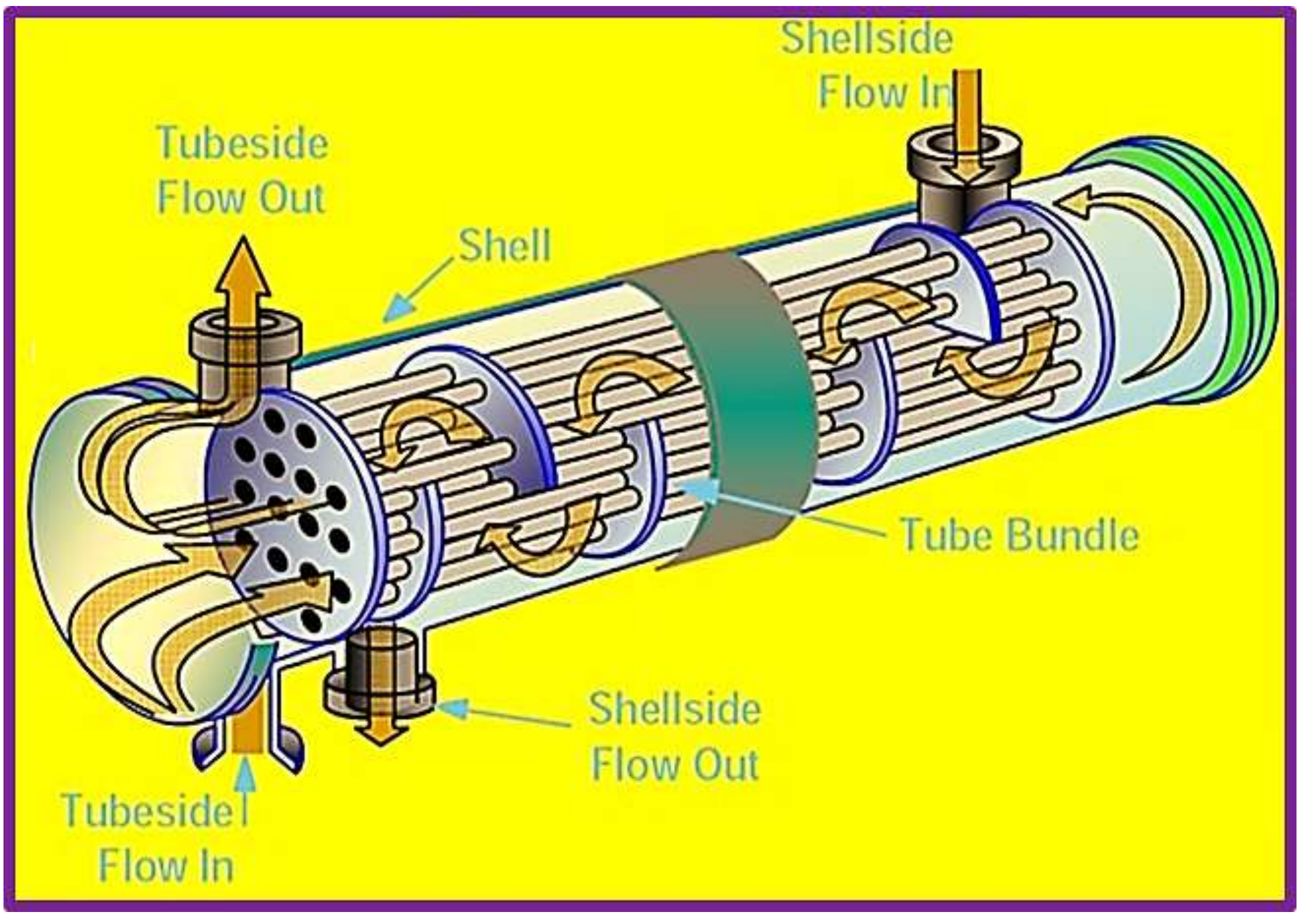
PDHonline Course M371 (2 PDH)

Shell and Tube Heat Exchangers Basic Calculations

Jurandir Primo, PE



2012

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088

www.PDHonline.com
www.PDHcenter.org

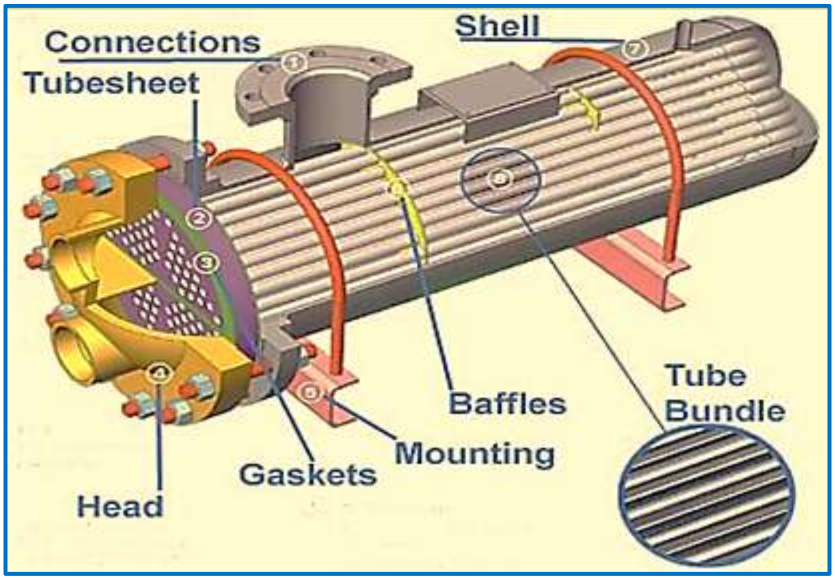
CONTENTS:

1.0 – INTRODUCTION:

In intercoolers**,** boilers, pre-heaters and condensers inside power plants as well as other engineering processes, heat exchangers are utilized for controlling heat energy. Heat exchangers are devices that regulate efficient heat transfer from one fluid to another. There are two main types of heat exchangers.

- The first type of a heat exchanger is called the **recuperative type**, in which heat are exchanged on either side of a dividing wall by fluids;

- The second type is **regenerative type**, in which hot and cold fluids are in the same space, which contain a matrix of materials that work alternately as source for heat flow.



The optimum thermal design of a shell and tube heat exchanger involves the consideration of many interacting design parameters, which can be summarized as follows:

Process:

1. Process fluid assignments to shell side or tube side.
2. Selection of stream temperature specifications.
3. Setting shell side and tube side pressure drop design.
4. Setting shell side and tube side velocity limits.
5. Selection of heat transfer models and fouling coefficients for shell side and tube side.

Mechanical:

1. Selection of heat exchanger TEMA layout and number of passes.
2. Specification of tube parameters - size, layout, pitch and material.
3. Setting upper and lower design limits on tube length.
4. Specification of shell side parameters – materials, baffle spacing and clearances.
5. Setting upper and lower limits on shell diameter - baffle cut and baffle spacing.

2.0 – BASIC CONCEPTS:

Thermodynamics comes from the Greek "*therme*", **heat**, and "*dynamis*", **power** - it is the branch of physics that studies the causes and effects of changes in temperature, pressure and volume. The **biggest problem in thermodynamics** is to learn and recognize **heat, work, force, energy, power** and other technical terms. Therefore, to facilitate the basic comprehension of the **terms** used for **shell and tube** heat exchangers calculations is very important to remember some concepts below:

Unit	Multiply	To Obtain
1 Btu	**1055.0**	J
	1.0550	kJ
	0.2521	kcal
	107.7	Kgf.m
	778.7	ft.lbf
1 cal	**4.18**	J
	0.00396	Btu
	0.00000116	kW.h
1 kcal	**1000**	cal
	3.9604	Btu

Joule - energy exerted by the force of one Newton acting to move an object through a distance of 1 m.

Unit	Multiply	To Obtain
1 J	**0.001**	kJ
	0.238	cal
	0.0002387	kcal
	0.102	kgf.m
	0.000947	Btu
	0.7375	ft.lbf

Watt – metrical unit for power.

Unit	Multiply	To obtain
1 W	**0.001**	kW
	0.00134	hp
	0.000102	hp (boiler)
	0.0002387	kcal/s
	0.102	kgf.m/s
	0.7375	ft.lbf/s
	44.2	ft.lbf/min
	0.000948	Btu/s
	0.000284	ton (refrig)

Cal: The **"Cal"** is the standard unit of measurement for heat. The gram calorie, small calorie or calorie (cal) is the amount of energy required to raise the temperature of **one gram of water from 19.5 °C to 20.5 °C under standard atmospheric pressure of 1.033 Kg/cm² (14.7 psi).**

Btu - British Thermal Unit: The **"Btu"** is the standard unit of measurement for heat. A Btu is defined as the amount of energy needed to raise the temperature of **one pound of water from 58.5°F to 59.5°F under standard pressure of 30 inches of mercury (14.7 psi).**

2.1. Temperature:

Celsius: Is a temperature scale (also known as centigrade) that is named after the Swedish astronomer **Anders Celsius** (1701–1744), who developed a similar temperature scale two years before his death. Then nominally, **0 °C** was defined as the freezing point of water and **100 °C** was defined as the boiling point of water, both at a pressure of one **standard atmosphere (1.033 Kg/cm²).**

Fahrenheit: Is the temperature scale proposed in 1724 by, and named after, the physicist **Daniel Gabriel Fahrenheit** (1686–1736). On the Fahrenheit scale, the **freezing point** of **water** was **32 degrees** Fahrenheit (°F) and the **boiling point 212 °F** at **standard atmospheric pressure (14.7 psi)**.

Kelvin: Is a scale that was named after the Scottish physicist **William Thomson** (1824 - 1907), 1st Baron Kelvin described about the need for an "absolute thermometric scale". The Kelvin and Celsius are often used together, as they have the same interval, and **0 Kelvin is** = **273.15 degrees Celsius**.

$\mathbf{C^o} = \dfrac{5\,(F^o - 32)}{9} =$

$\mathbf{F^o} = 1.8C^o\,(F^o + 32) =$

$\mathbf{C^o} = K^o - 273 =$

2.2. Pressure:

Pressure (P): Is the **force** per unit **area** applied in a direction perpendicular to the surface of an object. **Gauge pressure** is the pressure relative to the local atmospheric or ambient pressure.

