CORROSION

It means the deterioration of metals and their alloys as a result of chemical and electrochemical reactions with their environment. Corrosion is also defined as the degradation of metals outside mechanical pathways, so that the metal returns to its state in nature. Iron and steel are usually corroded in any environment where oxygen and water are present. The speed of corrosion varies with ambient conditions. For example, it increases with the speed or acidity of water in water, with the increase in temperature or aeration with the movement of the metal, with the presence of certain bacteria or some other effective factors. On the other hand, it is retarded with corrosion protective layers. The alkalinity of water also reduces the corrosion rate on steel surfaces. However, water and oxygen are always required for corrosion to occur. Both determine the amount of corrosion. For example, no corrosion is seen in steels in dry air. If the humidity in the air is below 30, the corrosion is negligible at normal or below normal temperatures.

Figure 1: Gear wheels exposed to corrosion

In this report, atmospheric corrosion effects will be taken into consideration due to the problem-oriented approach.

Atmospheric Corrosion

Exposure of metals to atmospheric corrosion is an inevitable event, no matter in which area of the structure it is used. Atmospheric corrosion is the most importance among all other types of corrosion, both in terms of money spent and the amount of material lost. Atmospheric corrosion varies according to various geographical regions and local conditions. The corrosion rate in industrial zones can be 100 times greater than in desert and polar regions. It has been determined that the steel plate located 24 m away from the seaside corrodes 12 times faster than a plate located 240 m away. The corrosion rate of steel at the seaside is 400-500 times greater than in desert regions. The rate of atmospheric corrosion depends on meteorological conditions and in particular the degree of industrial contamination. Atmospheres can be grouped into four main groups in terms of corrosion.

Slightly corrosive atmosphere; dry rural atmospheres fall into this class. The characteristic features of atmospheres in this class are as follows; annual precipitation is less than 300 mm, relative humidity is usually
less than 50%, distance from the sea is at least 50 km and there are no industrial pollutants in the environment.

Medium corrosive atmosphere; urban atmospheres with a small amount of industrial pollution fall into this class. The characteristic features of the atmospheres in this class are as follows; annual precipitation is between 300-1000 mm, relative humidity is between 50-65%, distance from the sea is at least 15 km, there are no heavy industrial pollutants in the environment.

Corrosive atmosphere; humid atmospheres where industrial pollution is present fall into this class. The characteristics of this class are as follows; annual precipitation is more than 1000 mm, relative humidity is between 50-80%, and there is a high concentration of sulfur dioxide.

Severe corrosive atmosphere; damp atmospheres that are heavily industrially contaminated fall into this class. The characteristic features of the atmospheres in this class are as follows; it is close to the sea to be affected by the sea winds, the relative humidity is very high, and there are excessive rates of industrial pollution.

