Chapter (6-C)

Corrosion Control
By
Materials Selection
and Environment Consideration

SERVICE LIFE OF EQUIPMENT

- Selection of a corrosion resistant material for the environment is a prerequisite to a good design.
- Materials and design are complimentary to each other and neither of the two can be ignored.
- **The following factors influence the service life of equipment:**

1. Atmospheric Environment
2. Corrosive environment and velocity of flow
3. Design
4. Selection of materials
5. Maintenance
6. Features promoting corrosion:

   e.g. Bimetallic connections.

Contributors to Corrosive Environments

1) Temperature.

- In our Region, temperatures are relatively high, especially in summer
- High temperatures in combination with high humidity (coastal areas) produce an accelerating effect on corrosion.

2) Humidity.

Corrosion progresses fast when the relative humidity exceeds 75%.

3) Rainfall.

Rain can be beneficial or harmful:

- **Excess rainfall washes corrosive materials and removes dirt, debris and other deposits which may initiate corrosion.**
- **Scanty rainfall may leave water droplets on the surface and lead to corrosion as salt is present in the air.**
- **Frequency of rainfall contributes to humidity.**

Contributors to Corrosive Environments

4) Pollution.

- Coastal Regions

  Atmosphere contains sodium chloride particles plus others, e.g. sulfur dioxide, sulfurous and sulfuric acid; among the worst offenders regarding corrosion.

  Sources: power stations, refineries, chemical and metal manufacturing plants.

- Desert

  Abundance of sand particles accelerates corrosion because of the hygroscopic nature of some constituents of sand particles.

- Cold Climate (e.g Europe)

  Presence of sodium chloride which is extensively used in deicing of roads in Europe and North America.

  Use of small amounts of NaCl can induce high levels of corrosion in road vehicles.

Contributors to Corrosive Environments

The atmosphere may also contain other pollutants, such as carbon monoxide, nitrogen oxides, hydrocarbons, etc.

5) Proximity to Sea.

- Seawater is considered to be equivalent to a 3.5% solution of sodium chloride.
- There is abundance of chloride in the marine environment and in industrial zones located in marine environment.
- A cumulative corrosive effect is caused by both chloride and sulfur dioxide.
  - Chlorides can absorb moisture at low relative humidities.
  - Saturated NaCl solution is in equilibrium with a relative humidity of 78%.