Unit	**Pascal** (Pa)	**bar** (bar)	**atmosphere** (atm)	**Torr** (Torr)	**pound per square inch** (psi)
1 Pa	**1** N/**m²**	0.00001	0.000009867	0.0075006	0.000145
1 bar	100000	106 dyn/cm2	0.9867	750	14.5
1 at	98066	0.980665	0.968	735.5	14.223
1 atm	101325	1.01325	**1 atm**	760	14.7
1 torr	133.322	0.013332	0.0013158	**1 mmHg**	0.0193
1 psi	0.006894	0.068948	0.068046	51.72	**1 lbf/in²**

2.3. Energy Unit Conversions:

Unit	Multiply	To Obtain
1 Btu/s	0.3002	Ton (refrig)
	1.056	kW
	1.435	hp
	106.6	kgf.m/s
	778.8	ft.lbf/s
1 joule/kilogram/K = J/(kg.K) = 1 joule/kilogram/°C = J/(kg.°C)	1.0	Joule/kilogram/°C = J/(kg.°C)
	0.001	Joule/gram/°C = J/(g.°C)]
	0.001	kilojoule/kilogram/°C = kJ/(kg.°C)
	0.000239	Calorie /gram/°C = cal/(g.°C)
	0.000239	kilocalorie /kilogram/°C = kcal/(kg.°C)
	0.000239	kilocalorie /kilogram/K = kcal/(kg.K)
	0.102	kilogram-force meter/kilogram/K
	0.000239	Btu/pound/°F = Btu/(lb.°F)
	0.000423	Btu/pound/°C = Btu/(lb.°C)
1 Btu/pound/°F = Btu/(lb°F)	1.0	kilocalorie /kilogram/°C = kcal/(kg.°C)
	1.8	Btu/pound/°C = Btu/(lb.°C)
	4186.8	joule/kilogram/K = J/(kg.K)
	4186.8	joule/kilogram/°C = J/(kg.°C)
	4.1868	joule/gram/°C = J/(g.°C)
	4.1868	kilojoule/kilogram/K = kJ/(kg.K)
	4.1868	kilojoule/kilogram/°C = kJ/(kg.°C)
	426.9	kilogram-force.meter/kilogram/K
	778.2	pound-force.foot/pound/°R

First Law of Thermodynamics: The principle of conservation of energy is, energy **cannot** be destroyed or created, **only transformed**.

Second Law of Thermodynamics: Heat transfers always occur from the **hotter** body to the **colder** body, spontaneously. This means that the processes of thermal energy transfer are **irreversible**.

Zero Law of Thermodynamics: When two bodies with different temperatures are in contact, the hotter one will transfer heat to the colder one. The temperatures become equal, reaching thermal equilibrium.

3.0 – BASIC CONCEPT OF SPECIFIC HEAT:

Specific Heat: Is defined as the amount of heat energy needed to raise 1 gram of a substance 1°C in temperature, or, the amount of energy needed to raise one pound of a substance 1°F in temperature.

$$Q = m.Cp.\,(T_2 - T_1) =$$

Where:

Q = Heat energy (Joules) (Btu);
m = Mass of the substance (kilograms) (pounds);
Cp = Specific heat of the substance (J/kg°C) (Btu/pound/°F);
$(T_2 - T_1)$ = Change in temperature (°C) (°F).

The higher the specific heat, the more energy is required to **cause a change** in temperature. Substances with higher specific heats **require more of heat energy** to lower temperature than do substances with a low specific heat.

Example 1: Using metric units and imperial units, how much energy is required to heat 350 grams (0.77 pounds) of gold from 10°C (50°F) to 50°C (122°F)?

Mass = 350g = 0.35 Kg = **0.77 lb**
Specific heat of gold = 0.129 J/(g.°C) = 129 J/(Kg.°C) x 0.000239 = **0.0308 Btu/(lb.°F)**

Q = m.Cp. $(T_2 - T_1)$ =

Metric Units:

Q = (0.35 Kg) (129 J/(Kg.°C) (50°C - 10°C) = 1806 J

Conversion:
1806 joules x 0.000947 = **1.71 Btu**

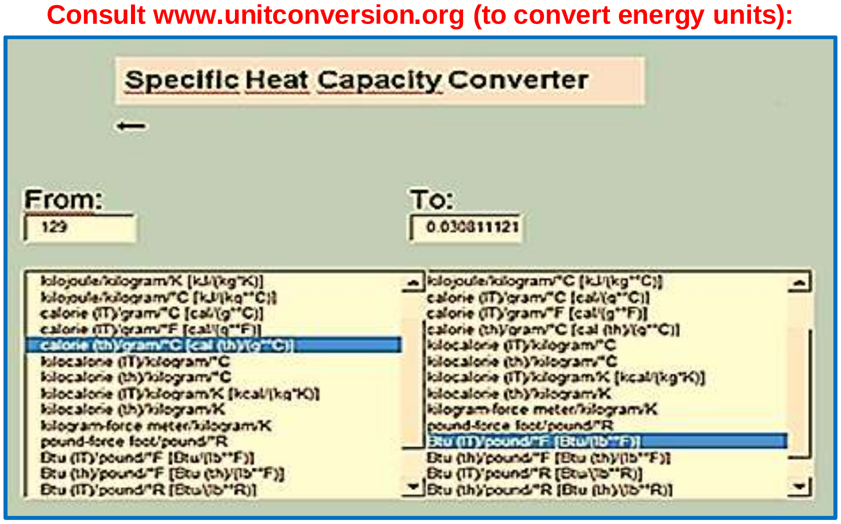
Evaluation in Btu :

Q = m.Cp. $(T_2 - T_1)$ =

Imperial Units:

Q = (0.77 lb) (0.0308 Btu/(lb.°F) (122°F - 50°F) = 1.71 Btu

Consult www.unitconversion.org (to convert energy units):



Some **specific heat values** for some materials are presented in the table below:

Product	Specific Heat Capacity - Cp	
	(J/ g °C)	*(Btu/lb °F)*
Alcohol, ethyl 32°F (ethanol)	2.3	0.55
Ammonia, 104°F	4.86	1.16
Castor Oil	1.8	0.43
Dowtherm	1.55	0.37
Freon R-12 saturated 0°F	0.91	0.217
Fuel Oil max.	2.09	0.5
Gasoline	**2.22**	**0.53**
Heptane	2.24	0.535
Kerosene	2.01	0.48
Gold	**0.129**	**0.0308**
Light Oil, 60°F	1.8	0.43
Light Oil, 300°F	2.3	0.54
Mercury	0.14	0.03
Octane	2.15	0.51
Oil, mineral	**1.67**	**0.4**
Olive oil	1.97	0.47
Petroleum	2.13	0.51
Propane, 32°F	2.4	0.576
Propylene Glycol	2.5	0.60
Sodium chloride	3.31	0.79
Soya bean oil	1.97	0.47
Toluene	1.72	0.41
Water, fresh	**4.19**	**1**
Water, sea 36°F	3.93	0.94

4.0 – HEAT EXCHANGERS CALCULATIONS:

The main basic Heat Exchanger equation is:

$$Q = U \times A \times \Delta T_m =$$

The log mean temperature difference **ΔTm** is:

$$\Delta T_m = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \dfrac{(T_1 - t_2)}{(T_2 - t_1)}} = \text{°F}$$

T_1 = Inlet tube side fluid temperature;
t_2 = Outlet shell side fluid temperature;
T_2 = Outlet tube side fluid temperature;
t_1 = Inlet shell side fluid temperature.

Note: When used as a design equation to calculate the required **heat transfer** surface area, the equation can be rearranged to become:

$$\mathbf{A = Q/\,(U \times \Delta T_m) =}$$

Where:

A = Heat transfer area (m^2) (ft^2);
Q = Heat transfer rate (kJ/h) (Btu\h);
U = Overall heat transfer coefficient (kJ/h.m².°C) (Btu/h°F);
ΔT_m **=** Log mean temperature difference (°C) (°F).

And:

C_t = Liquid specific heat, tube side (kJ/kg°K) (Btu/lb°F);
C_s = Liquid specific heat, shell side (kJ/kg°K) (Btu/lb°F).

4.1. The Overall Design Process:

Here is a set of steps for the process. Design of a heat exchanger is an iterative (trial & error) process:

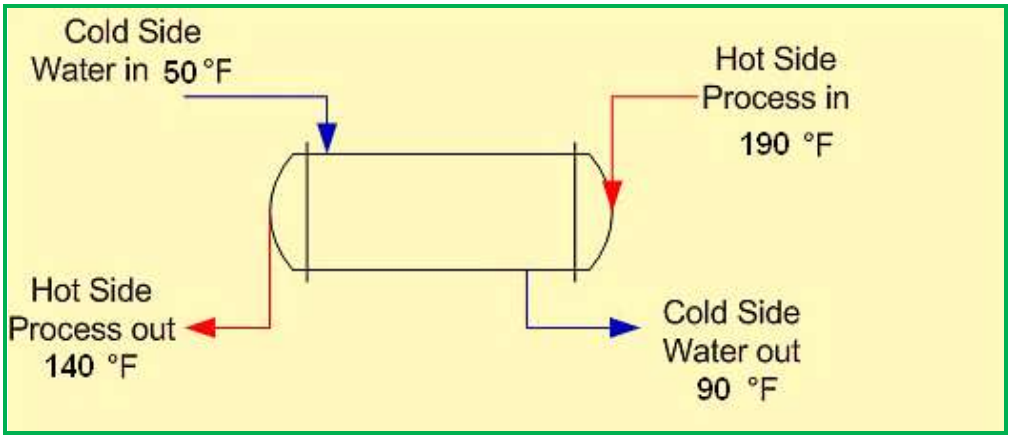
- Calculate the required heat transfer rate, **Q, in Btu/h** from specified information about fluid flow rates and temperatures.
- Make an initial estimate of the overall heat transfer coefficient, **U**, based on the fluids involved.
- Calculate the log mean temperature difference, **ΔTm**, from the inlet and outlet temperatures of the two fluids.
- Calculate the estimated heat transfer area required, using: **A = Q/(U ΔTm).**
- Select a preliminary heat exchanger configuration.
- Make a more detailed estimate of the overall heat transfer coefficient, **U**, based on the preliminary heat exchanger configuration.
- Estimate the pressure drop across the heat exchanger. If it is too high, revise the heat exchanger configuration until the pressure drop is acceptable.
- If the new estimate of **U** is different than the previous estimate, repeat steps 4 through 7 as many times as necessary until the two estimates are the same to the desired degree of accuracy.
  Input information needed. In order to start the heat exchanger design process, several items of information are needed as follows:

- ✓ The two fluids involved need to be identified;
- ✓ The heat capacity of each fluid is needed;
- ✓ The required initial and final temperatures for one of the fluids are needed;
- ✓ The design value of the initial temperature for the other fluid is needed;
- ✓ An initial estimate for the value of the **Overall Heat Transfer Coefficient, U**, is needed.

