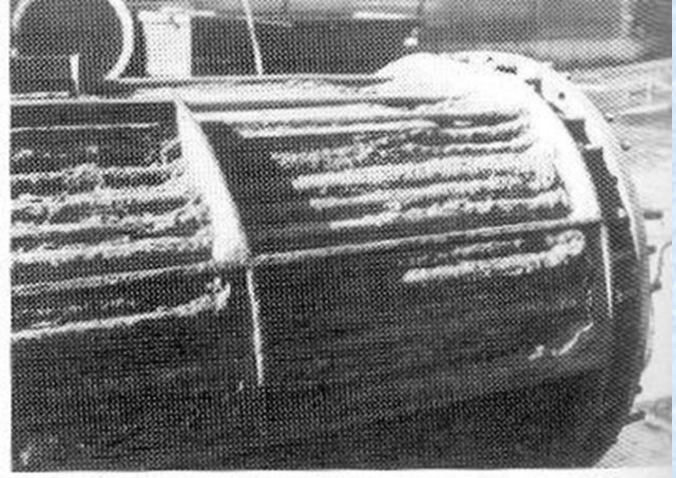

Corrosion, erosion & fouling in Heat Exchangers

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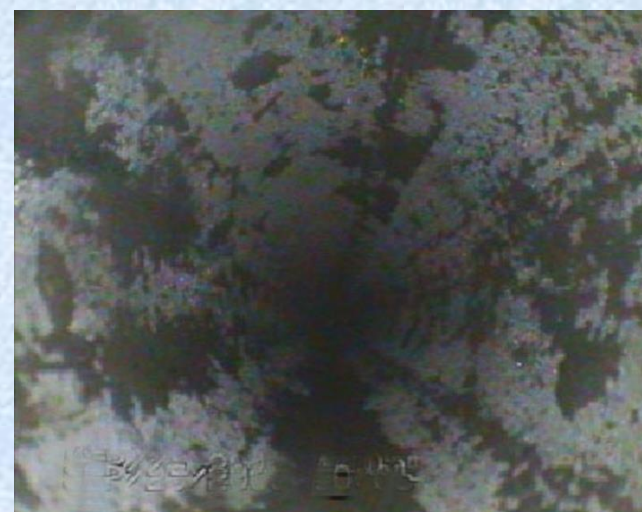

What is fouling?

- Deposition of unwanted material on a heat transfer surface.
- It was a problem at invent of process plants & it is a problem even now.

Effects of Fouling

Loss of production :

Downtime or running plant at reduced capacity

Loss of Energy :

Increase in power consumption of associated pumps/compressors. Partial or total by-pass of downstream heat recovery equipments.

Increased Capital Costs :

Over-sizing of exchanger and associated pumps / compressors to take care of reduced heat transfer after fouling.

Increased Maintenance Costs:

Periodic maintenance, cleaning of equipment & chemical-cleaning

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Categories of fouling

1. Chemical reaction fouling.
2. Bio-fouling
3. Precipitation (scaling) – cooling water
4. Corrosion fouling (of tube material)
5. Particulate fouling (Settlement)

Type of fouling

1. Chemical fouling : chemical changes within the fluid like salts depositing onto the heating elements as the solubility of the salts reduce with increasing temperature.
2. Biological fouling : Growth of organisms within the fluid which deposit out onto the surface.
3. Scaling : Deposition of water hardness on the surface w.r.to time usage.
4. Corrosion fouling : where a layer of corrosion products builds up on the surface of the tube forming an extra layer of high thermal resistance material.
5. Settlement fouling : due to lower flow velocities. Mounting the heat exchanger vertically can also minimise the effect as gravity would separate particles from the heat transfer surface.

Fouling is a combined result of

1. Heat transfer thru tubes
2. Material deposition on surface
3. Momentum of flow
4. Chemical reaction.
5. Surface roughness
6. Congealing / coating etc.

