The

HotVac® Hull Cure System

Technical Manual

HotVac Hull Cure, Bridgend, Wales

Contents

1. Introduction:

Mankind has been building boats for thousands of years, but despite this wealth of experience, the ‘perfect’ boat-building material has yet to be found. For just about every available material suffers from some kind of shortcoming, whether it be rot and nail sickness in wood, corrosion and fatigue in metals, or efflorescence in Ferro cement.

Of all the materials available today, glassfibre must be the nearest thing to the perfect boat-building material yet. After all, it is comparatively cheap to fabricate; light in weight yet remarkably strong; and can easily be moulded into complex shapes by relatively unskilled operators.

This unique combination of properties has brought the joys and benefits of boat ownership to millions of people around the world, who would never have been able to afford, or maintain, traditionally built boats. But if glassfibre has one ‘Achilles Heel’, it would be have to be “**Osmosis**”.

Osmosis first caused panic amongst owners of glassfibre boats during the late 1970’s, and has been the subject of pet theories and wild speculation around yacht club bars ever since. Ironically, the causes of osmosis have been well understood by industry scientists for many years, but the slow and very complex nature of this process, allied with the extremely high boiling points of the chemicals involved has meant that in the past, treatment was always a rather ‘hit or miss’ affair.

Recent advances in resin chemistry, and improved moulding techniques have significantly reduced the incidence of osmotic blistering in glassfibre hulls less than ten years of age. But despite these improvements, it is likely that most of the glassfibre boats afloat today will need to be treated for osmosis at some stage in their lives. And with more than 90% of all new pleasure boats built in glassfibre, there is clearly a need for fast, economic and reliable treatment.

It is often said that ***“necessity is the mother of invention”***, and this necessity inspired east coast Yacht Surveyor **Terry Davey** to invent and develop the revolutionary **HotVac** Hull Cure system. Like many good inventions, **HotVac** harnesses a well established scientific principle in a novel way, to provide an elegant, engineering solution to the long-standing problems of treating osmosis. Put simply, **HotVac** allows timely, successful and consistent treatment of osmosis in boatyard conditions.

How Does HotVac Work?

Osmosis in glassfibre is usually caused by high molecular weight alcohols, (such as propylene glycol), which are added to polyester boatbuilding resins in small quantities during manufacture; usually as ‘water scavengers’ to help remove unwanted *‘water of esterification’*.

These alcohols are strongly hygroscopic (i.e. water absorbing) in nature, and they migrate together under the influence of incoming moisture to form ‘foci’; usually just behind the protective gelcoat. This in turn creates an ‘osmotic cell’, in which the gelcoat provides the semi-permeable membrane, and osmotic pressure is generated.

This process will ultimately cause blistering in the gelcoat, which we recognise as “Osmosis”, although the blisters themselves may take ten years or more to develop.

Successful treatment of osmosis requires complete removal of glycols and other breakdown products, but with boiling points in the order of 200 °C, it will be seen that removal by normal means is next to impossible without completely destroying the laminate.

The **HotVac** system overcomes these hurdles by using a combination of heat and high vacuum; so that glycol and other breakdown products can be vaporised and removed at temperatures which are not harmful to the laminate. This is best illustrated by the Vapour Pressure Curve for Propylene Glycol, shown in the graph (Fig 1-1 below).

The **HotVac** system itself is comprised of a powerful vacuum pump, which is capable of creating a vacuum as low as 2 millibars absolute, and special silicone rubber blankets of approximately 0.75 M^2 each. These blankets are fitted with seals around their outside to retain vacuum, and can be heated to temperatures of 100 °C or more as required.

Being inherently flexible, the heated silicone blankets conform intimately to the shape of the yachts hull, and are easily applied after normal mechanical preparation as outlined in this manual. Small and specially shaped blankets are available for confined spaces, bows and unusual hull configurations.

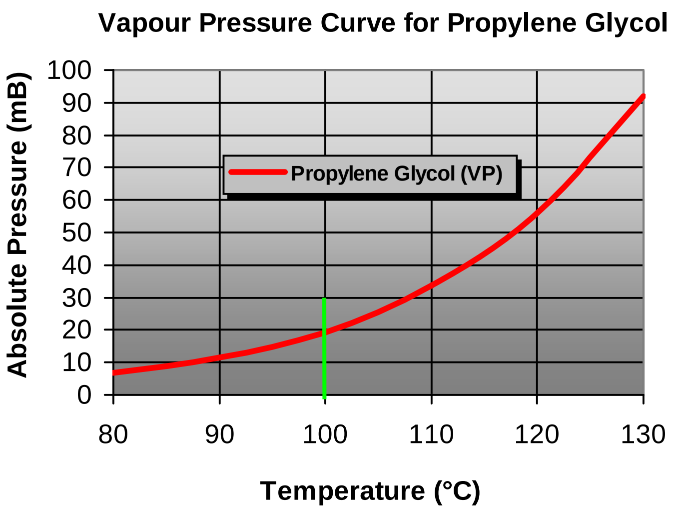

Fig 1-1. Vapour pressure Curve for Pure Propylene Glycol.

Each **HotVac** system can run up to four blankets at a time, which are applied in sequence around the yachts underwater area until it is completely dried. Alternatively, the blankets can be applied to selected areas as required, or used for localised repairs.

The blankets are usually applied for periods of between four and eight hours at a time for complete drying, but can be used for longer periods on heavier lay-ups, or where drying is slow.

The **HotVac** system cannot work miracles, but it has proved extremely successful for drying ‘problem’ boats, and also provides some guarantee of turnaround times; which is especially important where working boats or charter yachts are being treated. It also provides new opportunities for repairing sandwich construction boats and other advanced composites, which have often been uneconomic or impossible to repair by more traditional methods.

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2. Getting Started:

2.1. The HotVac® Hull Cure system has been engineered for simple and dependable operation in boatyard conditions, and should run reliably for thousands of hours if the following basic recommendations are followed:

2.2. **Lubricating Oil:**
Important: The Vacuum Pump is drained of all lubricating oil before leaving our works, and must be filled to the correct level before connecting the HotVac system to any electricity supply.

2.3. **We only recommend the use of Leybold Vacuum Pump oil as supplied by HotVac. The use of engine oils or compressor oil may damage your HotVac system, and will invalidate the guarantee.**

2.3.1. **Filling with Oil:**
Note: Stand the **HotVac** system on firm, level ground before filling with oil, or checking the oil level.

2.3.2. Open the equipment casing, and remove the cap from the oil reservoir (Fig 2-1). Fill the oil reservoir to the correct level using the **Leybold Vacuum Pump oil** supplied, until it reaches the correct level in the Sight Glass (Fig 2-2).

2.3.3. Avoid over-filling the pump with oil, or tilting the **HotVac** unit by more than 10 degrees during operation, as oil may block the Discharge Filter, forcing the pressure relief valve to operate. This will be evident by an oily mist discharging from the machine. Any excess oil should be drained through the Oil Drain Cock (Fig 2-3).

2.3.4. **Check the oil level daily whenever the equipment is in use.**

Fig 2-1. The Vacuum pump oil reservoir and filler cap.

Fig 2-2. The Oil Level sight in the Vacuum Pump Body.

2.3.5. **Changing the Oil:**
Vapour drawn from laminates during treatment will contaminate the lubricating oil. Some laminates will contaminate the oil more than others, so it is important to sample the oil regularly, and to change the oil before it becomes excessively contaminated.

2.3.6. **Note: Contaminated oil will cause premature wear of the Vacuum Pump, and may invalidate the guarantee.**

2.3.7. Change the oil by draining from the Oil Drain Cock (Fig 2-3), and refill as explained in Paragraph 2.3.2., taking care not to overfill. Dispose of used lubricating oils safely.

Fig 2-3. The Oil Drain Cock.

Fig 2-4. The discharge filter.

Fig 2-5. (Left) The Wire Mesh Filter.

This filter may become blocked by dust and debris sucked in through open vacuum manifold valves, and will cause slow pump running and loss of vacuum.

2.4. **Gas Ballast:**

A controlled stream of air is admitted to the pump rotor chamber through a small port at the top of the pump. This air dilutes vapours removed from the hulls being treated, and allows the pump to handle water vapour and potentially corrosive materials without damage. ***This port must not be blocked by dust or dirt.***

2.4.1. **However, great care must be taken to prevent any liquids from entering the pump, as these will cause ‘hydraulic lock’, resulting in serious damage to the pump and its motor.**

2.4.2. To avoid hydraulic lock, make sure that all sea-cocks and other openings beneath the heater blankets are sealed, or tightly shut before starting the vacuum pump. Moreover, do not apply the heater blankets over areas where liquid is draining from the hull. When the vacuum valves are first opened, watch the hoses closely for any indication of liquid entering the pump. **Shut the valves and stop the equipment immediately if liquid is seen. Do not continue until the cause has been located and rectified.**

2.5. Maintaining a Good Vacuum:

A high vacuum is vital to the success of the **HotVac** process. Leaks and poor connections will reduce the vacuum, and will significantly reduce performance. If a leak is suspected, the following process of elimination should be adopted:

2.5.1. With the pump running, shut all of the vacuum manifold valves. If the vacuum returns to normal values (i.e. below 5 millibars) the equipment is working correctly.

2.5.2. With the pump running, isolate the leak by opening each of the vacuum manifold valves in turn. If a normal vacuum (below 5mb) is maintained, the blanket and hoses attached to that valve are working correctly.

2.5.3. If the vacuum falls, and does not recover after opening a vacuum manifold valve, there is a leak in that circuit. (Note that more than one circuit may have an air leak, which will compound the problem).

2.5.4. When the leaking circuit(s) have been located, check all hoses and fittings for correct coupling, and examine the sealing mastic around the blankets concerned to ensure an air tight seal.