Note: In calculation, knowing the **first four items** allows determination of the required heat transfer rate, **Q**, and the inlet and outlet temperatures of both fluids, thus allowing calculation of the log mean temperature difference, **ΔT_m**. With values now available for **Q, U,** and **ΔT_m**, an initial estimate for the required heat transfer area can be calculated from the equation:

$A = Q / (U \times \Delta T_m) =$

Example 2: Estimate the **heat exchanger area** needed to cool **55,000 lb/h** of a light oil (**specific heat = 0.74 Btu/lb.°F**) from **190°F to 140°F** using cooling water that is available at **50°F**. The cooling water can be allowed to heat to **90°F**. An initial estimate of the **Overall Heat Transfer Coefficient** is **120 Btu/hr.ft².°F**. Also estimate the **required mass flow rate of cooling water**.



Solution: First calculate the **required heat transfer rate** for the above indicated light oil:

Imperial Units:

$Q = m.Cp. (T_2 – T_1) =$ 55,000 lb/hr x 0.74 Btu/lb°F (190 – 140) °F = **2,035,000 Btu/h**.

Next calculate the **log mean temperature difference (ΔT_m)**:

T_1 = Inlet tube side fluid temperature (light oil hot side = **190 °F**);
t_2 = Outlet shell side fluid temperature (water cold side = 90 °F);
T_2 = Outlet tube side fluid temperature (light oil cold side = **140 °F**);
t_1 = Inlet shell side fluid temperature (water cold side = **50 °F**).

$$\Delta Tm = \frac{(190 - 90) - (140 - 50)}{\ln \frac{(190 - 90)}{(140 - 50)}} = °F$$

$$\Delta Tm = \frac{(100) - (90)}{\ln \frac{(100)}{(90)}} = °F$$

$$\Delta Tm = \frac{10}{0.10536} = 94.9\ °F$$

The preliminary **area estimate of the heat exchanger** can now be calculated as:

A = Q / (U x ΔTm) =

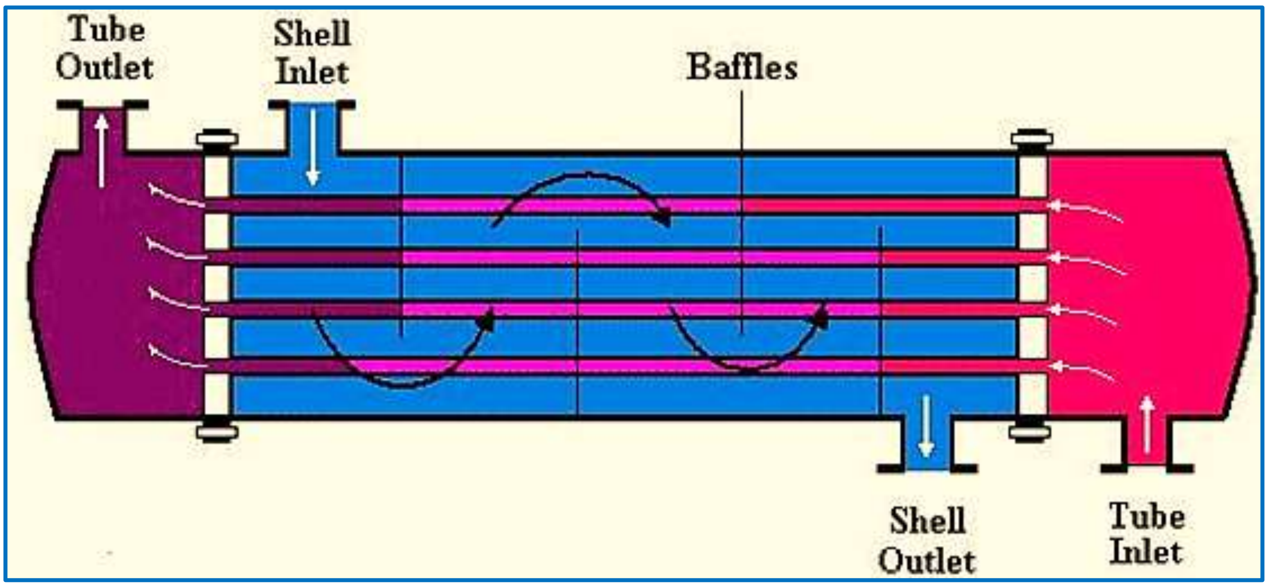
$$A = \frac{2,035,000 \text{ Btu/h}}{(120 \text{ Btu/h.ft}^2.°F).(94.9°F)} = \mathbf{178.7\ ft^2}$$

The required **mass flow rate of water** can be calculated from **Q = m x Cp x ΔTm**:

Rearranging:

$$m = \frac{Q}{Cp \times \Delta Tm} =$$

$$m = \frac{(2,035,000 \text{ Btu/h})}{(0.74\text{Btu/lb.°F})(94.9°F)} = \mathbf{28,978\ lb/h}$$



Example 3: Taking the shell and tube heat exchanger described in Example 1, **how many tubes** of **3.0-inch diameter** and **10 ft length** should be used?

Solution: The **surface area per tube** will be:

Sa = π x D x L = π (3/12) (10) ft² = **7.854 ft²** - (D – tube diameter in ft).

The number of tubes required would thus be:

$$n = \frac{178.7 \text{ ft}^2}{7.854 \text{ ft}^2} = \mathbf{22.7 \text{ tubes } (23 \text{ or } 24 \text{ tubes})}.$$

Obs.: The next step would be to check on the pressure drop for this tube configuration and the specified flow. If the pressure drop is acceptable, then the **Overall Heat Transfer Coefficient (U)** could be re-estimated for this heat exchanger configuration.

4.2. Calculation Concepts:

It is frequently necessary to determine the performance of a particular heat exchanger under conditions of other than that for which it was designed.

Input:

1. **Overall Heat Transfer Coefficient "U" (Btu/h.ft².°F)**. For the heat exchanger under design.
2. **Area (ft²)**. Heat transfer area of the heat exchanger under consideration.
3. Entering **temperature hot (°F)**. The fluid temperature on the **"hot" side** of the heat exchanger.
4. Entering **temperature cold (°F)**.The fluid temperature on the **"cold" side** of the heat exchanger.

Example 4: Assume a redesign of a **gasoline heat exchanger**, area **8.9 ft²**, flow rate hot **8 gpm**, operating on **135°F** to another heat exchanger operating on **150°F** flow rate hot **10.30 gpm**, using the Overall Heat Transfer Coefficient, **800 Btu/h.ft².°F.** What would be the impact in capacity, calculating only as a comparison?

Imperial Units:

- ✓ **1.0 - Input using 135 °F**:

1. Gasoline = **0.53 Btu/lb.°F**
2. Overall "U" = **800 Btu/hr.ft².°F**
2. Area = **8.90 ft²**
3. Entering temp hot = **135 °F**
4. Entering temp cold = **110 °F**
5. Flow rate hot = 8.00 gpm **= 2961.6 lb/h**

Capacity:

Q = 2961.6 lb/h x 0.53 Btu/lb°F (135 – 110) °F = **39,241 Btu/h**.

The ΔT_m can be calculated, since the indicated heat exchanger area is, **8.90 ft²:**

$$A = Q / (U \times \Delta T_m) =$$

$$8.90\ ft^2 = \frac{39{,}241\ Btu/h}{(800 Btu/h.ft^2.°F).(\Delta T_m\ °F)} =$$

$\Delta T_m = 5.5\ °F$

✓ **2.0 - Input using 150 °F:**

1. Overall “U” = **800 Btu/h.ft².°F**;
2. Area = **8.90 ft²;**
3. Entering temp hot = **150 °F**;
4. Entering temp cold = **110 °F**;
5. Flow rate hot = 10.30 gpm **= 3,813 lb/h.**

Capacity:

Q = 3,813 lb/h x 0.53 Btu/lb°F (150 – 110) °F = **80,835 Btu/h**.

A = Q / (U x ΔT_m) =

$$8.90 \text{ ft}^2 = \frac{80{,}835 \text{ Btu/h}}{(800 \text{Btu/h.ft}^2.°\text{F}).(\Delta T_m \text{ °F})} =$$

ΔT_m = 11.3 °F.

4.3. Concept of Overall Heat Transfer Coefficient, U:

For a given heat transfer service with known mass flow rates and inlet and outlet temperatures the determination of **Q** is direct and **ΔTm** can be easily calculated if a flow arrangement is selected (e.g. **Logarithmic Mean Temperature** difference for pure countercurrent or concurrent flow). The literature has many tabulations of such typical coefficients for commercial heat transfer services.

4.4. Heating up With Steam:

The amount of heat required to raise the temperature of a substance can be expressed as:

Q = m x cp x dT =

Where:

Q = Quantity of energy or heat (kJ) (Btu);
m = Mass of the substance (kg) (lb);
cp = Specific heat capacity of the substance (kJ/kg ^{o}C) or (Btu/(lb.°F);
dT = Temperature rise of the substance (^{o}C) (°F).

4.5. Non-Flow or Batch Heating:

In **non-flow** type applications the process fluid is kept as a **single batch** within a tank or vessel. A steam coil or a steam jacket **heats** the fluid from a low to a high temperature. Therefore, in heat exchangers the product or fluid flow is **continuously heated**. The mean rate of heat transfer for such applications can be expressed as:

q = m x cp x dT / t =

q = Mean heat transfer rate,(kW) (kJ/s) (HP) (Btu/s);
m = Mass of the product, (kg) (lb);
cp = Specific heat capacity of the product, (kJ/kg°C) (Btu/(lb.°F);
dT = Change in temperature of the fluid, (°C) (°F);
t = Total time over which the heating process occurs, (seconds).

