Basics of

Heat Exchangers

Classification of Heat Exchanger based on duty

Heater

Cooler

Condenser

Vaporizer

Types of Heat Exchanger

- Double Pipe Heat Exchanger
- Shell and Tube Heat Exchanger
- U-tube Heat Exchanger
- Plate type Heat Exchanger
- Spiral Heat Exchanger
- Finned Tube Heat Exchanger

- New Developments
  - Micro Heat Exchanger

Components of Shell and Tube Heat Exchanger

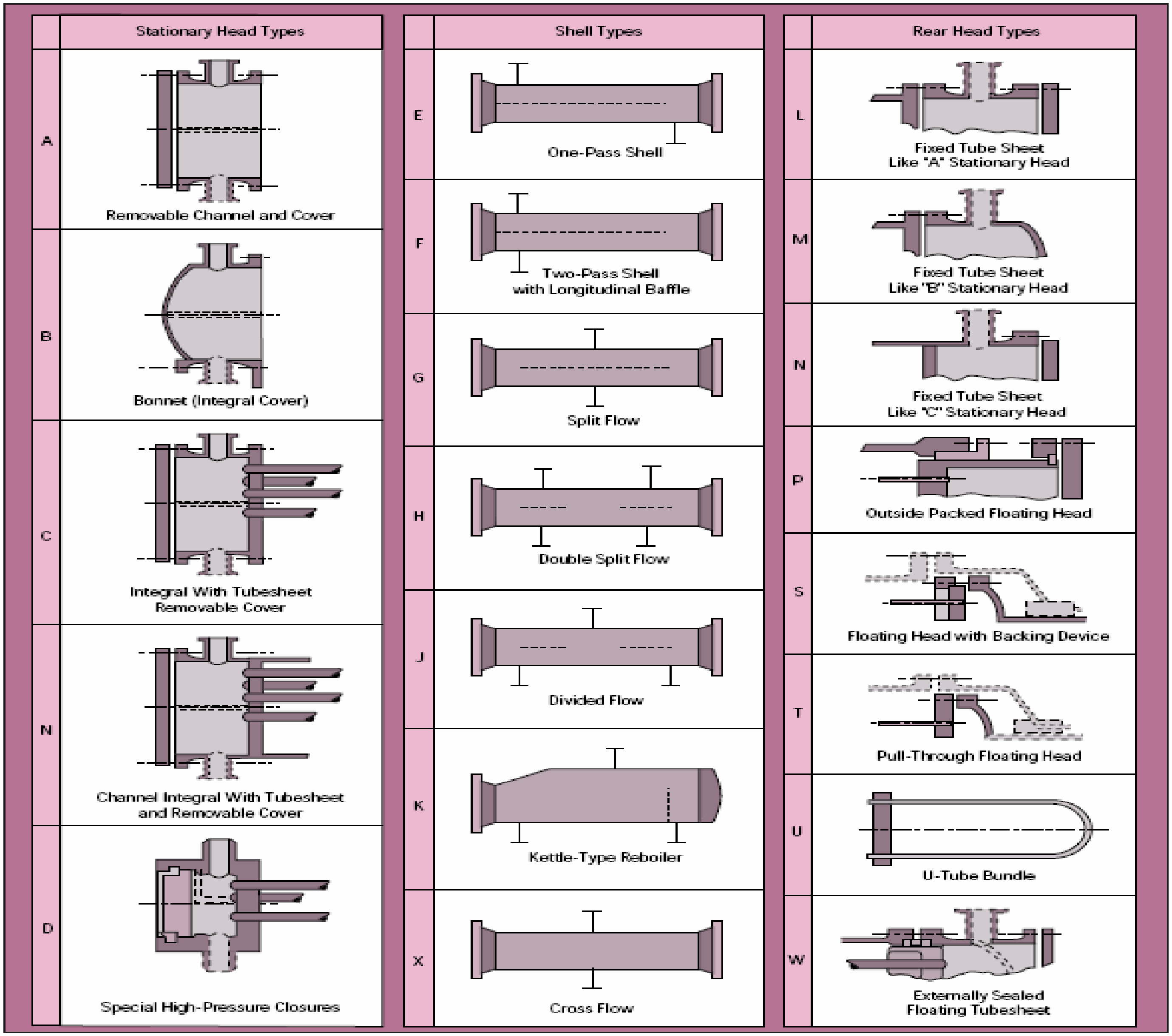
- Shell
- Shell cover
- Tubes
- Channel
- Channel cover
- Tubesheet
- Baffles

- Tie rods
- Spacers
- Pass-partition plate
- Impingement plate
- longitudinal baffle
- Sealing strips
- supports

Resources for Design

- Codes and Standards
  - **Standards of the Tubular Exchanger Manufacturers Association (TEMA)**
  - **BS 5500**
- Manufacturers Manuals
- Rules of Thumbs
- Past Experience

TEMA Designation



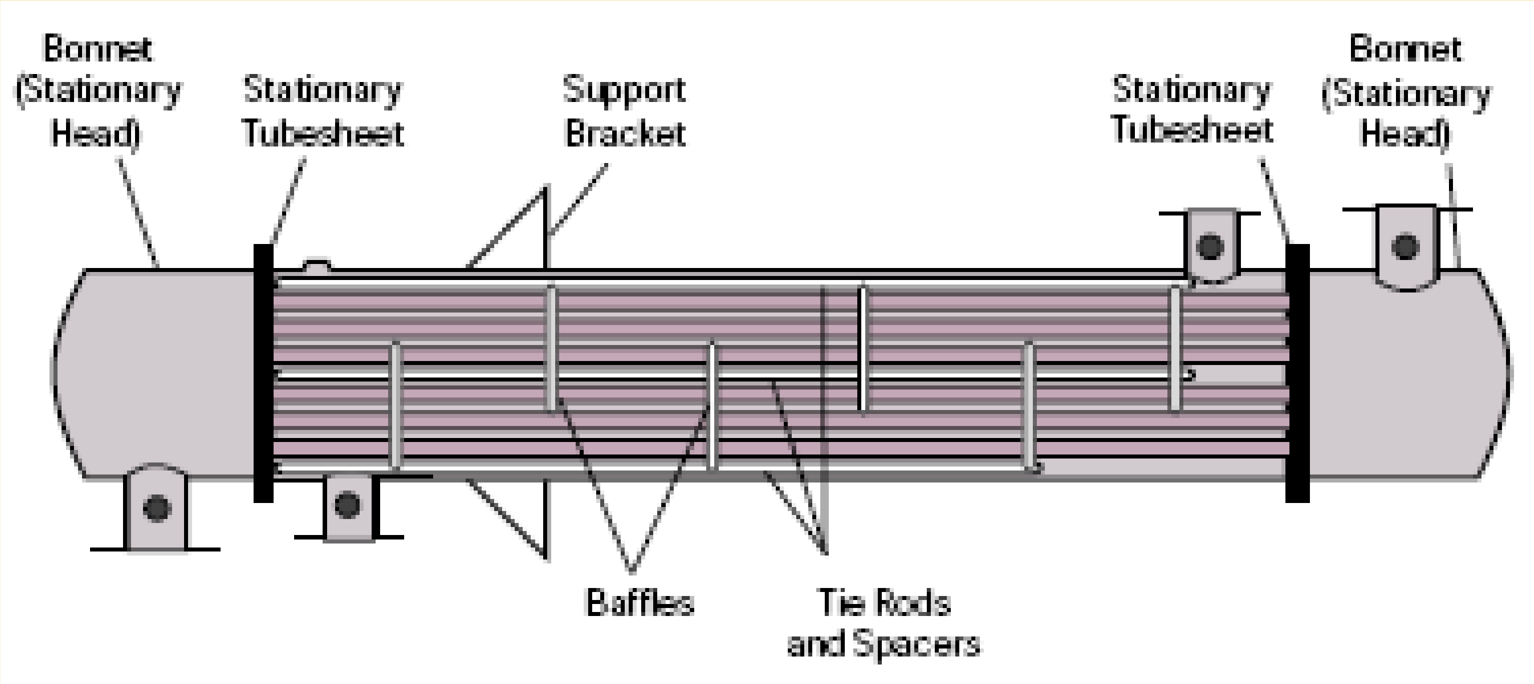
Classification based on construction

- Fixed tubesheet
  - A fixed-tubesheet heat exchanger has straight tubes that are secured at both ends to tubesheets welded to the shell.
  - The construction may have
    - removable channel covers (*e.g.,* AEL)
    - bonnet-type channel covers (*e.g.,* BEM)
    - integral tubesheets (*e.g.,* NEN)

