Corrosion 101

Information for those serious about protecting their assets from corrosion

PREVENT X PROTECT X PRESERVE

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Contents

Welcome

This e-book covers the use and application of vapor corrosion inhibitor (VCI) technology in the protection of assets such as firearms, boats, fishing gear, tools and cars from corrosion. Whilst VCI's where discovered by Shell in the 1930's their use and application is not widely known.

The e-book is divided in to two sections:

Technical Stuff – talks about why metal things corrode and the chemistry behind it;

Practical Stuff – gets straight in to applications using materials science technology to protect assets.

Along the way we'll talk about some basic chemistry, explain why corrosion of metals occurs and outline how VCI technology protects metals from corrosion.

If you understand the basic chemistry of why metals corrode it will make it easier to understand how best to protect them.

Some interesting applications and uses will be covered along with ideas on how to use VCI's to protect your equipment. Wherever you see blue text like this there is a link to a website or some other information. Click on it to find out more.

If you have any interesting applications or some photos to share please email us.

For those of you working in industries such as chemical, defence, engineering, infrastructure, manufacturing, marine, mining, oil and gas, paper or remanufacturing our industrial site may be of interest. Click here for more information on our industrial and commercial range.

The Technical Stuff

Corrosion in Metals

Everything in the world corrodes with different names used to describe the process. For example plastics degrade and breakdown when exposed to ultraviolet light. In the financial world assets such as buildings and machinery are depreciated, effectively writing down their dollar value year on year.

For metals corrosion is the destruction or deterioration of a metal due to a reaction with the environment that it is in. Ferrous metals such as iron and steel will rust whilst non-ferrous metals such as copper and silver will tarnish.

We can't stop corrosion we can only control the rate of corrosion. So by painting a steel beam the rate of corrosion is reduced but over time the paint coating will flake and peel, leaving the steel exposed to the elements and corrosion will begin.

Now for some technical detail.... All metals have a primary oxide layer (POL). This layer prevents the metal from corroding but is very thin, between 2 to 200 nanometres in thickness. The dark blue line below represents the primary oxide layer protecting the base metal, whether ferrous or non-ferrous. A metal familiar to most through its use in construction work is aluminium. Aluminium tends not to corrode as it has a very thick POL.

The POL is susceptible to mechanical destruction through processes such as cutting, drilling, welding and bending. It is also susceptible to chemical destruction through acids, corrosive gases and the like. Salts in our environment also cause corrosion (chloride and sulphate salts in particular) and finally electrolytes such as water take up ions thereby encouraging corrosion to occur. All these factors attack metals and can cause corrosion.

Interestingly perspiration from humans will cause metals to corrode. Finger perspiration consists of moisture, common salt and butanoic, uric and lactic acids which can cause metals to corrode.

Corrosion Cell

For corrosion to occur we need four elements. All FOUR elements need to be present.

1. Anode
2. Cathode
3. Conductor (the metal itself)
4. Electrolyte (usually water)

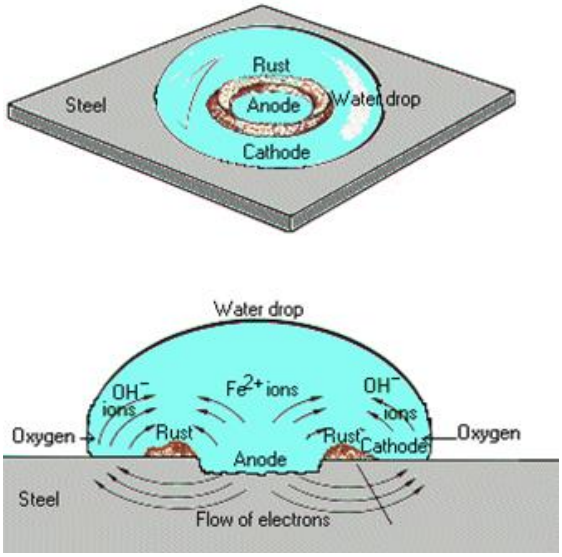


Figure 1 – Basic corrosion cell

By controlling any one of these four elements we can control corrosion.

For rust to form the anode becomes acidic and rust is then deposited at the cathode (the alkaline site). Pits form at the anode and peaks at the cathode.