Table with values for different applications and heat exchanger types:

Typical Overall Heat Transfer Coefficients in Heat Exchangers			
Type	**Application and Conditions**	**U W/(m².K)**	**U Btu/(h.ft².°F)**
Tubular, heating or cooling	Gases at atmospheric pressure inside and outside tubes	5 - 35	**1 - 6**
	Gases at high pressure inside and outside tubes	150 - 500	**25 - 90**
	Liquid outside (inside) and gas at atmospheric pressure inside (outside) tubes	15 - 70	**3 - 15**
	Gas at high pressure inside and liquid outside tubes	200 - 400	**35 - 70**
	Liquids inside and outside tubes	150 - 1200	**25 - 200**
	Steam outside and liquid inside tubes	300 - 1200	**50 - 200**
Tubular, condensation	Steam outside and cooling water inside tubes	1500 - 4000	**250 - 700**
	Organic vapors or ammonia outside and cooling water inside tubes	300 - 1200	**50 - 200**
Tubular, evaporation	Steam outside and high-viscous liquid inside tubes, natural circulation	300 - 900	**50 - 150**
	Steam outside and low-viscous liquid inside tubes, natural circulation	600 - 1700	**100 - 300**
	Steam outside and liquid inside tubes, forced circulation	900 - 3000	**150 – 500**
Air-cooled heat exchangers	Cooling of water	600 - 750	**100 - 130**
	Cooling of liquid light hydrocarbons	400 - 550	**70 - 95**
	Cooling of tar	30 - 60	**5 - 10**
	Cooling of air or flue gas	60 - 180	**10 - 30**
	Cooling of hydrocarbon gas	200 - 450	**35 - 80**
	Condensation of low pressure steam	700 - 850	**125 - 150**
	Condensation of organic vapors	350 - 500	**65 - 90**
Plate heat exchanger	Liquid to liquid	1000 - 4000	**150 - 700**
Spiral heat exchanger	Liquid to liquid	700 - 2500	**125 - 500**
	Condensing vapor to liquid	900 - 3500	**150 - 700**

Note: 1 Btu/(h.ft².°F) = 5.6785 W/(m².K). Coefficients are based on outside bare tube surface.

4.6. Flow or Continuous Heating Processes:

The mean heat transfer can be expressed as:

q = cp x dT x m / t =

q = Mean heat transfer rate (kW) (kJ/s) (HP) (Btu/s);
m / t = Mass flow rate of the product (kg/s) (lb/s);
cp = Specific heat capacity of the product (kJ/kg°C) (Btu/(lb°F);
dT = Change in temperature of the fluid (°C) (°F).

4.7. Calculating the Amount of Steam:

If we know the heat transfer rate - the amount of steam can be calculated:

m = q / h_e =

m = Mass of steam (kg/s) (lb/s);
q = Calculated heat transfer (kW) (kJ/s) (HP) (Btu/s);
h_e = Evaporation energy (latent heat) of the steam (kJ/kg) (Btu/lb) – (see steam tables).

Example 4: A quantity of water is heated with steam of 5 bar (72.5 psi) **from a temperature of** *35 °C (95°F) to 100 °C (212°F)* **over a period of** *1200 s***. The mass of water is** *50 kg (110 lb)* **and the** Specific Heat **capacity of** water is *4.19 kJ/kg°C (1.0* Btu/(lb.°F).

The heat transfer rate is:

Metric Units:

q = (50 kg) (4.19 kJ/kg °C) (100 °C - 35 °C) / (1200 s) =

q = 11.35 kJ/s = 11.35 kW

Imperial Units:

q = (110 lb) (1.0 Btu/(lb.°F) (212°F - 95°F) / (1200 s) =

q = 10.72 Btu/s = 15.4 HP

The amount of steam: At **5 bar g (72.5 psi)** considering absolute **6 bar**, saturation temperature **(T_s) is 158.9°C (318 °F)**, and the Latent Heat (or Specific Enthalpy) **h_e = 2085 kJ/kg** = **896.4 Btu/lb** (from steam tables).

Metric Units:

$$m = \frac{(11.35\ \text{kJ/s})}{(2085\ \text{kJ/kg})}$$

m = 0.0055 kg/s = (19.8 kg/h)

Imperial Units:

Converting **– h_e** = **2085 kJ/kg = 896.4 Btu/lb**, we find:

$$m = \frac{(10.72\ Btu/s)}{(896.4\ Btu/lb)}$$

m = 0.012 lb/s = (43.0 lb/h)

Example 5: Water flowing at a constant rate of *3.0 l/s* (0.79 gal/s) is **heated** from *10°C* (50°F) *to 60°C* (140°F) with **steam flow** at *8 bar*. **At** 8 bar g (absolute 9 bar), **saturation temperature** (T_s) is 175°C, **and** h_e = 2029 kJ/kg **(from steam tables). It** is assumed that **1 liter** of water **has a** mass of 1 kg.

Mass flowrate = 3.0 l/s (0.79 gal/s) x 1 kg/l = **3.0 kg/s (6.60 lb/s).**

h_e = **2029 kJ/kg** is equal to **872.3 Btu/lb**.

cp (water) = ***4.19 kJ/kg°C*** *is equal to* ***1.0*** **Btu/(lb°F.**

a) Metric Units:

q = (4.19 kJ/kg°C) (60°C - 10°C) (3 l/s) (1 kg/l) =

q = 628.5 kJ/s = 628.5 kW

b) Imperial Units:

q = (1.0 Btu/(lb.°F) (140°F - 50°F) (6.60 lb/s) =

q = 594 Btu/s = 840 HP

The steam flow rate can be expressed as:

Metric Units:

$$m = \frac{(628.5\ kJ/s)}{(2029\ kJ/kg)}$$

m = **0.31 kg/s (1,115 kg/h)**

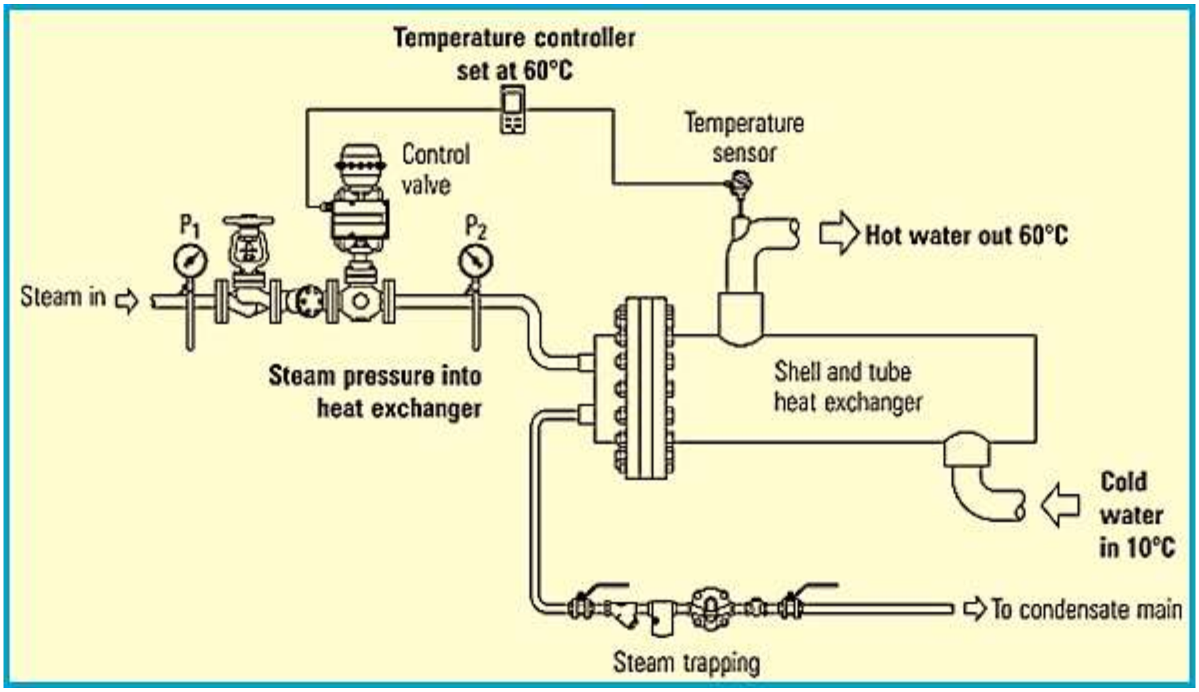
a) Imperial Units:

$$m = \frac{(595.7\ Btu/s)}{(872.3\ Btu/lb)}$$

m = 0.683 lb/s = (2,459 lb/h)

5.0. – TEMPERATURE CONTROLLED APPLICATIONS:

The term **heat exchanger** is used to describe **all types** of equipment where **heat transfer** is promoted from one fluid to another. For convenience, this broad definition will be applied to the term heat exchanger. In a temperature control application, the **inlet temperature** of the secondary fluid to the heat exchanger may **change** with time. This can be achieved by using a control valve on the inlet to the primary side of the heat exchanger, as shown in figure below:



5.1. Typical Temperature Control of a Steam/Water Shell and Tube Heat Exchanger:

A **control valve** is used to **vary the flow rate and pressure** of the steam so that the heat input to the heat exchanger can be **controlled**. Modulating the position of the control valve then controls the outlet temperature of the secondary fluid. A **sensor** on the secondary fluid outlet monitors its temperature and provides a signal for the controller to compare the actual temperature with the set temperature and, as a result, signals the actuator to adjust the position of the control valve.

On **partially** closing the control valve, the steam pressure and the temperature difference fall. Conversely, if the control valve is opened so that the steam mass flow and hence pressure in the heat exchanger rise, the mean temperature difference between the **two fluids** increases. Altering the steam pressure will also slightly affect the amount of heat energy available in the condensing steam as the enthalpy of evaporation actually falls with increasing pressure.

Example 6: A manufacturer is to design a heat exchanger in which the specification takes some steam at **4 bar g (58 psi g)** to heat secondary water from **10°C (50°F) to 60°C (140°F)**. It is assumed that **1.0 liter of water has a mass of 1.0 kg**.

Mass flow rate = 1.5 l/s (24 gpm) x 1 kg/l = **1.5 kg/s (3.30 lb/s)**.

The manufacturer uses a **Heat Transfer Coefficient 'U'** for the heat exchanger of **2500 W/m2°C (440 Btu/h.ft².°F).** Take the **Specific Heat** of water (cp) as **4.19 kJ/kg°C = 4190 J/ kg°C (1.0 Btu/lb.°F).**

Determine:

a) The design heat load;
b) The corresponding steam flow rate;
c) The minimum heating area required.

When the minimum heat load occurs when the inlet water temperature rises to **30°C (86°F)**, determine:

d) The minimum heat load;
e) The corresponding steam pressure in the heat exchanger;
f) The corresponding steam flow rate.