2.5.5. If the leak is not located by using this process, it is most likely that air will be leaking though a sea-cock or a small hole in the boat. Some very thin hulls, and those which are very poorly invested with resin may also cause a loss of vacuum.

2.5.6. **(Note:** Ambient temperatures of more than 30 °C (90°F) may cause the zero point of the vacuum pressure sensor to drift, usually to a higher figure. The pump absolute pressure may be checked by closing all the valves for a few seconds whilst the pump is running).

2.5.7. **Important: The digital pressure gauge operates a relay which controls power to the heaters. The heaters on all circuits will be turned off if the manifold pressure rises above 250 millibars.**

2.5.8. A graph showing the vapour curve of pure Propylene Glycol (one of the main contaminates in GRP laminates) is shown in Fig 2-1, below. ***For successful operation, vacuum must be maintained below the red line, whilst laminate temperature should not exceed 100 °C.***

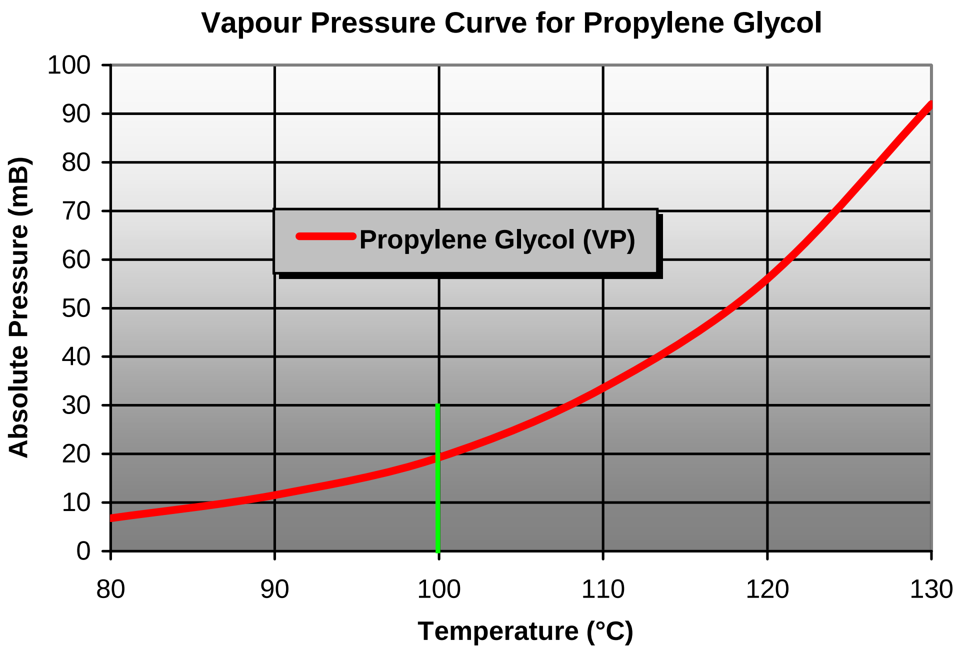

Fig 2-6. Vapour Curve for Pure Propylene Glycol.

For successful operation, vacuum must be maintained below the red line, whilst ideally, laminate temperature should not exceed 100 °C.

3. Fitting The Heater Panels:

3.1. **Introduction:**
The Heater Panels must only be fitted to a yachts hull when mechanical preparation has been completed, and the laminate has been thoroughly pressure washed with hot, fresh water to remove the bulk of any contaminants. **Thorough initial preparation will help the HotVac system to achieve optimum results.**

3.2. The laminate surface must also be clean, dry, and free of any dust or debris which may prevent the formation of a good vacuum seal.

3.3. **Preparing the Heater Panels:**
Each of the **HotVac** panels is fitted with a soft ‘bleed blanket’, which allows the passage of gas and vapour between the yachts hull, and the silicone rubber casing, where it is exhausted into the vacuum system. These blankets also help to regulate heat input into the laminate being treated.

3.3.1. The bleed blanket must be attached to the heater panel with several ‘tabs’ of double sided adhesive, spaced around the outside of the panel. (Fig 3-1). The bleed blanket can normally be expected to have a useful life of at least fifteen to twenty applications, but hulls with a heavy or sticky discharge will reduce this lifespan significantly, and more regular changes will required.

3.3.1.1. (Note: The tabs supplied by **HotVac** may be cut in half for economy).

3.3.2. When the bleed blankets have been fitted, a length of sealing tape must be fitted around outer edge of each heater panel, to provide an airtight seal between the panel and the yachts hull.

3.3.3. The edges of the panel ***must*** be clean, dry, and free of any dust before the sealing tape is applied..

3.3.4. Start by cutting the end of the tape with sharp scissors to achieve a square end (Fig 3-3). Apply the tape carefully around the outer edge of the heater panel, taking care to avoid gaps between the tape and the heater, and keeping the tape clean. When applying the sealing tape around corners, cut the protective film to allow an even radius, and to avoid kinking the tape (Fig 3-4).

3.3.5. When you have completed the circle, cut the tape squarely again with sharp scissors, to achieve a ‘butt end’ joint. **This is important to achieve a good vacuum seal.**

3.3.5.1. **(Note: The tape must always be cut from inside the heater panel working outwards, to avoid the risk of cutting the heater matrix!)**

3.3.6. If you run out of sealing tape before completing the seal, use the procedure described above to ensure a good joint between lengths of tape. Avoid joining the sealing tape on corners, as it may prove difficult to achieve a satisfactory seal.

3.3.7. **Do not remove the protective film from the tape until you are ready to fit the heater panel into place. Dust and debris on the adhesive surface will make it difficult to achieve a good vacuum seal.**

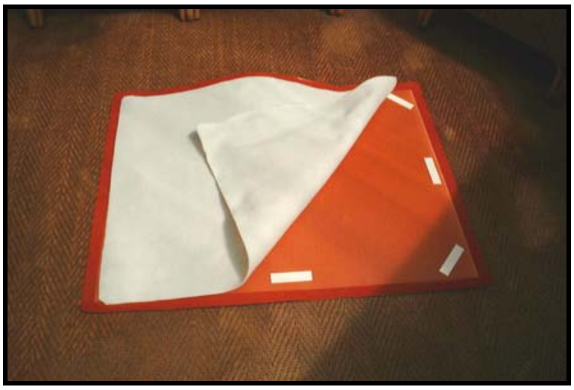

Fig 3-1. Double sided adhesive tabs fitted to a HotVac heater panel.

Fig 3-2. Cut the sealing tape at 90° from the inside to avoid damaging the heater matrix.

Fig 3-3. A square end will help to achieve an airtight 'but' joint.

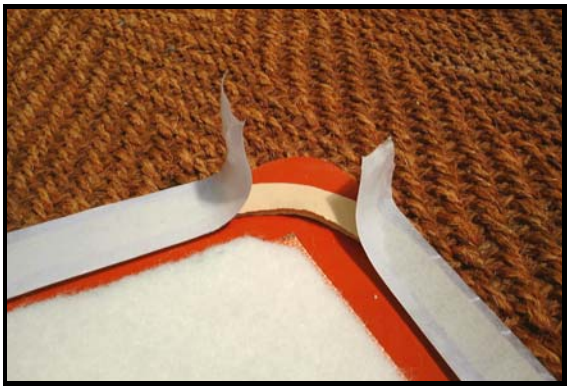

Fig 3-4. Cut the protective film from the sealing tape, and lay the tape in a smooth radius around corners. Avoid kinking the tape.

3.4. **Fitting the Panels to the Hull:**

Before offering the panels up to the hull, check that no leaking or open sea cocks will be accidentally covered.

3.4.1. If the heater must be fitted over a metal sea-cock, we strongly recommend that the fitting is covered with a piece of electrically non-conductive material to prevent any electrical short circuit, and to avoid excessive heat transfer.

3.4.2. As a further precaution, a circle of mastic sealant applied between the protective cover and the skin fitting will reduce the risk of leakage from inside the hull

3.4.2.1. (**Important:** Experience has shown that the seal achieved by 'tapered plug' sea-cocks is inadequate to maintain a good vacuum. This may result in foul water being drawn into the machine.

3.4.2.2. Tapered plug sea-cocks must only be covered if the plug is withdrawn from the body of the fitting, and the valve itself plugged with scrap sealant tape).

3.4.3. When the vacuum valves are opened, the vacuum should return to below 10 millibars within a few seconds. Failure to achieve a vacuum below 10mb with the valves open indicates a leak.

3.4.4. Small leaks may often be identified as localised 'cold spots', which are caused by air expanding rapidly under high vacuum. A 'sonic' leak finder may also be found helpful when searching for leaks. (See section 2.5 on page 8, above: **Maintaining a Good Vacuum**).

3.4.4.1. **Important: The digital pressure gauge operates a relay which controls power to the heaters. The heaters on all circuits will be turned off if the manifold pressure rises above 250 millibars.**

3.4.5. If the leak is caused by a deep crater or hull roughness, it may be necessary to peel back the heater and smooth out the undulation with a coarse disc sander.

3.4.6. When the heater panels are used on chines or 'spray' rails, it is likely that two people will be required to position them. Duct tape may be used to help secure the heater in position until vacuum is achieved.

3.4.7. **Important: Positioning the heater panel hose connection, cable connection or temperature sensors over a sharp edge or abrupt curve may cause serious damage to the heater when the full vacuum is applied.**

3.5. **Temperature Control:**

When each heater has been correctly positioned, and a good vacuum has been achieved, the electrical connections should be coupled, and the heater(s) switched on. The controller will initiate a short self test and start up sequence before indicating ambient temperature.