The presence of chlorides (Cl), sulphates (SO2) or nitrates (NO2) increase the rate of corrosion as each of these reacts with hydrogen (H2) to form an acid which breaks down the POL of the metal. Typically these elements will come from things like salt (sodium chloride) and acids.

Similarly, if the electrolyte evaporates then these chemicals are left behind as salts. Salt is hygroscopic and will absorb water which can result in corrosion reoccurring.

The Galvanic Table

The galvanic table is named after Luigi Galvani who in 1780 discovered that when two different metals (e.g., copper and zinc) are in contact and then both are touched at the same time to two different parts of a muscle of a frog leg, to close the circuit, the frog's leg contracts. This was called animal electricity and this discovery lead others such as Volta to invent metals based electricity leading to what is known today as the battery.

The galvanic chart ranks metals on their theoretical ability to resist corrosion. Anything to the left of the zero line is corrosion resistant. This includes metals such as gold, platinum and titanium.

Anything to the right of the zero line such as iron and steel is prone to corrosion. Of interest is that both copper and silver are prone to corrosion.

Also of interest is that aluminium is classified as being prone to corrosion. In everyday life this is not evident (aluminium windows and boats do not generally corrode). This is because aluminium has a very thick primary oxide layer which protects the metal. This is true in most aluminium grades apart from specialist aircraft alloys which are prone to corrosion.

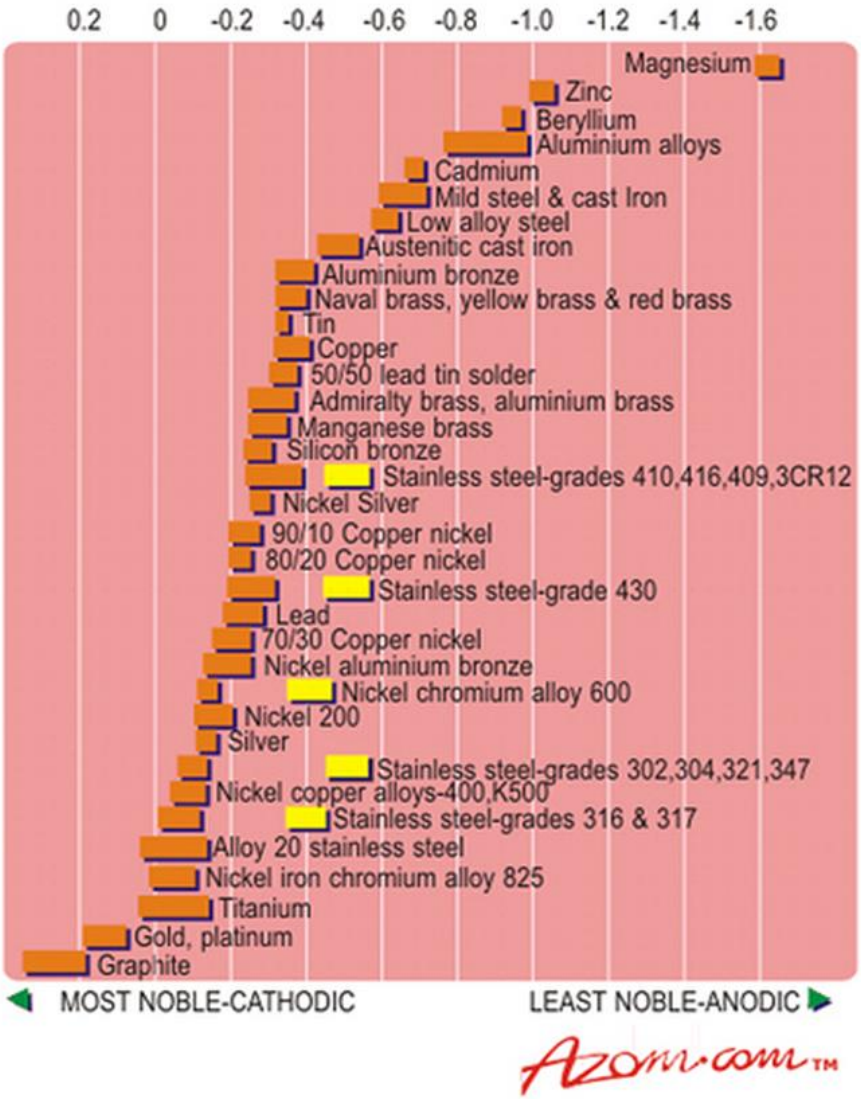


Figure 2 - Galvanic chart

Slowing Corrosion

We can slow the rate of corrosion by doing one of three things. These are:

1. Isolate the electrolyte (which is usually water)

The use of packaging, a desiccant (to absorb water) or coatings such as oil or paint are common ways to protect metal from water (electrolyte).