Calculations:

a) Find the design heat load using the heat transfer flow rate equation:

$\mathbf{Q = m \times cp \times \Delta T_{m} =}$

Where:

Q = Heat transfer flow rate (kJ/s) (kW) – (Btu/s) (HP);
m = mass of steam (kg/s) (lb/s);
cp = Specific heat capacity of the secondary fluid (kJ/kg°C) – (Btu/lb°F);
$\mathbf{\Delta T_m}$ = Temperature rise of the secondary fluid (K or °C).

a) Metric Units:

Q = 1.5 kg/s x 4.19 kJ/kg°C (60 – 10)°C =

Q = 314.25 kJ/s = 314.25 kW

b) Imperial Units:

Q = 3.30 lb/s x 1.0 Btu/lb.°F x (140°F - 50°F) =

Q = 297 Btu/s = 420 HP

b) Find the corresponding steam flow rate:

At **4 bar g, (39°F)** the saturation temperature **(T_s) is 152°C (305°F)**, and $\mathbf{h_e}$ **= 2108.1 kJ/kg = 2,108,100 J/kg = 906 Btu/lb** (from steam tables). Calculate the required steam flow at the design condition using equation below:

a) Metric Units:

$$\textbf{Steam flowrate (m)} = \frac{\text{kW x 3600 (kg/h)}}{h_e}$$

$$\textbf{Steam flowrate (m)} = \frac{314.25 \text{ x } 3600}{2108.1} \text{ (kg/h)}$$

Steam flowrate (m) = 536.6 kg/h

b) Imperial Units:

$$\textbf{Steam flowrate (m)} = \frac{297 \text{ x } 3600}{906 \text{ Btu/lb}} \text{ (lb/h)} =$$

Steam flowrate (m) = 1180 lb/h

c) Find the minimum heating area to meet the requirement.

Use the **LMTD (ΔT_m)** to calculate the minimum amount of heating area to satisfy the design rating:

$$\Delta T_m = \frac{(T_2 - T_1)}{\ln \dfrac{(T_s - T_1)}{(T_s - T_2)}}$$

ΔT_m = Logarithmic Mean Temperature Difference (LMTD);
T_s = Steam temperature = **(152 °C) (305°F);**
T_1 = Secondary fluid in temperature = **(10 °C) (50°F);**
T_2 = Secondary fluid out temperature = **(60°C) (140°F);**
In = The mathematical function known as "natural logarithm".

a) Metric Units:

$$\Delta T_m = \frac{(60 - 10)}{\ln \dfrac{(152 - 10)}{(152 - 60)}}$$

$$\Delta T_m = \frac{50}{\ln \dfrac{(142)}{(92)}}$$

$$\Delta T_m = \frac{50}{0.434}$$

ΔT_m = 115°C

b) Imperial Units:

$$\Delta T_m = \frac{(140 - 50)}{\ln (305 - 50)}$$

$$\Delta T_m = \frac{90}{\ln \frac{(255)}{(165)}}$$

$$\Delta T_m = \frac{90}{0.435}$$

$$\Delta T_m = 206°F$$

By re-arranging the general heat transfer equation (**$Q = U \times A \times \Delta T_m$**):

$$A = \frac{Q......}{U \cdot \Delta Tm} =$$

Where:

A = Heating area (m^2);
Q = Mean heat transfer rate (W);
U = Heat transfer coefficient ($W/m^2 C$);
ΔT_{M} = Mean Temperature Difference.

Obs: ΔT_M may be either **ΔT_{LM} (LMTD)** or **ΔT_{AM} (AMTD)**.

Metric Units:

$$A = \frac{314{,}250\ W}{2500\ W/m^2.°C \times 115.2°C}$$

$A = 1.09\ m^2$

Imperial Units:

$$A = \frac{1{,}072{,}800\ Btu/h}{440\ Btu/hr.ft^2.°F \times 239°F}$$

$A = 10.2\ ft^2$

d) Find the minimum heat load, when the **inlet water temperature is 30°C**:

$Q = m \times cp \times \Delta T$ =

a) Metric Units:

Q = 1.5 kg/s x 4.19 kJ/kg°C (60°C - 30°C) =

Q = 188.5 kJ/s = 188.5 kW

b) Imperial Units:

Q = 3.30 lb/s x 1.0 Btu/lb.°F x (140°F - 86°F) =

Q = 178.2 Btu/s = 252 HP

5.2. TDC Method - Temperature Design Constant:

When the data sets are not available and the **heat exchanger is already installed in service**, **TDC** can be calculated by observing the steam pressure (and finding the steam temperature from steam tables) and the corresponding secondary inlet and outlet temperatures at any load.

Once the exchanger size is fixed and the design temperatures are known, it easier to predict operating temperatures using what could be termed a heat exchanger **Temperature Design Constant (TDC).**

The **TDC method** does not require logarithmic calculations.

$$\mathbf{TDC} = \frac{T_S - T_1}{T_S - T_2}$$

Where:

TDC = Temperature Design Constant;
T_s = Steam temperature;
T_1 = Secondary fluid inlet temperature;
T_2 = Secondary fluid outlet temperature.

Example 7: Consider the following design conditions:

Steam Pressure = **4 bar g (58 psi g)**;
Inlet water temperature (T_1) = **10°C (50°F)**;
Outlet water temperature (T_2) = **60°C (140°F)**;
Steam temperature at 4 bar g (T_S) = **152°C (305.6°F)**.

a) Metric Units:

$$\textbf{TDC} = \frac{T_S - T_1}{T_S - T_2}$$

$$\textbf{TDC} = \frac{152 - 10}{152 - 60}$$

$$\textbf{TDC} = \frac{142}{92}$$

TDC = 1.543 (for this particular Heat Exchanger).

b) Imperial Units:

$$\textbf{TDC} = \frac{305.6 - 50}{305.6 - 140}$$

$$\textbf{TDC} = \frac{255.6}{165.6}$$

TDC = 1.543 (for this particular Heat Exchanger).

Note: The TDC equation can be transposed to find any one variable as long as the other three variables are known. The following equations are derived from the **TDC equation**.

a) To find the steam temperature at any load:

$$\mathbf{T_s} = \frac{(T_2 \text{ x TDC}) - T_1}{\text{TDC} - 1}$$

b) To find the secondary fluid inlet temperature at any load:

$$\mathbf{T_1} = T_S - [\text{TDC}\ (T_S - T_2)]$$

c) To find the secondary fluid outlet temperature at any load:

$$\mathbf{T_2} = T_S - \frac{(T_S - T_1)}{\text{TDC}}$$

Obs: For any heat exchanger with a constant secondary flow rate, the operating steam temperature can be calculated for any **combination** of **inlet temperature** and **outlet temperature**.

Example 8: The secondary **water outlet temperature** remains at **60°C**, and minimum load occurs when the **inlet temperature** is **30°C**. What will be the steam temperature at minimum load?

Inlet temperature = **30°C**

Outlet temperature = **60°C**

$$\mathbf{T_s =} \frac{(T_2 \times TDC) - T_1}{TDC - 1}$$

$$\mathbf{T_s =} \frac{(60 \times 1.543) - 30}{1.543 - 1}$$

$$\mathbf{T_s =} \frac{62.58}{0.543}$$

$T_S =$ 115.2°C = 239.3°F

Imperial Units:

e) Find the corresponding heat exchanger steam pressure and enthalpy at minimum load:

1) A steam temperature of **115.2°C (239.3°F)** corresponds a **steam pressure of 0.7 bar g.**

2) The **Specific Enthalpy** of evaporation **at 0.7 bar g (h_e) = 2 215 kJ/kg** (see steam tables).

f) Find the steam flow rate at minimum load:

From (**d**) the minimum heat load is **188.5 kW = 252 HP;**

From (**e**) the **h_e** is **2 215 kJ/kg = 952 Btu/lb.**

$$\textbf{Steam flowrate (m)} = \frac{kW \times 3600}{h_e} \ kg/h =$$

$$\textbf{Steam flowrate (m)} = \frac{188.5 \ kW \times 3600}{2\ 215 \ kJ/kg} \ kg/h =$$

Steam flowrate (m) = 306.4 kg/h (at minimum load):

Imperial Units:

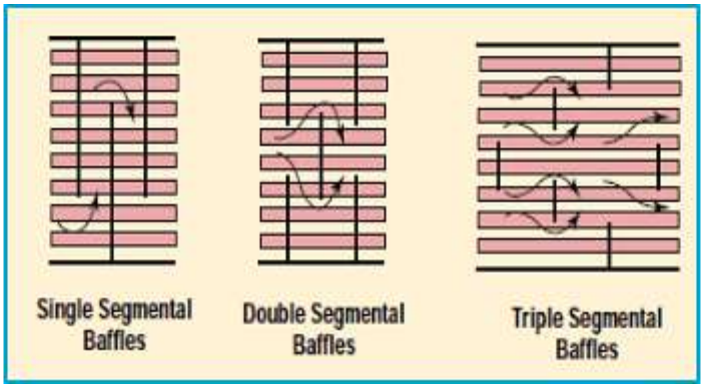
$$\textbf{Steam flowrate (m)} = \frac{178 \ Btu/s \times 3600}{952 \ Btu/lb} \ lb/h =$$

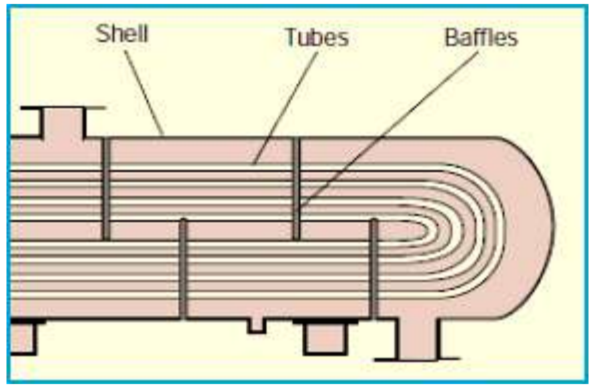
Steam flowrate (m) = 673 lb/h (at minimum load).

6.0. BAFFLE DESIGN - DEFINITIONS:

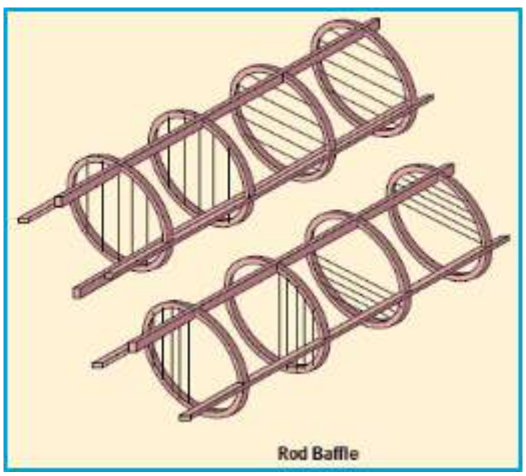
Baffles: Are used to support tubes and enable a desirable velocity for the fluid to be maintained at the shell side, and prevent failure of tubes due to flow-induced vibration. There are **two types** of baffles; **plate and rod**.

