FORD, BACON & DAVIS
A Limited Liability Company

AIChE
The Global Home of Chemical Engineers

Equipment Sizing and Specification: Shell and Tube Heat Exchangers

Presented by: Damon Motto, P.E. (LA #36791)

Agenda

- Safety Topic
- Heat Exchanger Geometry Fundamentals for Process Engineers
- Shell and Tube Heat Exchanger Design Software
- Process Engineering Workflow throughout the Project Cycle
- Demonstration

Safety Topic:
Don’t Let History Repeat Itself

- CEP Safety Beacon May 2016

Prevent Repeat Incidents

On Jan. 29, 2016, the U.S. Chemical Safety and Hazard Investigation Board (CSB) issued a report and video animation of an April 17, 2013, explosion in an agricultural chemical storage facility in West, TX (Photos 1–3). The explosion caused 15 fatalities, more than 260 injuries, total destruction of the plant, and widespread destruction of the surrounding community.

A few days later, on Feb. 5, 2016, the Chinese government released a report on an Aug. 12, 2015, explosion in a chemical warehouse in Tianjin, China. That explosion caused more than 170 fatalities, over 700 injuries, and over a billion dollars in financial loss.

Both of these incidents occurred in warehouses that stored ammonium nitrate (AN), a common fertilizer, as well as a variety of other chemicals. And in both incidents, a fire exposed AN to high temperatures, causing the explosion. The CSB report explains some of the dangers associated with AN: "AN exhibits three main hazards in fire situations: uncontrollable fire, decomposition with formation of toxic gases, and explosion."

AIChE
The Global Home of Chemical Engineers

Safety Topic

Did you know?

• The CSB report on the West, TX, explosion identifies 32 other explosions involving AN that date back to 1916 (including the 2015 Tianjin, China, explosion). In total, these explosions caused nearly 1,500 fatalities and thousands of injuries.

• The CSB list of AN explosions includes an April 16, 1947, explosion on the ship *Grandcamp* in Texas City, TX, which caused approximately 500 fatalities and 3,000 injuries. This incident is considered to be the deadliest industrial disaster in U.S. history.

What can you do?

• You may not handle AN or other materials with the potential to cause catastrophic damage in your plant, but if you use any hazardous materials or operate at hazardous process conditions, you should be aware of and understand past incidents related to those materials or process conditions.

• Ask other engineers, managers, and veteran employees to share information about past incidents at your plant and at other plants like yours. Understand what is being done to prevent similar incidents.

• Search the Internet for past incidents related to the materials and processes in your plant.

• For other examples of repeat incidents, see the February 2014 and February 2016 Beacons.

Learn from history so it doesn't repeat!

Heat Exchanger Geometry Fundamentals for Process Engineers

HX Geometry

- Resources for nomenclature/diagrams/guidelines
  - GPSA Databook Section 9
  - Perry's Section 11 (Heat Transfer Equipment)
  - AIChE CEP or e-library
  - Company or plant specific design guides