Contributors to Corrosive Environments

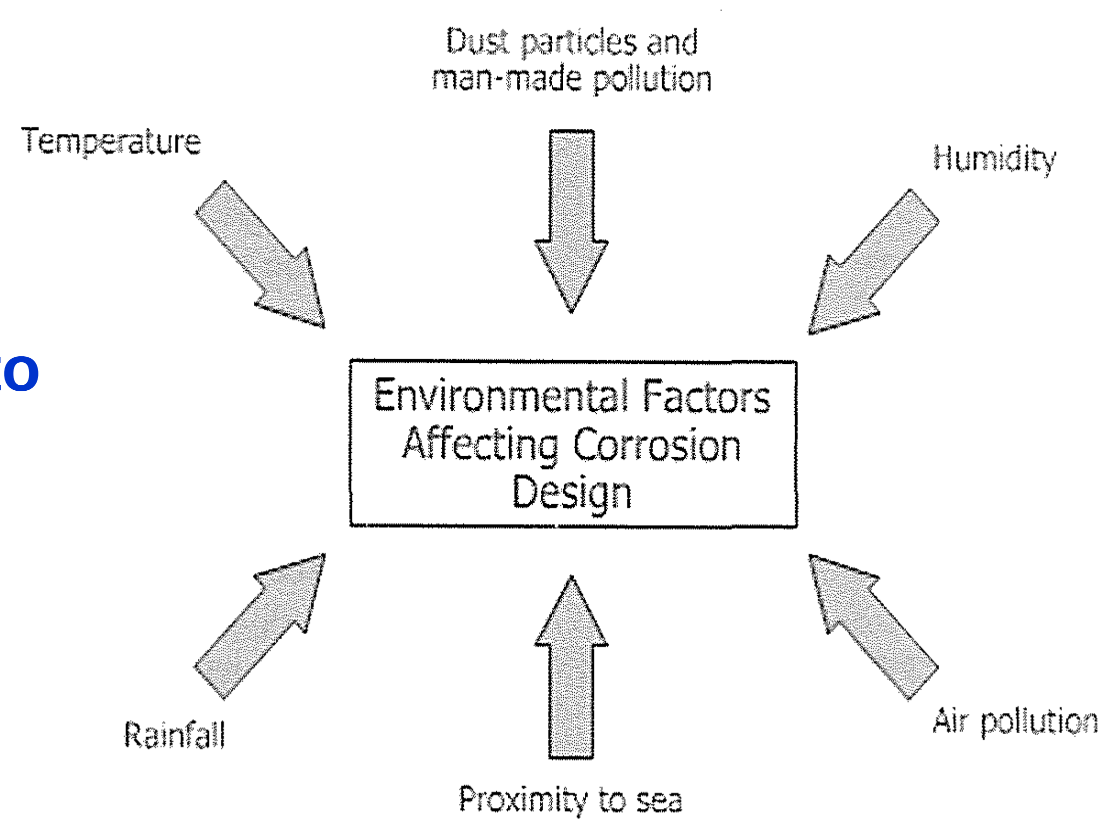

Figure 8.2 Environmental factors affecting service life of equipment

Alteration of Environment:

1. Lower the temperature reduces reaction rate.
2. Removing oxygen from liquids reduces corrosion.
3. Reducing ion concentration decreases corrosion rate.
4. Decrease velocity of fluids reduces erosion corrosion.
5. Adding inhibitors which are retarding catalysts reduce corrosion

MATERIALS EVALUATION AND SELECTION

- Material selection is critical to engineering design.
- Corrosion may be minimized by employing an appropriate design (as discussed earlier).
- The selection of appropriate materials in a given environment is a key factor for corrosion control strategy.
- The material selected (for specific service conditions) has to meet the criteria for:
- mechanical strength
- corrosion resistance, and
- erosion resistance

<u>The following is a list of factors affecting the performance of materials:</u>

1) Expected performance and functions of the product.
2) Physical characteristics.
3) Strength and mechanical characteristics.
4) Corrosion and wear characteristics.
5) Fabrication parameters.
6) Recycling possibilities.

CORROSION AND WEAR CHARACTERISTICS

- Improper selection of materials without consideration of their corrosion behaviour in aggressive service environment can lead to premature failure of components and plant shutdown.

- To avoid failures caused by corrosion:

  A. Materials selected should be compatible with the environment. They must possess sufficient resistance to corrosion for the designed life.

  B. Appropriate preventive maintenance practice must be adopted to maintain the integrity of the equipment /component.

CORROSION AND WEAR CHARACTERISTICS

- The selection of materials must be based on an extensive knowledge of the service environment.

- The behaviour of materials largely depends upon the following:

(a) Corrosive medium parameters (Figure 9.1).

(b) Design parameters

(stresses, bimetallic contacts, crevices, joints, sharp corners, non-homogeneous surface, etc.).