3.5.1. Select the required process temperature to start the heating process. A small red light between the digits will flash periodically as power is applied. The interval between pulses, and their duration will vary as the heater temperature rises towards its set point.

3.5.2. Best results are usually achieved at temperatures between 80 ~ 100 °C. Please note that the control system is pre-programmed to prevent the inadvertent selection of temperatures higher than 100 °C (212 °F).

3.6. **Setting the Temperature:**

To set the process temperature, proceed as follows:-

3.6.1. Press the ‘P’ button. The display will now indicate the set point.

3.6.2. Adjust the set point by pressing the ‘up or ‘down’ buttons until the desired value is displayed.

3.6.3. When the required process temperature has been set, the display will return to the normal temperature display mode within ten seconds.

3.6.3.1. (Note: The heater controls are pre-set at our works to limit the rise in temperature to no more than 3 °C per minute, and to a maximum temp of 100 °C. These limits are set to help avoid damage caused by thermal shock or overheating. Please contact **HotVac** for advice on re-programming if temperatures outside of these limits are required).

3.6.4. The heater matrix within the **HotVac** heater panels is designed to provide uniform heat input, and temperature across their entire surfaces. However, significant variations in hull thickness beneath individual heater panels, or internal features such as foam filled members or thermal insulation may result in the heater temperature rising locally above the set point. Similarly, if the temperature sensor is located over one of these features, the remainder of the panel may not achieve the necessary process temperature.

3.6.5. We therefore strongly recommend that the surface temperature of each heater panel is checked regularly with the Infra Red thermometer provided to identify any unacceptably hot or cold spots. (Fig 3-6).

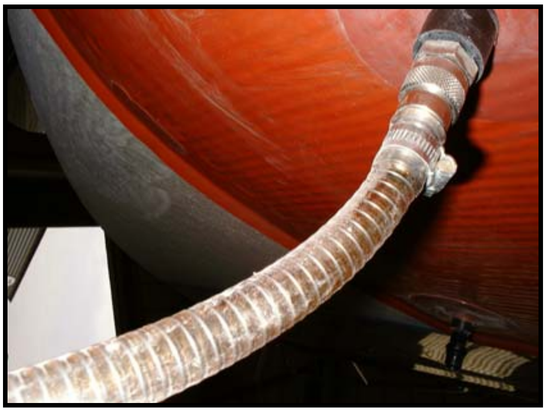

Fig 3-5. Check the vacuum hoses for liquid immediately after opening the manifold valves. The formation of small fluid droplets in the hoses is normal.

Fig 3-6. Use the Infra-Red thermometer to check the heater panels for hot or cold spots when the set point temperature has been reached.

3.7. When the process has been running for three or four hours, the first panel should be removed, and the hull examined visually, and checked with a moisture meter after cooling.

3.7.1. The average process time for an effective **HotVac** treatment is six hours per heater. Thin or lightly damaged laminates can often be treated successfully within shorter periods, whilst thick laminates, and those with deep seated problems may take up to twelve hours.

3.7.2. Process times longer than twelve hours usually indicate that the hull moulding is affected by more serious problems, and may require destructive testing to determine whether radical removal of damaged material is needed.

3.7.3. (**Note:** Moisture meter readings should not be taken until the laminate has cooled to ambient temperature. Measurements taken at higher temperatures are likely to be unreliable).

3.7.4. If the laminate appears visibly sound, and moisture meter readings are satisfactory, the heater panel should be moved on to another location, and the process repeated. However, note that heaters should be positioned so that subsequent processes will overlap slightly. Repeat this procedure until the entire underwater area has been covered.

3.8. **Ambient Conditions:**
The **HotVac** heater panels are designed to dissipate heat evenly from their outer surface. Placing insulation of any kind over the heaters will cause a dangerous increases in temperature, and may result in damage to the equipment and the moulding.

3.9. Wind or cold draughts blowing across the heater panels will cause excessive heat loss, and may prevent the heaters form achieving the correct process temperature. Electricity consumption will also be high.

4. General Safety Precautions:

The **HotVac** hull cure system uses high temperatures, high vacuum and mains voltage electricity. Safe operation is therefore essential to avoid the risk of accidents.

4.1. The process must only be carried out by persons who have received training from HotVac Hull Cure or their authorised representatives.

4.2. **Electrical Safety:**
The equipment is designed for either 220 volt 50 ~ 60 Hz single phase operation, or 415 volt 50 ~ 60 Hz three phase operation, as marked on the rating plate. The equipment must not be connected to any supply where the voltage is likely to deviate by more than ± 6% of the specified voltage.

4.3. Avoid the use of excessively long lengths of cable, or coiled cables, which will seriously reduce the supply voltage, and may cause overheating of the cables, and/or the vacuum pump motor. Damage caused to the **HotVac** equipment by operation at incorrect voltages will not be covered by warranty.

4.4. The heaters and heater cables operate at 220 volts AC. The machine is fitted with a ‘residual current’ (RCD) earth leakage breaker to minimise the risk of electric shock.

4.5. **Important: Disconnect the machine from the electricity supply before handling damaged or faulty heaters, cables or connectors.**

4.6. **General Safety:**
The vacuum pipes, electrical cables and electrical leads constitute a hazard in the workplace. Ensure they are protected, covered or clearly marked so as not to be a danger to pedestrian traffic or work colleagues.

4.7. Only parts, lubricants and consumables supplied or recommended by **HotVac** Hull Cure should be used.

4.8. **High Temperature:**
The heaters can operate at temperatures of 100 °C (212 °F) or more, and **must be allowed to cool before handling.**

4.9. The heaters are highly developed to provide even and carefully controlled heating. Safe operation of the heaters relies upon even dissipation of heat from the outer surface. Placing insulation of any kind over the heaters will cause a dangerous increases in temperature, and may result in damage to the equipment and the moulding.

4.10. Variation in heat flow patterns through GRP mouldings can result in unacceptably high temperatures in areas where heat is not dissipated evenly. Localised hot-spots may be caused by foam filled members and thermal insulation, Etc.

4.11. The hand held, laser sighted Infra Red thermometer (supplied with the equipment) must be used regularly to identify any unacceptably hot or cold. **Do not start the process if the infra-red thermometer is missing, damaged or inoperative.**

4.12. **Vacuum Manifold Valves:**
Make sure that the valves to the vacuum manifold are kept shut unless blankets are fitted to a moulding, and hoses and blankets are properly coupled. Opening the vacuum valves unnecessarily will result in dust and dirt being sucked into the equipment, causing premature wear and tear, and damage to the discharge coalescing filter.

Loss of vacuum will also reduce the performance of those blankets which are correctly fitted and connected.

4.13. **HotVac** Hull Cure recommends that the process is not left unsupervised for long periods.

5. So What is Osmosis?

In its classical form, Osmosis is defined as "The equalisation of solution strengths by passage of a liquid (usually water) through a semi permeable membrane". (See **Fig 5-1**, below).

However, whilst this definition gives us a clue to the basic nature of osmosis, its actually more applicable to trees and plants than to glassfibre laminates. This is because correctly laid up glassfibre laminates should be chemically inert (or 'passive') when manufactured, and so should not be capable of creating an osmotic cell, or encouraging osmotic breakdown.

Osmosis Explained

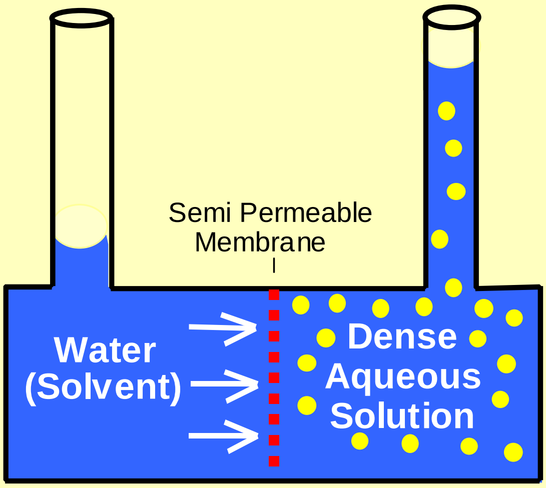

Fig 5-1. A Simple Osmotic Cell

Osmosis occurs where two solutions of differing density (or concentration) are separated by a semi permeable membrane, as shown in the diagram.

For our purposes, the membrane could be a polyester gelcoat or a paint film, although many other natural or synthetic materials would work just as well.

If both chambers were filled with an identical fluid, our cell could be said to be 'in equilibrium', and there would be no flow of liquid in either direction: but if we increase the density of the fluid in one of the chambers by adding a 'solute' such as sugar or common salt, the 'solvent' will be drawn through the membrane towards the chamber having the greatest density, in an attempt to return the cell to equilibrium.

The fundamental principle here is that 'stronger' solutions will always try to draw solvent from their weaker neighbours - but as the more concentrated solution becomes diluted, it must also increase in both volume and pressure - which in the case of glassfibre boats leads to the all too familiar gelcoat blistering!

Osmosis itself is an entirely natural process, which is used by plants and trees to draw moisture and nutrients from the soil, and plays an essential role in the function of cells in body tissues.

The osmotic process can be reversed by applying greater pressure than the 'osmotic pressure' (as in reverse osmosis water treatment systems), or by simply swapping the two solutions around, although there is no way of reversing the breakdown of glassfibre laminates.

However, as soon as a glassfibre hull is immersed in water, it will start to absorb moisture through the gelcoat, resulting in a gradual increase in laminate moisture content.

Initially this moisture does little damage, and much of it passes harmlessly through the hull and into the bilges, where it disperses as water vapour.

But given time, accumulations of moisture will start to break down (or hydrolyse) materials used to manufacture the laminate, liberating a series of chemically active breakdown products.