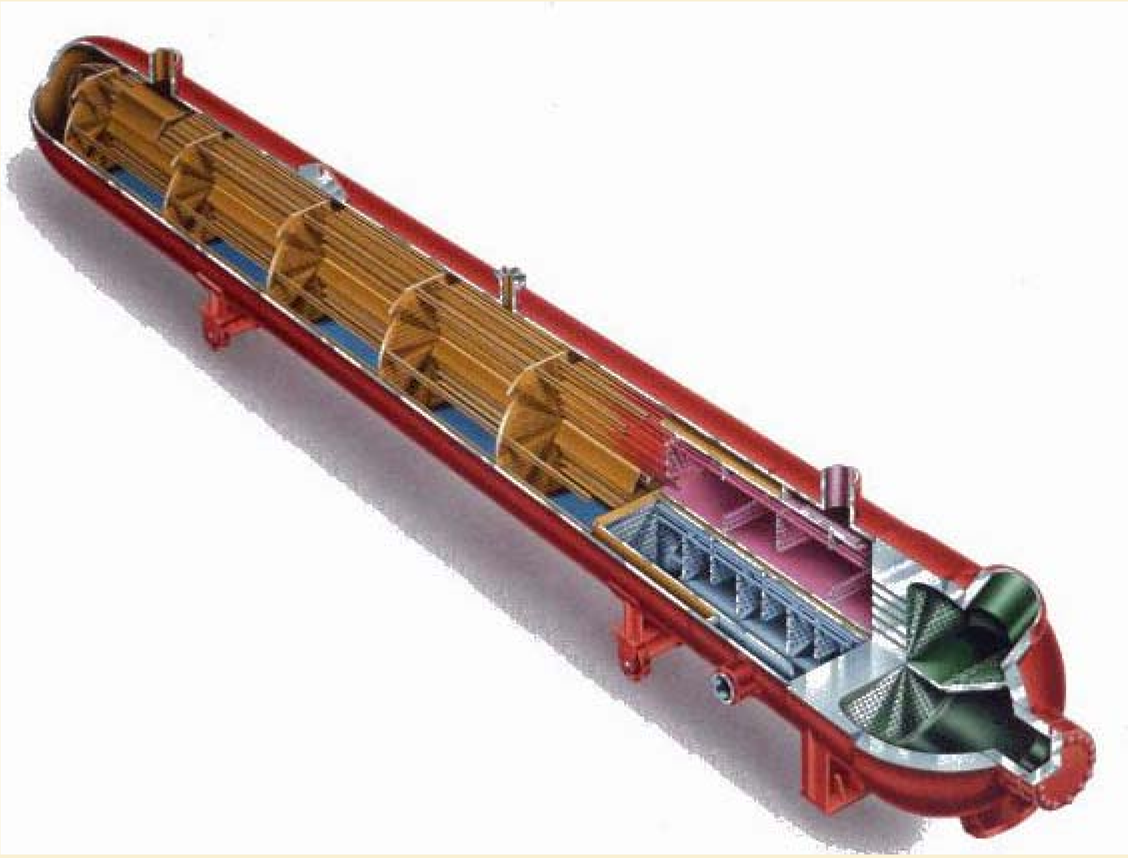
Features of Fixed Tube-sheet Heat Exchangers

- Low cost because of its simple construction.
- The fixed tubesheet is the least expensive Construction type, as long as no expansion joint is required.
- Tubes can be cleaned mechanically after removal of the channel cover or bonnet
- Leakage of the shell side fluid is minimized since there are no flanged joints.
- In the event of a large differential temperature between the tubes and the shell, the tubesheets will be unable to absorb the differential stress, thereby making it necessary to incorporate an expansion joint. This takes away the advantage of low cost to a significant extent.
- Disadvantage of this design is that since the bundle is fixed to the shell and cannot be removed, the outsides of the tubes cannot be cleaned mechanically.
- Its application is limited to clean services on the shell side.