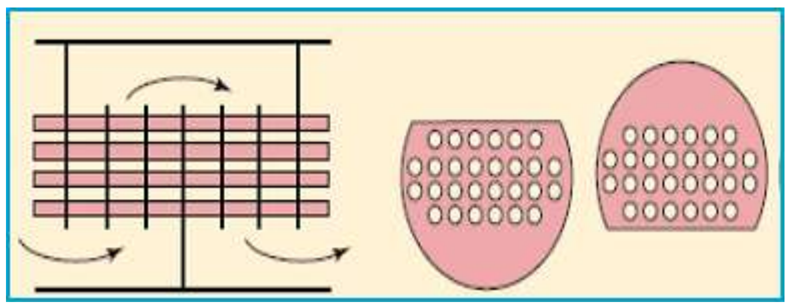
- ✓ **Plate baffles** may be **single-segmental, double-segmental, or triple-segmental**:





- ✓ **Rod Baffles:**





Shell side cross flow area a_S is given by:

$$a_S = \frac{D \times C \times B}{P_T}$$

Where:

a_S = Shell side cross flow area;
D = Shell Inside diameter;
C = Clearance between tubes;
B = Baffle spacing;
P_T = Tube pitch;

- **The minimum spacing (pitch)** of **baffles** normally should not be closer than **1/5 of shell diameter (ID) or 2 inches** whichever is greater.

- **The maximum spacing (pitch)** spacing **does not** normally **exceed the shell diameter**. Tube support plate spacing determined by mechanical considerations, e.g. strength and vibration.

Maximum spacing is given by:

$$B = 74\ d_o^{0.75}$$

Most failures occur when unsupported **tube length is greater than 80%** due the designer is trying to limit the shell side pressure drop.

Baffle cuts: Can vary **between 15% and 45%** and are expressed as ratio of segment opening height to shell inside diameter. The upper limit ensures every pair of baffles will support each tube. **Kern shell side pressure drop** correlations are based on **25% cut** which is standard for liquid on shell side.

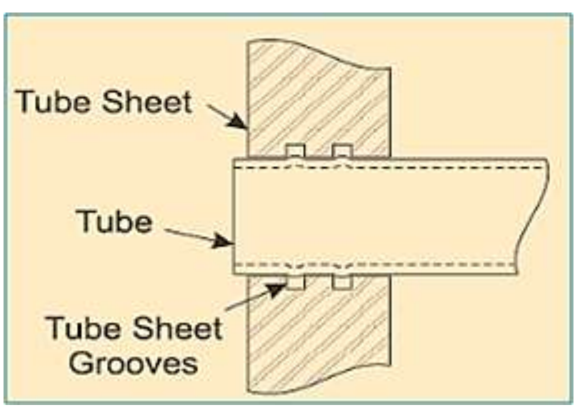
Baffle clearances: The **outer tube limit (OTL)** is the diameter created by encircling the outermost tubes in a tube layout. The actual **OTL is usually 1.5 times** the design pressure. It is used during a **hydrostatic test that detects leaks** at any joint on the heat exchanger.

For example **fixed tube-sheet clearances** are shown below:

Shell inside diameter mm (in) =	Clearance shell I.D and OTL mm (in) =
254 (10) to 610 (24)	11 (7/16)
≥ 635 (25)	13 (1/2)

6.1. Tube-Sheets:

Tube sheets: Are usually made from a **round flat piece of metal** with holes drilled for the tube ends in a precise location and pattern relative to one another. Tubes are attached to the tube sheet by pneumatic or hydraulic pressure or by roller expansion. **Tube holes** are **drilled and reamed** and can be machined with **one or more grooves**. This greatly increases the strength of the tube joint.

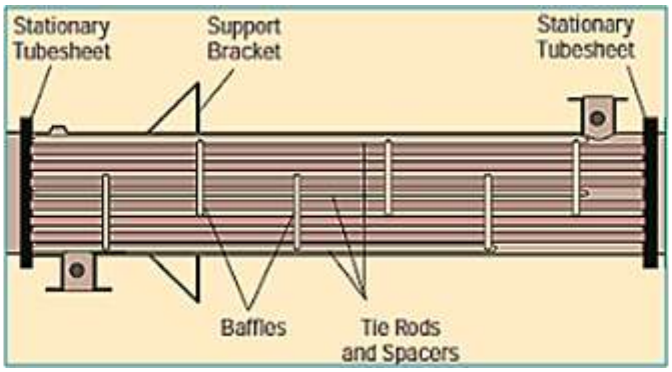


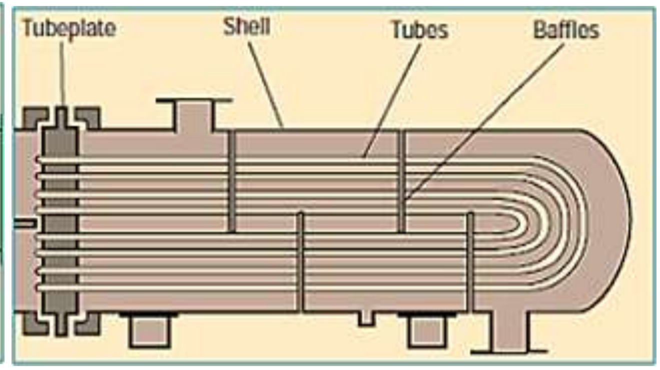
6.2. Heat Exchanger Bundles:

Tube Bundles: Are also known as **tube stacks** are designed for applications according to customer requirements, including direct replacements for existing units. There are **two types** of tube bundles:

a) **Fixed Tube Sheet:** A fixed-tube sheet heat exchanger has **straight tubes** that are secured at both ends by tube sheets welded to the shell.

b) **U-Tube:** As the name implies, the tubes of a U-tube heat exchanger are bent in the **shape of a U** and there is only one tube sheet in a U-tube heat exchanger.





a) Fixed-tube Sheet Heat Exchanger. **b) U-Tube Heat Exchanger.**

Bundle diameter, Db, can be estimated using constants shown:

$$D_b = d_o \quad (N_t / K_1)^{1/n} =$$

Where:

d_o = Tube Outside Diameter;
N_t = Number of tubes.

K_1 - n = see table below:

Triangular Pitch $p_t = 1.25\ d_o$					
Number Passes	1	2	4	6	8
K_1	0.319	0.249	0.175	0.0743	0.0365
n	2.142	2.207	2.285	2.499	2.675

Square Pitch $p_t = 1.25\ d_o$					
Number Passes	1	2	4	6	8
K_1	0.215	0.156	0.158	0.0402	0.0331
n	2.207	2.291	2.263	2.617	2.643

6.3. Tube Diameters:

The most common sizes used are Ø3/4" and Ø1". Use the smallest diameter for greater heat transfer area with a minimum of Ø3/4" tube due to cleaning considerations and vibration. For shorter tube lengths say < 4ft can be used Ø1/2" tubes.

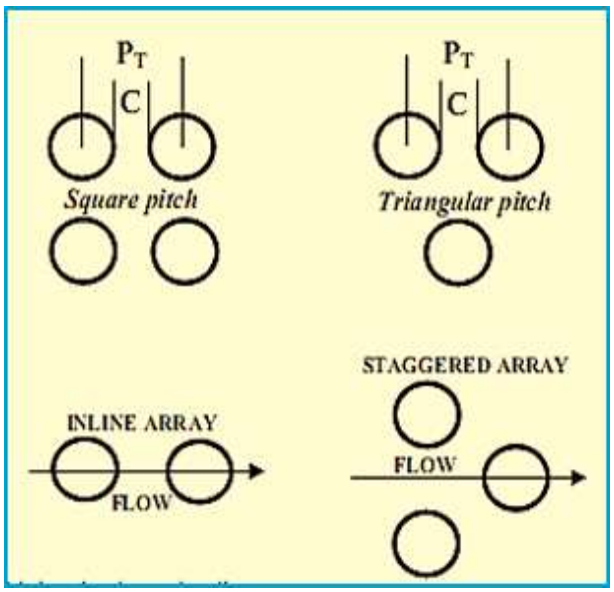
6.4. Tube Quantity and Length:

Select the **quantity of tubes** per side pass to give optimum velocity. **For liquids 3-5 ft/s (0.9-1.52 m/s)** can be used. **Gas velocities** are commonly used **50-100 ft/s (15-30 m/s).** If the **velocity** cannot be achieved in a single pass **consider increasing the number of passes**.

The heat transfer **required** to process and pressure drop constraints determines the **tube length**. To meet the design pressure drop constraints may require an increase in the number of tubes and/or a reduction in tube length. Long tube lengths with few tubes may carry shell side distribution problems.

6.5. Tube Arrangement:

- **Triangular Pattern:** Provides a more robust tube sheet construction.
- **Square Pattern:** Simplifies cleaning and has a lower shell pressure drop.



The **tube pitch** is defined as:

$$P_T = d_o + C$$

P_T = tube pitch;
d_o = tube outside diameter;
C = clearance.

Typical **dimensional arrangements**: all dimensions in inches.

Tube Diameter	Square Pitch	Triangular Pitch
5/8” (16 mm)	7/8” (22 mm) (Note = 1)	25/32” (20 mm)
¾” (19 mm)	1” (25 mm)	15/16” or 1” (24 or 25 mm)
1” (25 mm)	1 ¼” (32 mm)	1 ¼” (32 mm)
1 ¼” (32 mm)	1 9/16” (39 mm)	1 9/16” (39 mm)
1 ½” (38 mm)	1 7/8” (47 mm)	1 7/8” (47 mm)

Note: For shell = **≤12” square pitch = 0.8125 in.**

Note: The table above uses **minimum pitch 1.25 times tube diameter** i.e. **clearance of 0.25 times tube diameter,** the smallest pitch in **triangular 30º layout** for **turbulent or laminar flow** in clean service. For **90º or 45º layout** allow **6.4 mm clearance** for tube for ease of cleaning.

6.6. Corrosion Fouling:

Fouling: Means **deposit formation**, encrustation, deposition, scaling, scale formation, or sludge formation inside heat exchanger tubes.

6.7. Corrosion Definitions:

However if economics determine that **some corrosion is acceptable** and no data is available from past experience an allowance of **1/16 in (1.59 mm) is commonly applied**. **Typical fouling coefficients** are shown below. It can be shown that the design margin achieved by applying the combined fouling film coefficient is given by:

Results for Typical Fouling Coefficients (British Units)						
Fouling Resistances		Fouling Coefficients			Clean OHTC	Design Margin
Inside	Outside	Inside	Outside	Combined		
0.002	0.001	500	1000	333	50	1.15
0.002	0.001	500	1000	333	100	1.3
0.002	0.002	500	500	250	50	1.2
0.001	0.001	1000	1000	500	50	1.1

OBS.: Clean **OHTC** (Overall Heat Transfer Coefficient).