Acetic acid is the most obvious of these, and is liberated together with a smaller quantity of Hydrochloric acid from the emulsion binding agent used in the manufacture of Chopped Strand Matt.

But whilst this mixture may have a nasty, vinegary odour, and will turn litmus paper red, other breakdown products are far more damaging because they are ***hygroscopic***, (i.e. they attract and absorb water), and once liberated they help to accelerate the rate of laminate moisture absorption, and hence the rate of laminate breakdown.

As this circle of moisture absorption and laminate breakdown progresses, the volume of breakdown solutions within the laminate gradually increases; and as these compounds have a much higher 'molecular weight' than the original moisture (H_2O), they are unable to escape back through the gelcoat. This 'osmotic' effect may ultimately result in gelcoat blistering owing to hydraulic pressure within the laminate, although this will usually take many years to develop.

The diagram below shows how this process evolves:-

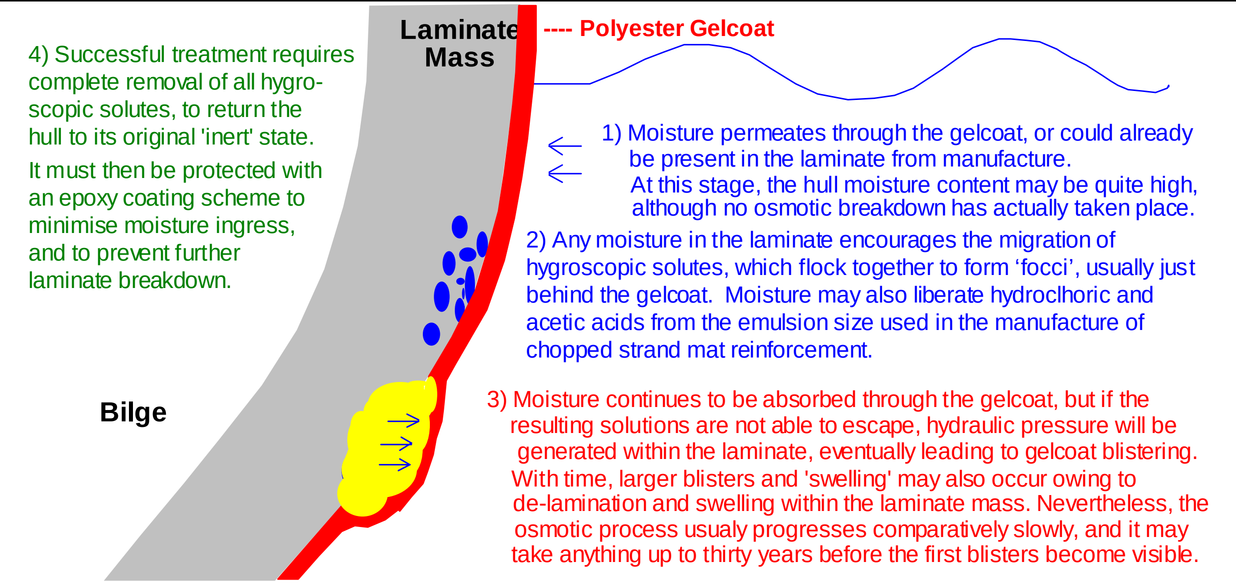

Fig 5-2 How Osmosis Develops in Glassfibre Laminates

So in ***practical*** terms, osmosis is probably best defined as "migration of hygroscopic solutes within a laminate owing to moisture ingress, which ***ultimately*** results in blistering of the gelcoat

However, whilst we have seen that osmosis is essentially a chemical phenomenon, it rarely occurs without some help from physical defects within the laminate. Faults which allow rapid moisture ingress such as wicking, and thin or crazed gelcoats will inevitably come to mind first, but far more serious problems will often be found just behind this glossy exterior.

Of all the physical defects found in osmotic yachts, 'underbound' laminate is by far the most common, and occurs when the glass reinforcing fibre is not thoroughly wetted and impregnated with resin during manufacture. Ideally, the glass cloth is laid up one layer at a time, and each thoroughly 'wetted' with resin before the next is applied**;** however, in practice, several layers of matt are often laid up together, with the inevitable result that some fibre remains underbound, possibly with some larger air inclusions.

It is certainly no coincidence that poorly bound laminates are found in so many osmotic hulls, as underbound matting provides an excellent 'reaction chamber' where even a small amount of moisture can create a great deal of damage. To make matters worse, underbound fibre is most often found directly behind the gelcoat, where it is best placed to absorb any incoming moisture.

An added complication is that air trapped inside the laminate helps to prevent complete cure of polyester resins (owing to an effect known as oxygen inhibition), with the result that resin hydrolysation is even more likely to occur.

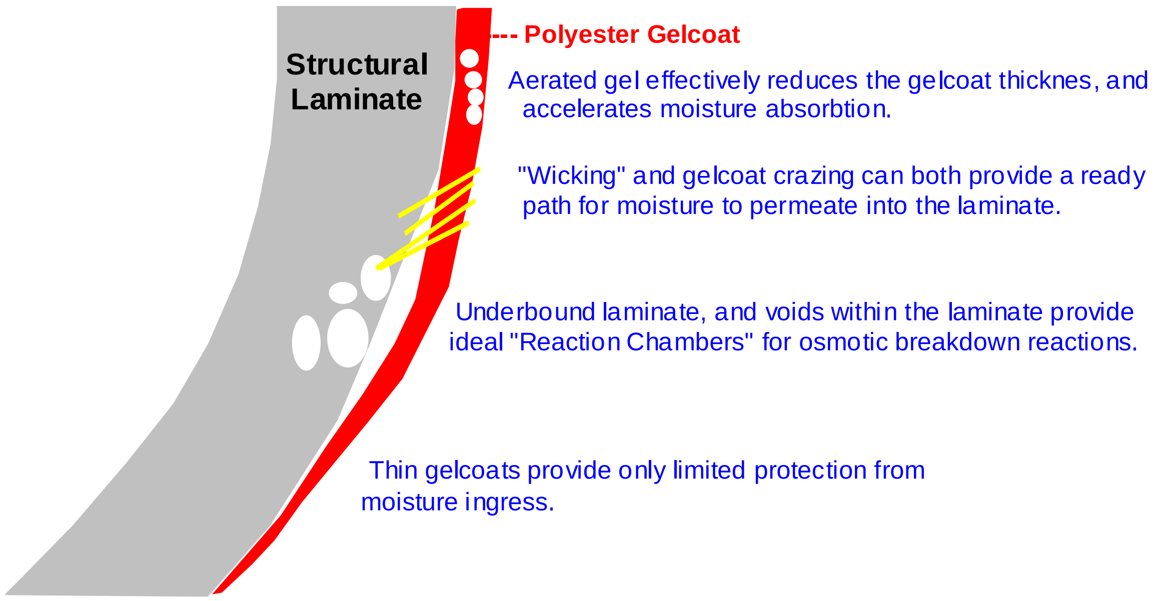

Fig 5-3. Typical Physical Defects Found in Glassfibre Laminates

So what bearing do these facts have on remedial treatment?

Conventional wisdom would suggest that osmosis is caused by water; therefore, if we can ‘dry out’ the hull, and then ‘seal it up’ with epoxy, all of our problems will be overcome. This rather simplistic notion has led to many innovative drying methods, with Infra Red heaters and Dehumidifiers being the most popular.

Perhaps the most original idea was the use of Vacuum Drying: The American journal ***‘Professional Boat Builder’*** carried a fascinating article on this subject some years ago, where industrial vacuum pumps had been used in an experiment to speed up the drying process. These pumps were connected to an elaborate system of pipes inside large sheets of polythene, which were then carefully taped around the yachts bottoms to provide a large ‘Vacuum Bag’.

The theory was that any moisture would quickly evaporate under high vacuum, and that drying could be then completed in days rather than weeks. Despite initial optimism, vacuum drying was found to be no more successful than conventional methods, with many boats stubbornly refusing to dry. Furthermore, when the pumps were switched off, moisture levels began to rise again.

This failure to dry is one of the most common difficulties encountered when treating osmosis, and suggests that perhaps we have missed the point somewhere along the way. Indeed we have**;** in fact our ‘conventional wisdom’ is seriously flawed on two counts, both of which present major obstacles if we don't know what the problem is.

The first is that laminate breakdown of the type we are discussing involves a number of ***irreversible*** reactions, which cannot be remedied by simply ‘drying out’ the hull, ***even if there is no evidence of osmotic blistering.***

The second is that some of the breakdown products liberated by osmotic laminates are extremely hygroscopic, and they will ***readily absorb significant quantities of moisture from any available source.***

Whilst this moisture can be ***temporarily*** removed by heating, it starts to return as soon as the heat source is removed, thereby sustaining the very breakdown process that we are trying to eliminate.

This effect is clearly demonstrated in the diagrams and graphs below, which show that these compounds ***must*** be completely removed during the preparation stage if osmosis treatment is to be successful.

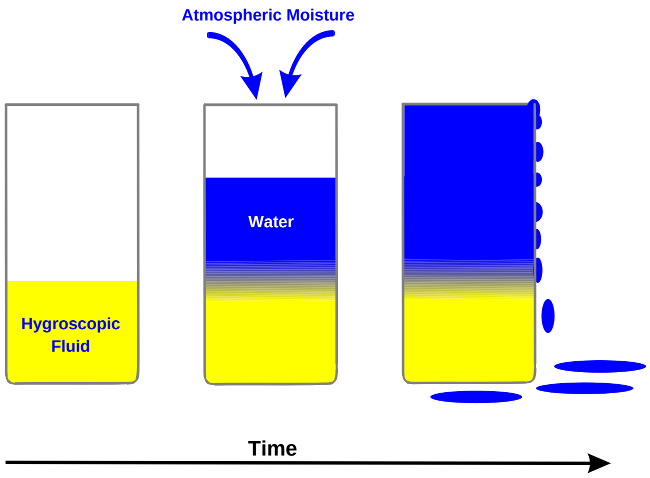

Fig 5-4. Diagram illustrating the moisture absorbent properties of hygroscopic fluids.

