TECHNICALLY speaking

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Volatile Corrosion Inhibitors Offer Effective Protection for Processing and Shipment of Metal-Based Products

In 2002 the United States government released the results of a two-year study on the direct costs associated with metallic corrosion in U.S. industry. Titled "Corrosion Costs and Preventive Strategies in the United States," the study—which was initiated by NACE International, mandated by the U.S. Congress in 1999, and conducted by CC Technologies Laboratories, Inc.—concluded that the total annual estimated direct cost of corrosion in the U.S. is $276 billion. At the time, that figure represented approximately 3.1% of the nation's gross domestic product![1]

Not only is this an astonishing figure, but it also represents wasted resources. In addition to these direct costs, there are substantial secondary costs for the metal manufacturing and fabrication industries. The costs of product rejections and associated loss of customer goodwill all add up to have a significant impact on the bottom line. In order to reduce costs and conserve resources, industry needs to implement cost-effective corrosion reduction methods.

VCIs AS COST-EFFECTIVE CORROSION INHIBITORS

Volatile corrosion inhibitors or vapor corrosion inhibitors (VCIs) are terms that can be used interchangeably. VCIs are a class of chemical compounds that volatize into the air and inhibit corrosion on metal substrates. Their vapors form an extremely thin film on metal surfaces, rendering them passive to the process of corrosion. VCIs are especially efficient and cost-effective inhibitors compared to greases, oils, and other adherent films.

Typically, a packaging material such as paper or poly film is the carrier for VCI chemicals. However, the carrier can be many substrates such as corrugated, semi-rigid plastics, or other items that can be included as part of the packaging system. VCI packaging is used for shipping, storage, and in-process applications. Storage requirements can range from months to several years, depending upon how the VCI is used and how much concentration is in the enclosed area.

VCIs offer many advantages over traditional methods of metal protection. Greases, oils, and rust preventative liquids are messy, must be applied, and subsequently cleaned off the surface. They present cleaning, environmental, and disposal problems for part processors and end users. Other adherent films, such as paints, are expensive and impractical for parts that should be kept as bare metal.

VCIs are easy to use, cost effective, and environmentally safe. They do not have to be removed prior to part processing or use. VCIs eliminate process steps by combining corrosion protection and packaging in one step. They are an especially effective method of protecting metal parts of varying geometries because they are able to reach inaccessible recessed areas and crevices on part surfaces. Also, VCIs replenish inside the enclosed package to provide long-term protection. There are numerous documented applications where the use of VCIs has significantly reduced costs and improved customer satisfaction.

CASE STUDY FOR A VCI APPLICATION

Ford Motor Company is a world leader in the production of automotive vehicles, products, and services. In 2002 and 2003, the Ford Van Dyke Transmission Plant, which produces transmission components, received numerous customer complaints of corrosion on transmission clutch covers. The cost of these complaints and the derusting efforts to resolve them exceeded $125,000 per year, not including transportation, rework, and administrative costs, or costs incurred by its customers in handling and managing returns.

A supplier familiar with ARMOR and its VCI technology referred ARMOR VCI to Ford with a request to evaluate the situation. ARMOR and its distributor met with key plant personnel to gather information about the problem and identify the supply chain process. The processes were assessed and a test plan was proposed on how to improve their process and implement VCI technology. Since the implementation of the VCI solution, corrosion complaints have been virtually eliminated.

"We had a problem: Our plant was spending more than $125,000 per year in derusting costs on just one particular part alone," said Art Brdak, quality manager, Ford Motor Company–Van Dyke Transmission Plant. "ARMOR stepped in, conducted a thorough analysis of the situation, and devised a solution that has saved us more than $100,000 each year. It was the best thing we could have done, and we could not be happier with the results."

HOW VCIs WORK

Most VCIs are organic salts that have sufficient vapor pressures under ambient conditions to travel to the surface of the metal. VCI molecules have a high affinity for metallic surfaces and are transmitted as vapors by diffusion, then physically adsorbed onto the metal surface.[2] The VCIs are particularly attracted to and adsorb on metals for which there are unoccupied electron orbitals.