Sedimentation fouling

- Sedimentation can take place due to salt formation at higher temperature .
- Deposition of foreign particles due to low flow velocities
- Sedimentation mostly takes place in liquid services.
- It can also take place in gas phase with heavy density particles
- Sedimentation can be avoided by keeping a watch on temperature control.
- Check on fluid velocities, viscosity & metal roughness

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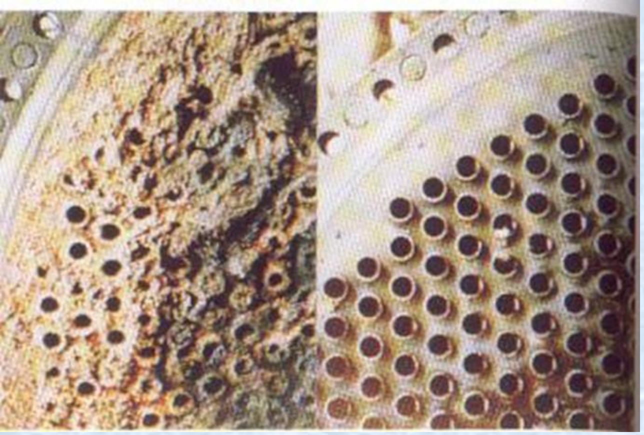
Corrosion in Heat Ex

1. It is a chemical reaction of metal parts of exchanger components with the process fluid.
2. Reasons :

- Formation of oxides / chlorides / Sulphates etc. or other type of salts.
- Surface pitting
- Stress corrosion cracking
- Galvanic corrosion
- Crevice corrosion (in between tube to tube sheet joint)



Deposition properties

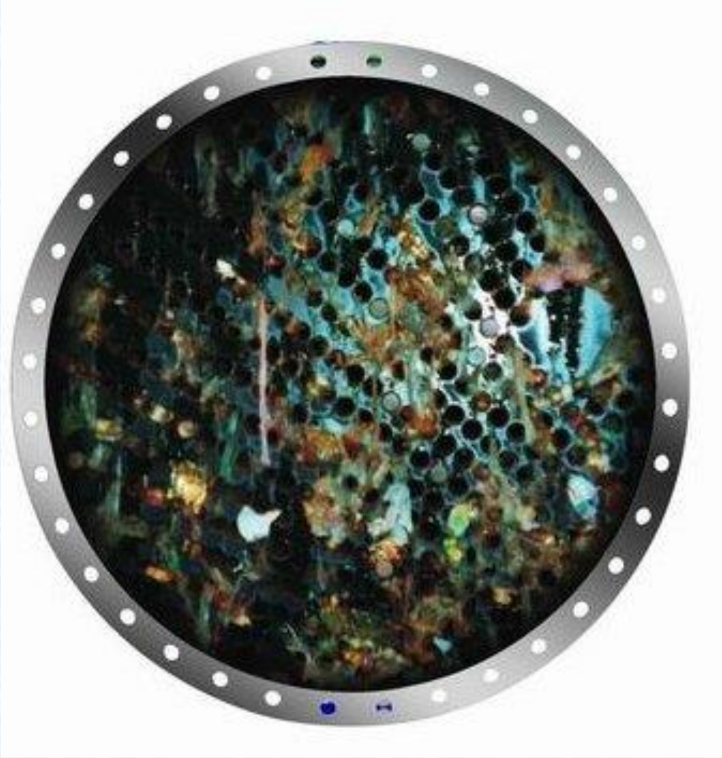
- Thickness of deposit increases with time.
- Mechanical strength of the deposit increases due to change in crystalline structure or chemical composition of deposit.
- It can be reduced by introduction of suitable chemical additive or intermittent chemical cleaning.
- Aging can work both ways some time may strengthen or weaken fouling deposits. But in any case it retards the heat transfer.

Particulate fouling

- Accumulation of finely divided solids suspended in the process fluid on the heat transfer surface
- Some time settling by gravity due to lower flow velocities, resulting in sedimentation fouling
- Frequently superimposes on precipitation and corrosion being caused by certain types of chemical reaction

Bio-fouling (organic)

- ❖It is attachment of macro-organisms and/or micro-organisms to a heat transfer surface, along with the adherent fluid properties often generated by the latter.