The usual culprit in both of these cases is propylene and/or ethylene glycols, both of which are high molecular weight alcohols, often used as a ‘moisture scavenger’ to remove *water of esterification* from the polyester resin after ‘cooking’. Additionally, these glycols are sometimes found in the pigment dispersions used for colouring gelcoats. However, unlike the sort of alcohols that we drink (i.e. ethanol), glycols are thick, syrupy liquids, often having a rather sweet sickly odour.

The real problem though, is that apart from being hygroscopic, glycols are impossible to remove by ‘conventional’ methods owing to their high boiling points. As an example, pure propylene glycol has a boiling point of 198 °C, or nearly twice that of water**!**

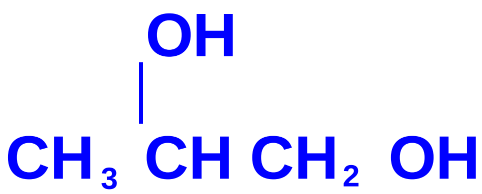

Fig 5-5. Chemical Formula of Propylene Glycol

Some readers will also be aware that glycols have other uses, including the manufacture of hydraulic brake fluid, (usually polyalkylene glycol ether). This illustrates our problem perfectly**:** Glycols are used in brake fluids because of their very high boiling points, and because they are involatile, (i.e. they don't evaporate) even at under-bonnet temperatures of 80 °C and more. However, they do need to be replaced periodically, as they readily absorb moisture from the atmosphere. Glycols are also found in some cosmetics, where they are useful for their moisture retaining properties**;** so if you have ever wondered why some hulls refuse to dry out, despite months of waiting and hundreds of pounds worth of electricity, now you know why**!**

Fortunately, there is a very easy and entirely logical solution to these problems, as like all alcohols, glycols are ‘Polar’ in nature, so they are readily soluble in fresh water. A less obvious benefit is that they also conduct electricity, so they can even be detected with a good moisture meter. Indeed glycol is often confused with moisture when moisture readings are taken.

This all makes good sense, but it still begs the question, ‘*why can't we just seal the hull up with a few coats of epoxy?*’ The answer to this question is that ***all paint coatings (including, epoxies, polyurethanes and gelcoats) are slightly moisture permeable to moisture.*** Consequently, when the yacht is re-launched, any incoming moisture is simply ‘mopped up’ by glycol in the laminate, and will usually result in renewed blistering of the coating scheme after a season or two afloat.

Localised Osmosis treatments are rarely successful for the same reasons, as the treatment can only be effective in the area treated, whilst the remaining laminate is almost certainly ‘Osmotic’, if though blisters may not yet be visible.

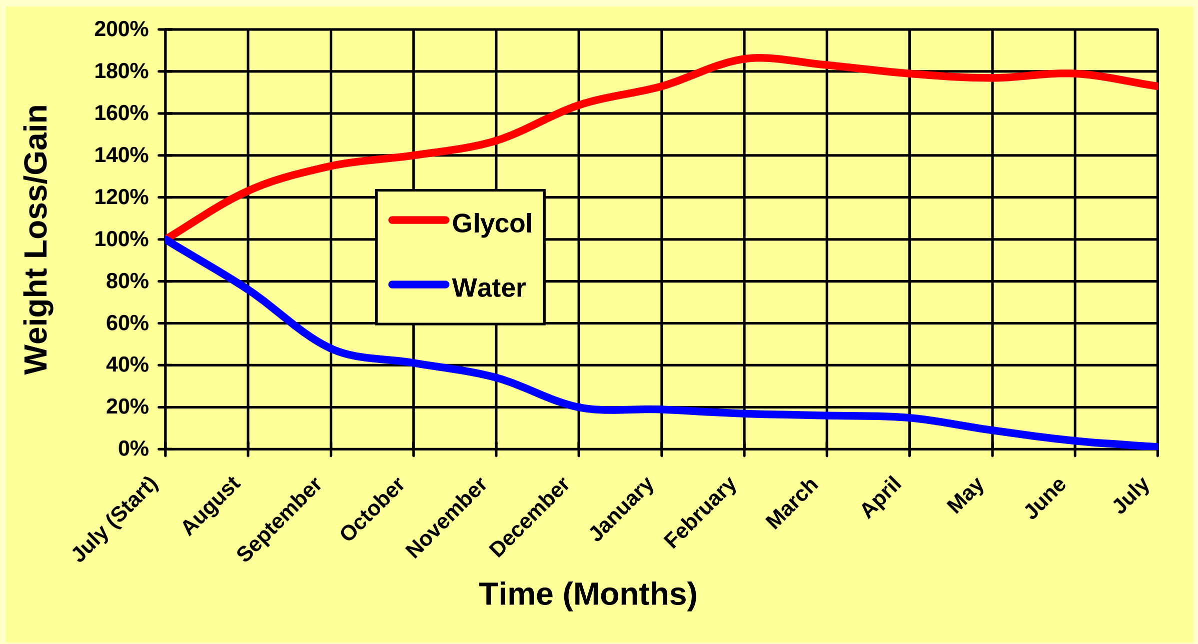

Fig 5-6. Comparative Graph showing how Glycols Absorb Moisture over Time.

Two identical 250 Ml glass beakers were used in this experiment. One of the beakers was filled with 100 grams of propylene glycol, and the other with 100 grams of tap water. The samples were then allowed to stand for twelve months in an unheated, well ventilated boat shed, and weighed regularly to give the figures above.

6. Choosing and Using Electronic Moisture Meters:

A good moisture meter is an indispensable tool when inspecting or treating glassfibre laminates; but like any instrument, moisture meters have their peculiarities and limitations, which it is always better to know and understand before starting work.

How Do Moisture Meters Work?

Moisture meters determine moisture content by applying a high frequency signal between two electrodes, which are held against the laminate surface. As moisture content increases, the electrical capacitance measured between the electrodes rises, and is interpreted by the meter to indicate a value on it's display.

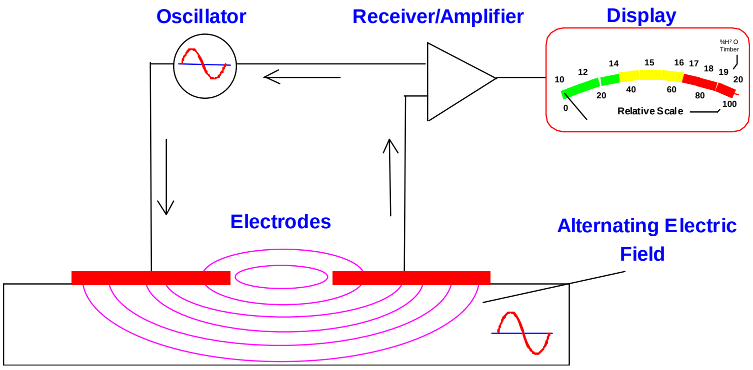

Fig 6-1. Schematic of a Typical Electronic Moisture Meter

Whilst this technique gives a useful indication of moisture content, the spacing of the two electrodes and the thickness of any gelcoat is critical to the readings given. As a general rule, the gap between the two electrodes dictates the maximum depth to which moisture can be detected in a laminate, (i.e. the larger the gap, the greater the depth of signal), with sensitivity dropping off rapidly beyond this point.

This is an important factor, as the moisture we are looking for is most likely to be found within the core of the laminate itself, rather than on the surface, or in the comparatively dense gelcoat.

The reason for this anomaly is that most electronic moisture meters were originally designed for use on timber and masonry; both of which are comparatively homogenous in nature. Any moisture in these materials tends to be quite evenly distributed, so reliable moisture readings can be easily be taken from the surface. There is also no such thing as a "standard" for electronic moisture measurement in either the construction or marine industries.

Consequently, moisture meter manufacturers have always enjoyed considerable freedom in the design and specification of their instruments, with the result that many different designs have evolved over the years, all with widely varying electrical and measurement characteristics. And unfortunately, once a design and calibration standard has been accepted by the market, it is difficult for the manufacturer to then change that design, even though the changes may well bring substantial improvements in performance.

By contrast, glassfibre boat hulls are essentially 'laminar' in nature, being comprised of a series of layers of glass cloth and resin, with a dense protective gelcoat on the outside.

This means that moisture readings must be taken ***through*** the gelcoat, the thickness of which is usually unknown. A further complication is that the hygroscopic breakdown products found in osmotic laminates result in moisture becoming concentrated where hydrolysis has taken place; which could be several millimetres beneath the surface.

The danger here is that a moisture meter which reads only from the surface may well indicate that an osmotic laminate is perfectly dry; either because the gelcoat is very thick, or because moisture has become concentrated away from the surface.

Yet another problem is that epoxy resins and coatings such as Blakes SFE200, SP Ampreg and International Gelshield *Plus* can retain significant quantities of moisture for several weeks after lifting out, so that a surface reading instrument will give erroneously high readings, even though the laminate may be perfectly dry.

Given this information we clearly need to understand the limitations of our instruments, and where possible, to choose a meter which gives an indication of overall laminate moisture content.

Choosing a Moisture Meter:

To demonstrate the characteristics of the most popular meters, a series of 'response curves' were plotted using gelcoat shims to see how deeply the instruments could detect moisture.

The sensitivity of each moisture meter was plotted against varying thickness of white isophthalic gelcoat, which had been cast to exact dimensions between sheets of plate glass.