The VCIs form a barrier on the metal surface. The protective vapors expand within an enclosed space until equilibrium of their partial vapor pressures is reached. The VCIs reach the metal surface and condense to form a thin film that is only a few molecules thick.[3]

Once the VCI is adsorbed, the electrochemical process of corrosion is interrupted. The VCI layer separates the metal from the environment, providing a barrier to oxygen and water. The VCI components will even displace adsorbed water molecules from the metal surface as they form a protective layer. With the protective barrier in place, the corrosion cell cannot form.

VCIs also passivate the metal surface. In the presence of even traces of moisture, the VCI components dissolve and develop strong ionic activity. The ions or atoms present in the protective layer change the potential of the metal surface. Coordination bonds are formed between unshared electron pairs on the VCI ions and the metal.[3] This causes a shift in potentials toward nobler values.

For iron and steel, the corrosion process also involves the dissolving of metal ions from the metal lattice into the electrolyte solution. The VCI inhibitor forms an electron donor–acceptor bond with the metal and thus limits the dissolution of metal ions into the solution. These physical and chemical characteristics lead to self-regulating behavior in their corrosion-inhibiting properties.

VCIs AS SELF-REGULATING CORROSION INHIBITORS

VCIs are ideally suited for use in packaging applications. They can be incorporated into standard packaging materials and are self regulating in the protection they provide. Higher temperature and humidity levels promote corrosion on metal surfaces. As temperature and humidity increase, VCIs become more active and provide greater protection. This behavior is due to the chemical nature and related vapor pressures of the VCI components.

Humidity Effects. Since moisture provides the electrolyte, which is required for corrosion reactions, humidity is a major factor for the corrosion rate of metals. In general, the corrosion rate increases as humidity increases. The critical level of relative humidity in order for significant corrosion to occur is 60%.[4] As moisture levels increase, VCIs become more active. The presence of moisture increases the concentration of VCI in the air space and on metallic surfaces.

Higher humidity levels increase the concentration of VCIs in the packaging environment (the packaging carrier contains VCI salts). When moisture is present in and on the carrier, the salts partially dissolve to form ions and small concentrations of whole acid and whole base components.[5] The vapor pressure of the VCI salt solution is higher than that of the salt complex in the packaging carrier. VCIs vaporize from the solution, resulting in more VCIs evolving from the VCI packaging materials into the solution. This process effectively increases the vapor pressure and concentration of the VCIs within the packaging environment.

When moisture is present on metallic substrates, VCI salts dissolve to form ions. The VCI ions are attracted to the metal surface, displacing moisture and reducing salt concentration in the moisture layer. To maintain equilibrium, more organic salt leaves the air space and becomes diluted in the moisture layer. More VCI evolves from the packaging carrier entering the air space. This process continues until the metal surface is covered with a complete nano-coating of VCI, or until there is no more moisture present on the metallic surface.

Temperature Effects. Temperature can have a significant effect on the corrosion of metals. Like many other chemical reactions, corrosion rates increase as temperature increases. For most packaging applications, processing, storage, and shipping occur within the temperature range of 0° to 75°C. Within this temperature range, the corrosion rate doubles for every 10° to 15°C rise in temperature. This temperature effect is amplified if a catalyst is present on the metal surface.

In the presence of certain contaminants the corrosion rate can increase exponentially.[6] If the rate of the corrosion reaction is determined by its initial step, then the catalyzed corrosion rate increases exponentially with temperature in a manner governed by the Arrhenius expression:

$$r = A \exp(-E/RT)$$

r = A exp (–E/RT), where:
r = corrosion rate
A = a constant
E = activation energy
R = gas constant
T = absolute temperature

The diagram in Figure 1 shows an example of this type of behavior for low-alloy steel immersed in dilute hydrochloric acid.[6]

The VCI concentration increases in the packaging environment as temperature increases. Vapor pressure is the pressure of a vapor in equilibrium with its non-vapor phase, such as a solid. It measures the tendency of molecules to escape to the vapor form. The vapor pressure of any substance increases non-linearly with temperature according to the Clausius-Clapeyron relation.[7] Vapor pressure increases at an ever-increasing rate as temperature increases.