2. Isolate the anode or the cathode

This is typically done using a process called cathodic protection where a cheaper metal such as zinc is sacrificed to protect the main metal. Cathodic protection is used to protect large structures such as bridges, pipelines, jetties, etc.

3. Control the flow of electrons

By stopping the flow of electrons (electricity) from the anode to the cathode we can prevent corrosion. This is achieved by the use of inhibitors such as vapor corrosion inhibitors (VCI).

Forms of Corrosion

There are several forms of corrosion including galvanic, uniform, localised, pitting and stress corrosion. Corrosion manifests itself in the following forms.

Red rust

The most common form of corrosion, red rust is also known iron oxide. For the chemically minded the formula for rusting is shown below. Of interest is that 2 electrons are released every time a molecule of iron rusts, this increases the flow of electricity (remember the corrosion cell) and increases the rusting process.

Water is the electrolyte

$$\mathbf{Fe + 2H_20 = Fe(OH)_2 + 2H^+ + 2e}$$

Extra electrons released increase the speed of rusting

The full formula for those interested…

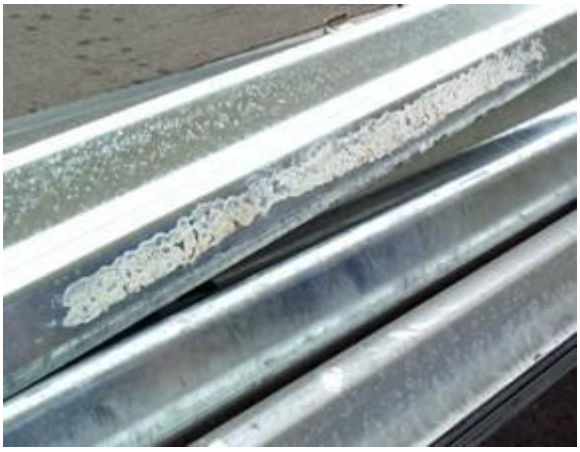
$Fe \leftrightarrow Fe^{2+} + 2e^-$	Iron atoms form soluble Fe^{2+} ions
$Fe^{2+} \leftrightarrow Fe^{3+} + e^-$	Fe^{2+} ions are oxidized to Fe^{3+} ions
$Fe^{2+} + 3OH^- \leftrightarrow Fe(OH)_3 + e^-$	Insoluble ferric hydroxide precipitates
$Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3 + 3H^+$	Insoluble ferric hydroxide precipitates
$Fe + 3H_2O \leftrightarrow Fe(OH)_3 + 3H^+ + e^-$	Insoluble ferric hydroxide precipitates
$Fe + 2H_2O \leftrightarrow FeO_2H^- + 3H^+ + 2e^-$	Ferrite ions go into solution
$FeO_2H^- + H_2O \leftrightarrow Fe(OH)_3 + e^-$	Soluble ferrites precipitate as ferric hydroxide

Picture 1 - Rusty flange

Rust always forms in the areas where metal has been worked. The process of forging, drilling and machining affects the primary oxide layer leaving the base metal vulnerable to corrosion.

White rust

White rust forms on galvanised surfaces where zinc is being sacrificed. If you own a boat trailer you might see this process occur which is an early indication that the galvanizing (zinc) is being depleted meaning the steel underneath will start rusting.