HX Geometry

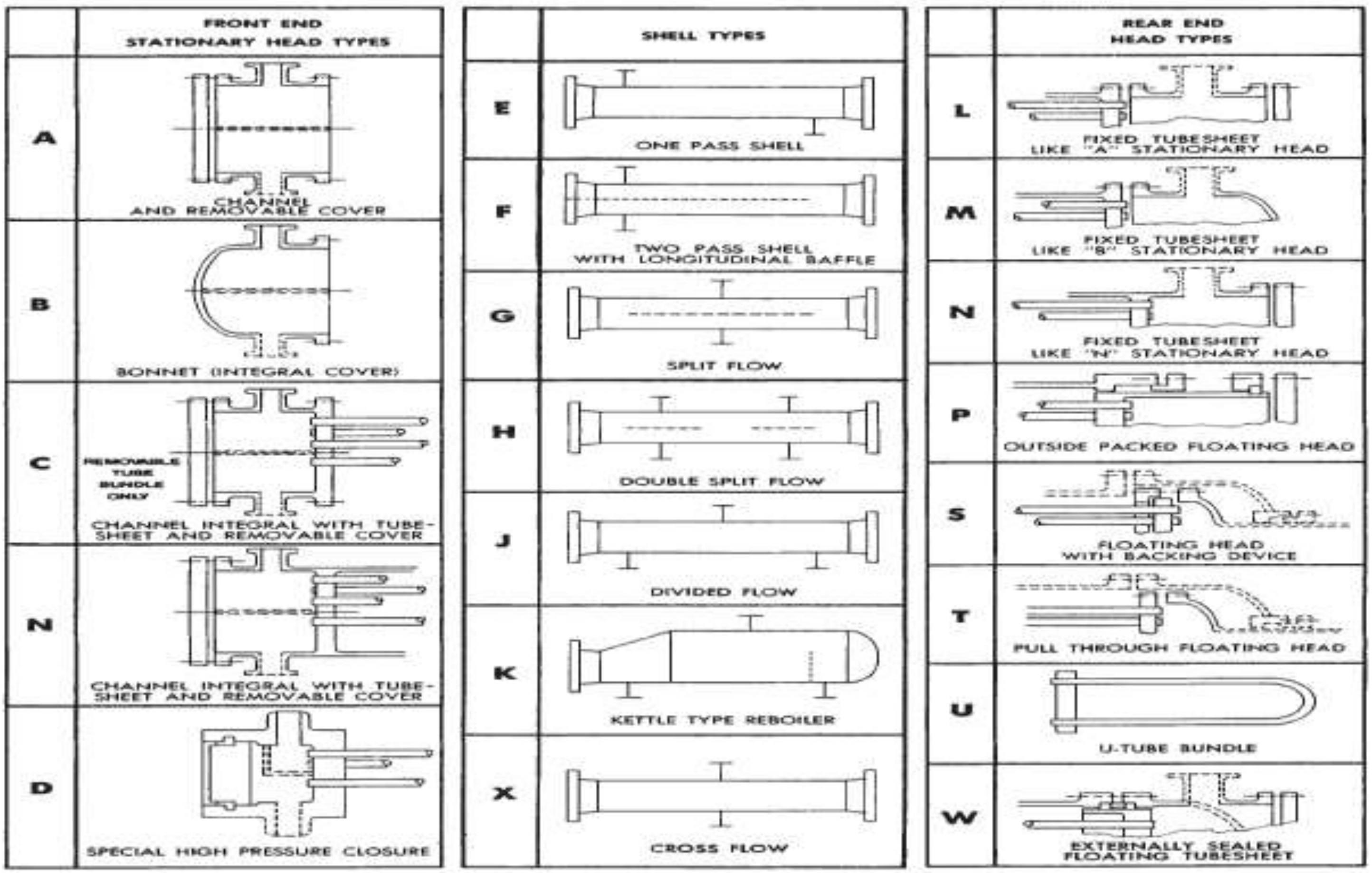


FIG. 11-35 TEMA-type designations for shell-and-tube heat exchangers. (Standards of Tubular Exchanger Manufacturers Association, 6th ed., 1978.)