The gelcoat shims were then placed over a 'dummy' laminate, made up of several layers of chopped strand glass, which had been doped with a mixture of water, acetic acid and propylene glycol, and sealed into a thin polythene bag to prevent evaporation during the test.

All of the moisture meters gave a 100% of scale reading when placed directly on the test sample.

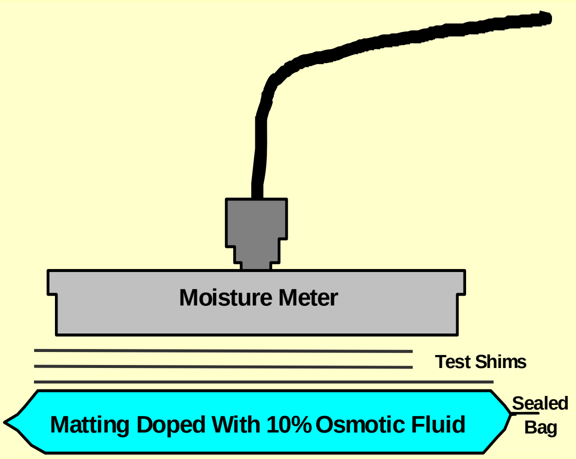

Fig 6-2. Test Method Used To Compare Instruments

In the first graph, the Mk II and Mk II Sovereign meters are tested on both Scale A and B, with a curve from the Tramex Skipper set to Scale 1 for comparison.

As would be expected, the curves from the Sovereign meters are very similar, and show that the Mk II instrument was designed and calibrated to give comparable readings to the earlier Mk I model.

However, the gap between the two electrodes on the Sovereign meters is only 2.5 millimetres, which limits the instruments sensitivity to moisture through gelcoats of more than 1.25 millimetres or so.

This is clearly shown by the graph. It should also be noted that many yachts have gelcoat thicknesses of considerably more than 3 mm.

By contrast, the Tramex Skipper meter shows much better depth of penetration, giving a far more useful indication of overall laminate moisture content.

This is primarily due to the wide electrode spacing, and low operating frequency of the Tramex instrument, which can reliably detect moisture 12 ~ 15 mm beneath the laminate surface.

Nevertheless, a second meter, such as the Sovereign is often useful when trying to locate the exact position of moisture, as it is very selective in its operation. The Sovereign also has a comparatively small footprint, and so can easily be used in confined spaces.

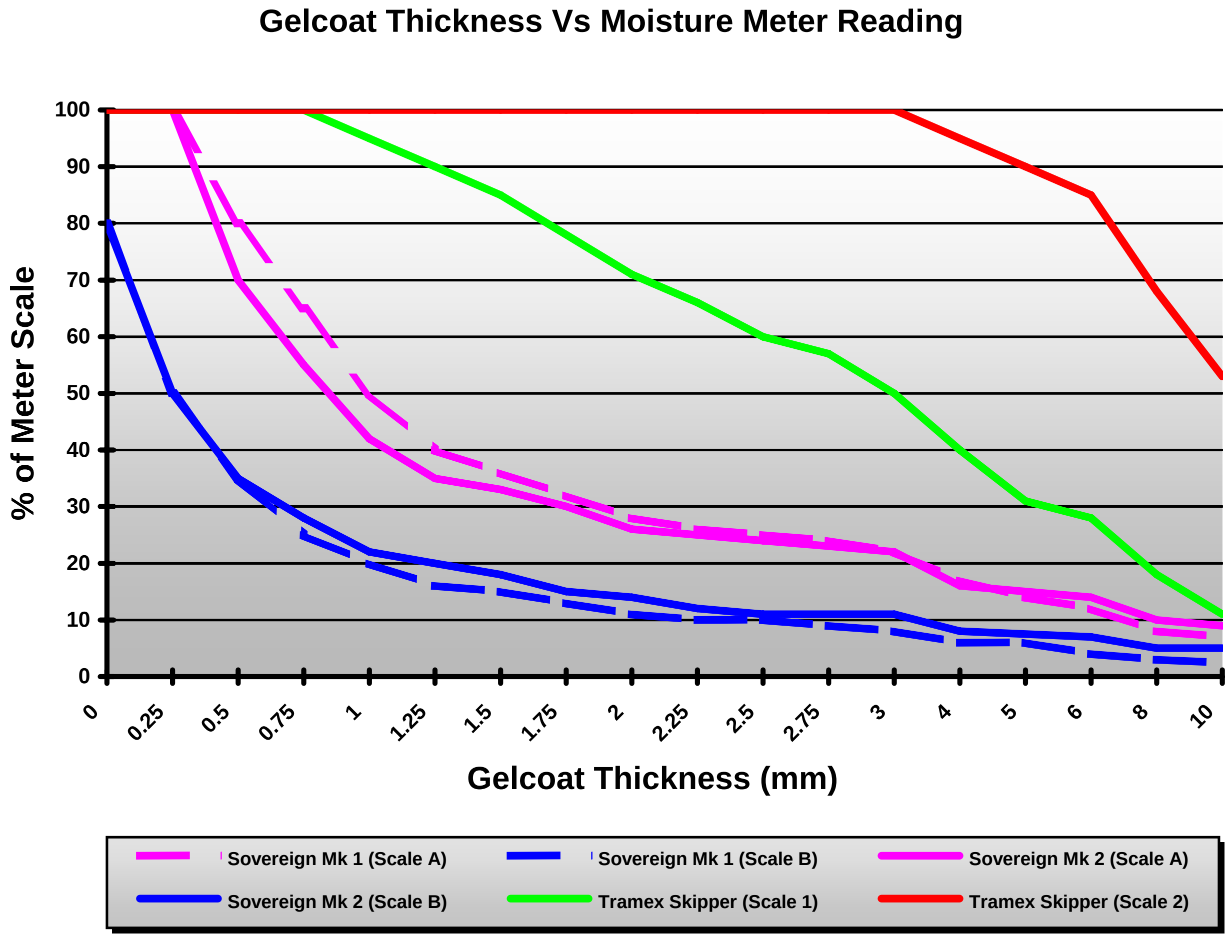

Fig 6-3. Moisture Meter Response Curves

Using a Moisture Meter:

Whichever moisture meter you choose, and whatever its capabilities, it must be used at the right time and under the right conditions if it is to give reliable and meaningful readings.

The first and most important point is that moisture readings must not be taken too quickly after lifting out. Even a new hull in perfect condition will show a raised moisture content when first lifted, but what we are interested in is whether the hull ***retains*** moisture after a period on hard-standing.

Ideally, boats should be allowed to stand for at least two or three weeks in dry conditions before readings are taken; but seven days should be regarded as an absolute minimum.

Readings taken within seven days are likely to be erroneously high, and should be discounted unless subsequent readings are also high.

Similarly, it is essential that the yacht is dry internally, and has been well ventilated for several days before the test. As would be expected, any water slopping around in the bilges will give high moisture readings around the lowest areas of the hull, and may also cause condensation and high readings elsewhere.

More obviously, readings should only be taken in dry conditions, and when surfaces are visibly dry. Small quantities of sea salt trapped in antifoulings can absorb and retain a certain amount of moisture, which will distort readings. Likewise, surface condensation will give erroneously high readings, and it is not satisfactory to simply wipe the surface dry with a rag or tissue.

Nevertheless, moisture meter readings can usually be taken without removing antifouling; but if readings are unexpectedly high, or if the antifouling scheme is unusually thick, it is well worthwhile removing two or three small ‘coupons’ to expose the bare gelcoat, and to see if readings improve.

The only exception is where antifoulings such as Copperbot or Graphspeed have been used, as these products contain electrically conductive materials, and will give erroneously high readings unless removed.

Interpreting Moisture Meter Readings:

Much is made of the difficulty of interpreting moisture readings, but the principle is quite straightforward.

Firstly, we should be looking for trends rather than absolute readings, in much the same way as using a barometer. We should also be looking to see whether moisture readings fall quickly after lifting out, or whether they remain persistently high.

As noted above, moisture readings will almost certainly be high immediately after lifting out, but if the laminate is sound, then readings will start to fall noticeably within a week, and should fall to ‘acceptable’ levels within a month or so on hard-standing.

This description would be consistent with a laminate which was at ***Stage One*** in our diagram, and would normally apply to boats which are new, or have been afloat for less than four or five seasons.

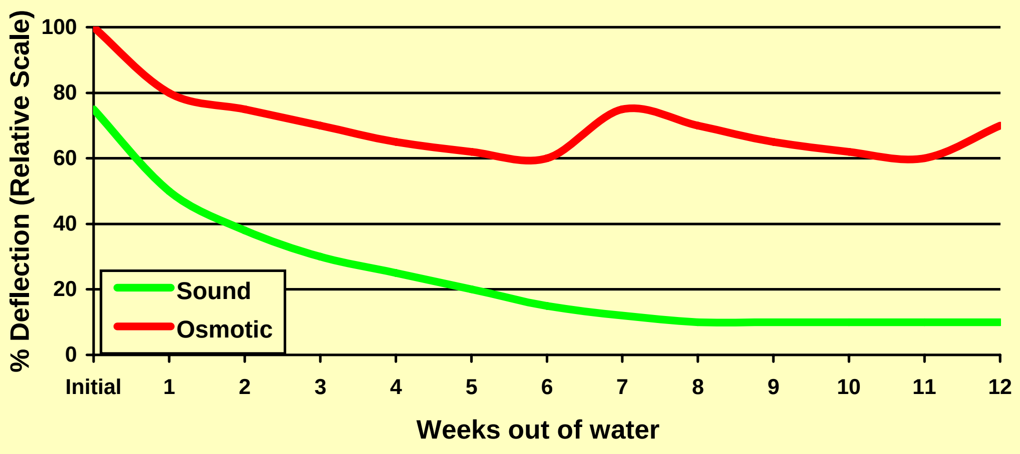

Fig 6-4. Typical Moisture Readings from Sound and Osmotic Laminates

The moisture content of a sound laminate will fall steadily after lifting, as shown by the green line. By contrast, an osmotic laminate will tend to retain moisture for long periods after lifting, and may even show variations in reading depending on weather conditions.