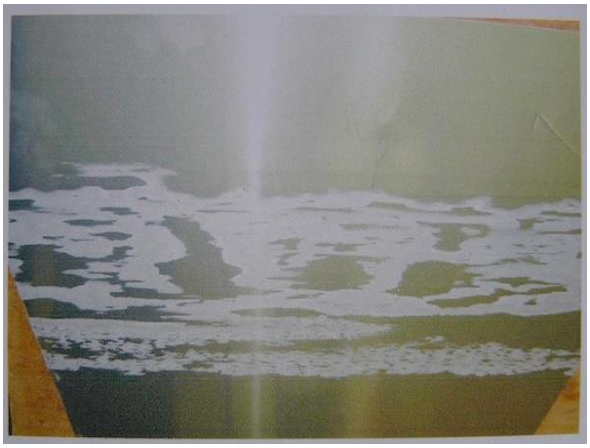


Picture 2 - White rust

Here we can see the zinc galvanising being depleted and exposing steel underneath

White rust – during working of aluminium

Some specific grades of aluminium (generally used in the aviation industry) may be susceptible to white rust. General commercially available aluminium is corrosion free due to a very thick primary oxide layer on the metal.

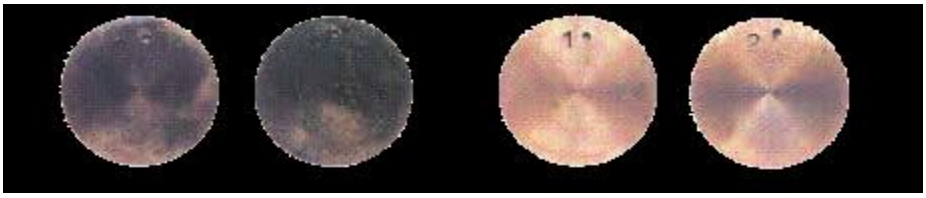


Picture 3 - White rust on aluminium

Corrosion of non-ferrous metals

Non-ferrous metals such as brass, bronze, silver and copper all tarnish (corrode). Given that metals such as silver, copper and solder are used in electrical equipment this can be of concern when electrical equipment is subjected to harsh environments.

Tarnishing will increase the metals resistance to electrical currents which will give rise to hotspots, electrical faults and possible fire.



Picture 4 - Tarnish on copper (left) and bright copper (right)

Introduction to VCI Technology

VCI Technology

Vapor corrosion inhibitors (VCI) were first discovered by Shell in the 1930's. Shell released a product called Dichan in 1937 and this found extensive use in industry until the 1960's when Shell exited the VCI business. Dichan worked reasonably well to protect metals from corrosion but it had a very high vapor pressure so could only protect metals in close proximity and for a limited time. It was also hygroscopic meaning it attracted water which encouraged corrosion when used in certain climatic conditions.

The second generation of VCI's were developed in the 1970's and these used secondary amine compounds.

In the 1980's the third generation of VCI's were developed using primary and tertiary amine compounds.

Since 2010 the fourth generation of VCI's is available with improved performance and a focus on environmental sustainability.

How VCI's Work

Corrosion inhibiting molecules are released that adsorb on exposed metal surfaces. The graphic below shows the VCI molecules represented by the yellow circles. The adsorbed inhibitor molecules on the surface of the metal disrupt the electro-chemical process that would otherwise occur as oxygen, water, contaminants and acid gases react with the exposed metal surface causing corrosion.

The second graphic shows the VCI molecules active inside a space such as a toolbox or gun safe working to protect the metal from corrosion. The VCI molecules travel on air. So wherever the air can move to so does the VCI.

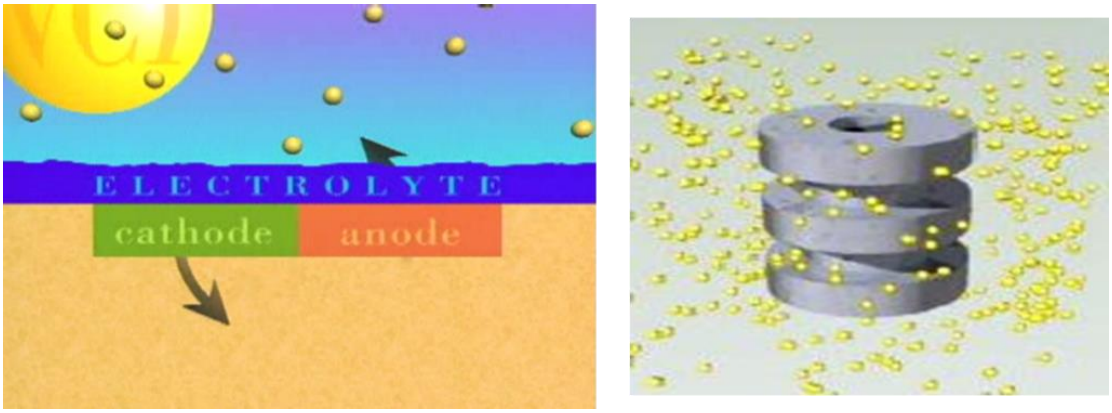


Figure 3 –VCI molecules (represented by the yellow circles) stop electrons from flowing thereby stopping corrosion