Perry's Chemical Engineers' Handbook, 7th edition

HX Geometry

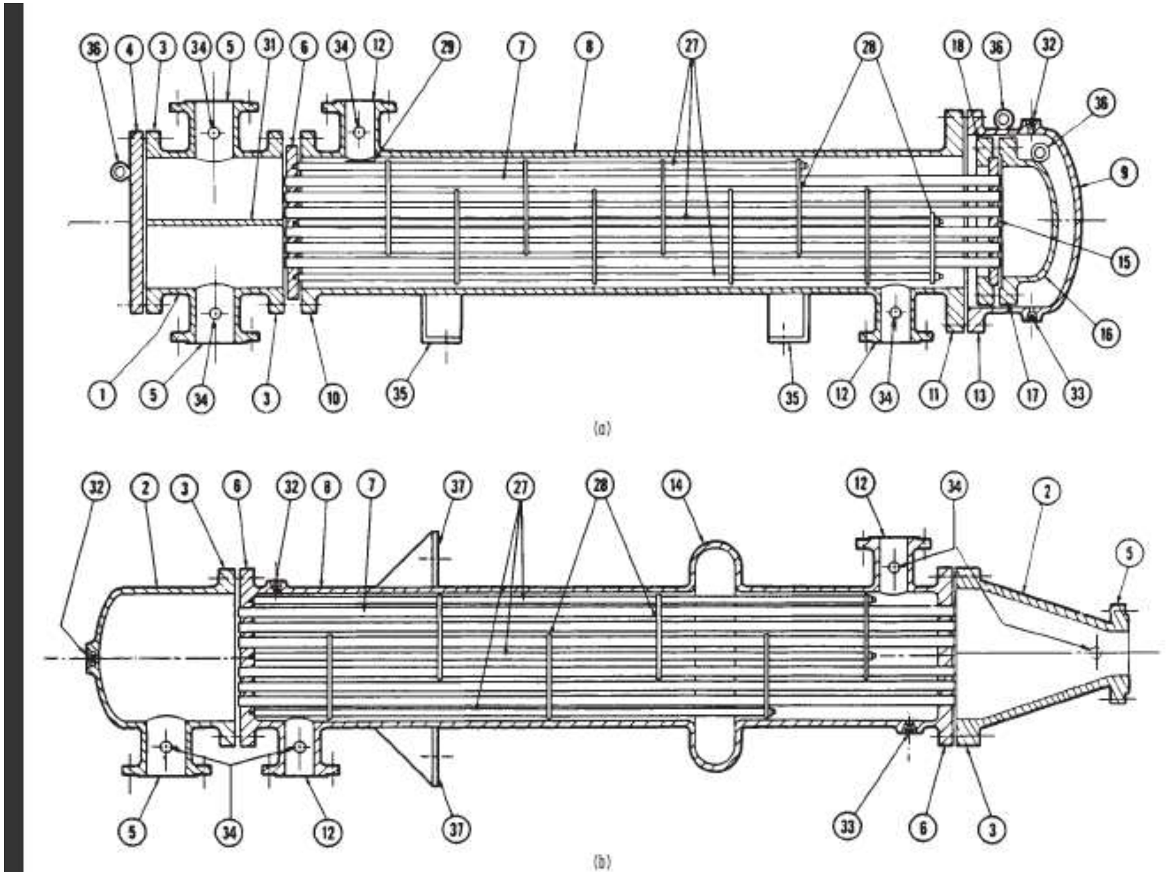


FIG. 11-36 Heat-exchanger-component nomenclature. (*a*) Internal-floating-head exchanger (with floating-head backing device). Type AES. (*b*) Fixed-tube-sheet exchanger. Type BEM. (Standard of Tubular Exchanger Manufacturers Association, *6th ed.*, 1978.)

Perry's Chemical Engineers' Handbook, 7th edition

HX Geometry

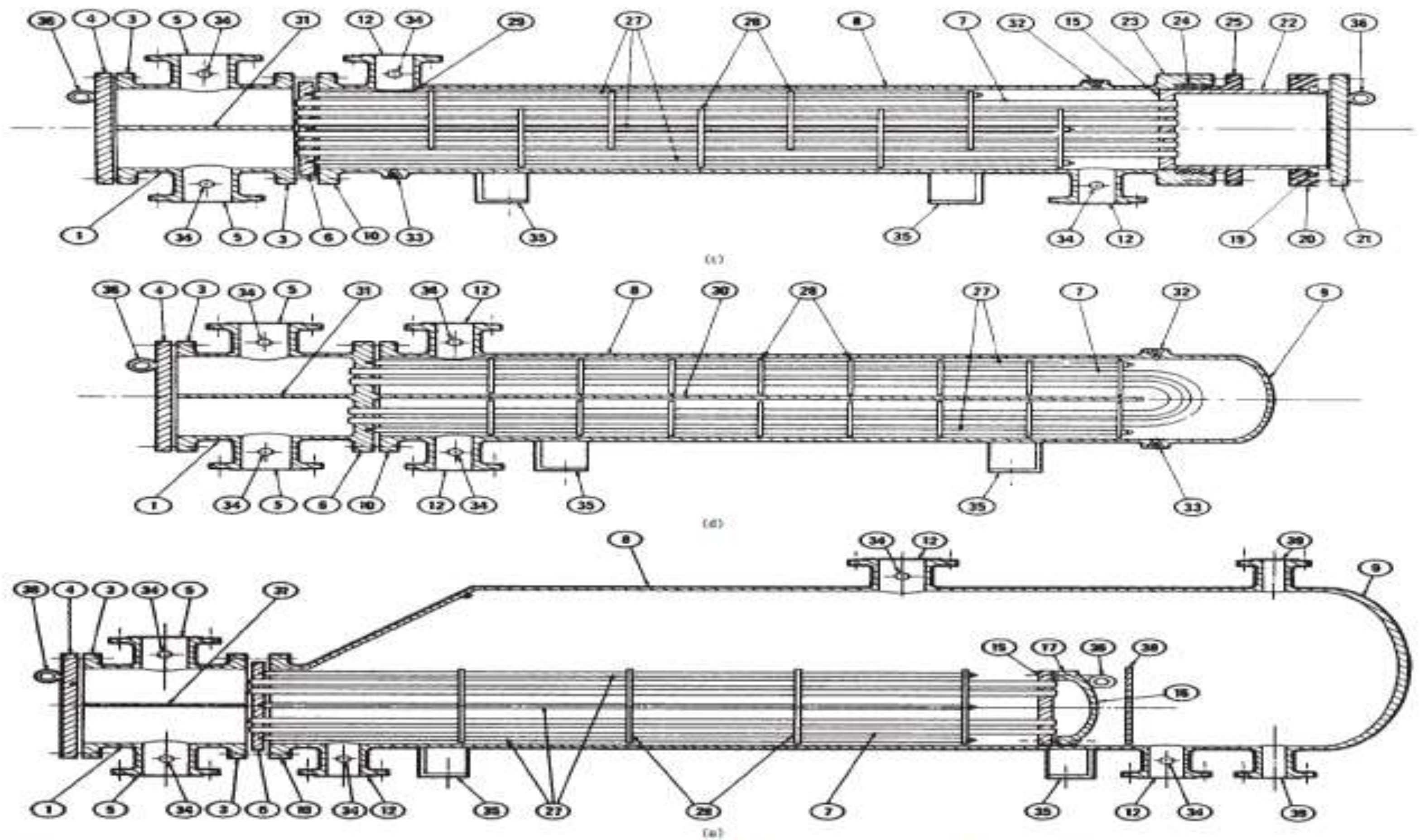


FIG. 11-36 (Continued) Heat-exchanger component nomenclature. (c) Outside-packed floating-head exchanger. Type AEP. (d) U-tube heat exchanger. Type CFU. (e) Kettle-type floating-head reboiler. Type AKT. (Standard of Tubular Exchanger Manufacturers Association, 6th ed., 1978.)