(c) **Material parameters (NEXT).**

Material parameters

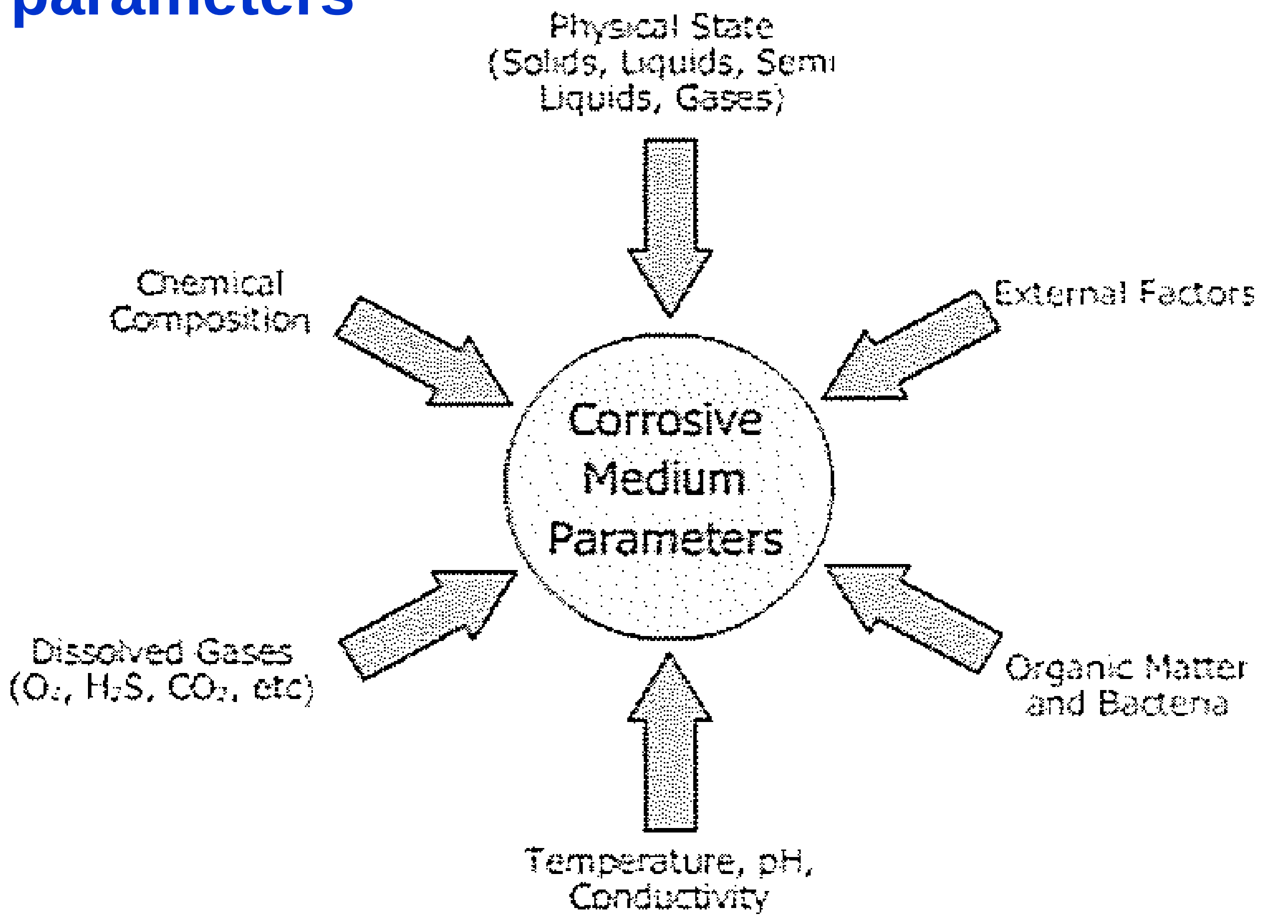

Figure 9.1 Parameters of corrosive fluids contributing to corrosion

Material parameters

The following are the **material parameters** which may affect corrosion resistance:

1) Impurity segregation on grain boundaries.

This leads to weakening of grain boundaries and accelerates corrosion attack.

Examples:

- In 18-8 steels, depletion of chromium due to formation of chromium carbide promotes inter-granular attack (IGA).
- The formation of Mg_2Si at the grain boundaries in Al-Mg alloys leads to weakening of grain boundaries and promotes corrosion of Al-Mg alloys.

2) Micro-structural constituents.

A heterogeneous microstructure forms anodic and cathodic sites which promotes corrosion.

Intermetallic precipitate serves as anodic and cathodic sites and they may be anodic or cathodic to the matrix.