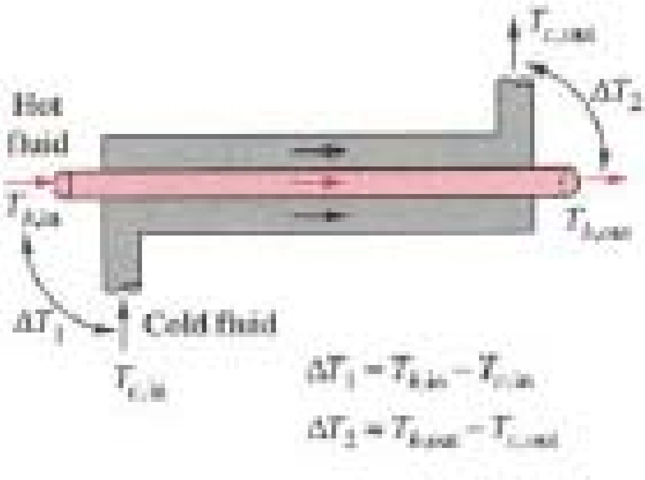
Fixed Tube-sheet Heat Exchanger



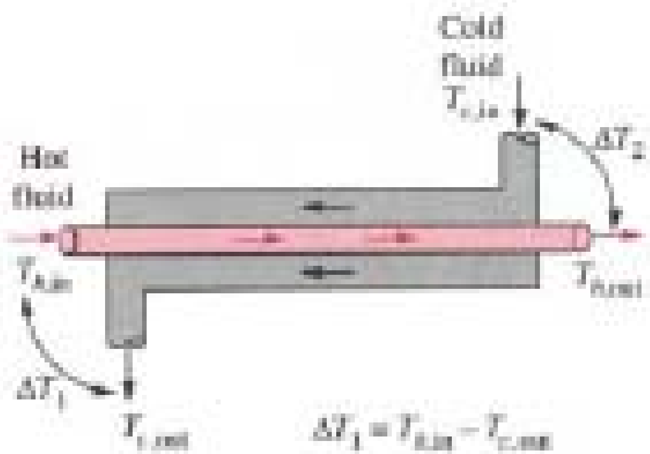
Fixed Tube-sheet Heat Exchanger



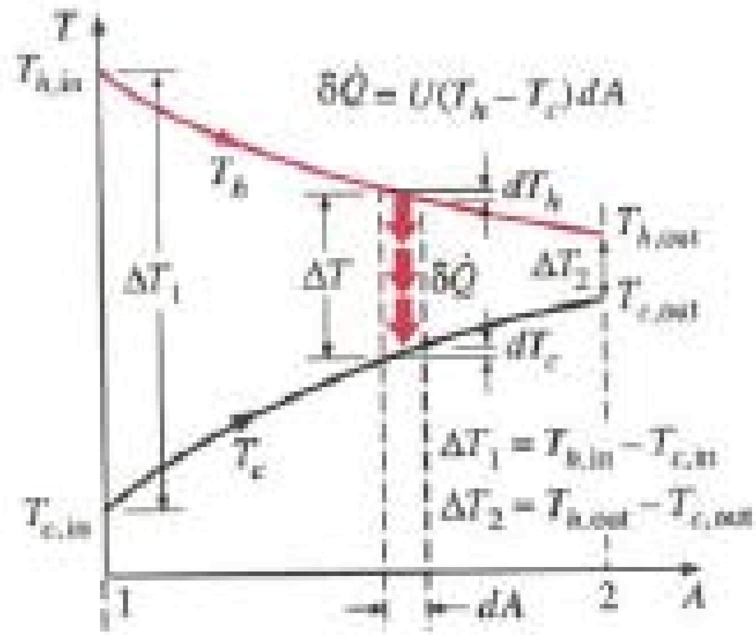
Importance of LMTD



(a) Parallel-flow heat exchangers



(b) Counter-flow heat exchangers



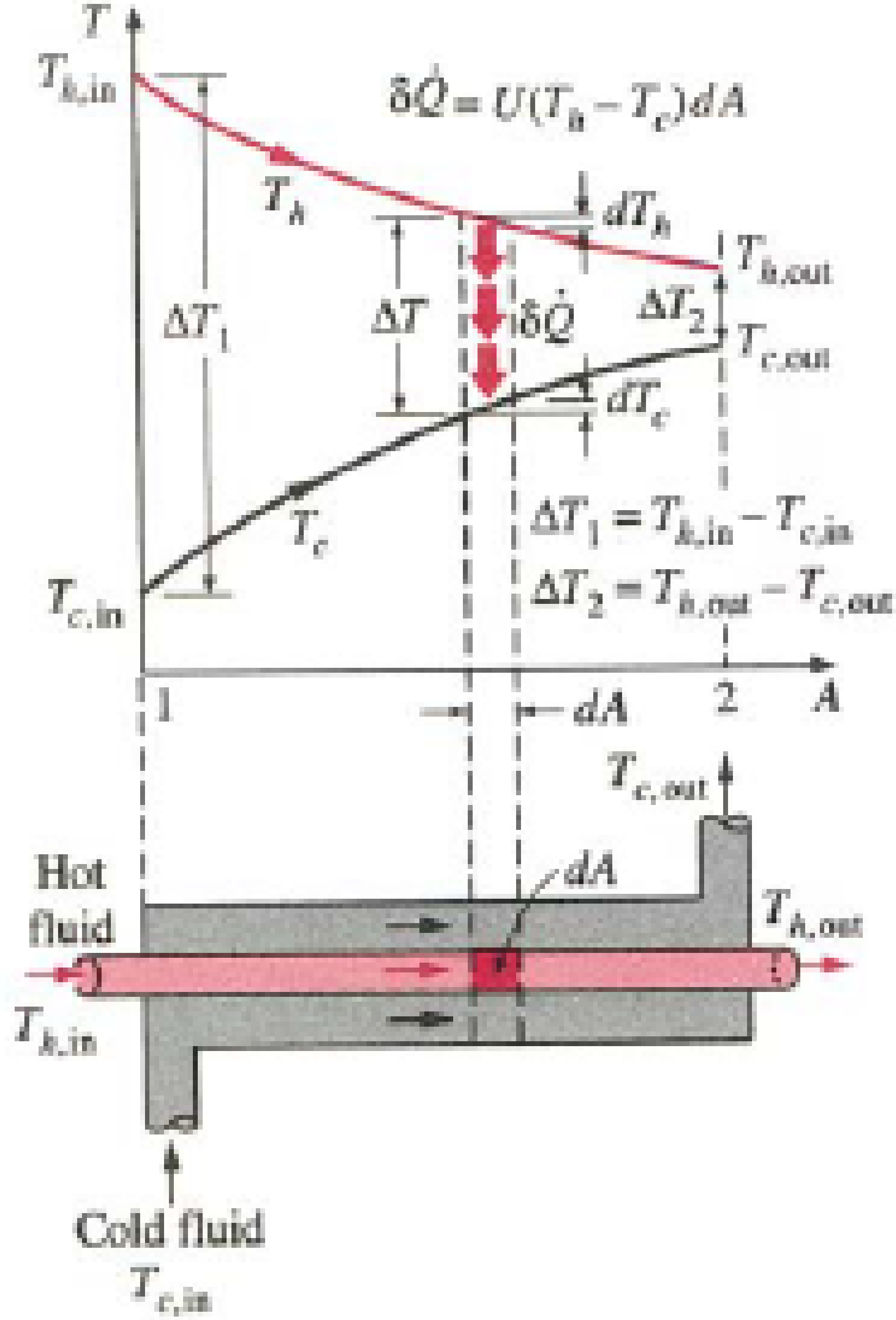
$$Q = UA\,(\Delta T)$$

Need to determine ΔT.
This is not straightforward as for the parallel flow case.

Parallel Flow

$$Q = UA \cdot LMTD$$

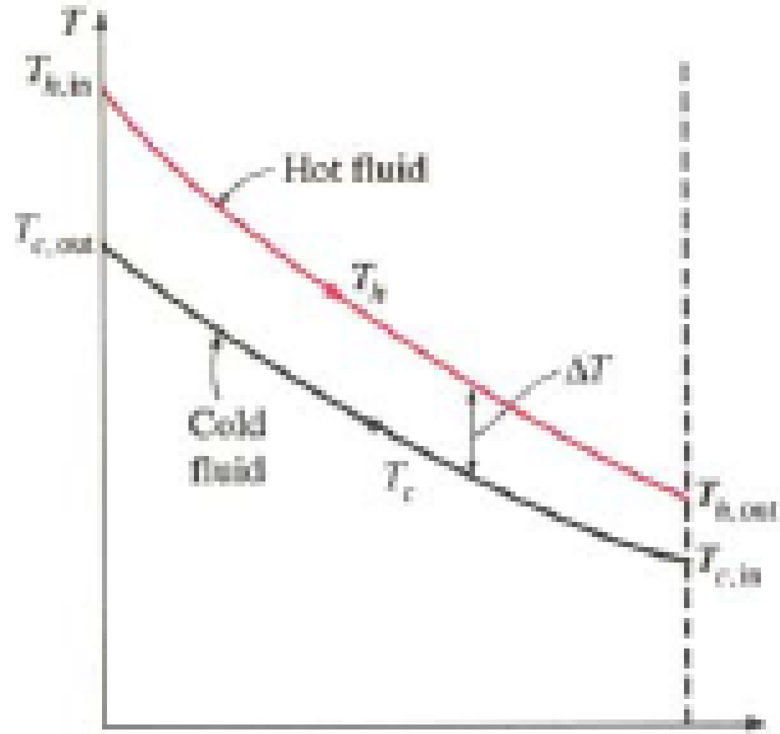
$$LMTD = \frac{\Delta T_{out} - \Delta T_{in}}{\ln\left(\dfrac{\Delta T_{out}}{\Delta T_{in}}\right)}$$

