parts. Usually confined to horizontal units.	1.28
U-Tube; U-Bundle	10-1D 10-1K	Only one tube sheet required. Tubes bent in U-shape. Bundle is removable.	High temperature differentials which might require provision for expansion in fixed tube units. Clean service or easily cleaned conditions on both tube side and shell side. Horizontal or vertical.	Bends must be carefully made or mechanical damage and danger of rupture can result. Tube side velocities can cause erosion of inside of bends. Fluid should be free of suspended particles.	1.08
Kettle	10-1E	Tube bundle removable as U-type or floating head. Shell enlarged to allow boiling and vapor disengaging.	Boiling fluid on shell side, as refrigerant, or process fluid being vaporized. Chilling or cooling of tube side fluid in refrigerant evaporation on shell side.	For horizontal installation. Physically large for other applications.	1.2–1.4
Double Pipe	10-2A 10-2B 10-2C 10-2D	Each tube has own shell forming annular space for shell side fluid. Usually use externally finned tube.	Relatively small transfer area service. or in banks for larger applications. Especially suited for high pressures in tube above 400 psig.	Services suitable for finned tube. Piping-up a large number often requires cost and space.	0.8–1.4
Pipe Coil	10-3A 10-3B	Pipe coil for submersion in coil-box of water or sprayed with water is simplest type of exchanger.	Condensing, or relatively low heat loads on sensible transfer.	Transfer coefficient is low, requires relatively large space if heat load is high.	0.5–0.7
Open Tube Sections (Water cooled)	10-4	Tubes require no shell, only end headers, usually long, water sprays over surface, sheds scales on outside tubes by expansion and contraction. Can also be used in water box.	Condensing, relatively low heat loads on sensible transfer.	Transfer coefficient is low, takes up less space than pipe coil.	0.8–1.1
Open Tube Sections (Air Cooled) Plain or finned tubes		No shell required, only end headers similar to water units.	Condensing, high level heat transfer.	Transfer coefficient is low, if natural convection circulation, but is improved with forced air flow across tubes.	0.8–1.8
Plate and Frame	10-5B	Composed of metal-formed thin plates separated by gaskets. Compact, easy to clean.	Viscous fluids, corrosive fluids slurries, High heat transfer.	Not well suited for boiling or condensing; limit 350-500°F by gaskets. Used for Liquid-Liquid only; not gas-gas.	0.8-1.5
Spiral	10-5C 10-5D	Compact, concentric plates; no bypassing, high turbulence.	Cross-flow, condensing, heating.	Process corrosion, suspended materials.	0.8-1.5
Small-tube Teflon	10-5A	Chemical resistance of tubes; no tube fouling.	Clean fluids, condensing, cross-exchange.	Low heat transfer coefficient.	2.0-4.0

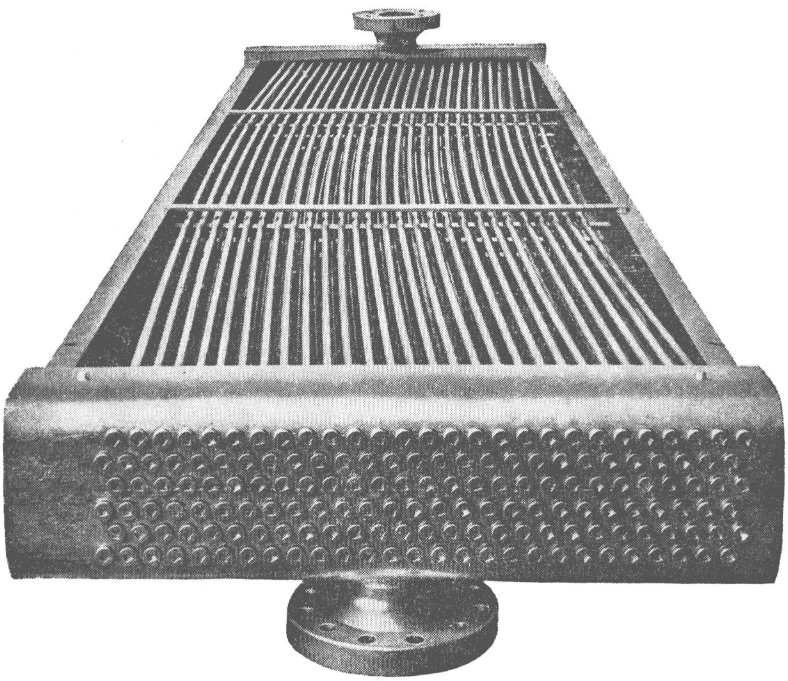


Figure 10-4. Open tube sections. (By permission, Griscom-Russell Co., Massillon, Ohio.)

This Code does not cover the rolling-in of tubes into tube sheets.

For steam generation or any equipment having a direct fire as the means of heating, the ASME *Boiler Code*[6] applies, and many states and insurance companies require compliance with this.

The Tubular Exchanger Manufacturer's Association[107] as an association of heat exchanger equipment fabricators has developed a standard for basic construction. It covers essentially all important features for good exchanger fabrication including ASME Code construction, standardization of mechanical design procedures, tolerances and dimensions applicable to many units. Thermal performance design and rating is not a part of these standards.

The three classes of TEMA Mechanical Standards for *unfired* service are:[107]

Class R—basically built as a rugged unit to withstand severe service. It serves the petroleum and heavy chemical industry.

Class C—basically built as a general purpose unit for moderate requirements of commercial and general process applications.

Class B—basically built for general purpose chemical process requirements and is designed for overall compactness.

These classes are explained in the TEMA Standards, and in Rubin[99, 100]. Table 10-2 summarizes the basic differences.

2. Thermal Rating Standards

The TEMA Code[107] does not recommend thermal design or rating of heat exchangers. This is left to the rating or design engineer, since there are many unique details associated with individual applications. TEMA does offer some common practice rating charts and tables, along with some tabulations of selected petroleum and chemical physical property data in the third edition (1952) and sixth edition (1978).

3. Exchanger Shell Types

The type of shell of an exchanger should often be established before thermal rating of the unit takes place. The shell is always a function of its relationship to the tube sheet and the internal baffles. Figures 10-1 and 10-6 summarize the usual types of shells; however, it should be remembered that other arrangements will satisfy a particular situation.

The heads attached to the shells may be welded or bolted as shown in Figure 10-7. Many other arrangements may be found in references.[37, 38, 61]

4. Tubes

The two basic types of tubes are (a) plain or bare and (b) finned—external or internal, Figure 10-8. The plain tube is used in the usual heat exchange application. However, the advantages of the more common externally finned tube are becoming better identified. These tubes are performing exceptionally well in applications where their best features can be utilized.

Plain tubes (either as solid wall or duplex) are available in carbon steel, carbon alloy steels, stainless steels, copper, brass and alloys, cupro-nickel, nickel, monel, tantalum,

(text continued on page 15)