6.8. Typical Fouling Resistances Coefficients:

Cooling Water Fouling Resistances Coefficients (ft² h °F/Btu)					
Hot Fluid Temperature		Up to 240 °F	240 °F to 400 °F		
Water	**Temperature**	Up to 125 °F	Over 125 °F		
	Velocity	Up to 3 ft/s	Over 3 ft/s	Up to 3 ft/s	Over 3 ft/s
Boiler Blowdown		0.002	0.002	0.002	0.002
Boiler Feed (Treated)		0.001	0.005	0.001	0.001
City Water		0.001	0.001	0.003	0.002
Condensate		0.0005	0.0005	0.0005	0.0005

Cooling Tower	Treated Make-up	0.001	0.001	0.002	0.002
	Untreated Make-up	0.003	0.003	0.005	0.004
Distilled Water		0.0005	0.0005	0.0005	0.0005
Muddy Water		0.0003	0.0002	0.0004	0.0003
River Water	Minimum	0.002	0.001	0.003	0.002
	Average	0.003	0.002	0.004	0.003
Sea Water		0.0005	0.0005	0.0001	0.0001

6.9. Fouling Factors [m^2K/W]:

Process	Fluid	Fouling Factors
Gas and Vapor	Hydrogen	0.00176
	Steam	0.00009
	Organic solvent vapors	0.00018
	Compressed air	0.00035
	Natural gas	0.00018
Liquids	Cooling Fluid	0.00018
	Organic heat transfer fluids	0.00018
	LPG, LNG	0.00018
	Caustics	0.00035
	Vegetable Oils	0.00053
Products	Gasoline	0.00018
	Kerosene	0.00018
	Light gas oil	0.00035
	Heavy gas oil	0.00053
	Heavy fuel oils	0.00088
	Light cycle oil	0.00035
	Heavy cycle oil	0.00053
	Light coke gas oil	0.00053
	Heavy coke gas oil	0.00070
	Liquid products	0.00018
	Absorption oils	0.00035
	Reboiler streams	0.00053
	Lube oil processing streams	0.00053
	Solvent	0.00018

Chemical Processing Fouling Coefficients - (ft² h °F/Btu)		
Gases and Vapors	Acid Gases	0.025
	Solvent Vapors	0.001
Liquids	Caustic Solutions	0.002
	DEG and TEG Solutions	0.002
	MEA and DEA Solutions	0.002
	Vegetable Oils	0.003
	Ammonia	0.001
	Chlorine	0.002
	CO2	0.001
Liquids	Ethanol Solutions	0.002
	Ethylene Glycol Solutions	0.002
	Hydraulic Fluid	0.001
	Methanol Solutions	0.002
	Refrigerant Liquids	0.001
	Sodium Chloride Solutions	0.003
Oils	Engine Lube Oil	0.001
	Fuel Oil # 2	0.002
	Transformer Oil	0.001

7.0. BASIC PHYSICAL PROPERTIES:

Property	*Units*	*Water*	*Liquids*	*Steam*	*Air*	*Vapors*
Heat Capacity	KJ/kg °C	4.2	1.0 - 2.5	2.0	1.0	2.0 - 4.0
	Btu/lb °F	1.0	0.239 - 0.598	0.479	0.239	0.479 - 0.958
Density	kg/m³	1000	700 - 1500		1.29@STP (1.0 bar, 0°C)	
	lb/ft³	62.29	43.6 - 94.4		0.08@STP (14.7 psia, 60°F)	
Latent Heat	kJ/kg	1200 - 2100	200 - 1000			
	Btu/lb	516 - 903	86 - 430			
Thermal Con-ductivity	W/m °C	0.55 - 0.70	0.10 - 0.20	0.025 - 0.070	0.025 - 0.05	0.02 - 0.06
	Btu/h ft °F	0.32 - 0.40	0.057 - 0.116	0.0144 - 0.040	0.014 - 0.029	0.116 - 0.35
Viscosity	cP	1.8 @ 0 °C	**	0.01 - 0.03	0.02 - 0.05	0.01 - 0.03
		0.57 @ 50 °C				
		0.28 @ 100 °C				
		0.14 @ 200 °C				
Prandtl Nbr		1 -15	10 - 1000	1.0	0.7	0.7 – 0.8

**** Viscosities of organic liquids vary widely with temperature.**

8.0. PRESSURE DROP ESTIMATE:

The following preliminary conservative estimates are given for **pressure drops due to friction**. It can be noticed that an **additional pressure change occurs** if the exchanger is placed vertically.

Initial Process Design Pressure Drop Estimates		
Process Description	Pressure Drop (psi)	Pressure (kPa)
Liquid streams with no phase change	10	70
Vapor streams with no phase change	2	14
Condensing streams	2	14
Boiling streams	1	7

9.0. EXPERIENCED-BASE RULES:

Experience is typically what turns a **good professional into a great professional**. It means someone who can **at least estimate** the size of a vessel without doing too many calculations. The **rules below are for estimation** and are not necessary to replace rigorous calculations when such calculations should be performed. These rules can save you hours and hours of stages of analysis and design. The rules to be considered are:

1. For the heat exchanger equation, **Q = U.A.F (LMTD)**, use **F = 0.9** when charts for the LMTD correction factor are not available.
2. Most commonly used **tubes are 3/4 in. (1.9 cm)** in outer diameter on a 1 in triangular spacing at 16 ft (4.9 m) long.
3. Typical **velocities** in the tubes should be **3 - 10 ft/s (1 - 3 m/s)** for **liquids** and **30 - 100 ft/s (9 - 30 m/s)** for **gases**.
4. **Pressure drops** are about **1.5 psi (0.1 bar)** for vaporization and **3-10 psi (0.2 - 0.68 bar)** for other services.
5. The **minimum approach temperature** for shell and tube exchangers is about **20 °F (10 °C)** for **fluids** and **10 °F (5 °C)** for **refrigerants**.
6. Double pipe heat exchangers may be a good choice for **areas from 100 to 200 ft² (9.3-18.6 m²).**
7. Spiral heat exchangers are often used to slurry interchangers and services containing solids.
8. Plate heat exchanger with gaskets can be used up to **320 °F (160 °C)** and are often used for interchanging duties due to their high efficiencies and ability to "cross" temperatures.

Notes:

- A **Ø1 ft (30 cm) shell** contains approximately **100 ft² (9.3 m²)**.
- A **Ø2 ft (60 cm) shell** contains approximately **400 ft² (37.2 m²)**.
- A **Ø3 ft (90 cm) shell** contains approximately **1,100 ft² (102 m²)**.

10.0. SIZING HEAT EXCHANGERS ONLINE:

CALCULATION INPUT – (PRACTICAL EXAMPLE) - See the Engineering Page:

Duty:

Required Heat Transfer Duty	cal/h Btu/h	2,000,000 7,931
Overall Heat Transfer Coefficient, U	W/m^2 C Btu/h ft °F	1,000 176

Fluids:

		Hot Fluid	Cold Fluid
Medium		**Steam**	**Water**
Volumetric Flowrate	m^3/h	95	4.75
Density	kg/m^3	0.7	995
Inlet Temperature	° C	105	38
Specific Heat Cp	kJ/kg K	2.0476	4160

Exchanger Data:

Number of Shells in Series **1**

Shell and Tube Side

	Shell Side	Tube Side
Fluid	Cold Fluid	Hot Fluid
Number of Passes	**1**	**1**

CALCULATION RESULTS:

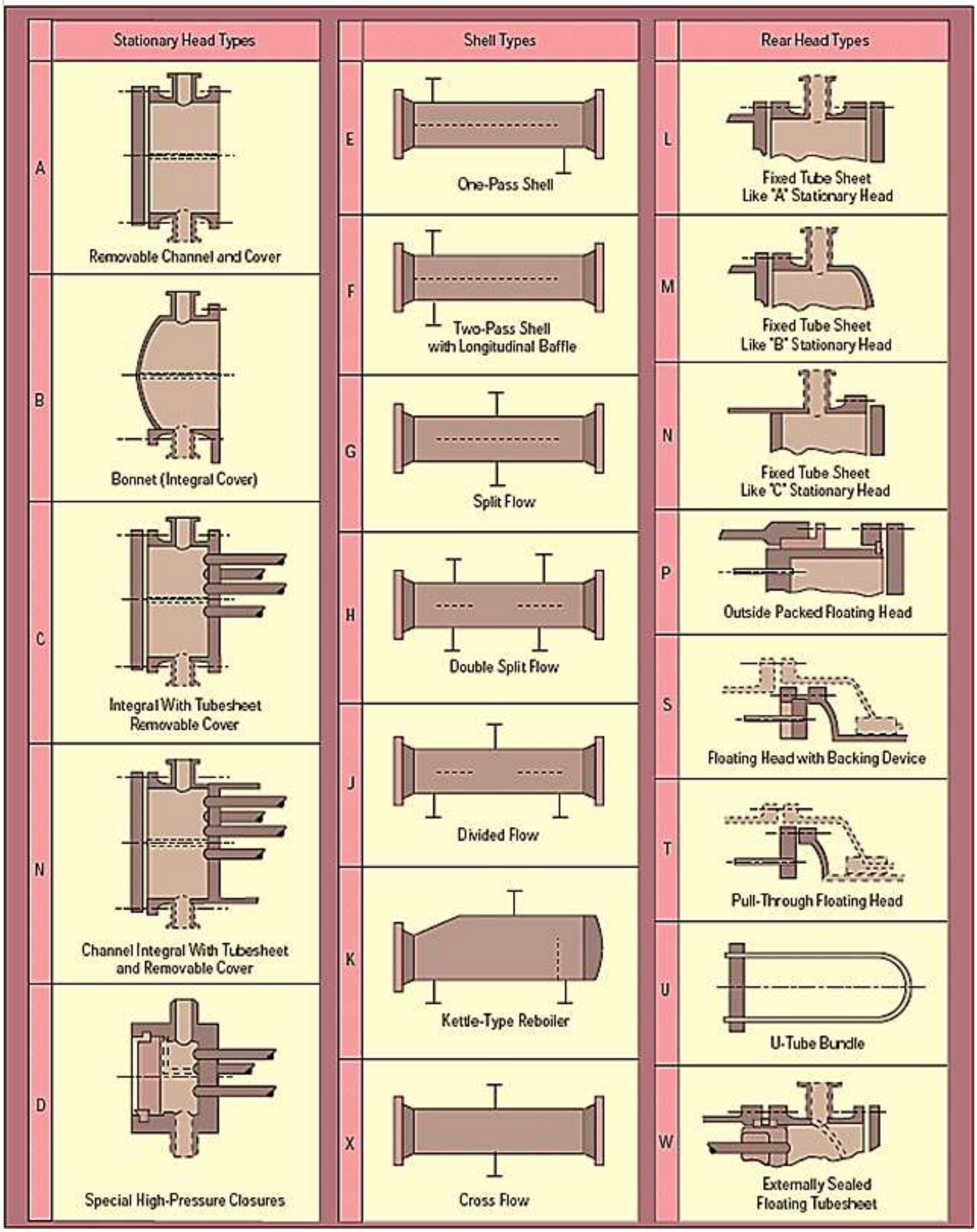
	Shell Side		**Tube Side**	
Fluid	**Cold Fluid**		**Hot Fluid**	
Medium	**Water**		**Steam**	
Flowrate	4.75 m^3/h	2.796 ft^3/min	95 m^3/h	55.915 ft^3/min
Density	995 kg/m^3	62.116 lb/ft^3	0.7 kg/m^3	0.044 lb/ft^3
Mass Flowrate	1.313 kg/s	2.894 lb/s	0.018 kg/s	0.041 lb/s
Specific Heat (Cp)	4160 kJ/kg K	993.599 Btu/lb ° F	2.048 kJ/kg K	0.489 Btu/lb ° F
Fouling Factor	0 m^2 K/W	0 h ft^2 °F/Btu	0 m^2 K/W	0 h ft^2 °F/Btu
Inlet Temperature	38 ° C	100.4 ° F	105 ° C	221 ° F
Outlet Temperature	38 ° C	100.401 ° F	43.504 ° C	110.308 ° F

