A heat exchanger is a device used for transferring heat from a **hot fluid** to a **cold fluid**.
There are literally hundreds of possibilities for Heat Exchangers being used in Industrial, Process and Manufacturing applications:

HOT or COLD
Production of electricity
APPLICATIONS FOR HEAT EXCHANGERS

Building’s central heating, swimming pool
Ice Making
APPLICATIONS FOR HEAT EXCHANGERS

Beverage & Beer Cooling
APPLICATIONS FOR HEAT EXCHANGERS

Hydraulic, Engine Oil Coolers
THREE TYPES:

1. **DOUBLE-PIPE**
2. **SHELL-AND-TUBE**
3. **CROSS-FLOW**
TYPES OF HEAT EXCHANGERS

1. DOUBLE-PIPE HEAT EXCHANGERS
1. DOUBLE-PIPE HEAT EXCHANGERS

Two TYPES in this group:

1a. counter-flow

1b. parallel-flow
1. DOUBLE-PIPE HEAT EXCHANGERS

1a. parallel-flow:
fluids flow in the same direction

1b. counter-flow:
fluids flow in opposite directions
2. SHELL-AND-TUBE HEAT EXCHANGERS
3. CROSS-FLOW HEAT EXCHANGERS
3. CROSS-FLOW HEAT EXCHANGERS

the two fluids flow at right angles to each other. Cross flow heat exchangers may be further subdivided:

(a) Unmixed flow arrangement  (b) Mixed flow arrangement
HEAT EXCHANGERS calculations

clean surface assumption

\[ U_i = \frac{1}{\frac{1}{h_i} + \frac{r_i}{k} \ln \left( \frac{r_o}{r_i} \right) + \frac{r_i}{r_o h_o}} \]

\[ U_o = \frac{1}{\frac{r_o}{r_i} \frac{1}{h_i} + \frac{r_o}{k} \ln \left( \frac{r_o}{r_i} \right) + \frac{1}{h_o}} \]

\[ A_i = 2\pi r_i L \]

\[ A_o = 2\pi r_o L \]

- IMPORTANT NOTE
- since \( U_i A_i = U_o A_o \) Then Q is the same irrespective of which U.
### Typical U-values

<table>
<thead>
<tr>
<th>Application</th>
<th>U (W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam Condenser</td>
<td>1000 – 5600</td>
</tr>
<tr>
<td>Feedwater heater</td>
<td>1000 – 8500</td>
</tr>
<tr>
<td>Water-to-water heat exchanger</td>
<td>850 – 1700</td>
</tr>
<tr>
<td>Finned-tube heat exchanger, water in tubes, air across tubes</td>
<td>25 – 55</td>
</tr>
<tr>
<td>Water-to-oil heat exchanger</td>
<td>100 – 350</td>
</tr>
<tr>
<td>Steam to light fuel oil</td>
<td>170 – 340</td>
</tr>
<tr>
<td>Steam to heavy fuel oil</td>
<td>56 – 170</td>
</tr>
<tr>
<td>Steam to kerosene or gasoline</td>
<td>280 – 1140</td>
</tr>
<tr>
<td>Finned-tube heat exchanger, steam in tubes, air over tubes</td>
<td>28 – 280</td>
</tr>
<tr>
<td>Ammonia condenser, water in tubes</td>
<td>850 – 1400</td>
</tr>
<tr>
<td>Alcohol condenser, water in tubes</td>
<td>255 – 680</td>
</tr>
<tr>
<td>Gas-to-gas heat exchanger</td>
<td>10 – 40</td>
</tr>
</tbody>
</table>
Sources of fouling

a build-up of deposits due to harsh working environment and impurities in the working fluid/s,
these will add a thermal insulating layer on either side of the heat exchanger surface, $R_{fi}$ and $R_{fo}$ respectively, and as such the overall heat transfer coefficient will be Lowered.
OVERALL HEAT TRANSFER COEFFICIENT

\[ U_i = \frac{1}{\frac{1}{h_i} + R_{fi} + \frac{r_i}{k} \ln\left(\frac{r_o}{r_i}\right) + \frac{r_i}{r_o} R_{fo} + \frac{r_i}{r_o h_o}} \]

\[ U_o = \frac{1}{\frac{r_o}{r_i h_i} + \frac{r_o}{r_i} R_{fi} + \frac{r_o}{k} \ln\left(\frac{r_o}{r_i}\right) + R_{fo} + \frac{1}{h_o}} \]
# Fouling factors