Most glassfibre hulls become chemically osmotic within seven or eight seasons unless protected with an epoxy coating scheme, although blistering can take many years more to develop.

However, if readings do not fall as expected, this would almost certainly indicate that the laminate is ‘chemically osmotic’; or in other words, the laminate has already started to hydrolyse, has liberated some hygroscopic breakdown products, and is therefore retaining moisture.

This description would be consistent with a laminate which was at ***Stage Two*** in the diagram, and would normally apply to boats which have been afloat for more than five or six seasons, and especially those boats which have been kept in warm or fresh waters.

Nevertheless, whilst persistently high moisture readings usually indicate an “osmotic” condition, this does not necessarily mean that the hull will blister within a short time; indeed, experience has shown that many boats can be chemically osmotic for ten years or more before blisters become visible; and the older the boat, the more slowly it will blister.

We must also be aware that high moisture readings can also be caused by many other factors apart from osmosis: Locally high readings are often caused by internal features such as water tanks, metal cables, fittings, and moulded in bulkheads.

Summary:

- Moisture readings must be taken at least seven to ten days after lifting out if they are to give useful information. Readings taken before this time will be erroneously high;
- Laminates laid up with isophthalic resins can give low readings within an hour or two of lifting out, but the type of lay-up resin used is often unknown.
- Remember the limitations of your moisture meter: It is ***not*** an osmosis meter!
- Think of the moisture meter as a barometer, and look for trends rather than absolute values;
- Persistently high moisture meter readings usually indicate an osmotic laminate, which **must not** be coated with an other epoxy coating system.
- A steady fall in readings usually indicates a sound laminate, which would benefit from being protected with a good epoxy system.
- Target moisture levels for the most popular meters are as follows**:-** [1]

Tramex Skipper Moisture Meter Set to ‘Scale 2’**:**	15% H_2O or lower (50 on Relative Scale)
Sovereign Marine Moisture Master Set to ‘Scale A’**:** (Mark One or Mark Two instruments)	5% H_2O or lower (10 on Relative Scale)

Fig 6-5. Table of Recommended Moisture Meter Readings

[1] Important Note: The % H_2O figures indicated on electronic moisture meters relate only to moisture in timber, and do not indicate the true moisture content of GRP laminates.

7. Preparing for Treatment:

Whether an osmosis prevention scheme is to be applied, or full osmosis remedial treatment is to be carried out, good preparation is essential for optimum results and long term protection. Before looking at any of the preparation methods in any detail, let us first look at what we will want to achieve from this exercise**:**-

Where application of an osmosis preventative scheme is required, preparation will usually be confined to cleaning and degreasing the gelcoat, followed by abrasion to provide a good mechanical 'key'. Nevertheless, the importance of this work must not be underestimated, for epoxies have no natural affinity to polyester gelcoats, and rely entirely upon good mechanical adhesion for their renowned performance. Note that degreasing must always be carried out prior to sanding, as it will be found much more difficult afterwards.

In situations where full remedial treatment is required, preparation must achieve the following objectives **:-**

- All underbound laminate must be removed;
- The hull must be completely free of ethylene and propylene glycols and other organic solutes, (sometimes referred to as "breakdown products";)
- The laminate must be thoroughly dried;
- A good mechanical key must be provided for paint coatings or any new laminate;

Abrasive grit blasting and slurry blasting have traditionally been the most popular methods of preparation, although they produce very irregular surface profiles which require extensive filling and fairing if a satisfactory finish is to be achieved.

In view of these problems, gelcoat peelers have become very popular owing to their ability to remove a pre-set thickness of gelcoat and laminate. However, whilst this method minimises the amount of filling required, experience has shown that that grit or slurry blasting is essential after gelcoat peeling to expose any unsound laminate, and to provide a good mechanical key for paint coatings. Furthermore, the relatively large surface area provided by blasting helps the drying process and the removal of laminate breakdown products.

The requirements for laminate preparation are discussed more fully in the manuals provided by coatings manufacturers.

Fig 7-1. A Gelcoat Peeler in use.

Gelcoat peeling is much faster and cleaner than grit or slurry blasting, but does not, by itself, provide a suitable standard of preparation for glassfibre.

Fig 7-2. Slurry Blasting a Glassfibre Hull

Grit Blasting and Slurry Blasting are a noisy, dirty operations, but they provide by far the best standard of surface preparation. Hulls which have been gelcoat peeled should be grit or slurry blasted to remove any remaining unsound material, and to provide a good mechanical key for the coating scheme.

Visual Preparation Standards:

Preparation standards for glassfibre tend to be very subjective and extremely variable, with the result that many osmosis treatments fail quite unnecessarily.

By far the largest number of osmosis treatment failures are caused by failure to remove sufficient gelcoat and/or laminate, with the result that laminate breakdown products are trapped within the hull, where they continue to absorb moisture.

However, many other problems arise because inadequate preparation has resulted in wicking, or poor adhesion of the coating scheme.

Inadequate preparation also prolongs drying.

To help avoid failures, and to avoid the costs of additional preparation, the next three pages contain photographs of prepared laminates, with information about their suitability.

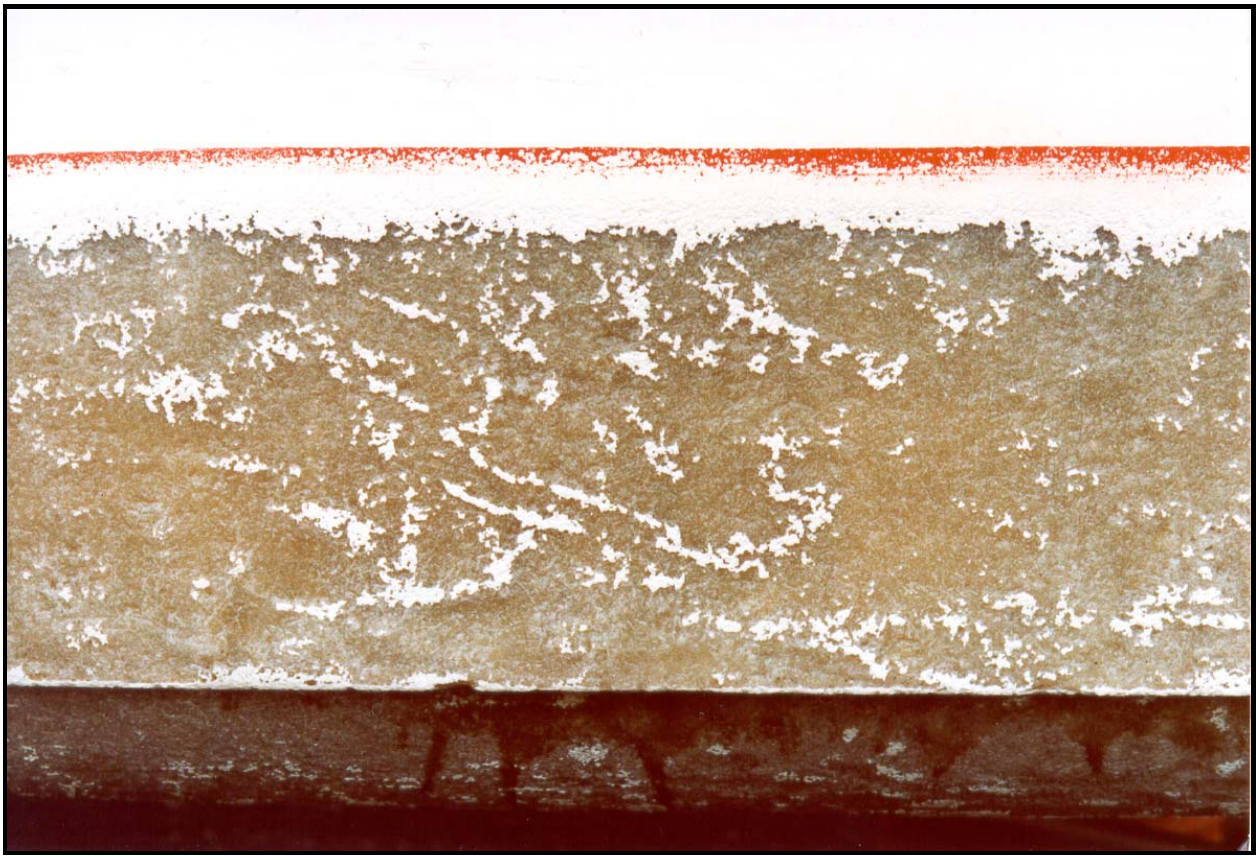

Fig 7-3. A Laminate Satisfactorily Prepared by Slurry/Grit Blasting

Note that most of the gelcoat has been removed from this laminate, effectively removing all unbound reinforcing fibre. Where practicable this is an ideal preparation method, as it greatly reduces the risk of glycol retention after washing, and will consequently speed the drying process significantly.

A single coat of SP Systems Ampreg 20 would be recommended as a 'saturation primer', and to ensure optimum adhesion of the GelProtect SFE200 coating scheme.

Fig 7-4. A Lightly Blasted Laminate

This standard of preparation is ideal for new or nearly new boats where an osmosis prevention scheme is required, (i.e. Preparation Standard 2b), but is unsuitable for osmosis treatment.