LMTD and Heat Exchange Surface:

Log Mean Temperature Difference (LMTD)	24.61 ° C	76.29 ° F
Correction factor F	1.0	1.0
Corrected Mean Temperature Difference	24.61 ° C	76.2 ° F
Total Heat Exchanger Surface	**0.09 m^2**	**1.02 ft^2**

11.0. TYPES OF SHELL CONSTRUCTIONS:

Shell Constructions:



TEMA-E: This shell is the **most common shell type**, as it is most suitable for most industrial process cooling applications.

TEMA-F: This shell design provides for a longitudinal flow plate to be installed inside the tube bundle assembly. This plate causes the shell fluid to travel down one half of the tube bundle, then down the other half, in effect producing a counter-current flow pattern which is best for heat transfer.

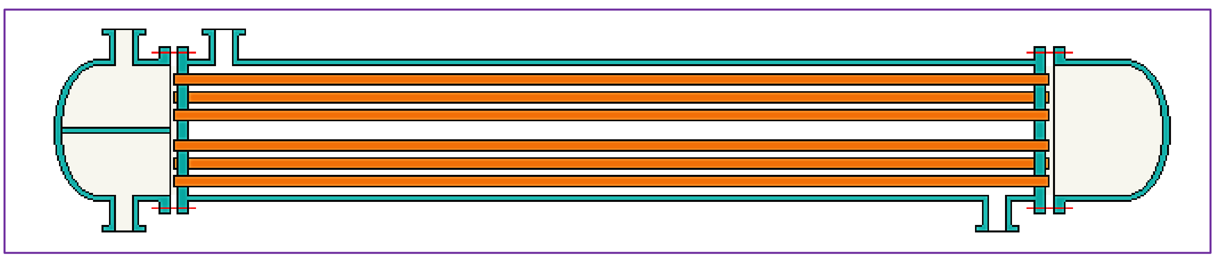
TEMA-G and H: These shells are most **suitable for phase change applications** where the bypass around the longitudinal plate and counter-current flow is less important than even flow distribution.

TEMA-J: This shell is **specified for phase change duties** where significantly reduced shell side pressure drops are required. They are commonly used in **stacked sets** with the single nozzles used as the inlet and outlet. A special type of J-shell is used for flooded evaporation of shell side fluids.

TEMA-K: This shell, also termed as **"kettle reboiler"**, is **specified when the shell side stream will undergo vaporization.** The liquid level of a K shell design should just cover the tube bundle, which fills the smaller diameter end of the shell. This liquid level is controlled by the liquid flowing over a weir at the far end of the entrance nozzle.

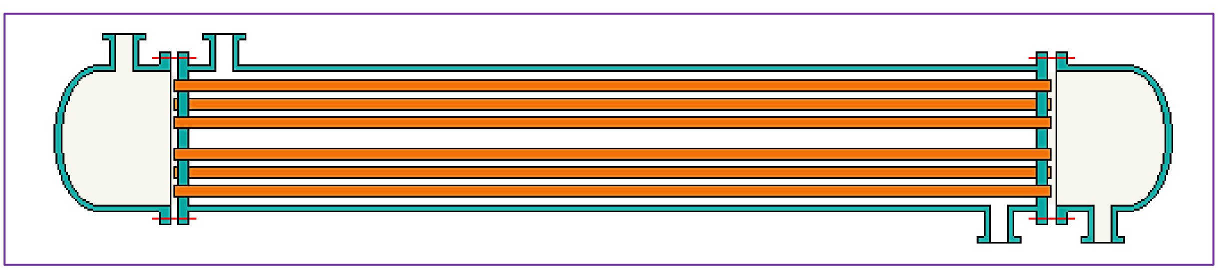
TEMA-X: This shell, or **cross flow shell is most commonly used in vapor condensing applications**, though it can also be used effectively in low pressure gas cooling or heating. It produces a very low shell side pressure drop, and is therefore most suitable for vacuum service condensing.

12.0. EXAMPLES OF THE TEMA DESIGNATIONS:

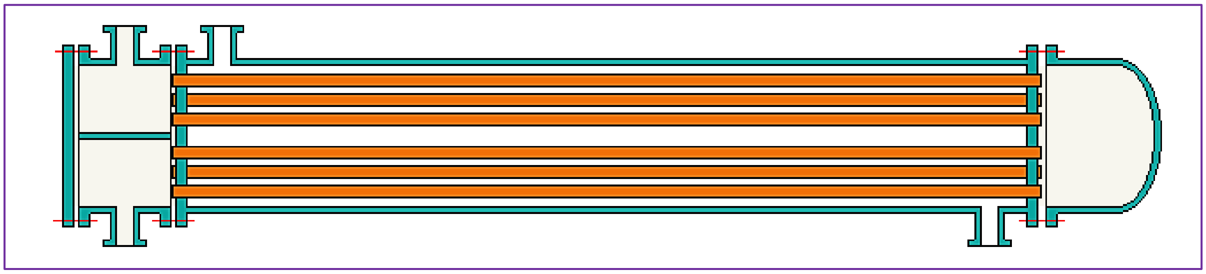


BEM: Bonnet (Integral Cover), One Pass Shell, Fixed Tubesheet Bonnet.

Fixed Tubesheet Heat Exchanger: Is a version with **one shell pass and two tube passes** and a very popular version as the heads can be removed to clean the inside of the tubes. The front head piping must be unbolted to allow the removal of the front head, if this is undesired this can be avoided by applying a **type A** front head. In that case only the cover needs to be removed. It is not possible to clean the outside surface of the tubes as these are inside the fixed part. Chemical cleaning can be used.

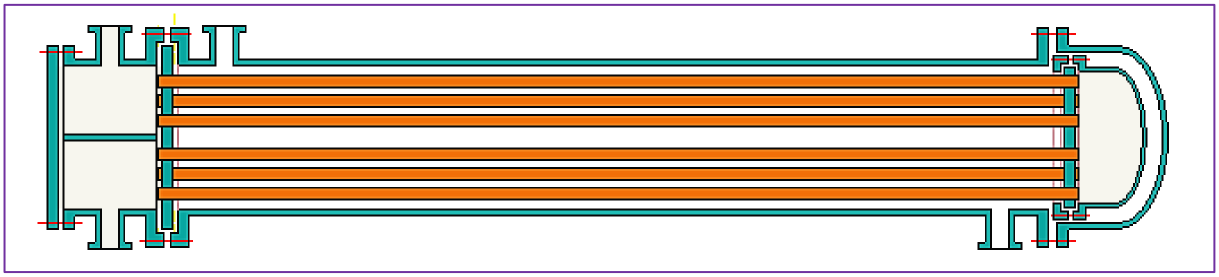


BEM: This is the same type of heat exchanger as above, but with **one tube pass**.



AEM: Channel with Removable Cover, One Pass Shell, Fixed Tubesheet Bonnet.

This is almost the same type of heat exchanger as the first BEM, the removable cover allows the inside of the tubes to be inspected and cleaned without unbolting the piping.



AES: Channel and Removable Cover, One Pass Shell, Floating Head with Backing Device.

Floating Head Heat Exchanger: A floating head is excellent for applications where the difference in temperature between the hot and cold fluid causes unacceptable stresses in the axial direction of the shell and tubes. For maintenance both the front and rear end head, including the backing device must be disassembled. If pulling from the front head is required, a type AET should be selected.

TUBE SHEET TUBE HOLE COUNT (Perry Table 11-3)					
Table B 3/4od tubes on 15/16 triangular pitch					
Shell ID		TEMA L or M			
mm	in	Number of Passes			
		1	2	4	6
203	8	64	48	34	24
254	10	85	72	52	50
305	12	122	114	94	96
337	13.25	151	142	124	112
387	15.25	204	192	166	168
438	17.25	264	254	228	220
489	19.25	332	326	290	280
540	21.25	417	396	364	348
591	23.25	495	478	430	420
635	25	579	554	512	488
686	27	676	648	602	584
737	29	785	762	704	688
787	31	909	878	814	792
838	33	1035	1002	944	920
889	35	1164	1132	1062	1036
940	37	1304	1270	1200	1168
991	39	1460	1422	1338	1320
1067	42	1703	1664	1578	1552
1143	45	1960	1918	1830	1800
1219	48	2242	2196	2106	2060
1372	54	2861	2804	2682	2660
1524	60	3527	3476	3360	3300
1676	66	4292	4228	4088	4044
1829	72	5116	5044	4902	4868
1981	78	6034	5964	5786	5740
2134	84	7005	6934	6766	6680
2286	90	8093	7998	7832	7708
2438	96	9203	9114	8896	8844
2743	108	11696	11618	11336	11268
3048	120	14459	14378	14080	13984

LINKS AND REFERENCES:

https://www.lcec.us/used-heat-exchangers
https://en.wikipedia.org/wiki/Shell-and-tube_heat_exchanger
https://www.alfalaval.com/

ASHRAE: at: www.ashrae.org.
TEMA: The Tubular Exchanger Manufacturers Association at: www.tema.org.
OSHA Technical Manual at: www.osha.gov**.**
Cooling Tower Thermal Design Manual at: www.daeilaqua.com.
Tower Design Free Online eBook Collection at: www.pdftop.com/ebook/tower+design.