Perry's Chemical Engineers' Handbook, 7th edition

HX Geometry

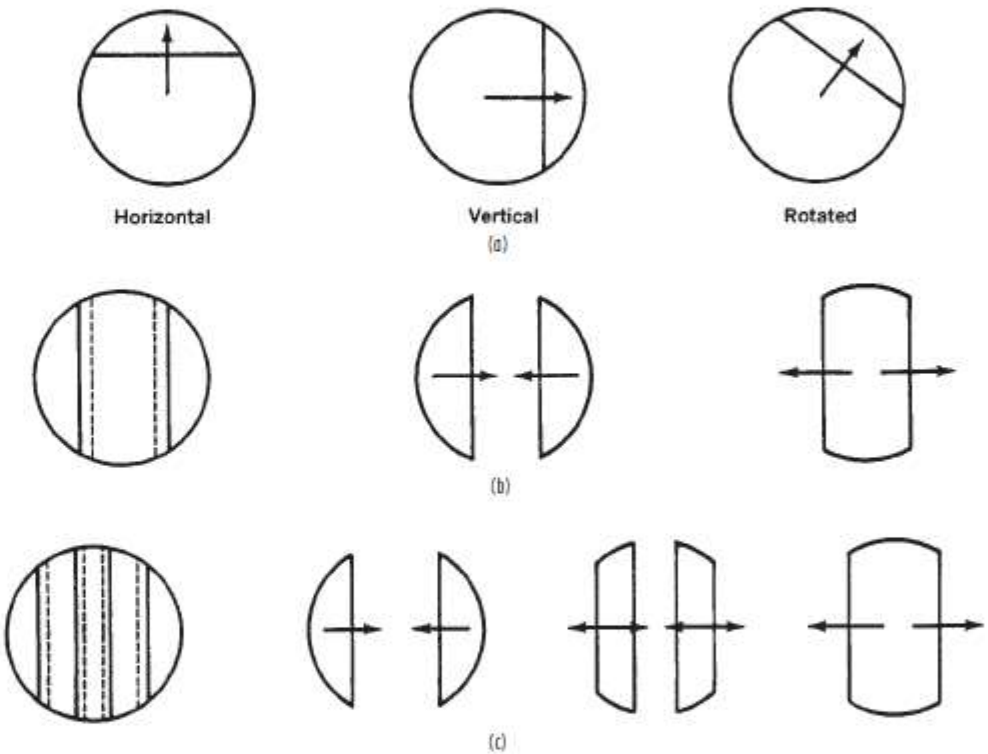


FIG. 11-40 Baffle cuts. (*a*) Baffle cuts for single segmental baffles. (*b*) Baffle cuts for double segmental baffles. (*c*) Baffle cuts for triple segmental baffles.