<table>
<thead>
<tr>
<th>Type of fluid</th>
<th>Fouling factor, $R_f$ m² K/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seawater, below 50ºC</td>
<td>0.0001</td>
</tr>
<tr>
<td>Above 50ºC</td>
<td>0.0020</td>
</tr>
<tr>
<td>Treated boiler feedwater above 50ºC</td>
<td>0.0002</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>0.0009</td>
</tr>
<tr>
<td>Lubrication oil</td>
<td>0.0007</td>
</tr>
<tr>
<td>Alcohol vapours</td>
<td>0.0001</td>
</tr>
<tr>
<td>Steam, non-oil-bearing</td>
<td>0.0001</td>
</tr>
<tr>
<td>Industrial air</td>
<td>0.0004</td>
</tr>
<tr>
<td>Refrigerating liquid</td>
<td>0.0002</td>
</tr>
</tbody>
</table>
Three Methods in use to appraise heat exchangers:

a. LMTD method for double-pipe heat exchangers

b. Corrected LMTD method for other types of heat exchangers

c. Effectiveness – NTU method
The heat transfer process in a heat exchanger can be described as follows.

heat transfer between fluids across solid boundary

= Heat lost by hot fluid
= heat gained by cold fluid

\[ Q = U \ A \ \Delta T_m \]

\[ = m_h \cdot C_{p_h} \cdot (T_{hi} - T_{ho}) \]

\[ = m_c \cdot C_{p_c} \cdot (T_{co} - T_{ci}) \]

with subscripts h, c representing the hot and cold fluids,
and i, o for inlet and outlet respectively.
The heat exchange for a small segment is $dQ = U \ dA \ \Delta T$

$$
\frac{d(\Delta T)}{\Delta T} = \frac{dT_A - dT_B}{Q / U \ . dA}
$$

$$
\ln \frac{\Delta T_o}{\Delta T_i} = \frac{\Delta T_o - \Delta T_i}{Q / U \ . A}
$$

$$
Q = U \ . A \ . \left( \frac{\Delta T_o - \Delta T_i}{\ln \left( \frac{\Delta T_o}{\Delta T_i} \right)} \right)
$$
THE CORRECTION METHOD

This method for evaluating the performance of heat exchangers has the advantage that it does not require the calculation of the logarithmic mean temperature difference. Its main advantage is by using correction factors for heat exchangers which are NOT the standard parallel or counterflow.
One shell pass and an even number of tube passes.
Conversion factor, $P$

\[ Z = \frac{T_i - T_a}{t_o - t_i} \]

\[ P = \frac{(t_o - t_i)}{(T_i - t_i)} \]

Crossflow with both fluids unmixed.
Crossflow with one fluid mixed.
This method for evaluating the performance of heat exchangers has the advantage that it does not require the calculation of the logarithmic mean temperature difference. The method depends on the evaluation of three dimensionless parameters:

- NTU
- EFFECTIVENESS
- CAPACITY RATIO
Shell-and-tube (one shell pass; 2, 4, 6, etc., tube passes)
Shell-and-tube (n shell passes; 2n, 4n, 6n, etc., tube passes)
Crossflow (both streams unmixed)
WORKED EXAMPLES

\[ (b+\text{un}) \times IC = \frac{1}{(b^2-p)} A \]
SOLVED EXAMPLE 8.2

It is desired to cool 0.6 kg/s of oil, from 125 °C to 65 °C.

Water is available with a flow rate of 0.5 kg/s at a temperature of 10 °C. The overall coefficient of heat transfer is 85 W/m² K. Determine the length of 3-cm I.D. tubing required for counterflow and for parallel-flow heat exchange.