Examples:

- $CuAl_2$ precipitate is cathodic to the aluminum matrix and Mg_2Si is anodic to the matrix.
- Al 6013-SiC composite corrodes at the Al matrix / SiC interface because of the preponderance* of intermetallic secondary phases.
- A non-homogeneous distribution of SiC contributes to accelerated corrosion.

*Predominance / significance

3) Surface treatment, such as galvanizing, phosphating and painting increase the resistance of materials to corrosion.

Examples:

- Galvanizing improves the resistance of steels to corrosion and is widely used in *automobile industry*.
- Galvanized pipes are widely used for transport of hot water in domestic plumbing systems.
- If the temperature, however, exceeds 650°C, reversal of polarity (steel becomes anodic) can cause corrosion of the galvanized pipes.

4) Alloying elements and film formation

Examples:

- Alloying elements in steels, e.g. Cr, Ni or Mo contribute to the production of a protective oxide layer which makes steel passive.
- Addition of Cu to Al alloy increases the strength but decreases the corrosion resistance.
- Scandium (Sc) addition to Al-Mg-Si alloys significantly increases their strength without decreasing their corrosion resistance.
- Coatings of epoxy and polyurethanes provide a longer life to structures exposed to corrosive environments.

FABRICATION PARAMETERS

Following are the fabrication parameters required for analyzing material selection:

1) **Weldability**

– Welding procedures (such as electric arc welding , friction welding, spot welding, etc.) need to be carefully selected to minimize the effect of corrosion.

  - For instance, gas welding in the sensitive temperature range may cause Intergranular cracking.

2) **Machinability**

– Machining operations, such as drilling, milling, shearing, turning, may lead to enhancement of corrosion if they are not properly controlled.

– Drilling fluids are highly corrosive and need to be handled with care.

FABRICATION PARAMETERS

3) Surface modification procedures (e.g. cladding, galvanizing and metallizing "applying metallic coatings"):

1. They increase the resistance of the materials to corrosion.
2. The success of the coating depends on the bonding between the coating and the substrate and surface preparation before the application of coatings according to the international standards.
3. Surface preparation techniques include hand, power tool cleaning and abrasive blast cleaning.

Cladding (covering):

- **The base metals are typically carbon steel, stainless steel, alloy steel, copper and aluminium.**
- **The cladding metals are mainly stainless steel, titanium, aluminium, copper, copper alloys, nickel, nickel alloys, tantalum, and zirconium.**

STRATEGY OF MATERIALS SELECTION

The following steps lead to the screening and ranking of candidate materials:

a) The material attributes must meet the required design requirements.

For example, if the service temperature for a commercial steel component in an oxidizing environment is prescribed at 1100°C, 25 Cr-20 Ni steel would be a suitable choice.

Other steels, such as 13 Cr Steel, 18 Cr steel would be screened out because their limiting service temperature are below 750°C.

b) Find candidate materials which can do the job. How good a job can be done by other materials can be known by determining their material indices.

STRATEGY OF MATERIALS SELECTION

A combination of mechanical properties which characterize the performance of material gives maximized or minimized material attributes.

c) Supporting information: Screening helps to short list the candidate materials and considerably narrows down the range of selection. To further narrow the choice of candidates, support information is explored comprising:

1) Handbooks, such as ASM Handbook, CRC Handbook of Materials, etc.
2) Data sheets from suppliers.

STRATEGY OF MATERIALS SELECTION

3) Data sheet from professional organizations, such as Nickel Development Association (NDA); Copper Development Association (CDA); American Iron and Steel Institute (AISI), etc.

4) Websites of suppliers.

5) Personal contacts.

d) Local environment: The suitability of a product or equipment in a local environment is essential to service life.

e) The final material choice will evolve the completion of a systematic screening process.

MATERIALS AND FLUID CORROSIVITY

- Corrosion resistance of materials depends on the nature of the corrosive environment.

1. A material may be very corrosion-resistant in an environment and yet fail in another environment. A knowledge of the corrosivity of the environment, is therefore, very useful for selection of materials.