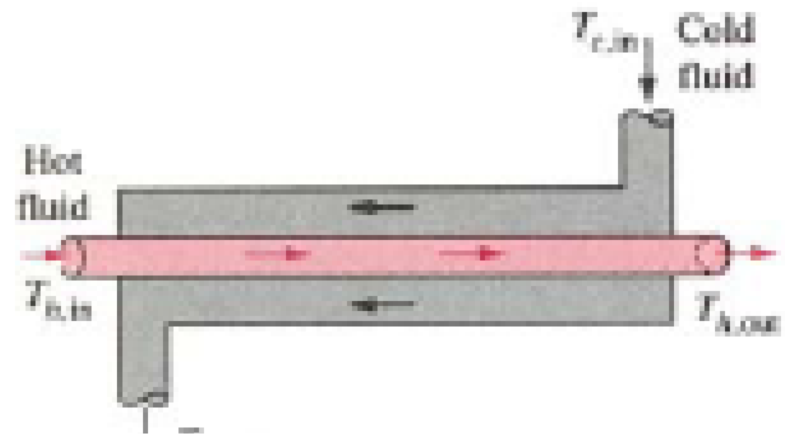


Counter Flow

$$Q = UA \cdot LMTD$$

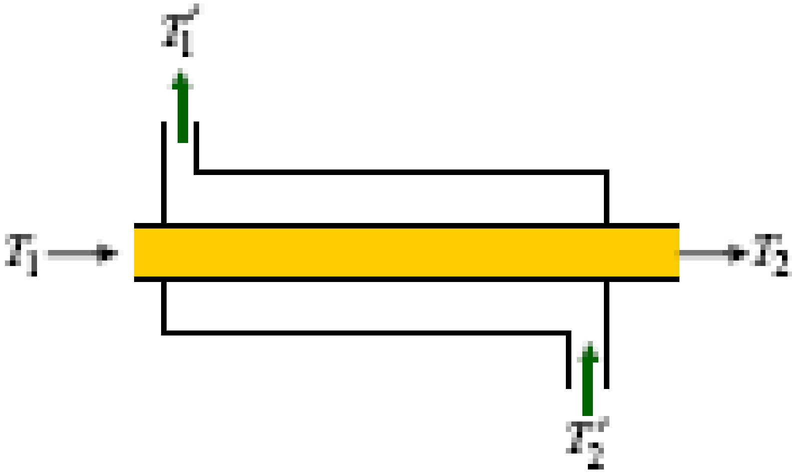
$$LMTD = \frac{\Delta T_{out} - \Delta T_{in}}{\ln\left(\frac{\Delta T_{out}}{\Delta T_{in}}\right)}$$





To calculate Q, we need both inlet and outlet temperatures:

$$Q = UA\Delta T_m = UA\left(F_T \Delta T_{lm}\right)$$



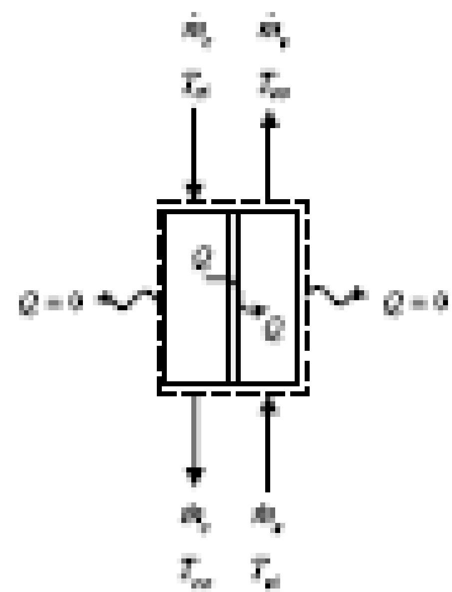
$$\Delta T_{lm} = \frac{\left(T_1' - T_1\right) - \left(T_2' - T_2\right)}{\ln \dfrac{\left(T_1' - T_1\right)}{\left(T_2' - T_2\right)}}$$

Effectiveness

The *heat exchanger effectiveness*, ε, is defined as the ratio of the rate of heat transfer in the exchanger, Q, to the maximum theoretical rate of heat transfer, $Q_{\max}$, i.e.,

$$\varepsilon = \frac{Q}{Q_{\max}}$$

The maximum theoretical rate of heat transfer is limited by the fluid stream with the smallest heat capacity rate, i.e.



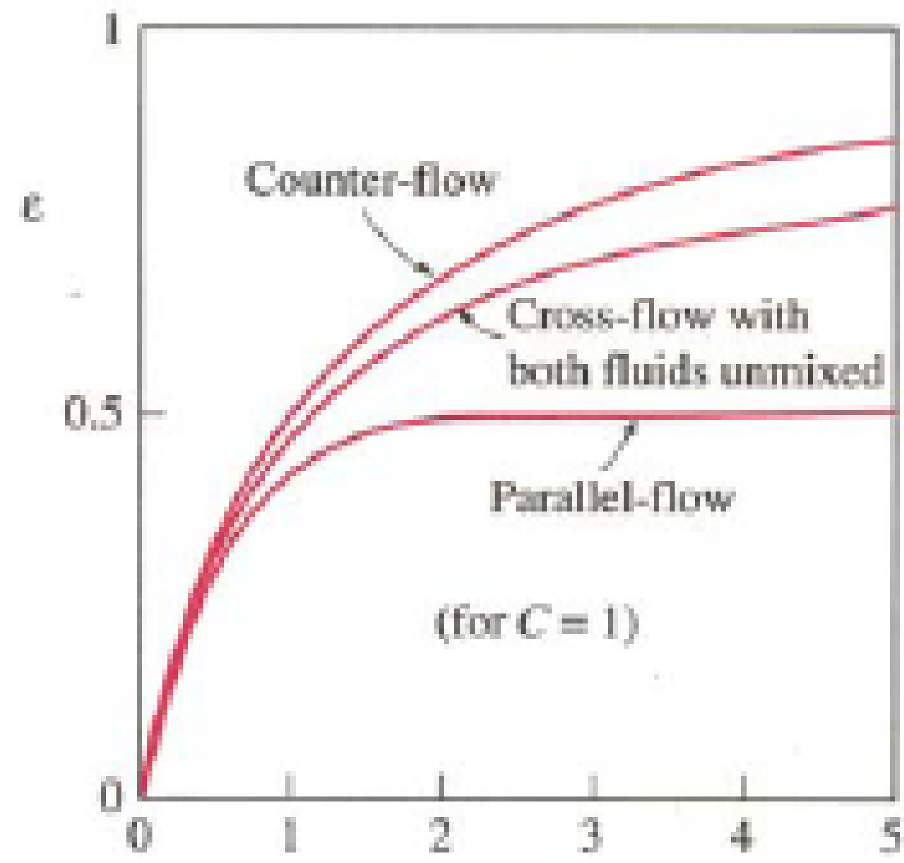
$$\varepsilon = \frac{(\dot{m}c_p)_s (T_{so} - T_{si})}{(\dot{m}c_p)_{\min} (T_{ci} - T_{si})}$$

where $(\dot{m}c_p)_{\min}$ the is the smaller of $(\dot{m}c_p)_s$ or $(\dot{m}c_p)_c$.

NTU

The *number of transfer units* (NTU) is an indicator of the actual heat-transfer area or physical size of the heat exchanger. The larger the value of NTU, the closer the unit is to its thermodynamic limit. It is defined as,

$$NTU = \frac{UA}{(\dot{m}c_p)_{\min}}$$



Capacity Ratio

The *capacity ratio*, C_r, is representative of the operational condition of a given heat exchanger and will vary depending on the geometry and flow configuration (parallel flow, counterflow, cross flow, etc.) of the exchanger. This value is defined as the minimum heat capacity rate divided by the maximum capacity rate, i.e.,