Data given:

\[ C_{p_{oil}} = 2.10 \text{ kJ/kgK} \]
\[ C_{p_{water}} = 4.18 \text{ kJ/kgK} \]
SOLUTION EXAMPLE 8.2

Equating heat contents of water and oil:

\[ \Delta T_w = \frac{[m.C_p.\Delta T]_{oil}}{[m.C_p]_w} = \frac{(0.60)(2.10)(60)}{(0.50)(4.18)} = 36.17 \]

\[ \therefore \]

hence \( T_{wo} = 36.17 + 10 = 46.17^\circ C \)
for counter-flow: \( \Delta T_o = 65 - 10 = 55 \)
and \( \Delta T_i = 125 - 46.17 = 78.8 \)

\[
LMTD = \frac{\Delta T_i - \Delta T_o}{\ln(\Delta T_i / \Delta T_o)} = \frac{78.8 - 55}{\ln(78.8 / 55)} = 66.19
\]

\[
Q = [m.C_p.\Delta T]_{oil} = (0.60).(2.10).(60) = 75.6 \text{ kW}
\]

\[
A = \frac{\Delta Q}{U \times LMTD} = \frac{75600}{85 \times 66.19} = 13.43 \text{ m}^2
\]

\[
L = \frac{A}{\pi.D} = \frac{13.43}{\pi(0.03)} = 142 \text{ m}
\]
For parallel flow:  \( \Delta T_i = 125 - 10 = 115 \)
and  \( \Delta T_o = 65 - 46.17 = 18.83 \)

\[
LMTD = \frac{\Delta T_i - \Delta T_o}{\ln(\Delta T_i/\Delta T_o)} = \frac{115 - 18.83}{\ln(115/18.83)} = 53.14
\]

\[
A = \frac{Q}{U \times LMTD} = \frac{75600}{(85)x(53.14)} = 16.7 \, m^2
\]

\[
L = \frac{A}{\pi d} = \frac{(16.7)}{(\pi)(0.03)} = 177m
\]

The parallel-flow configuration requires larger area to achieve the same heat transfer.
SOLUTION EXAMPLE 8.2

for counter-flow: \[ \Delta T_o = 65 - 10 = 55 \]
and \[ \Delta T_i = 125 - 46.17 = 78.8 \]

\[ LMTD = \frac{\Delta T_i - \Delta T_o}{\ln(\Delta T_i/\Delta T_o)} = \frac{78.8 - 55}{\ln(78.8/55)} = 66.19 \]

\[ Q = [m \cdot C_p \cdot \Delta T]_{oil} = (0.60)(2.10)(60) = 75.6 \text{ kW} \]

\[ A = \frac{\Delta Q}{U \times LMTD} = \frac{75600}{85 \times 66.19} = 13.43 \text{ m}^2 \]

\[ L = \frac{A}{\pi D} = \frac{13.43}{\pi(0.03)} = 142 \text{ m} \]
How to get the most out of your heating
Since $Q = A \cdot U \cdot dT$

dT as it comes
U is almost constant for a given situation

A if increased, Q will be increased
The use of fins in heat exchangers
WHY FINS?

Fins IMPROVE heat transfer by increasing the heat exchanger area.

Unfinned

Finned
(a) Integral with the base, ie rolled on, or extruded
(b) Welded/soldered/brazed or even glued to the surface
(c) Mechanically attached; either:
   (i) embedded in groove, or
   (ii) tension wound
Typical fins are

- **Annular, or Flat**; for either 3 profiles:
  - **Rectangular**
  - **Triangular**, and
  - **Parabolic**
THEORY OF FINS

fin efficiency

\[ \eta_F = \frac{\tanh (mL)}{mL} \]

where

\[ m = \sqrt{\frac{hP_x}{kA_x}} \]

\[ P_x = 2w + 2t \]

\[ A_x = w \times t \]
Total heat due to fins and bare surfaces:

\[ Qt = Q_{\text{fin}} + Q_{\text{base}} = h A_f \eta_f \Delta T + h A_b \Delta T \]

Where:
- \( h \) is the convection heat transfer coefficient.
- \( \Delta T \) is the temperature difference between the base surface and the fluid bulk.
- \( A_b \) is the unfinned base surface area.
- \( A_f \) is the finned surface area.
THEORY OF FINS