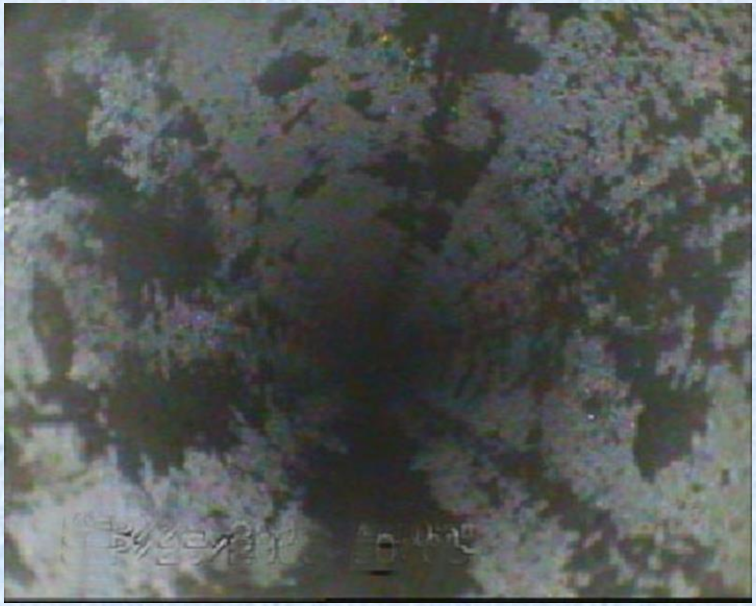
- ❖Mostly in cooling water applications

Bio-fouling (organic)

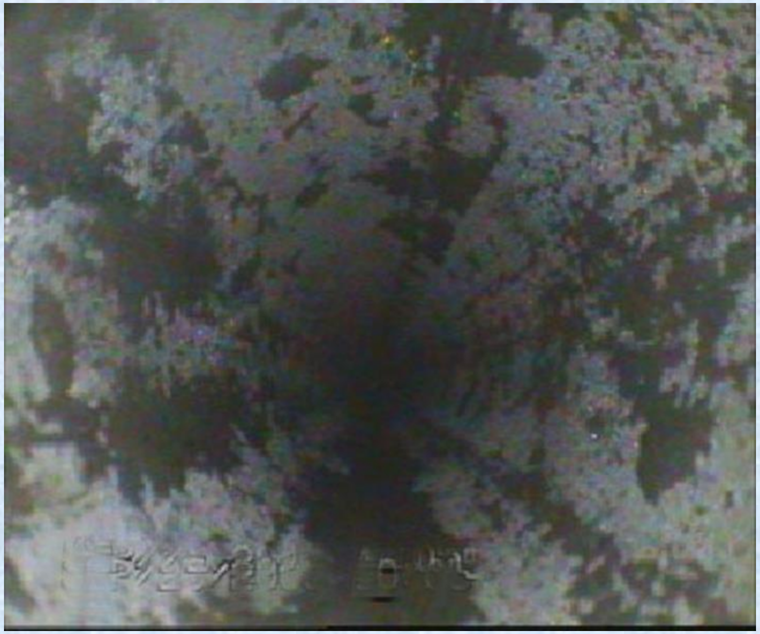
- Combines or superimposes on precipitation and particulate fouling.
- Mostly occurs in condensers with cooling water. Degree varies with water source and season.
- Bacterial growth can usually be controlled by chlorination & temperature.

Corrosion fouling

- The heat transfer surface itself reacts to produce corrosion products which foul the surface.
- These fouled layers if not removed by external forces protect the surface from further corrosion..



Corrosion fouling



- Heavy HC streams at temperature about 290C and higher cause corrosion of CS tubes and other components due to high-temperature sulfur corrosion.
- Often difficult to clean. Some times possible by chemical cleaning.

Precipitation

- Precipitation is higher with higher temperature.
- It increases With superheat of the substances.
- The precipitation of dissolved substances takes place on the heat transfer surface

Chemical reaction fouling

- Deposits formed at the heat transfer surface by chemical reaction in which the surface material itself is not a reactant.
- Such fouling results in oil sludge, organic polymers and insoluble decomposition products.
- Chemical reaction fouling is sensitive to Surface temperature of the exchanger body parts.