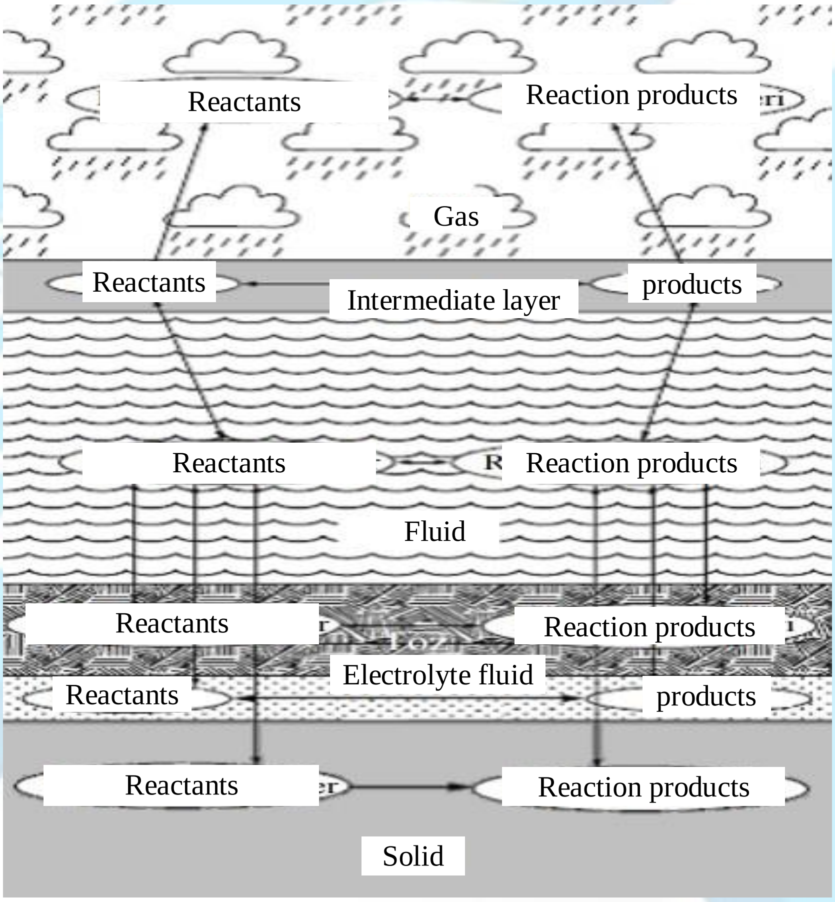

Figure 2: Atmospheric corrosion formation cycle

It can be misleading to gather atmospheres within such obvious limits in reality. Meteorological events change in very short periods of time. The amount and type of components that pollute the environment, salts accumulated on the surface, impurities and their change over time are very important. On the other hand, the duration and frequency of wetness of the surfaces also greatly affect the corrosion rate. In many cases, local effects at the micro level due to the location of a structure can also have significant consequences in terms of corrosion. However, in practice, certain criteria must be available to take anti-corrosion measures. For this purpose, various classifications are included in the standards. To give an idea, the corrosion rate of steel in various class atmospheres is provide in Table 1. The corrosion rate values in Table 1 are provided as the annual average of 10-year corrosion. The corrosion rate in the initial period is 2-3 times higher than the average value.

Atmosphere Type	Corrosiveness Degree	Corrosion Rate (μm/year)
Dry rural atmosphere Dry industrial atmosphere	Mildly Corrosive	1-5
Dry humid atmosphere City atmosphere	Moderately Corrosive	10
Industrially contaminated humid atmosphere	Corrosive	20
Intensively contaminated sea atmosphere	Severely Corrosive	35

Table 1: Corrosion rate of steel in different atmospheres

Atmospheric corrosion is generally not catastrophic in its effects. However, its results increase maintenance costs and shorten the life of even the best material by a certain amount. The rate of atmospheric corrosion depends on the design of the product, the choice of appropriate material, the method of manufacture and quality, as well as environmental factors. The most important of these factors are air humidity, degree of air pollution, annual precipitation, air temperature and wind speed.

- **Effect of Air Humidity**

In the clean atmosphere composition found in its natural state, there are no other components that will corrode except water vapor. Water vapor in the air can cause corrosion even when it is less than saturated. If the relative humidity is more than 70%, a thin film of liquid is formed as a result of condensation on the metal surface due to the day and night temperature difference. 70-80% relative humidity causes a sharp increase in the corrosion rate. The minimum relative humidity that causes the formation of liquid film on the metal surface is called ‘Critical Relative Humidity’. When the humidity is lower than this value, there is no liquid layer on the metal surface. However, liquid water may be present in very thin capillary spaces. If solid particles with capillary properties such as dust and dirt are present on the metal surface, it is easier for the water vapor to condense.