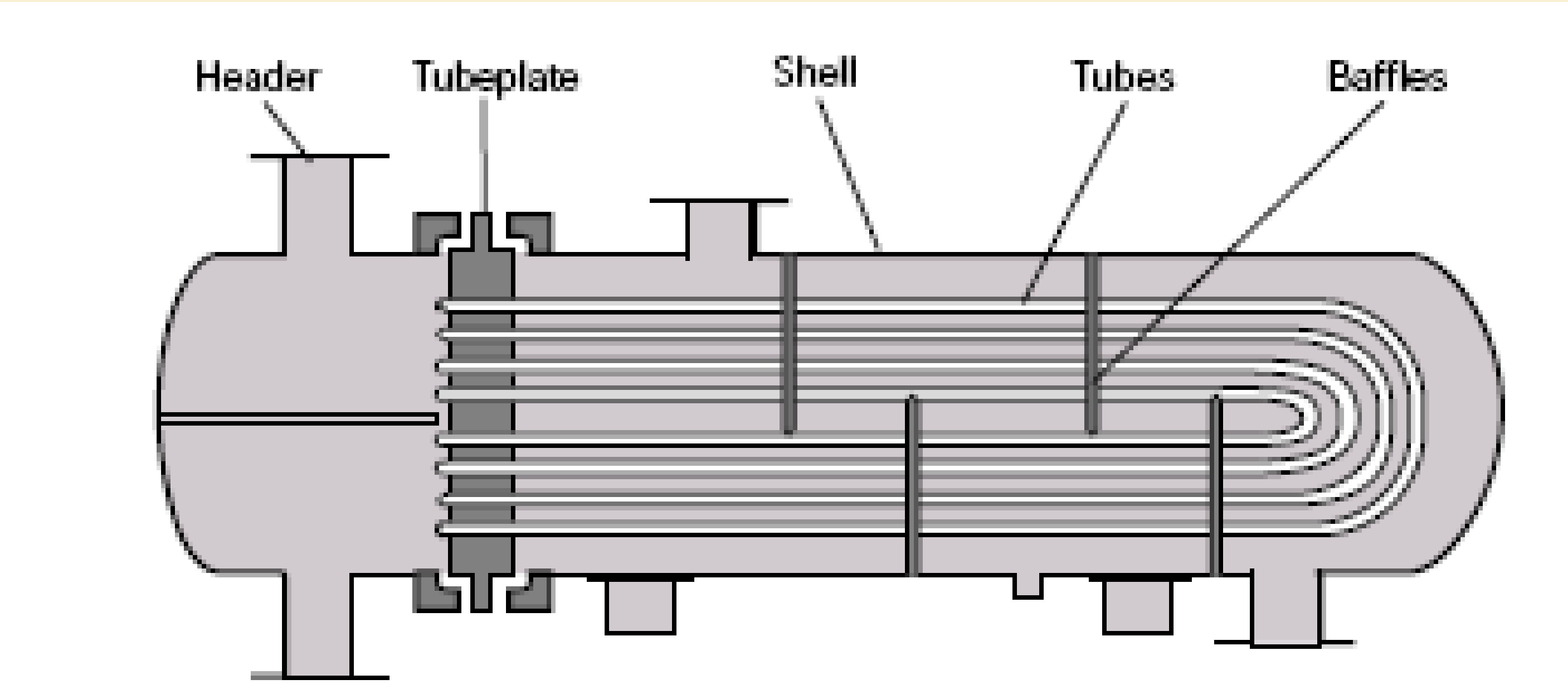
$$C_r = \frac{(\dot{m}c_p)_{\min}}{(\dot{m}c_p)_{\max}}$$

It is important to note that the capacity ratio will be directly proportional to the ratio of the mass flow rates if the specific heats of the flows are fairly constant.

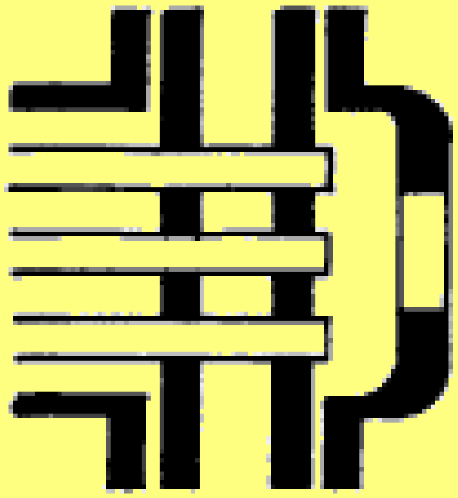
U-tube Heat Exchanger

- Needs only one tube-sheet
- Lower cost for the single tube-sheet is offset by the additional costs incurred for the bending of the tubes and the somewhat larger shell diameter (due to the minimum U-bend radius), making the cost of a U-tube heat exchanger comparable to that of a fixed tube-sheet exchanger.
- As one end is free, the bundle can expand or contract in response to stress differentials.
- In addition, the outsides of the tubes can be cleaned, as the tube bundle can be removed.
- The insides of the tubes cannot be cleaned effectively, since the U-bends would require flexible-end drill shafts for cleaning.
- U-tube heat exchangers should not be used for services with a dirty fluid inside tubes.

U-tube Heat Exchanger

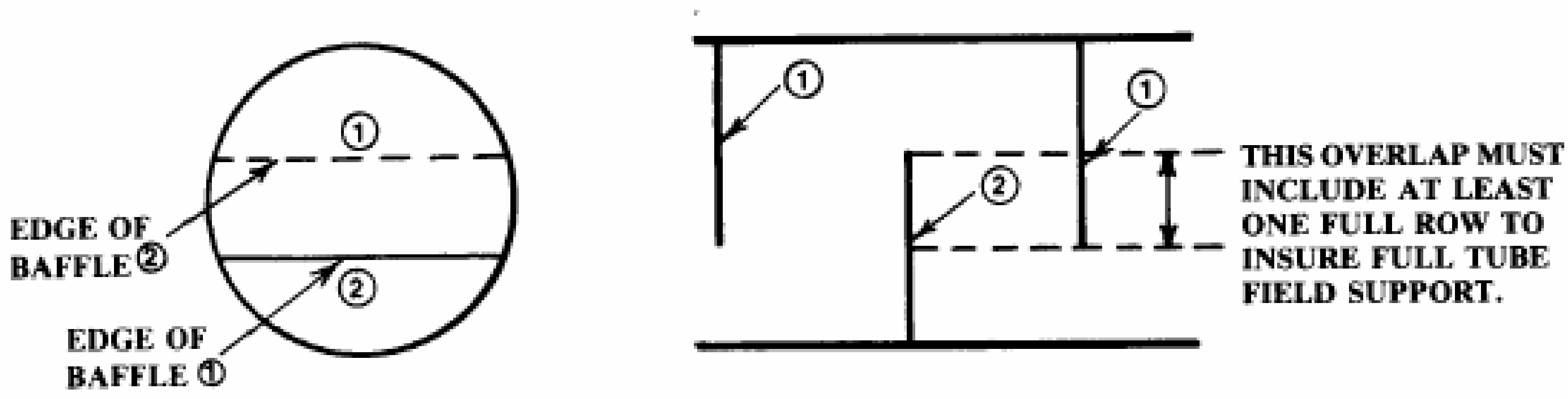


Double Tube Sheets

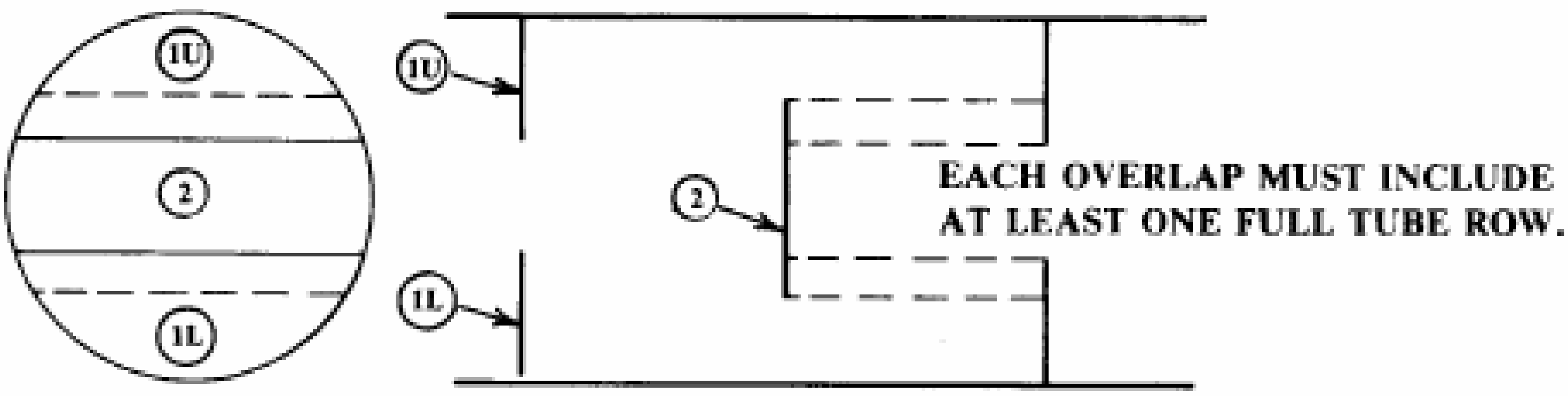


Schematic Diagram of a Double Tube Sheet.