Perry's Chemical Engineers' Handbook, 7th edition

HX Geometry

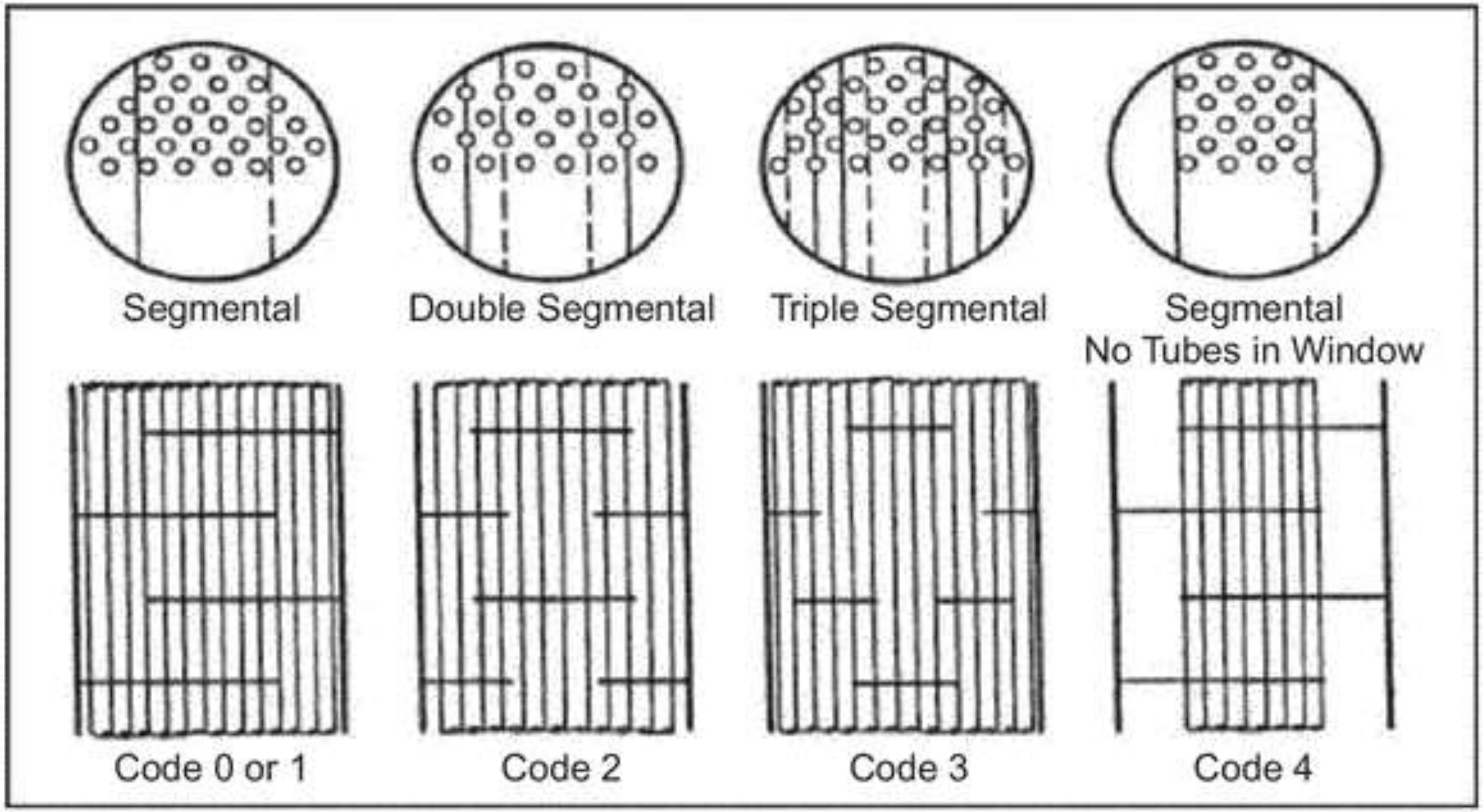


Figure 2.16 Baffle plates.

Heat Exchanger Equipment Field Manual, Stewart and Lewis

HX Geometry

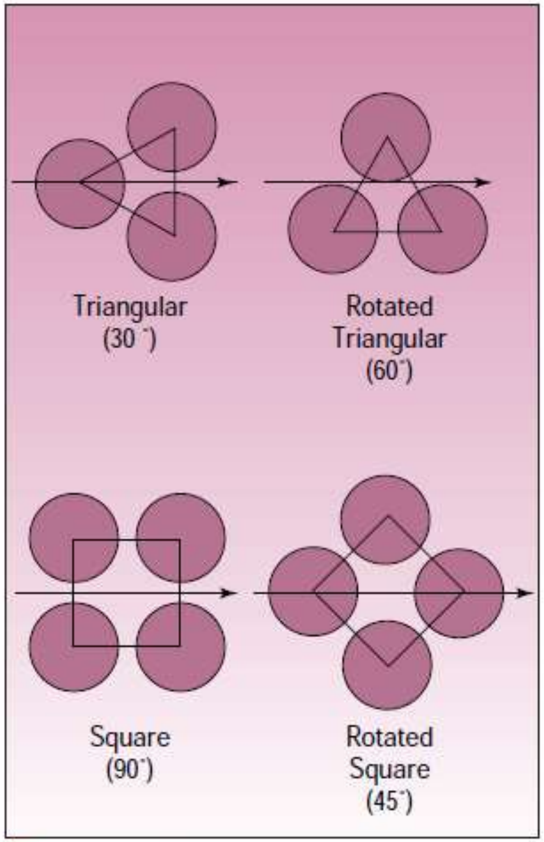
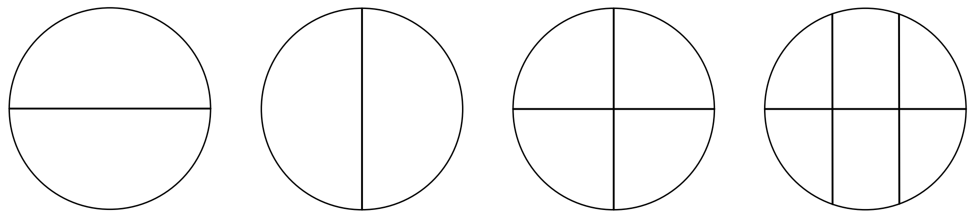


Figure 6. Tube layout patterns.