Parameters which affect fouling

- Nature of fluid
- Fluid velocity – high velocity minimizes all modes but requires more pumping power. However one has to be careful about mechanical erosion due to increase in velocity.
- Wall temperature affects scaling, bio-fouling, chemical reaction rates
- Tube material surface roughness

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The stages of fouling

Step 1	Initiation	Delay, nucleation, induction, incubation, surface conditioning
Step 2	Transport	Mass transfer
Step 3	Attachment	Surface integration, sticking, adhesion, bonding
Step 4	Removal	Release, re-entrainment, detachment, erosion, spalling
Step 5	Ageing	Aging with respect to time

Taking care of fouling in design

1. Fouling allowance provides margin for additional surface area.
2. Percentage additional area is worked out on shell side as well as tube side
3. For a newly commissioned plant impact of additional surface area needs careful analysis.
4. Too much over margin It is not always desired as it changes the product temperature from process consideration.
5. Fouling resistance should cater only to fouling and not to uncertainties in design, future plant capacity increase, etc.

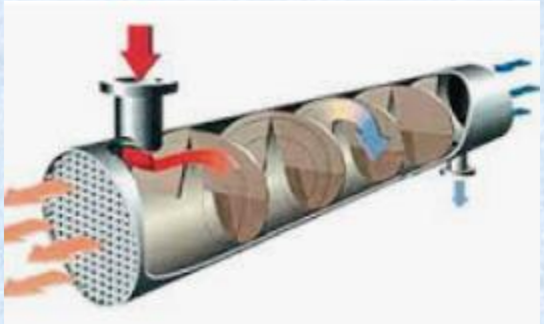
Selection of fouling resistance

Considering complexity of the process it is important to monitor fouling

- By recording and analyzing system pressure drop. But it is tedious & time consuming.
- Fouling resistance in design is picked up by using past experience & operations feedback .

choosing right type of exchanger to minimize fouling

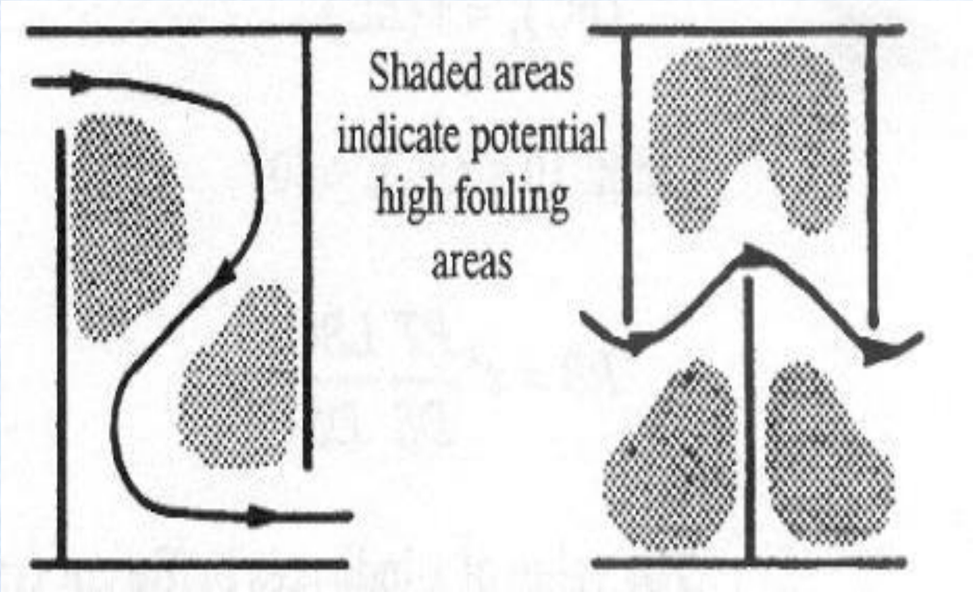
- Use heat exchanger types that foul less like :
  1) Plate,
  2) Spiral,
  3) Helixchangers
  4) Twisted Tube.



- Tube side easier to clean, hence dirty fluids are mostly taken to tube side.
- Trade-off between initial cost and operating cost.