Arrangements of Baffles

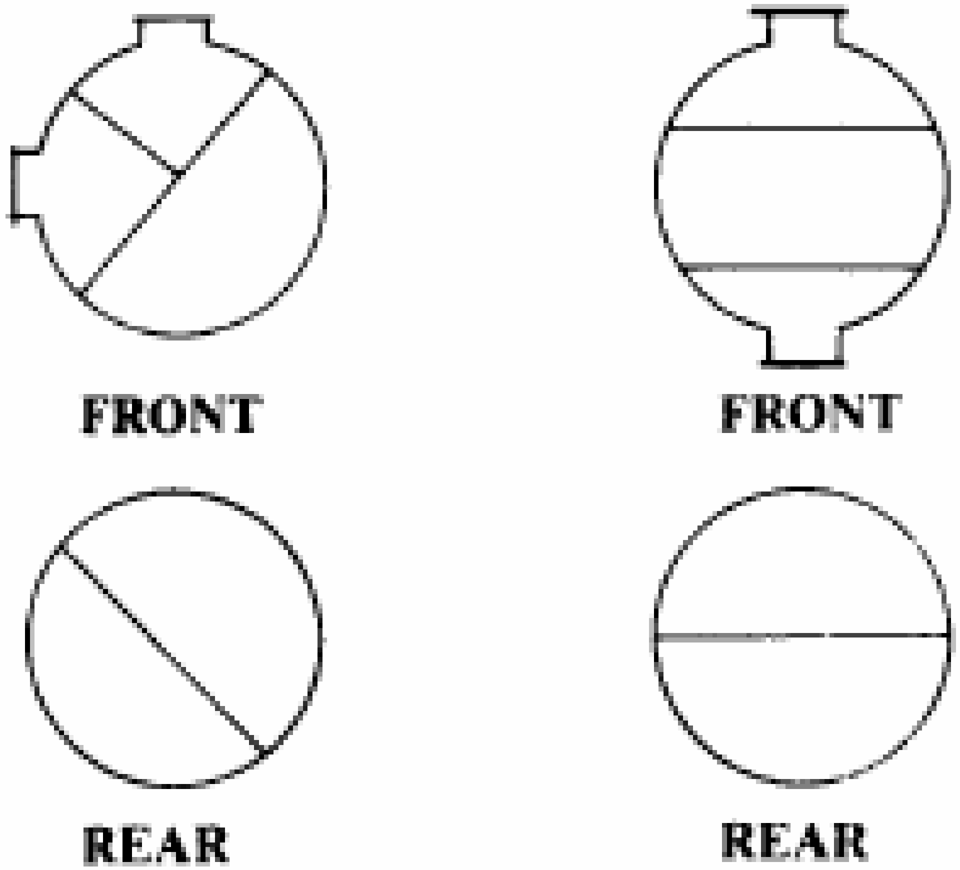


Sketch of Typical Segmental Baffle Arrangements.



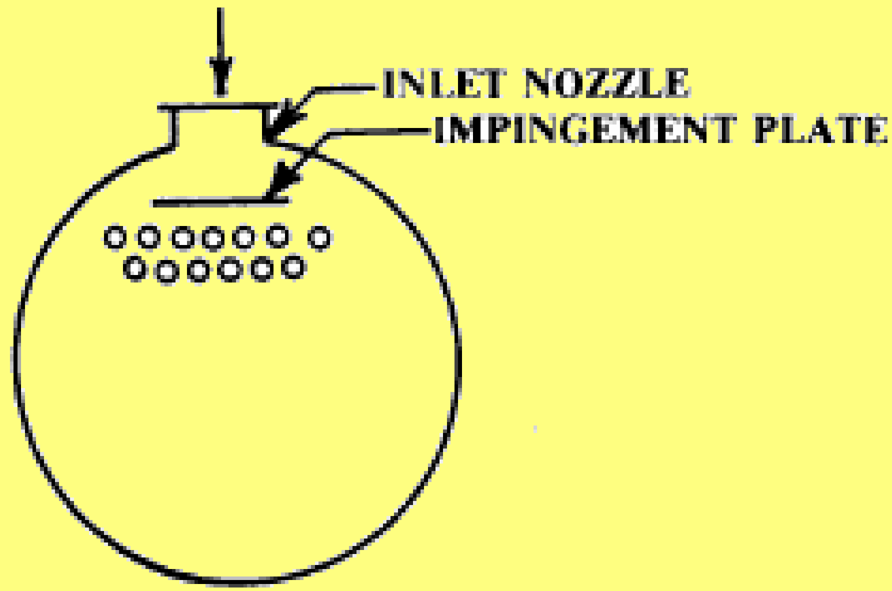
Sketch of a Double Segmental Baffle Arrangement.

Pass Partitions



Alternative Pass Divider Arrangements for Four Tube Passes.

Impingement Plate



Schematic Diagram of Placement of an Impingement Plate Under the Entrance Nozzle.

Design Strategy for Controlling Shell and Tube Heat Exchangers

- **Trouble due to process**
  - Fluctuations in the heat demand of the process
- Solution
  - Heat exchanger must be designed for the worst case and must be controlled to make it operate at the particular rate required by the process at every moment in time.

Design Strategy for Controlling Shell and Tube Heat Exchangers

- Trouble due to tool
  - Characteristics of heat exchanger changes with time.
  - Fouling
  - Vibration in tubes
  - Lower heat transfer coefficient
- Solution
  - The most common change is a reduction in the heat transfer rate due to fouling of the surfaces.
  - Exchangers are initially oversized to allow for the fouling which gradually builds up during use until the exchanger is no longer capable of performing its duty.
  - Once it has been cleaned it is again oversized.