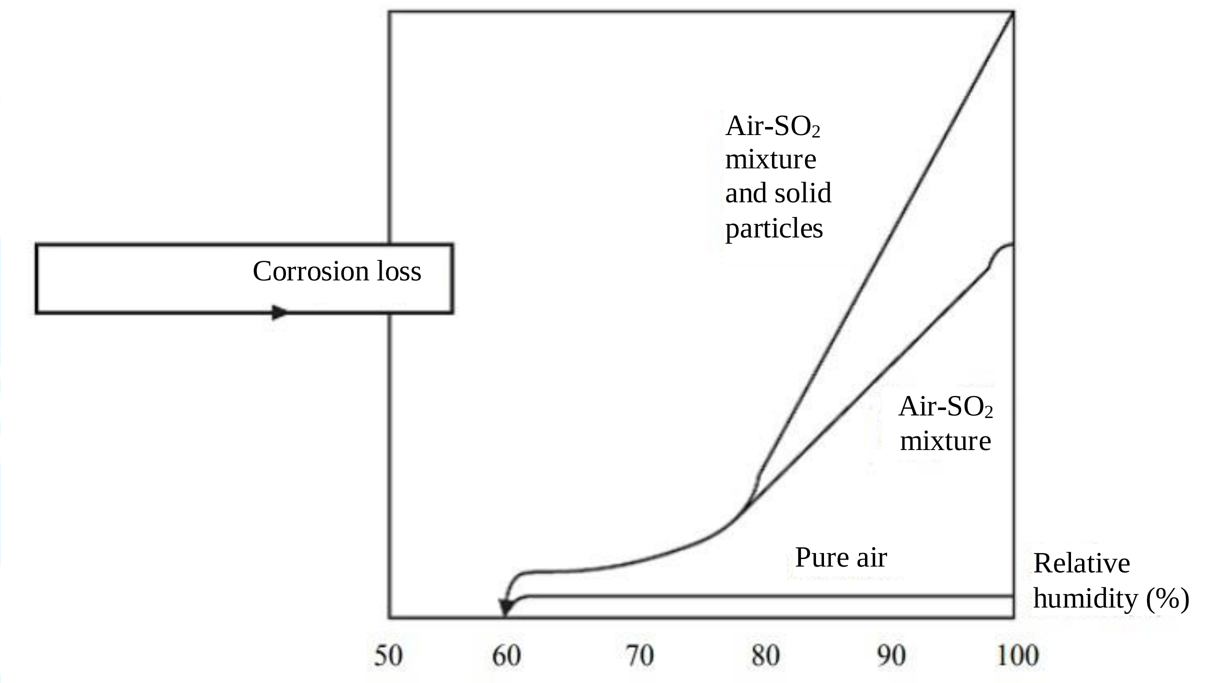

Figure 3: Air pollution, relative humidity, corrosion relationship

- **Effect of Industrial Pollution**

The most effective factor in terms of atmospheric corrosion is industrial pollution. Various chemical gases, vapors and solid particles are mixed into the atmosphere from industrial processes, especially combustion events. Figure 3 shows the effect of air pollution on corrosion. Sulfur oxides are the most common and most effective of the chemical gases in the air. These oxides combine with water vapor in the air to form acids. Apart from this, other acids, ammonia and chlorides can also be mixed into the atmosphere. Particularly in atmospheres open to sea, there are microscopic salt particles carried by the wind. These are deposited on metal surfaces that are open to the atmosphere. Typical concentrations of some pollutant components present in the atmosphere are given in Table 2.

Contaminants	Location	Concentration (mg/m3)	
Sulfur dioxide	Industrial region	Winter	350
		Summer	100
	Rural region	Winter	100
		Summer	40
Ammonium	Industrial region		4.8
	Rural region		2.1
Chlorine *Chlorine measured in precipitation (mg/L)	Industrial inland region	Winter	7.9
		Summer	5.3
	Rural shore	Winter	57
		Summer	18
Solid Particles	Industrial region	Winter	250
		Summer	100
	Rural region	Winter	60
		Summer	15

Table 2: Atmospheric pollutants and their typical concentrations

- **Effect of Temperature**

Since the atmospheric corrosion rate depends on the residence time of the liquid film formed on the metal surface, the temperature has a great effect on the corrosion event. As long as the temperature is low, drying on the metal surface will be delayed and the corrosion phenomenon will continue. Therefore, the rate of atmospheric corrosion is higher in regions where the temperature is low than in regions where the temperate climate prevails. Apart from this, the constantly changing temperature plays a role as a corrosion enhancer as it facilitates condensation on the metal surface.