Could have fins, on the inner and outer surface/s

\[
\frac{Q}{A_i} = \frac{\Delta T}{1 \cdot \frac{A_i}{\eta_i h_i} + \frac{\Delta x}{k} + \frac{1}{\eta_o h_o} \cdot \frac{A_i}{A_f}}
\]
TUTORIAL PROBLEMS

\[ \frac{(b+uN) \times IC}{(b^2-P)} = A \]
SOLVED EXAMPLE 8.7

Investigate the effect of weight on heat transfer for three materials: Copper, Aluminium and Stainless steel in an environment where the convection heat transfer coefficient $h = 25 \text{ W/m}^2\text{ K}$. It is to investigate the suitability of iron fins of dimensions 100mm long, 20mm thick and 1m width.
SOLUTION EXAMPLE 8.7

\[ P = 2w + 2t = 2 \left( 1.00 + 0.02 \right) = 2.04 \text{m} \]

\[ A = w \times t = 1 \times 20 \times 10^{-3} = 0.020 \text{ m}^2 \]

\[ L_c = L + \frac{t}{2} = 100 + \frac{20}{2} = 0.11 \text{m} \]

\[
m = \sqrt{\frac{hP_x}{kA_x}} = \sqrt{\frac{2.04}{0.02}} \sqrt{\frac{h}{k}} = 10.1 \sqrt{\frac{h}{k}}
\]
### SOLUTION EXAMPLE 8.7

<table>
<thead>
<tr>
<th>Material</th>
<th>k</th>
<th>$\rho$</th>
<th>Weight ratio</th>
<th>$\eta$</th>
<th>Q</th>
<th>Q/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>385</td>
<td>970</td>
<td>3.464</td>
<td>0.974</td>
<td>1.033</td>
<td>0.290</td>
</tr>
<tr>
<td>Aluminium</td>
<td>170</td>
<td>280</td>
<td>1</td>
<td>0.943</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>17</td>
<td>855</td>
<td>3.053</td>
<td>0.648</td>
<td>0.687</td>
<td>0.225</td>
</tr>
</tbody>
</table>

**Notes**

Al lighter than both, weight ratio nearly 1/3
Although Al has a lower fin efficiency than Cu, its Q/W is 4 times better than both.
SOLVED EXAMPLE 8.9

The cylinder barrel of a motorcycle is constructed of 2024-T6 aluminium alloy and is of height $H = 0.15$ m and outside diameter $D = 50$ mm. Under typical operating conditions the outer surface of the cylinder is at a temperature of 500 K and is exposed to ambient air at 300 K, with a convection coefficient of 50 W/m$^2$ K. Annular fins of rectangular profile are typically added to increase heat transfer to the surroundings. Assume that five such fins ($k = 150$ W/mK), which are of thickness $t = 6$ mm, length $L = 20$ mm and equally spaced, are added. What is the increase in heat transfer due to addition of the fins?
(a) Without the fins, the heat transfer rate is

$$A_{wo} = H \cdot 2\pi r \cdot L$$

$$Q_{wo} = h \cdot A_{o} \cdot (T_{b} - T_{\infty})$$

$$Q_{wo} = 50 \cdot (0.15 \times 2\pi \times 0.025) \cdot (500 - 300)$$

$$= 236 \text{ W}$$
SOLUTION EXAMPLE 8.9

(b) \[ P = (2\pi \times 45/1000 + 6/1000) \times 2 = 0.577 \text{ m} \]

\[ A = (2\pi \times 45/1000 + 6/1000) = 1.69 \times 10^{-3} \text{ m}^2 \]

\[ m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{50 \times 0.577}{150 \times 1.69 \times 10^{-3}}} = 10.652 \]

\[ \eta_f = \frac{\tanh(ml)}{ml} = \frac{\tanh(10.652 \times 0.02)}{10.652 \times 0.02} = 0.985 \]

\[ A_b = L_b \times 2 A_f r_1 = (0.15 - 5 \times 0.06) \times 2\pi \times 25/1000 = 0.01885 \times 10^{-2} \text{ m}^2 \]

\[ A_f = 5 \left[ 2 \times \pi \times (r_2^2 - r_1^2) \right] = 0.044 \text{ m}^2 \]

\[ Q_b = h A_b \Delta T_b = 50 \times 0.01885 \times (500 - 300) = 188 \text{ W} \]

\[ Q_f = h A_f \eta_F \Delta T_b = 50 \times 0.985 \times 0.044 \times (500 - 300) = 433 \text{ W} \]

\[ Q_t = Q_f + Q_b = 188 + 433 = 621 \text{ W} \]