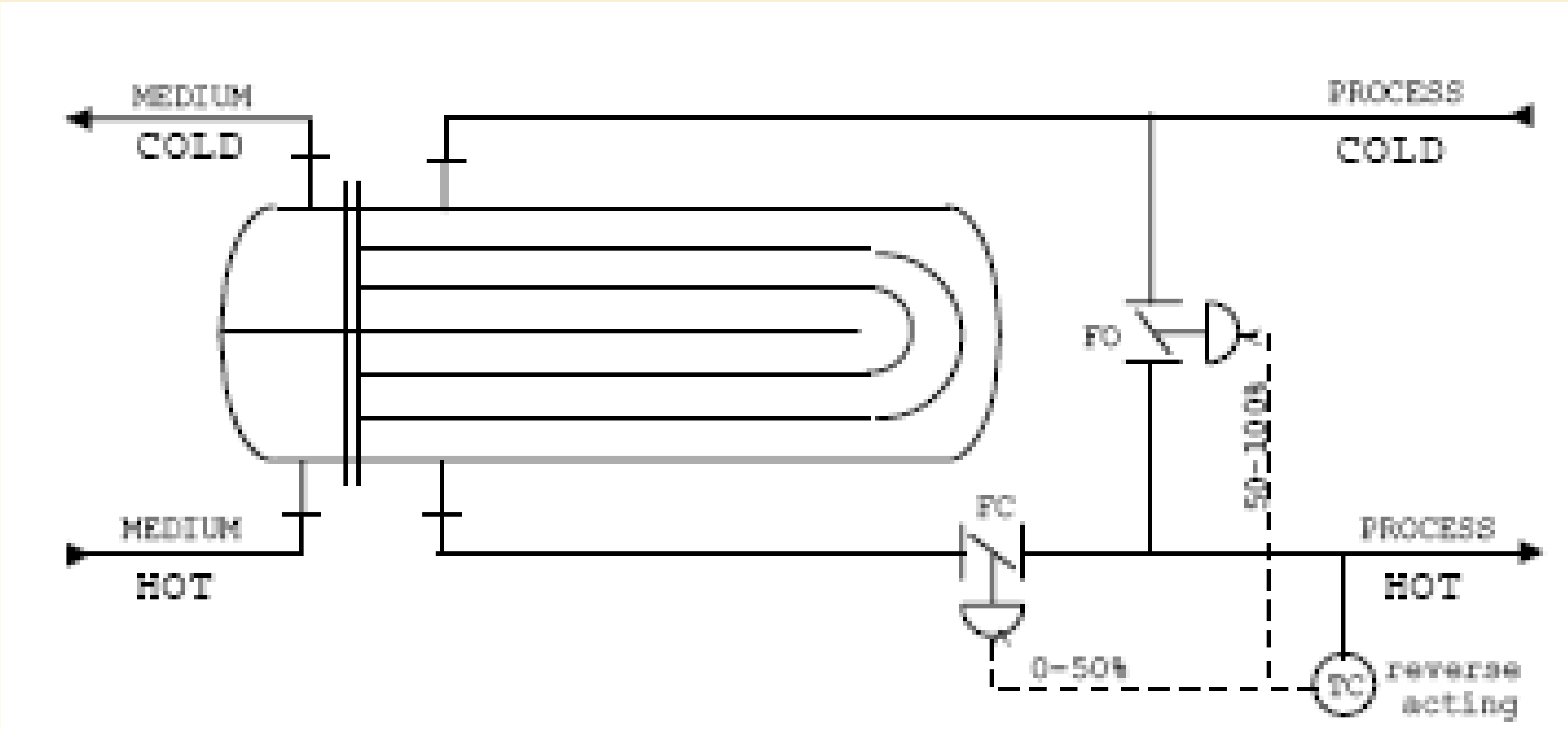
Design Strategy for Controlling Shell and Tube Heat Exchangers

- Bypassing The Process Fluid
  - Process temperature can be controlled by manipulating process flow if a bypass is installed.
  - As the outlet temperature rises in case of a heater, more fluid is bypassed around the ex-changer without being heated.
  - As the two streams are blended together again, the correct temperature is achieved.

Design Strategy for Controlling Shell and Tube Heat Exchangers

- Split Range: Tricks For Bypassing / Manipulation
  - Arranging the valve controls
  - Attempt to minimize pressure drop at all times, or Attempt to keep the pressure drop constant.
  - In neither case interruption in the the total flow is acceptable.
  - To minimize pressure drop, a butterfly valve is the likeliest choice.

Design Strategy for Controlling Shell and Tube Heat Exchangers

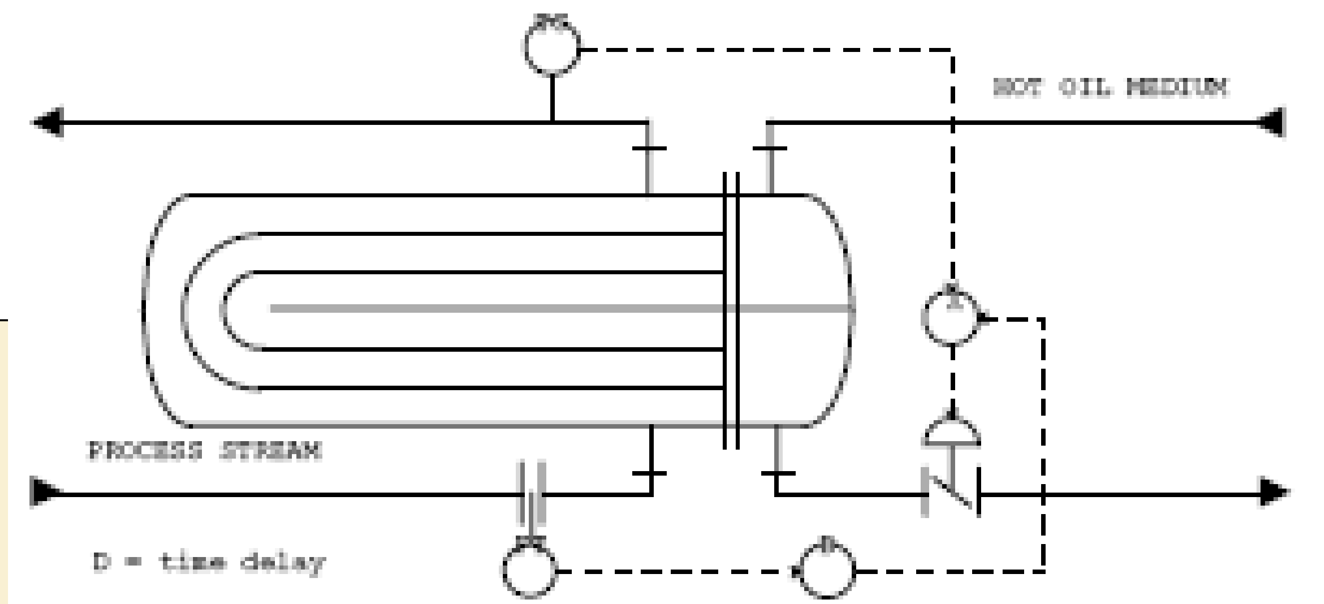


Design Strategy for Controlling Shell

- Problem : Wide open butterfly has some pressure drop. It may be greater than that of the heat exchanger itself.
  - This means that even when the valve is wide open only half the flow, or less, will bypass the exchanger.
- Solution:
  - To accomplish a greater degree of bypass, a restriction must be placed on the flow through the exchanger.
  - The restriction should be adjustable since conditions change and we do not want more restriction than necessary.
  - The easiest way to do this is with a hand valve. Since these valves are often in relatively inaccessible places, remote actuators may be added. Once that is done it becomes an obvious matter to arrange automatic controls so that once the bypass is fully open, the restriction valve starts to close, and vice versa.