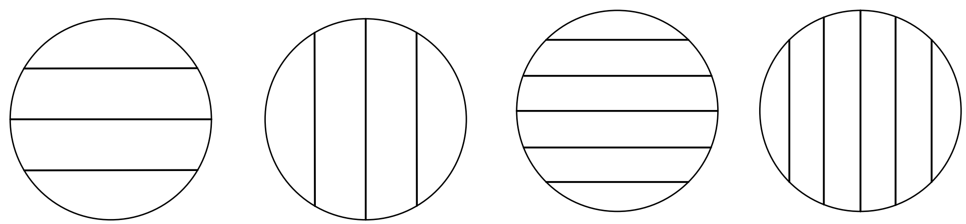
Effectively Design Shell and Tube Heat Exchangers, CEP Feb 1998, Mukherjee

COMMON TUBE PASS LAYOUTS

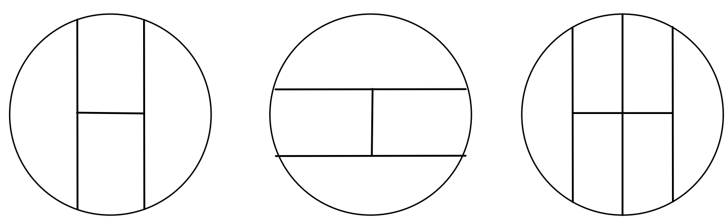
Quadrant or Segment



Ribbon



H-banded



HX Geometry

- Leakage streams
  - A stream
    - Flow between the tube and the tube hole in the baffle. Not detrimental but B stream is better
  - B stream
    - Not a “leakage stream”. This is where you want most of the flow
  - C stream
    - Bundle bypass stream
    - Hard to visualize. Flows around outer edge of the baffle.
  - E stream
    - Baffle to shell leakage. Flow that slips between the baffle and the shell
  - F stream
    - Pass partition leakage. Flow down/across the pass partition

HX Geometry

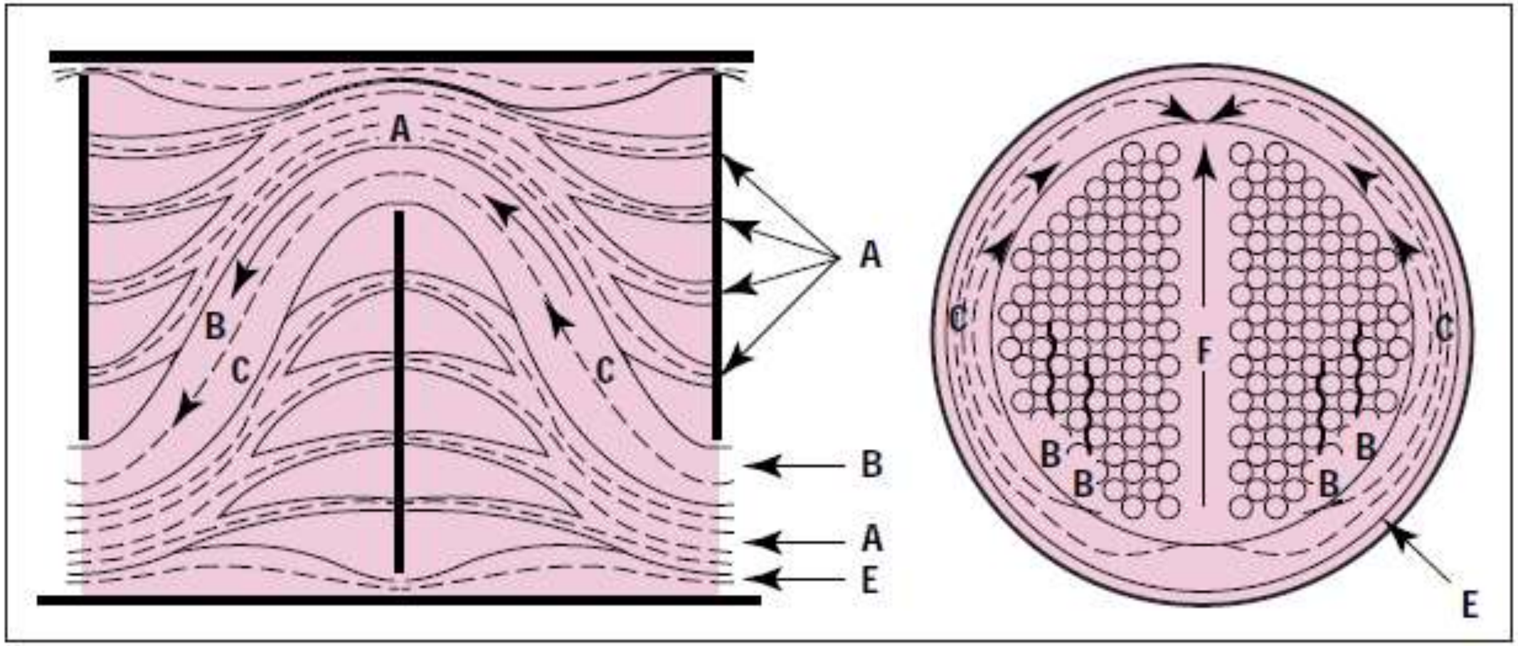


Figure 11. Shellside flow distribution.