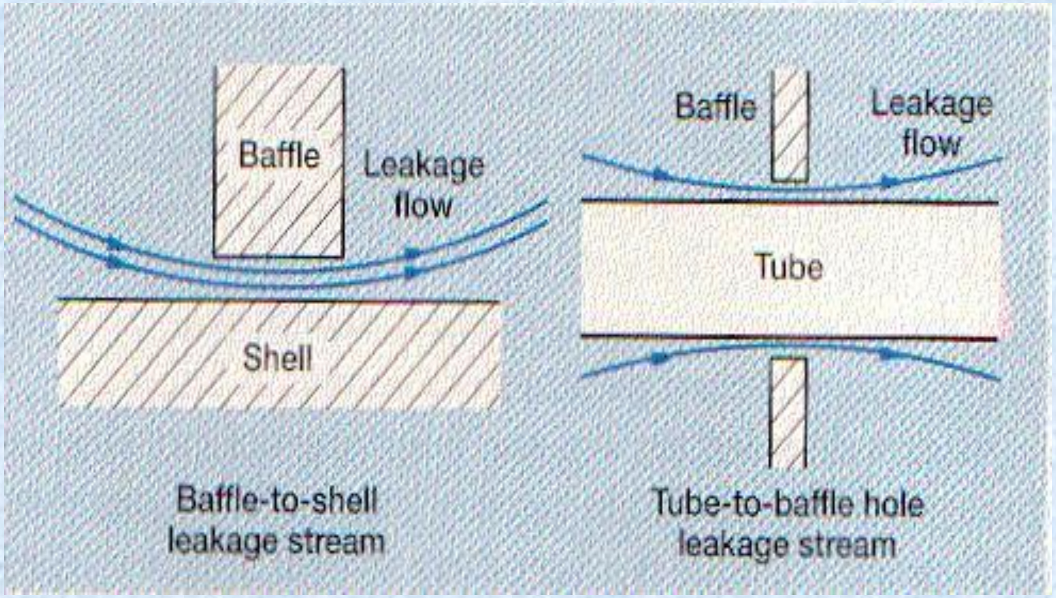
In case dirty fluid on shell side

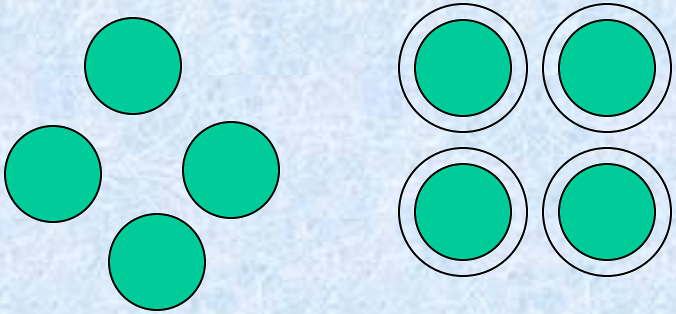
- Use floating-head or U-tube design.
- Use square or rotated square tube layout.
- Minimize dead spaces by optimum baffle design.
- Maintain high velocity shell side



In case dirty fluid on shell side

- Use larger tube pitch for very dirty services.
- Check pressure drop with zero clearances or fouling layer thickness
- Use square or rotated square pitch .





Fouling – Formation of non-metal layer

- Formation layer in side / out side of tubes
- Deposition of solids in Channel & or Shell.
- Chocking of tubes / inlet / outlet nozzles.

Fouling Inside tube decreases :

- Reduction in flow area
- Increase in Tube side pressure drop
- Increase in tube side velocity
- Reduction in heat transfer through tube wall

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Designing for Fouling service (contd.)

- Use Plate type or Spiral exchangers - these heat exchangers have inherent characteristics to handle fouling fluids .
- Corrugated plates / stubs (in case of Spiral) create high turbulence which helps on avoiding build-up of deposits.
- Removable plate / cover design ensures complete and thorough cleaning

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Designing for Fouling service

- Use Helix exchanger, with fouling fluid on shell side.
- For S & T exchanger, allocate the fouling fluid to tube side.
  - Use higher diameter tubes
  - Maximize tube side velocity with increased tube passes / more shells in series
  - Consider on-line chemical cleaning.
  - Use spare tube bundle / spare shell.