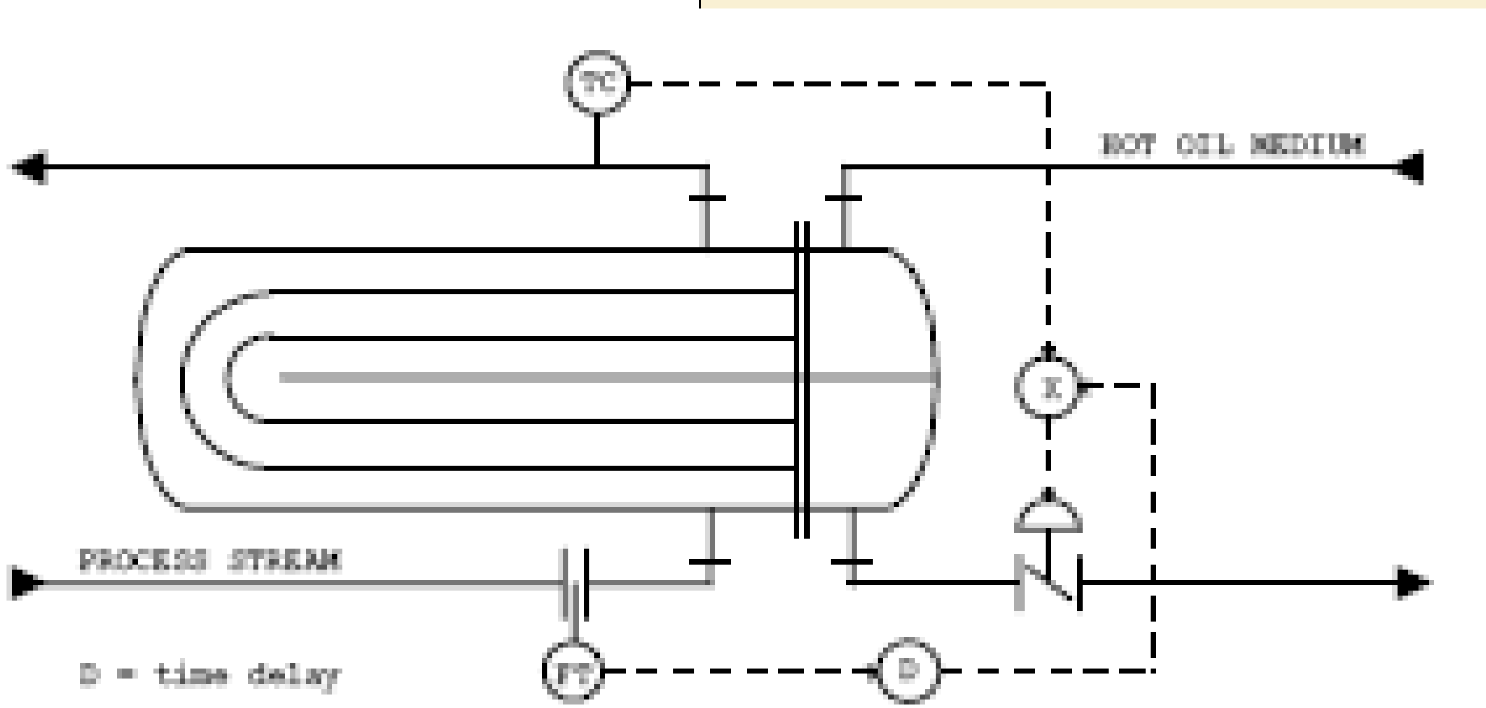
- **Medium Side Throttling**
  - Avoid using a process side bypass valve with fluids that are being heated and have a tendency to break down or scorch.
  - These include many food products and also petroleum products or other chemicals that may polymerize or coke at high temperatures.
  - The problem is that the outlet temperature is a blend of the bypass stream and the stream through the heater.
  - The peak temperature to which any part of the stream is exposed may considerably exceed that of the combined outlet.

- Hot oil is being supplied to heat a process stream. It is desired to keep the process stream at a constant temperature. There is no reason to maintain the flow of oil in excess of what is needed -- it can be throttled to control the temperature. In this case the valve is placed on the outlet of the exchanger.

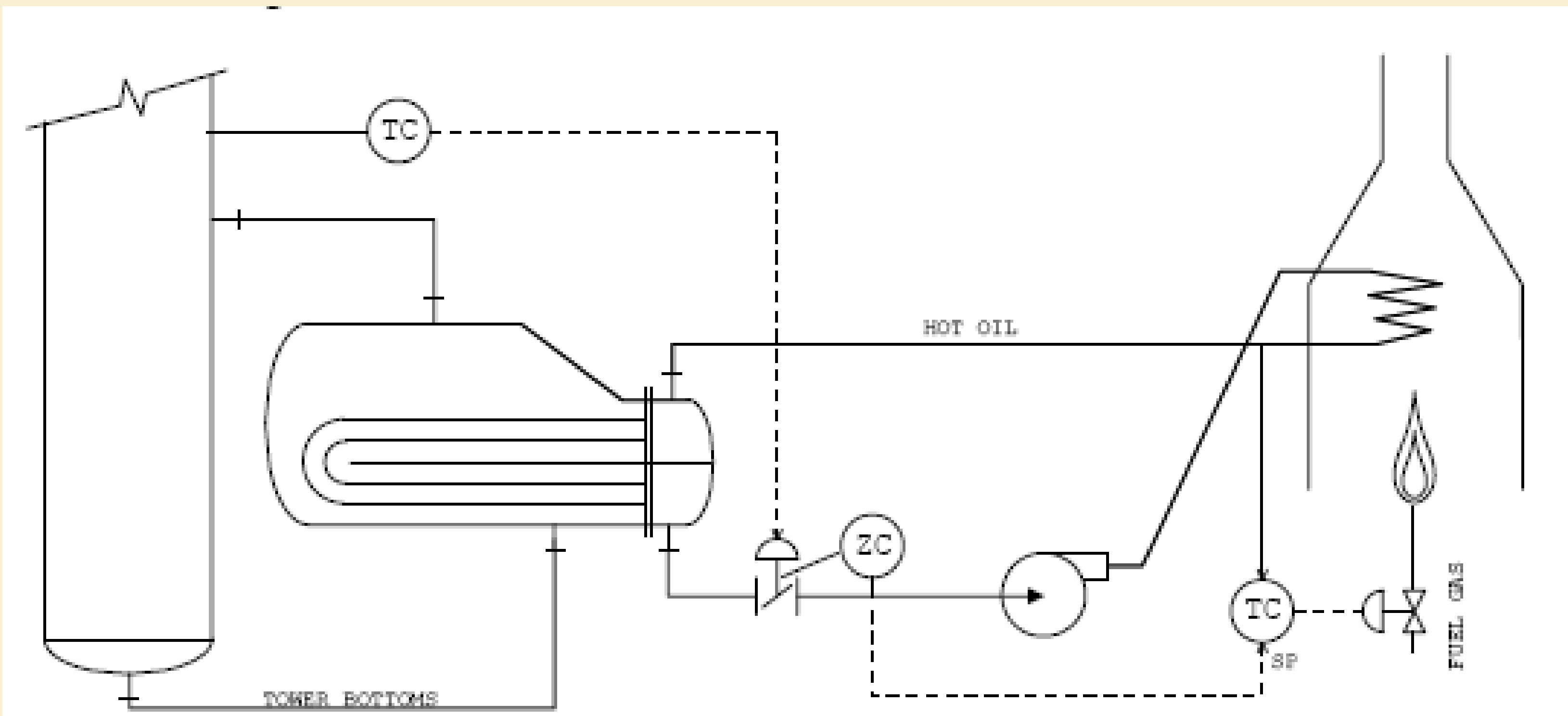


Advanced Control Strategy

- Feed Forward Control



- **It is required to keep the temperature at the bottom of the tower constant. The heating medium is hot oil which is being heated by a fired heater and circulated by a pair of pumps. Since the tower bottoms is being boiled, and is also very clean, it goes on the shell side. The oil goes through the tube side where the outlet is throttled by a butterfly valve. A position transmitter has been added to the valve. Its output goes to a Position Controller with a setpoint of about 80% open. The output of the Position Controller is cascaded to the setpoint of the Temperature Controller of the furnace. The effect is to maintain the furnace, and the hot oil, at the lowest temperature consistent with the heat demand of the tower. It works as follows:**
- **a) As the heat demand rises, the valve opens further.**
- **b) When the valve is open beyond 75%, the setpoint to the furnace Temperature Controller is raised.**
- **c) As the temperature of the hot oil rises, the valve closes to near the 75% value.**
- **d) As the heat demand of the tower falls, the valve closes below 75%.**
- **e) As the valve closes, the setpoint to the furnace is lowered until the valve is once again at its 75 % target.**


TC
HOT OIL
ZC
TC
SP
FUEL GAS
TOWER BOTTOMS