Key features of VCI include:

- "Smart" VCI with a long life and large protection volume;
- Stimulates the formation of the primary oxide layer on the metal;
- Can withstand small holes in packaging or air leaks;
- No need to remove air from an item wrapped in VCI plastic, just stop air flow;
- The VCI layer on a metal part can be as thin as one to two molecules and is visible under an electron microscope;
- When exposed to air, desorption of the inhibitor takes place within two hours but once enclosed again re-adsorbs in the same amount of time;
- VCI plastic film inhibits corrosion on metal for between 2 to 5 years (dependent on surface cleanliness of the part and storage conditions).

Health and Safety

VCI's are used in over 50 countries around the world and have been in use for many years.

Within Australia the VCI is approved for use under the Australian Industrial Chemicals Introduction Scheme.

Internationally the VCI is approved by the US Food and Drug Administration, approved by the US EPA, California EPA, National Toxicology Centre and counterparties in the European Union, Japan and Russia. As such the use of VCI requires no safety gear. However we recommend the use of gloves when handling metals so as to protect the metal surface from human perspiration.

Environmental

Products are safe to dispose of through normal waste streams. The VCI plastic is recyclable and can be placed in recycling bins at the end of its life.

The same master batch used to make our VCI plastic is being used across Europe by leading car makers due to its environmental credentials.

The Difference Between Desiccants and Vapor Capsules

The number one question we are asked about our VCI vapor capsules when attending gun shows and the like runs along these lines: "Is it a desiccant like silica gel that absorbs water?"

The answer is NO!

Desiccants such as our high performance desiccant (see page 24) and normal silica gel simply absorb water. That is all they do. Water molecules are attracted to the desiccant and then locked away thereby protecting metal from corrosion.

A VCI vapor capsule works as an emitter. It emits the VCI in to the surrounding space. It will protect all metal items in the defined volume for the lifetime specified. VCI acts in an active fashion to protect metals from corrosion. Desiccants work in a passive fashion.

Desiccants and VCI vapor capsules can be used together or separately. For high humidity environments such as north of the Tropic of Capricorn the use of a desiccant first to dry the air is recommended as otherwise the VCI may not be able to keep up.

The Practical Stuff

Applications

Applications for the use of VCI's to protect metals from corrosion are only limited by your imagination. We regularly have customers share photos of new uses such as protecting wood working tools or using a car cover to protect household goods during a renovation.

Here we present some typical applications as well as some submitted by customers. If you have any unique applications that you are happy to share please email them to us at sales@xrust.com.au and we'll include them in future editions of the e-book.

Firearms and Ammunition

VCI's offer a simple yet effective rust prevention solutions for firearms, firearm parts and ammunition. Our rust prevention products protect both ferrous and non-ferrous metals from rust and corrosion whilst having no impact on optics or fine timber finishes.

Choose from a variety of anti-rust gun storage solutions including vapor capsules designed to protect the contents of a gun safe through to multipurpose VCI firearm protection plastic products and barrel strips for longer term protection.

Our rust prevention gun storage products save you from having to use products like WD-40 on your firearms and is quick, easy and cost effective to implement.

Short term protection

For short term protection for firearms stored in a gun safe or gun room the use of vapor capsules is a quick and easy process. Simply remove them from the original packaging and place inside the gun safe/room.

They will emit the VCI which will find its way in to every part of the firearm and provide protection from corrosion for up to one year.

Picture 5 - Gun safe protected with a vapor capsule and barrel strips

For half height gun safes use the small VC1 vapor capsule. For full height (1500 mm) gun safes use the medium VC2 vapor capsule and for gun rooms, up to 26 cubic metres in volume use the large VC6 vapor capsule.

Vapor capsules can be combined so for example for a double door safe use two medium capsules.