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Physical cleaning of tubes by drilling

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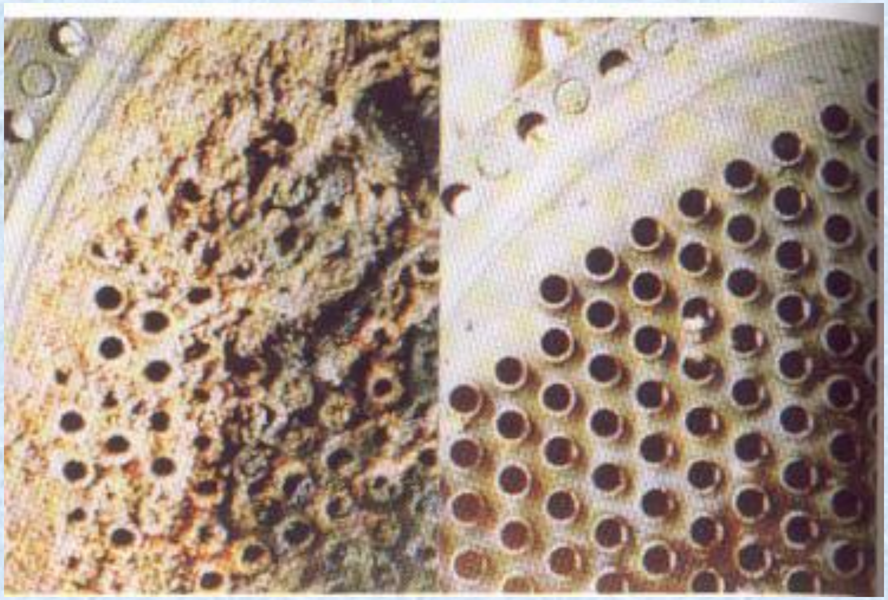
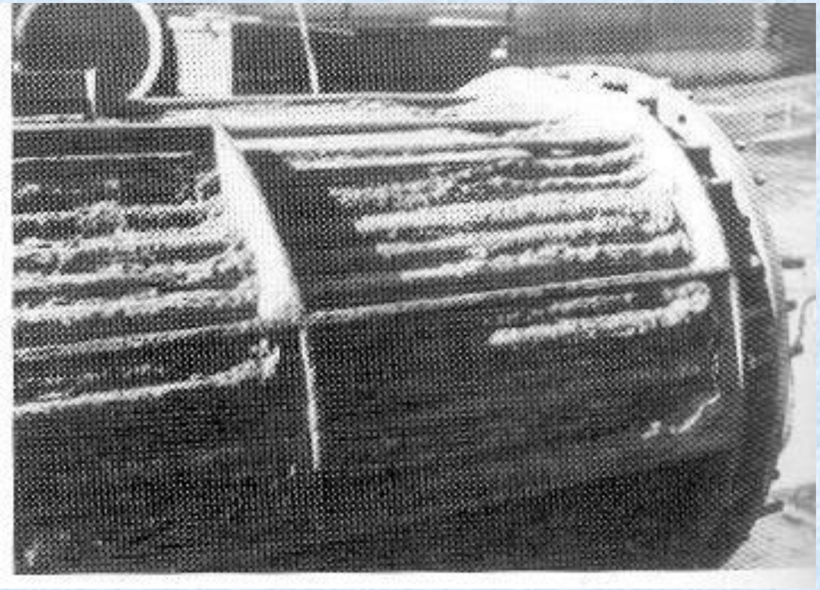
Fouled tube bundle

Scaled Tube sheet



Fouled Exchanger Bundle



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Galvanic corrosion

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Problems associated with cooling water

❖ Sea water based condensers, have the worst corrosion characteristics in comparison to River water or under ground water .

❖ Besides all the cooling water is dozed with acids and chemicals (Sodium Hypochlotite, Chlorine etc.) to avoid Bacterial and micro-organism growth.

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Problems associated with cooling water

- Generally in Coolers tubes are made of stainless steel / brass / bronze/ Cupronickel / Titanium depending severity of corrosion.
- Currently use of copper bearing alloys is not recommended in new projects due to environmental concerns of toxic copper alloys mixing with discharge water.
- Titanium condenser tubes are usually the best technical choice, however very expansive.