Effectively Design Shell and Tube Heat Exchangers, CEP Feb 1998, Mukherjee

HX Geometry

- Fouling
  - Usually accounted for in a fouling factor
    - Fouling resistance on tube and shell
  - Can be combined as a Total Equivalent Fouling Resistance (TEFR)
  - Sometimes an “oversurface” factor is applied to area for fouling
  - Carefully choose fouling factors to prevent oversizing
  - Multiple fouling mechanisms but in general higher velocity leads to less fouling

Shell and Tube Heat Exchanger Design Software

Design Software

- Software can be packaged as a suite of products.
  - Shell and Tube design and rating
  - Tube vibration analysis
  - Air Cooler design and rating
  - Others
    - Plate and frame, plate-fin, spiral plate, hairpin, jacketed pipe, and fired heater, etc.
- This presentation focuses on thermal and hydraulic design of shell and tube heat exchangers

Design Software

- Strengths
  - Thermal rating/design
    - Calculate heat transfer coefficients (U) and film coefficients (h)
  - Hydraulic rating/design
  - Analyze temperature, pressure, velocity, ρv^2 profiles/values in the exchanger
  - Quantify leakage streams
  - Conforming to TEMA standard
    - Defaults to TEMA standard for some inputs. Will warn if inputs don't meet TEMA standards
  - Analyze boiling/condensation mechanisms
  - Analyze flow regimes in the exchanger

Design Software

- Weaknesses (of the thermal/hydraulic module)
  - Mechanical
    - Do not trust mechanical calculations (tube, shell, nozzle, tubesheet thicknesses)
    - Have mechanical engineer check calculations
    - In general, these calculations and warnings seem to be conservative
  - Vibration
    - With a few exceptions, vibration analysis in shell and tube modules is conservative. If no warnings, then typically there is low risk of vibration issues.
    - Vibration warnings for existing exchangers should be investigated further (possibly FEA software).
  - Piping hydraulics (Reboilers only)
    - Recommend to check flow regimes and pressure drop calculations using other methods

Design Software

- 3 different U values with different meanings
  - $U_{SERVICE}$
    - Also called $U_{required}$
    - $U_{service} = \frac{Q}{(A)(LMTD)(FT)}$
  - $U_{CALCULATED}$ or U_{ACTUAL} or U_{FOULED}
    - $U_{calculated} = \frac{1}{\frac{1}{h_i}+\frac{1}{h_o}+\frac{1}{r_i}+\frac{1}{r_o}+\frac{x}{k}}$
  - U_{CLEAN}
    - $U_{clean} = \frac{1}{\frac{1}{h_i}+\frac{1}{h_o}+\frac{x}{k}}$

Design Software

- Typically, software can be run in different modes
  - Design Mode
    - Based on a minimum number of inputs, will vary shell diameter, baffle spacing, tubepasses, tube length, etc.
    - Will run short cut calculations on every possible combination and output a table with results
    - Pick the best option, and run rigorous calculations in Rating mode

Design Software

– Rating Mode
  - Specify exchanger inlet conditions and outlet conditions of one side
    – Alternately, overall duty can be specified instead of outlet condition
  - Used to evaluate existing exchanger or quantify new exchanger overdesign
  - Based on a given geometry, calculates all three U values
  - $Overdesign = \left(\frac{U_{calculated}}{U_{service}} - 1\right) x100\%$
  - Note that overdesign and Total Equivalent Fouling Resistance (TEFR) are not the same.

Design Software

– Simulation Mode
  - Specify exchanger inlet conditions
    – Has one less degree of freedom than Rating mode
  - Used to estimate how exchanger will perform at a certain set of process conditions or degree of fouling
  - Very useful for relief calculations
  - Program will iterate until overdesign is zero
    – Usually converges to +/- 2% overdesign
    – $U_{calculated} = U_{service}$
    – $\left[\frac{Q}{(A)(LMTD)(FT)} = \frac{1}{\frac{1}{h_i}+\frac{1}{h_o}+\frac{1}{r_i}+\frac{1}{r_o}+\frac{L}{k}}\right]$

Design Software

- Specifying fluid and thermodynamic properties
  - User specified grid
    - Table of Properties vs.. Temperature are given at multiple pressures.
    - Program will interpolate. Specify pressures and temperatures that bracket the operating conditions (both bulk and tube wall) to prevent extrapolation.
    - Manually type in properties
    - Copy/paste from Excel
    - Import from process simulation software
      - Input composition and generate properties through simulator Thermo engine
      - Select a stream from an existing simulation
  - Program Calculated
    - Composition is input into program
    - Choose between design software thermo or attach thermo from process simulation
    - Software will calculate all the properties it requires as the program is run
    - This option typically requires more calculation time.