All vapor capsules protect for one year and are safe to use on fine wood finishes, optics and electronics. In fact they will help protect electronics (copper and silver) from tarnishing.

We have also started making our own vapor capsules in Australia. These offer the same protection as the medium VC2 but at lower cost. Further details can be found here. As an aside, for anyone using these we would love a picture of the capsule inside the gun safe.

Long term protection

If you want to store your firearm or ammunition for longer periods then the use of VCI plastics is recommended. Firearm tube is made with proprietary VCI impregnated in to the plastic. It is 200 mm wide, 150 micron thick (0.15 mm) so heavy duty and comes in one continuous length which can then be easily cut to any length to suit your firearm.

Picture 6 - Long term protection using VCI firearm tube

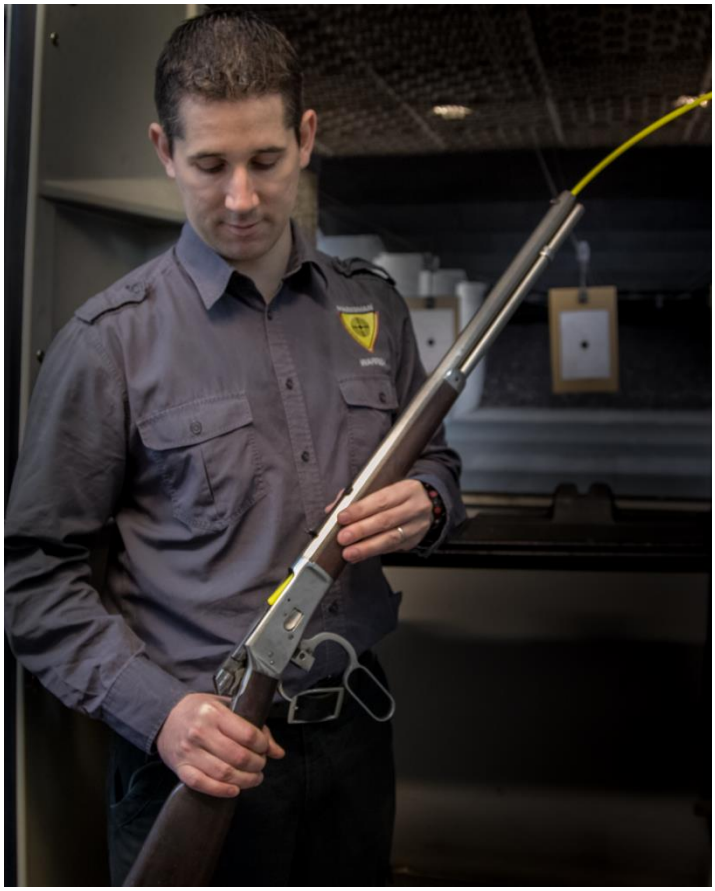
To use simply cut to length to suit the firearm, clean the firearm and then place inside the tube taking care not to leave fingerprints on the firearm. Then seal both ends with tape or using a heat sealer and the VCI will protect for up to two years. Depending upon storage conditions the VCI will protect for longer, anywhere up to five years. There is no need to remove air from the package, simply seal so as to stop the flow of air.

For smaller firearms such as pistols use the firearm bag which measures 400 x 400mm and comes with an easy to use zip lock closure.

Drawer liners (see page 22) can also be used to line ammunition boxes to provide 3 years of protection.

For targeted protection for rifles and other long firearms use barrel strip. Note that barrel strip comes in two diameters:

6.35mm (0.25") for large caliber firearms
5.08mm (0.20") for standard caliber firearms and suitable for use with 22's.



Picture 7 – Barrel strip

Barrel strip can also be used to protect pistols as shown below. Simply cut the barrel strip to length to suit the pistol. Also note the use of a VCI ziplock bag to provide extra protection during storage.

Picture 8 – Pistol storage using barrel strip and VCI bag

There are also rifle bags which are felt lined and made from heavy duty plastic. These protect for up to three years and are suitable for longer term storage or for providing protection to firearms whilst being moved.

Cars

Rust prevention is a necessity for car owners. The look, safety, reliability, and value of a car depend on its owner's care and rust control. Cars are a major investment and can be a rust magnet. There are so many parts, nooks, and crannies on cars that standard rust prevention technologies often fail.