Although it is true that corrosion increases with increasing temperature, it should be noted that the decrease in relative humidity and the complete drying of the environment are excluded from this generalization due to increasing temperature. If we are to generalize, it can be said that a temperature change of 30℃ creates a 10-fold increase in the corrosion rate.

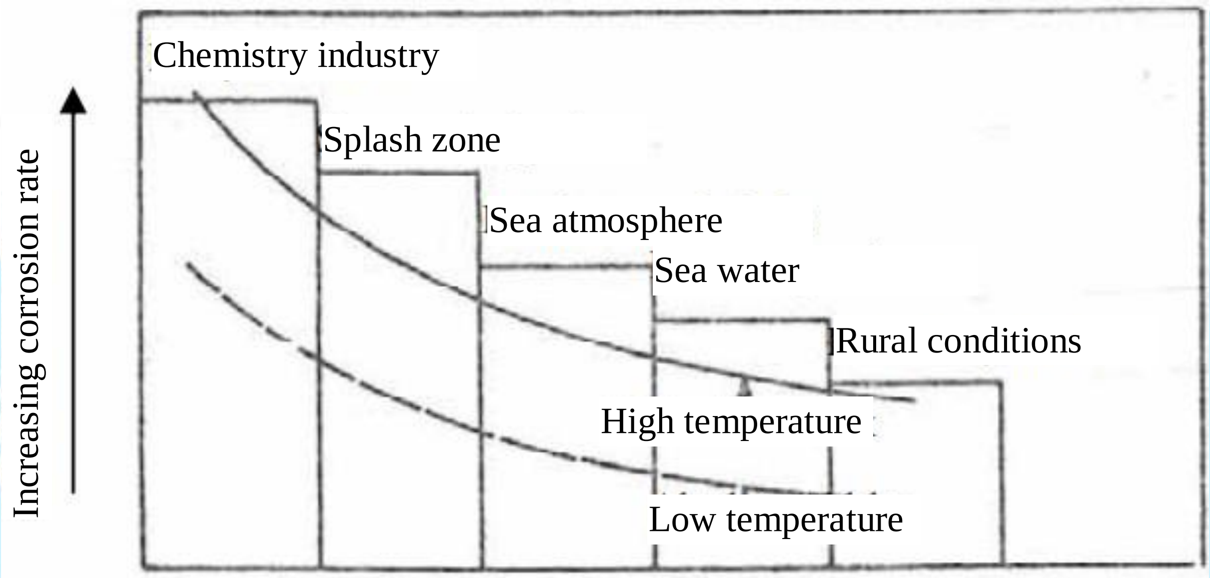

Figure 4: Temperature-Corrosion relationship

- **Effect of Precipitation and Wind**

Water is absolutely necessary for atmospheric corrosion to proceed. Therefore, there is a direct relationship between the annual precipitation amount and the corrosion rate. However, the frequency and drying time are as important as the amount of precipitation. Therefore, wind speed and direction in the region also play an important role. Wind accelerates drying and causes the dirt and dust collected on the surface to drift away.

Corrosion Preventive Measures During Storage and Transportation on Semi-Finished Product Basis

A wide range of semi-finished materials are used in our company. It is beneficial to take a number of protective measures against corrosion during the storage and transportation of these semi-finished products, which are smaller in size compared to the finished products. Among the main protective measures, VCI technology is at the forefront.

VCI (Volatile Corrosion Inhibitors) Technology

Today, the old methods used in the fight against metal corrosion (dirty, troublesome and exensive methods such as lubrication, coating with wax) are abandoned and VCI corrosion technology is used instead as a clean, easy to apply and modern method.

Special chemicals in VCI packaging products have a volatile structure. When the metals to be protected are wrapped or packaged with VCI products, volatile VCI chemicals spread to the environment and form a molecular protective layer (barrier) on the surface of the metal. This protective layer effectively protects the metal against all kinds of corrosion by preventing moisture, salt, environmental pollution and other active substances that can cause corrosion from binding to the metal surface.

VCI packaging products have a wide range of products for both short-term and long-term protection. With VCI formulations designed according to different metal surfaces, it provides superior protection from 1 to 5 years when used correctly. Thanks to the high concentration of VCI, the VCI vapor phase in the environment is continuously and completely formed, and qualified protection is provided in long-term shipments.