2. Water plays a predominant role in a corrosion reaction since it is an electrolyte, an essential component of a corrosion cell.

3. Pure water is a poor conductor arid not significantly corrosive up to 170°C.

MATERIALS AND FLUID CORROSIVITY

- In the presence of salts, acids and dissolved gases, like hydrogen sulfide, carbon dioxide (CO_2) and oxygen (O_2), the degree of corrosivity of water is significantly increased.

  The following are the common aggressive environments encountered by materials:

  1) Industrial environment
  2) Marine environment.
  3) Oilfield environment.
  4) Pollution environment.

INDUSTRIAL ENVIRONMENT

- The industries contributing to the industrial environment include chemical, petrochemical, fertilizer, pulp and paper, and all other process industries.

  The following are the major corrosive fluids encountered in a wide spectrum of industry:

  a) Acids (inorganic & organic, i.e. mineral & carboxylic).

  b) Strong alkalies (bases).

  c) Salt water.

  d) Dissolved gases, e.g H_2S, CO_2, and oxygen.

INDUSTRIAL ENVIRONMENT

e) Pollutants, e.g. particulate matter, sulfur oxides, CO, NO_x, ozone and lead.

f) Soil pollution, e.g. bacteria, oil spills, natural gas contaminants, sewage contaminants and pesticide degradation products.

- The success of service performance of materials would depend on their ability to offer sufficient resistance to corrosion in industrial environments.

RANKING OF PERFORMANCE OF MATEREALS

- The ranking of materials is based on the basis of the degree of corrosion resistance they offer in a given environment.
- The best way to evaluate corrosion resistance is to determine their **rate of corrosion** according to the standards of:
  - ASTM (American Society for Testing of Materials)
  - NACE (National Association of Corrosion Engineers)

Table 9.5 Ranking of materials

Ranking	Range (mmy^{-1})	Example
Excellent	Up to .01 mmy^{-1}	Ti in high velocity seawater at 41 m/s
Good	Greater than .01 mmy^{-1} but not higher than 0.5 mmy^{-1}	6% Al–Brass in polluted seawater 70-30 Cu–Ni in seawater at 41 m/s
Satisfactory	Greater than 0.5 mmy^{-1} but not higher than 1.0 mmy^{-1}	Al–Bronze in pump impellers in seawater
Unsatisfactory	Higher than 1.0 mmy^{-1}	Carbon steel in high velocity seawater

COST EFFECTIVENESS IN MATERIAL SELECTION

A. Design life

This is based on a specified amount of time required to recover investment and operating costs, plus a reasonable profit margin.

B. Quality level

A quality level assigned to an item of fabricated equipment indicates the required level of testing and inspection.

Quality can be defined as ‘*fitness for the purpose’.*

C. Corrosion allowance

Corrosion allowance is related to the corrosion rate and the designed life of the equipment.

COST EFFECTIVENESS IN MATERIAL SELECTION

Carbon steel is cost-effective because it remains economical even after the adding cost of extra wall thickness required to maintain corrosion allowance.

D. National codes

National codes and standards can be used as guidelines for selection of material and fabrication of equipment.

E. Economic consideration

Initial cost, operating costs and maintenance costs must be given full consideration in the process of *materials selection*.

F. Availability

This is an important consideration. An alternate material must also be specified in case the recommended material is not available.

Selection of Metals and Alloys for Certain Corrosive Environment

No	Environment	Proper material
1	Nitric acid	Stainless steels
2	Caustic	Nickel and nickel alloys
3	Hydrofluoric acid	Monel (Ni-Cu)
4	Hot hydrochloric acid	Hastelloys (Ni-Cr-Mo) (Chlorimets)
5	Dilute sulfuric acid	Lead
6	Non-staining atmospheric exposure	Aluminum
7	Distilled water	Tin
8	Hot strong oxidizing solution	Titanium
9	Ultimate resistance	Tantalum
10	Concentrated sulfuric acid	Steel