VCI concentration on the metal surface will increase as temperature increases. Henry's Law for dilute solutions states that more vapor

molecules will dissolve into liquid layers as temperature and partial vapor pressures increase.[8] So, as temperature and vapor pressure increase, more and more VCI molecules will dissolve into the moisture layer on the metal. In turn, more VCI salt ions deposit on the metal surface, providing increased corrosion protection.

CONCLUSIONS

Metal manufacturing and fabrication companies need to implement cost-effective corrosion reduction methods. In the current competitive environment, resources must be conserved and product rejections reduced. Present business conditions require corrosion solutions for the processing, storage, and shipment of metal-based products. Following are some benefits of VCIs:

- **VCIs are very effective corrosion inhibitors that will protect metal parts of all shapes and sizes.**
- **VCIs effectively replace greases, oils, and other adherent films, and they do not have to be removed prior to part processing. This significantly reduces cleaning, disposal, and environmental costs.**
- **VCIs eliminate application costs by combining corrosion protection and packaging in one step.**
- **VCIs replenish inside the enclosed package to provide long-term protection.**

VCIs are also self regulating in the protection they provide. Corrosion rates increase at higher temperature and humidity levels. As temperature and humidity increase VCIs become more active within the packing environment and provide greater protection.

- **The corrosion rate increases as humidity increases, with a critical level of relative humidity of 60% for significant corrosion to occur.**
- **As humidity increases, VCI salts dissolve, increasing the concentration of VCIs within the packaging environment and on the metal surface.**
- **The corrosion rate doubles for every 10° to 15°C rise in temperature.**
- **As temperatures rise, the vapor pressure of VCIs increases within the packaging environment, resulting in an increased concentration of VCIs on the metal surface.**

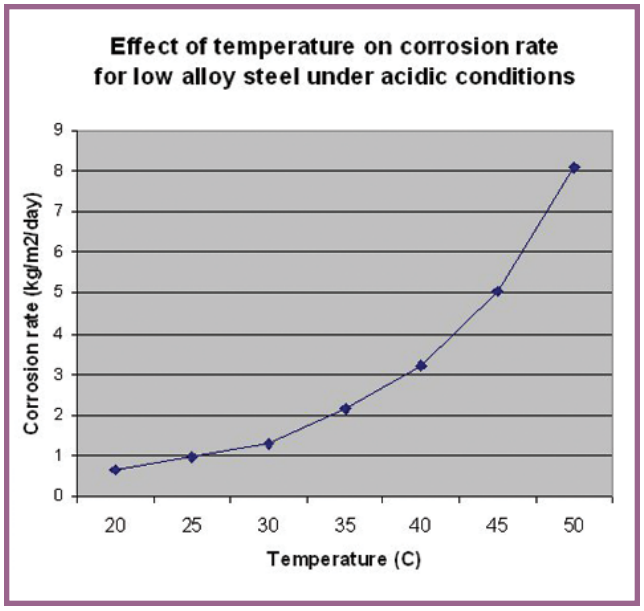

Figure 1: Low-alloy steel immersed in dilute hydrochloric acid.[6]

VCIs are part of the solution to the worldwide corrosion issue. They are cost effective and help conserve resources. When incorporated in packaging materials they are easy to use and very efficient.

NOTES

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BIO

Robin McConnell is currently president & technical director of Armor Protective Packaging, an international company that provides corrosion management systems for metal products. Prior to his position at Armor, McConnell served as vice president and general manager of the Crown Group, a provider of coatings and assembly services to the automotive industry. Throughout his 28-year career, McConnell has been involved in technical R&D positions with major producers of coatings, adhesives, and corrosion inhibitors for the industrial transportation industry.