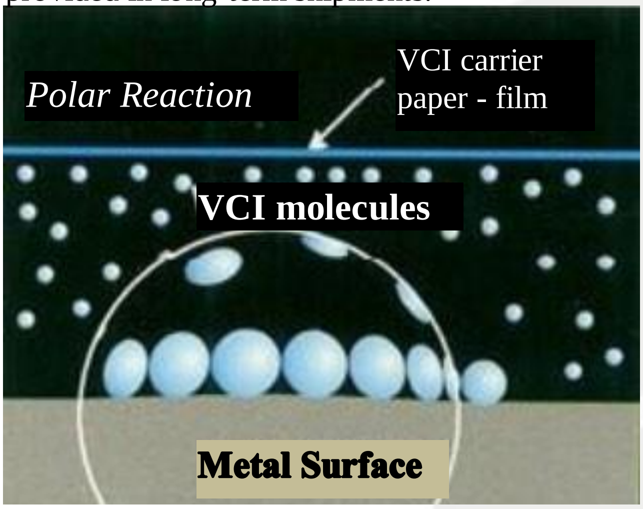

Figure 5: VCI technology working principle

Protective Products Recommended to Use

1. VCI Paper (Oily Paper)

Considering its cost and ease of use, it is one of the most prominent preservation methods in the storage and shipment of semi-finished products. These papers, which can be purchased in rolls, can be easily used by cutting and wrapping according to the semi-finished product to be stored. It provides great protection against corrosion. Today, it is predicted that competing gear companies benefit from the same method.

Figure 6: VCI roll paper

2. VCI Wrap

Polyethylene VCI series polyethylene Wrap protects all kinds of metals against corrosion under stocking or shipment conditions thanks to its strong VCI (Evaporative anti-corrosion) ingredients and superior physical properties. It eliminates the application of laborious, dirty and non-contemporary lubrication, ensuring that metal parts are shipped ready for use and clean. Products specially designed for all kinds of applications and parts also provide physical protection of materials from external factors with their structural properties. Coating the material coated with VCI paper with VCI wrap as an additional preservative is considered as the definitive solution in long-term storage. Similar applications are made in the industry.

Figure 7: Coating the material coated with VCI paper with VCI wrap over

3. VCI Bag

Polyethylene VCI series polyethylene bag protects all kinds of metals against corrosion under stocking or shipment conditions thanks to its strong VCI (Evaporative anti-corrosion) ingredients and superior physical properties. It eliminates the application of laborious, dirty and non-contemporary lubrication, ensuring that metal parts are shipped ready for use and clean. Products specially designed for all kinds of applications and parts also provide physical protection of materials from external factors with their structural properties. The semi-finished product coated with VCI paper and VCI wrap may be stored in VCI bags to enhance the protection.

Figure 8: Metal part retained by VCI bag

4. Dehumidifier Packs

It is used to keep the humidity in the environment away from humidity in case of humidity and condensation problems caused by humidity due to changing weather conditions during storage and shipment, by placing it on the warehouse shelves (kardex) where semi-finished products are stored or inside the package of the semi-finished product during the shipment phase. It can be used as an additional measure against corrosion.

Figure 9: Dehumidifier packs

5. Separators

Contact of metals with each other is considered one of the causes that trigger corrosion. Separators used to separate this contact can be used to prevent contact-induced corrosion.

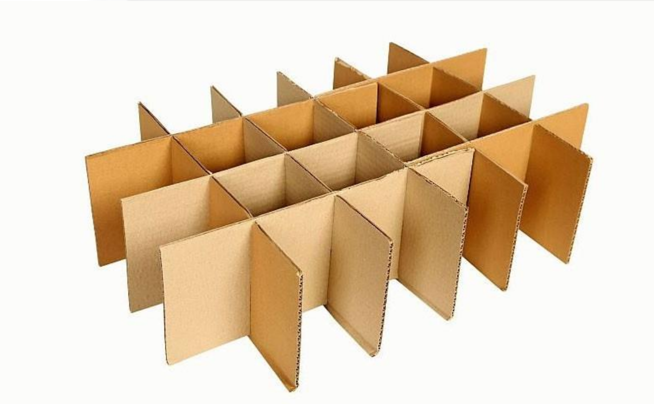

Figure 10: Cardboard Separator

Corrosion Preventive Measures During Storage and Transportation on Finished Product Basis