Design Software

- Vibration
  - For new exchanger, make sure software does not identify any potential vibration issues
  - For existing exchangers, perform further analysis if program gives warnings on:
    - Fluid-elastic instability
    - Critical velocity
    - Vortex shedding
    - Longest Unsupported Tube Span in U-Bend
    - High ρv^2 (this is also an erosion issue)
  - Acoustic vibration is tricky to predict and to mitigate

Process Engineering Workflow throughout the Project Cycle

Workflow

- FEL-0 / FEL-1
  - Estimate required surface area for cost estimate
  - May or may not use design software
- FEL-2
  - Estimate required surface area for cost estimate
  - Preliminary sizing ("rough-in" a design for development of P&IDs and other deliverables)
  - Use design mode
- FEL-3
  - Datasheet
  - Comparing technical offerings of multiple vendors
  - Evaluations of preliminary vendor information
  - Some clients request that EPC firms do rigorous sizing
  - Use rating mode
- Detailed Design
  - Checking of vendor design and documents

Workflow

- FEL-0 / FEL-1
  – Use heat and mass balance or simulation for duty and LMTD
  – Use tables in Perry's, GPSA, etc. for typical U values
  – Calculate surface area
    - Q=UA(LMTD)
    - $A = \frac{Q}{(U)(LMTD)}$
  – Alternately, use quick sizing tool in process simulation if typical value can't be found

Workflow

- FEL-2
  - For simple exchangers,
    - Fill out datasheet
    - Update any calculations from FEL-1 based on updated heat and mass balance, etc.
    - Can use the same typical U value as before or can run design software to get a better estimate
  - For more complex exchangers,
    - like thermosiphons, heat exchangers in networks, any fluids with skin temperature limits, applications with 2-phase flow, etc.,
    - Run a very preliminary design software calculation to start developing what the exchanger will look like on P&IDs (e.g. number of shells in parallel/series, temperature control scheme, etc.)
    - Run off-design cases in rating/simulation mode to troubleshoot possible issues
    - This can help to head off any issues that may come as a surprise later

Workflow

- FEL-3/Detailed Design
  - For most clients, at this point the vendor does the heavy lifting and EPC firm reviews and check-rates the vendor drawings
  - Some clients prefer that the EPC firm process and/or mechanical engineers do extensive work on exchanger design to fully specify the exchanger (e.g. tubes, baffles, shell size, tie rods, sealing strips, skid bars, etc.). The vendor receives the design, develops drawings, and builds the exchanger. Be careful to explicitly state who, if anyone, will provide thermal or hydraulic guarantee

Demonstration

Demonstration

- Demonstration
  - Design of E-4 in HYSYS Example File “MODELING A CRUDE VACUUM SYSTEM WITH PREHEAT TRAIN.hsc”
  - Crude vs. Diesel Product Exchanger
  - TEMA Type AES
  - 1” BWG 12 tubes
  - Diesel fouling factor = 0.0015 hr-sqft-F/Btu
  - Crude fouling factor = 0.003 hr-sqft-F/Btu

AIChE
The Global Home of Chemical Engineers

Demonstration

Shell side	Tube side	Design U	Includes total dirt
Liquid-liquid media			
Aroclor 1248	Jet fuels	100–150	0.0015
Cutback asphalt	Water	10–20	.01
Demineralized water	Water	300–500	.001
Ethanol amine (MEA or DEA) 10–25% solutions	Water or DEA, or MEA solutions	140–200	.003
Fuel oil	Water	15–25	.007
Fuel oil	Oil	10–15	.008
Gasoline	Water	60–100	.003
Heavy oils	Heavy oils	10–40	.004
Heavy oils	Water	15–50	.005
Hydrogen-rich reformer stream	Hydrogen-rich reformer stream	90–120	.002
Kerosene or gas oil	Water	25–50	.005
Kerosene or gas oil	Oil	20–35	.005
Kerosene or jet fuels	Trichlorethylene	40–50	.0015
Jacket water	Water	230–300	.002
Lube oil (low viscosity)	Water	25–50	.002
Lube oil (high viscosity)	Water	40–80	.003
Lube oil	Oil	11–20	.006
Naphtha	Water	50–70	.005
Naphtha	Oil	25–35	.005
Organic solvents	Water	50–150	.003
Organic solvents	Brine	35–90	.003
Organic solvents	Organic solvents	20–60	.002
Tall oil derivatives, vegetable oil, etc.	Water	20–50	.004
Water	Caustic soda solutions (10–30%)	100–250	.003
Water	Water	200–250	.003
Wax distillate	Water	15–25	.005
Wax distillate	Oil	13–23	.005

Perry's Chemical Engineers' Handbook, 7th edition

Demonstration

- Estimate area with typical U
    - U = 20 to 35 Btu/F-sqft-hr
  - Q=10.4 MMBTUH, LMTD=320 F
  - A= 929 to 1625 sq. ft (plus design margin)
- Use quick sizing tool
- Use design software in design mode

Questions, Comments, or Suggestions?

Email: drmotto@fbd.com

Office: (504) 412-7469

Cell: (516) 680-5115