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Problems associated with cooling water

- The tube to tube sheet joint is always in contact with circulating water, most vulnerable for various type of corrosion.
- The dozing chemicals make water more corrosive in nature and it works as electrolyte. Recirculation of cooling water makes it more corrosive. (periodic discharge & fresh make up is needed)
- This results in electrolytic corrosion (or Galvanic Corrosion)..
- To overcome this galvanic corrosion, Cathodic protection is provided in side Channel boxes of exchangers, by providing sacrificial anodes.

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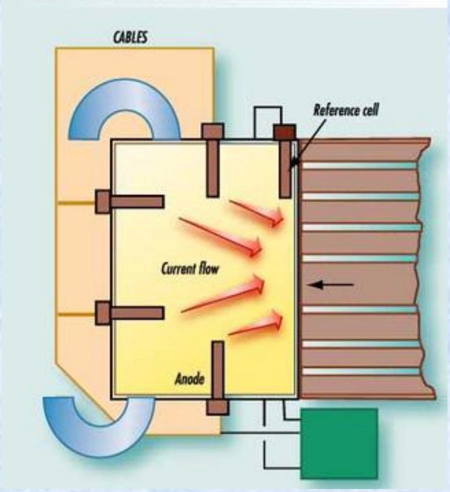
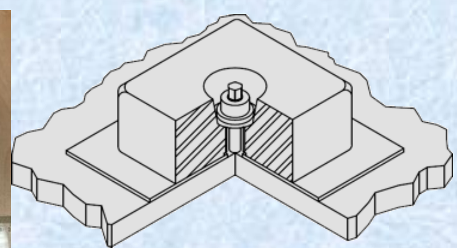
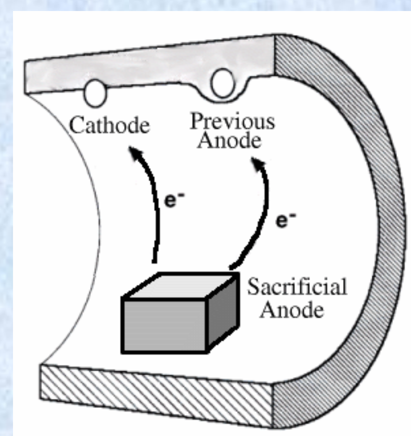
Sacrificial anodes

FIGURE 4
WATER BOX CATHODIC PROTECTION



- Anodes are made of Zinc / Mg / Al alloys.
- Mounted by bolting to pass-partition plates .
- These anodes require periodic inspection and replacement.
- As a secondary protection channel side is also protected inside by epoxy paint.





HDPE tube inserts

Tube to tube sheet joint is most vulnerable part for galvanic corrosion. It is due to :

- Dissimilar metals tube (Copper based) and tube sheet CS).
- Eddy formation at the tube inlet causes erosion of tube to tube sheet joint.
- Most of the sea water condensers these tube inserts are used to protect the joint from erosion.

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Erosion in Heat Exchangers

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Erosion in Heat Exchangers

- Erosion is gradual removal of material causing thinning of material.
- Most of the erosion takes place in tubes in side, exchanger inlet and exit nozzles.
- Erosion near Tube to tube sheet joint
- External erosion of tubes due to high inlet and exit velocities on shell side.

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Reason for Erosion

- Presence of suspended solids in the fluid stream.
- Tube flow velocities higher.
- Higher ρv^2 causing gradual removal of material (pitting) & thinning of material.
- In order to reduce inlet and exit erosion:

  (a) Impingement plates are used to protect tubes

  (b) Inlet and out let nozzles size is kept larger than connection pipe size.

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Metal Erosion

1. Exceeding Fluid velocity on either shell or tube side wears metal from the tube surfaces.
2. At lower velocities corrosion makes a protective layer, however higher velocities remove this protective layer & erosion is accelerated.
3. Metal erosion occurs most often inside tubes, in U bends in bend portion & near the tube entrances.
4. Attached photo is tube erosion due to flashing on “U” bend.

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Metal Erosion

1. Shell side entrance areas often experience severe metal loss due to high-velocity fluid hitting & entering the heat exchanger.
2. When a single stream divides into smaller streams, turbulence results with a very high localized velocity & thus erosion.
3. This can be prevented by inserting an impingement baffle as well as increasing the inlet nozzle size.

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Thank you

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