A wide variety of finished product models are used in our company. Unlike semi-finished products, finished products are generally more complex and contain semi-finished products. The first point to be considered is that the semi-finished products have been successfully protected from corrosion. Otherwise, the product, which has already been assembled with corroded parts during the assembly phase, is not expected to perform its function. In this regard, some problems arise during the corrosion protection phase of the finished product formed with semi-finished products that have been successfully preserved from corrosion. Due to these problems, the preservation techniques used in semi-finished products may be insufficient for the finished products in some cases. A number of methods are used to overcome these problems.

1. VCI Bag

As with semi-finished products, larger sized bags can be useful for finished products. However, considering the dimensions and weights of the products, issues may occur such as tearing of these anti-corrosion bags.

2. VCI Wrap

Again, as in semi-finished products, it can be ensured that a product placed in a VCI bag is also protected by wrapping method.

3. Styrofoam

One of the measures that can be taken to prevent packaging tearing, tipping, bumping, etc. of the products placed in VCI bags and wrapped is styrofoam that can be used in the appropriate mold. With this application, which can be made in each mold specific to the product, it will be possible to prevent the products from damaging both themselves and their packaging with any impact, especially during transportation.

Figure 11: Styrofoam mold

4. Vacuum Pack

The vacuum pack method can be one of the correct preservation methods in terms of its applicability to smaller transmissions (PTO), except for intermediate transmission or reducer-type products. Thanks to special vacuum packs, products that are cut off from physical contact with the external environment can achieve longer storage and shipping life.

5. Dehumidifier Packs

As applied in semi-finished products, during shipment, it may be possible to remove moisture, which is the most important factor that can cause corrosion, by placing it next to the packaged product or in it depending on the situation.

It is possible that these applications, which can be applied relatively easily, may be insufficient in some extreme cases (product shipment to tropical countries, long-distance sea transfer, etc.). There are several types of anti-corrosion measures used by international companies and observed by experienced workers to prevent such extreme situations.

1. Lip Seal Method

In this method, it can be explained that an intermediate transmission that is not foreseen to leak liquid is completely filled with protective oil and there is not enough oxygen source to be exposed to corrosion. Examples of these oil types are Castrol Rustilo 181, ESSO Rust BAN 397 and Valvoline Tectyl 846 oils. However, this method cannot be used in large-volume transmissions. Because the amount of oil to be used in large transmissions will increase, it can cause high financial damages.

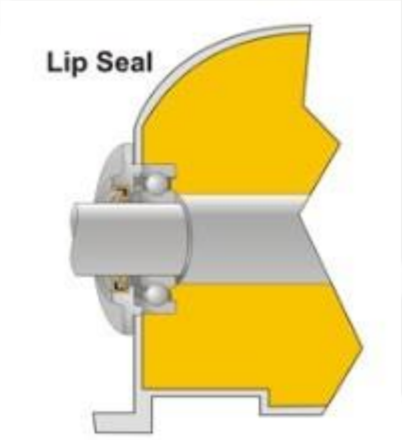

Figure 12: An example illustration of the use of Lip Seal

2. Labyrinth Seal Method

In order for this method to be available, the transmission must not only leak liquids, but also gas. For this reason, the use of labyrinth-type seals is recommended. Unlike the 1st method, the gearbox is not completely filled with anti-corrosion oil, but an oil level of 5-10% is used. In the working principle, it is aimed to form a protective layer on the inner part of the transmission by the continuous evaporation of the protective oil inside. Ashland Oil, Tectyl 859A and Cortec VP corrosion reducers can be given as examples.