Although nearly all car companies put some form of rust protection on their cars the results are limited. Not even the paint on the exterior of the car can escape rust's negative effect. In fact, according to the Automobile Association of America "more cars are destroyed by rust than by accidents."

Sometimes, automobile owners attempt to prevent rust by using a 'car cover,' but traditional car covers only do just that: 'cover' your car, leaving it exposed to the electrochemical reactions that actually cause rust and corrosion.

Picture 9 - Car cover protecting a Subaru

Our car cover will preserve all the hard work you've put into your car and keep it protected from dirt, grime, moisture and anything else that happens to land on your car as well as protecting it from rust by providing active VCI protection. This protects not only the mechanical elements of the vehicle but also the electrics and electronics.

The car covers will protect for up to 3 years and can also be used to "hold" a restoration project by slowing down the rate of corrosion until you can attend to the problem more permanently.

Features of the car cover include:

- ✓ Corrosion proof and rust inhibiting
- ✓ Water resistant
- ✓ Dust proof
- ✓ Mould proof
- ✓ UV stable for outdoor use

Please note although the material used to make the car covers is water proof the covers are not completely waterproof due to the effects of sewing in the zippers and the liner.

Picture 10 - Old Mercedes protected

Before you place your order, measure your vehicle to determine which size is most appropriate. You'll want a snug fit, though still leaving enough room to zip your car cover shut. Contact us if you need help sizing your vehicle.

Sizing

Car covers come in two sizes designed to suit the majority of vehicles.

Medium cover:
Measures 5,080 mm long x 2,220 mm wide x 1,520 mm high

Large cover:
Measures 5,485 mm long x 2,360 mm wide x 1,825 mm high

Motorbikes

Like the car covers the motorbike cover is a comprehensive storage system. Anti-corrosion technology is built into the zip-up motorbike cover providing rust protection for up to 3 years.

Picture 11 – Motorcycle cover

This is the ultimate solution for seasonal motorbike storage, for preserving high-value bikes or for "holding" an old motorbike until restoration can occur.

The motorcycle cover is:

- ✓ Corrosion proof and rust inhibiting
- ✓ Water resistant
- ✓ Mould proof
- ✓ Dust proof
- ✓ UV stable for outdoor use

To use your motorbike cover, simply clean and cool your motorbike, wheel it over the cover and zip it closed. The rust and corrosion inhibitors will remain active for up to 3 years after the date of purchase.

Picture 12 – Motorcycle cover

Please note that although the material used to make the motorbike cover is water proof the covers are not completely waterproof due to the effects of sewing in the zippers and the liner.

As for the car cover the motorbike cover can be used to "hold" restoration projects. So if you have an old BSA that you haven't quite got around to working on the motorbike cover can be used to protect it until full restoration can take place.

Sizing

Motorbike covers come in two sizes designed to suit the majority of bikes.

Small cover:
Measures 3,430 mm long x 1,778 mm wide

Large cover:
Measures 3,680 mm long x 1,778 mm wide

Boats

By their very nature boats and equipment stored on boats is highly susceptible to corrosion. VCI's can be used to protect everything from boat engines to fishing gear to boat electrics.

Inboard marine engine

Corrosion damage is especially prevalent in marine applications, where a constant salt air environment, often combined with high temperatures and humidity levels, increases the threat of corrosion.

Corrosion in these areas poses serious risks as it causes frequent malfunctions and reliability problems that are not only costly to repair, maintain or replace, but also puts the people that rely on this equipment at risk. Often efforts to combat corrosion have included activities such as oiling, fibre glassing or painting to remove or "cover up" corrosion.

Picture 13 – Inboard Engine

All of these methods are inefficient and potentially costly. Vapor capsules release a corrosion poreventing vapor with a radius of 30 cm to 2 metres within any enclosed area. This vapor invisibly protects your boat from rust and corrosion, ensuring your boat remains in top shape and condition. Picture 13 shows use of vapor capsules inside an inboard engine bay.

Fishing gear

Fishing gear such as lures, rigs, hooks and reels are prone to corrosion from either fresh water or salt water. For tackle boxes the use of a desiccant sachet and/or a vapor capsule will help keep your gear corrosion free. Zip lock VCI bags can also be used for long term storage of items such as reels, hooks and lures.