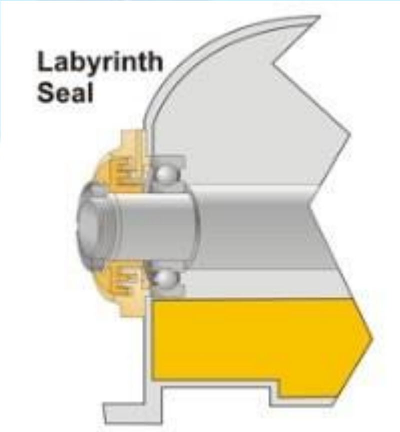

Figure 13: Illustration of the use of Labyrinth Seal

3. Oil Mist Method

It is a preservation method created by simply injecting anti-corrosion steam into the transmission without putting any liquid into it. However, this method is more expensive and difficult to apply compared to the first two methods. However, it stands out as one of the definitive solution methods.

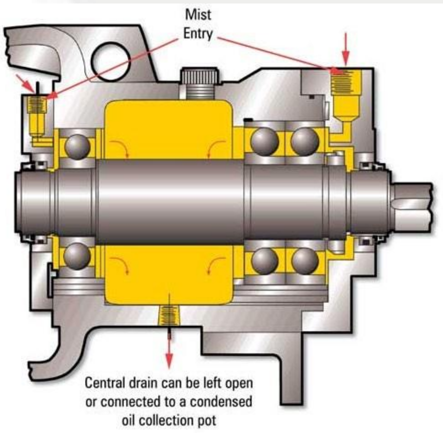

Figure 13: An example illustration of the use of Oil Mist

People who can be considered experienced have mentioned this situation in certain forum websites.

They, too, suggest similar solutions.

Sample Question;

I am interested to know safe (for rust) way of transporting gear box from Europe to India.

During testing of the GB the oil splashes all over the interiors of GB and lubrication happens.
The oil is drained after testing and only a film of oil remains on the internal parts.
Can this film protect the GB from rusting during sea freight from Europe to India (~6 weeks)

We also did a quick testing:
Sample dipped in this GB oil withstood 17 hours of salt spray life (ASTM B117)

The question is: Is it sufficient to protect the GB's internal parts from rusting.

Figure 14: A person concerned about corrosion of internal parts related to transmission shipment

Answer;

Depending on time of year especially, your equipment will go through heat/cool cycles and will breath in moisture laden and worse, salt laden air. If the temperatures are low enough, the metal parts will "sweat" internally as well as externally.

My biggest dread and the most damage I experienced when I shipped gearboxes from Europe (via Rotterdam) to the USA was when they were at sea during the coldest months. I have had some pretty rusty stuff show up - stuff that was oily when it left due to having been filled and drained.

Your choice is:

1. Roll the dice and do nothing and with crossed fingers hope that the residual oil will hang in there. It might, but...

2. Coat the internal parts with a preservative or rust preventative that you know will hang in there - probably not doable in a gear box.

3. Completely seal the gearbox so that there can be no possiblity of ingress of moisture/salt laden air. Probably easier said than done. And if doable, then beware of and allow for pressure differences internal to external due to temperature fluctuations.

4. Place dessicant bags in the crates, and wrap the gearboxes as well as possible with moisture proof cloth or paper. And if there is access to gearbox internals, place dessicant bags inside the gearbox with instructions for removal clearly posted on the equipment.

Method 4 was done for the most part with the large gearboxes I imported and it worked reasonably well. Method 2 was used for the individual parts, gears, shafts, pieces parts, etc.

When I had a choice, I tried to time the shipments so that they would be on the north Atlantic during the warmest weather. I had some bad cold weather experiences.

Figure 15: Suggestions to prevent corrosion

CONCLUSION

Corrosion is one of the most difficult types of wear to prevent. However, it is a type of problem that must be prevented. Because in the long term, internal parts that rust and corrode can cause irreparable damage, such as loss of efficiency, seal deformation, subsequent leakage problems, and even worse, gear loss. These damages can cause unwanted results from compromising the quality of the product at an advanced stage to customer dissatisfaction and even customer loss. Taking the necessary measures in this regard will be of great importance in extending the life of the manufactured finished products and semi-finished products after production and increasing the quality.