Picture 14 - Tackle storage protected by vapor capsules
Vapor capsule inside tackle box and one outside

Remember that the best way to look after these items is to rinse them off with fresh water, allow to dry and then store them.

Caravans and Campers

To protect enclosed or semi-enclosed spaces from corrosion use vapor capsules or plastabs. These will protect for up to 2 years and can be used inside tool kits or to protect electrical boards and electronic gear. You can also place either a vapor capsule or plastab inside the drawbars or chassis if these are made from tube and accessible.

Handyman and Trades

Everyone understands how important it is to keep tools in immaculate condition both for looks and better use and performance. But achieving such a high standard involves constant care and maintenance that is time consuming.

Preserve and protect your tools with drawer liners or vapor capsules. This will save you from having to use oil and products such as WD-40 on the contents of your storage containers every year. Drawer liners offer inexpensive and long life corrosion protection. Simply cut to size to suit your exiting storage toolbox or cupboard. Drawer liners are rubber backed, offer a non-slip surface and provide up to 3 years of corrosion protection. Drawer liners can also be used to line ammo boxes.

Picture 15 – Drawer liners

Picture 16 shows a wood working plane stored inside a VCI zip lock bag. Note that the date of first use of the VCI bag has been written down. The bag needs to be replaced after two years, so by October 2016. In the meantime it will provide inexpensive protection for a quality woodworking tool.

Picture 16 - Woodworking plane stored in a VCI zip lock bag

Note date of first use recorded on the bag

Desiccants

As described at the start of this e-book VCI's work in an active fashion in providing corrosion protection. Desiccants on the other hand work in a passive fashion and merely absorb water until they can absorb no more.

Desiccants can be used in conjunction with VCI's. In situations such as gun safes we would recommend that the desiccant is used OUTSIDE of the gun safe so as to not to encourage more water molecules to be attracted to the inside of the gun safe. The only exception to this would be is if the gun safe is air tight. A VCI vapor capsule can then be used on the inside of the gun safe to provide active protection.

We carry high performance desiccant sachets. Unlike silica gel these desiccant sachets use magnesium chloride to attract and lock away water.

Figure 4 shows the weight of water absorbed by silica gel and magnesium chloride. As can be seen magnesium chloride is up to seven times more effective so a 150 gram sachet does the same work as 1 kg of silica gel but at a fraction of the cost.

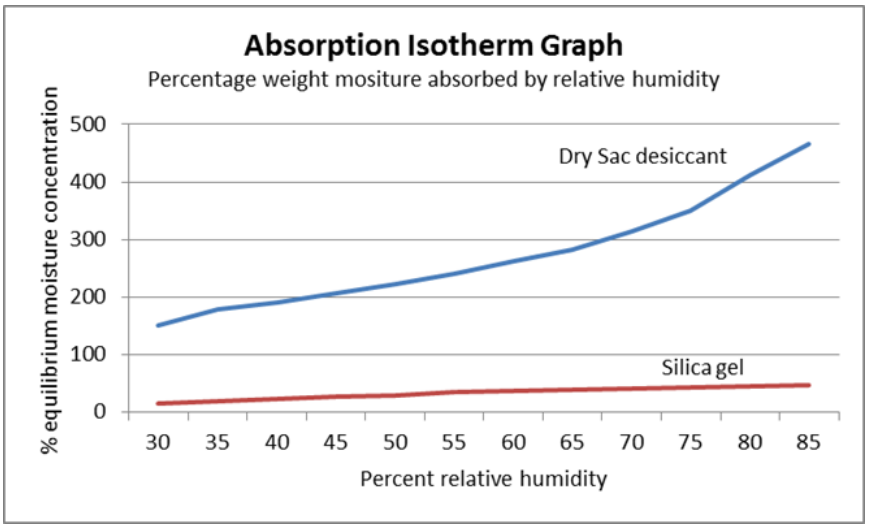


Figure 4 – Absorption isotherm graph

Ideal for use in the following applications:

- ✓ Storage of items such as clothing or shoes
- ✓ Optics and photographic gear
- ✓ Storage of paper goods such as books or photos
- ✓ Dry bags
- ✓ Electrical enclosures
- ✓ Electronic equipment
- ✓ Local or export shipments of goods