However, note the many small areas of gelcoat removed by the slurry blasting process, indicating that the underlying laminate is likely to be in poor condition. When the gelcoat was removed, the underlying laminate was found to be quite poorly bound, and had a strong odour of acetic acid.

It is worth noting that this vessel had been 'drying' for several months without success. When the gelcoat was removed and the laminate washed, drying was completed within three weeks.

By using the ***HotVac*** *system, rapid laminate drying can be assured under widely varying conditions, although best results will always be achieved if the hull is thoroughly prepared before applying the* ***HotVac*** *panels.*

Fig 7-5. A Laminate Satisfactorily Prepared by Gelcoat Peeling and Slurry Blasting

This hull was prepared by gelcoat peeling, followed by aggressive slurry blasting. This has effectively removed all unbound reinforcement, and has opened up hundreds of voids and air inclusions, giving a characteristic 'pock marked' appearance.

A laminate prepared to this standard will 'dry' far more readily than a hull with a smooth finish, and will ensure good adhesion for epoxy coatings.

However, if a significant thickness of laminate has been removed, this must be replaced with a similar thickness of glass cloth, laid up with a suitable structural epoxy.

Polyester lay-up resins are not suitable for this process, as they have poor surface curing properties, and tend to inhibit the cure of epoxy resins and epoxy coatings applied over them.

Fig 7-6. A Laminate Unsatisfactorily Prepared by Gelcoat Peeling.

The limitations of gelcoat peeling are clearly evident in this photograph: note the unbound fibre which has not been removed, and the fossilised wasp in the centre of the picture! In practice it will be found difficult to treat a hull prepared to this standard, as the smooth surface will not encourage the absorption or release of moisture, and the underbound areas of laminate are likely to harbour free glycol and acidic compounds.

To avoid these problems, gelcoat peeling must always be followed by grit blasting to remove underbound laminate, to increase surface area, and to provide a satisfactory surface profile for good coating adhesion.

Laminate Washing and Drying:

Washing the prepared laminate with fresh water is an important part of the osmosis treatment process. If carried out correctly, this technique will help to remove free glycol and acidic compounds from the laminate, which is essential if treatment is to be successful. Thorough washing will also pay dividends when using the **HotVac** process later, by reducing the quantity of residues which have to be extracted through the system.

To achieve this, the exposed laminate should be thoroughly pressure washed several times with fresh water, preferably heated to 75 to 90 °C. However, the use of detergents is ***not*** recommended when washing, as once applied to the porous surface, these can be very difficult to remove, and being water soluble, they will undermine the new epoxy coating scheme.

When the washing stage has been completed, the hull should first be allowed to dry ***naturally*** for a few days, either under cover, or with a polythene ‘skirt’ taped above the boat's waterline with duct tape.

It is ***essential*** to make sure that bilges are kept dry, and the inside of the yacht is well ventilated throughout the treatment process, as any internal water or condensation will slow drying, and will also give false moisture meter readings. It is also important that plastic or rubber tanks inside the yacht are supported clear of the hull skin, and that any un-ventilated bilge spaces are opened and ventilated.

Residues of oil, dirt and salty water should also be removed from bilges and engine compartments by hot fresh water washing to encourage drying. This is especially important if the **HotVac** process is to be used later, as it is essential to avoid drawing these materials through the laminate being treated.

Fig 7-7 Infra Red Heaters In Use.

Infra Red heaters and de-humidifiers are useful during the coating stage, but must never be used to ‘force dry’ wet laminates.

However, the use of heat and dehumidification is ***not*** recommended during the initial drying stage. Whilst heating and dehumidification are not harmful in themselves, they will encourage deceptively low moisture readings, whilst residues of free glycol are still present in the laminate. This in turn may lead the unwary into coating the hull prematurely, and will almost certainly result in failure later. Furthermore, removal of moisture will reduce the mobility of glycol and other organic solutes remaining in the laminate, so they become more difficult to remove.

Whilst the majority of yachts will respond well to this technique, and may even dry sufficiently to allow coating, experience has shown that application of the **HotVac** system is beneficial in nearly every instance, especially where hulls do not dry as expected.

Note: It is not possible to take accurate moisture readings whilst the laminate is being heated. It is therefore recommended that any heating is switched off, and a ‘stabilisation’ period of 36 hours allowed before readings are taken.

Remember that no amount of heat or dehumidification will remove glycol from a glassfibre laminate at normal atmospheric pressures.

Target Moisture Levels:

Target moisture levels for the most popular meters are as follows:- [2]

1.	Tramex Skipper Moisture Meter Set to ‘Scale 2’**:**	15% H_2O or lower (50 on Relative Scale)
2.	Sovereign Marine Moisture Master Set to ‘Scale A’**:** (Mark One or Mark Two instruments)	5% H_2O or lower (10 on Relative Scale)

Fig 7-8. Table of Recommended Moisture Meter Readings

(Please read the section entitled ***Choosing and Using Moisture Meters*** on page 21 for further information on this subject).

Coating may commence as soon as these moisture levels have been achieved, although we recommend that the yacht is kept in warm and dry conditions for at least two or three days beforehand (i.e. over a weekend) to equalise laminate and workshop temperatures. It is also a good time to move the paint and fillers into the workshop, so that they too will be warm when coating starts.

Boats That Will Not Dry:

If the washing procedures and **HotVac** processes outlined in this manual are followed, the majority of boats will dry satisfactorily, and will be ready for coating within a short period after gelcoat removal.

Nevertheless, there will be occasions when boats simply refuse to dry, or will only do so very slowly; which in both cases should warn us that applying a high performance epoxy coating schemes such as Blakes SFE200 or International Gelshield *Plus* is likely to end in failure.

The most common reason for reluctant drying, (and indeed for failure of osmosis treatments generally), is that insufficient gelcoat and laminate was removed during the gelcoat peeling and slurry blasting stages; with the result that glycols and other organic solutes are trapped within the hull, where they retain moisture.

Examples like those in Fig 7-4 are typical. But even those hulls which appear well prepared can hide unbound material beneath the surface. This is a particular problem where boats have been prepared by gelcoat peeling alone, as the planning tool is incapable of distinguishing between sound and unsound laminate, with the result that weak and unbound material can remain undetected.

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[2] Important Note: The % H_2O figures indicated on electronic moisture meters relate only to moisture in timber, and do not indicate the true moisture content of GRP laminates.

To verify that this is the case, cut out an area of the prepared surface with a sharp wood chisel, so that the condition of the laminate can be properly established. If the underlying material is poorly bound, has a greasy feel, and/or has a vinegary odour, this indicates that further preparation and washing is required.

(This examination can of course be carried out during initial preparation, to avoid the cost and inconvenience of additional preparation later on).

Fig 7-9. Cutting into a Laminate to See Why it Won't Dry.

In this example, the comparatively sound green lay-up was hiding a very badly consolidated white lay-up behind.

However, if the laminate is found to be sound, and has no noticeable odour when opened, then we need to look for other causes.

Look for the obvious first, such as water in bilges, and surface moisture. Also, remember that metal fittings, integral tanks and chain lockers can all give high moisture readings.

However, there are a small number of boats which always give high moisture readings; either because of raw materials used in their lay-up, or because they are so badly consolidated that glycol and other organic solutes permeate right through the hull; from where they are next to impossible to remove. These residues are also likely to be associated with over-stressed fibres, poor interlaminar adhesion, and actual separation of the laminations themselves.

There are two possible remedies in this situation: The first is to prepare the hull using "best known practice" as detailed in this manual, and ***with the agreement of the owners***, to apply the epoxy scheme knowing that moisture readings are unacceptably high, and that failure may result.

Clearly this should be regarded very much as a last resort, and it must be emphasised that no guarantees of performance can ever provided for vessels treated in this way.

The other alternative is peel off the affected laminate until sound material is exposed, with a view to re-laminating the hull with several layers of epoxy/glassfibre before applying a standard osmosis treatment scheme. Use of the **HotVac** process on the exposed laminate will ensure that all free glycol and other organic residues are removed before the new laminate is applied.

Experience has shown that this treatment is usually very reliable, although the cost of treatment is significantly increased, and very few boatyards will be prepared to offer any long term guarantee. Nevertheless, this option provides an excellent long term solution for 'problem boats', and is an ideal treatment where significant thicknesses of poorly bound laminate must be removed.

Appearance of Laminates after HotVac Treatment

Application of the **HotVac** process to glassfibre boat hulls can result in clearly visible changes to the laminates appearance.

The degree of desiccation (or ‘drying’) attained by the **HotVac** process will often produce a significant improvement in the clarity (or transparency) of non pigmented (or clear) laminates. This is primarily caused by the removal of moisture, which has a different refractive index to polyester resins, and so causes a characteristic ‘milky’ or ‘cloudy appearance’ in clear resins and varnishes.

This clarity often exposes previously unseen stress cracks, mechanical damage and poorly consolidated reinforcement, which would otherwise have remained hidden. Amongst the most common defects revealed are old repairs, ‘star crazing’ as a result of impact damage, and damage from grounding. Some hulls may also show evidence of excessive stress between bilge keels, and around ribs and stringers; particularly towards the bows where wave impact is usually greatest.

Where these weaknesses are exposed, the owner must be made aware of the situation, and an appropriate schedule of repairs put into effect.

8. Preparing for Coating:

Before applying the initial priming coat, ensure that both the temperature and relative humidity of the working area is satisfactory for the application of epoxy coatings, and that the laminate being treated has also warmed up to workshop temperature.

A minimum temperature of 15 °C (60 °F), and a maximum Relative Humidity of 60% is recommended when applying and curing epoxy materials.

In view of the importance of maintaining good curing conditions, it is recommended that a recording electronic Thermo hygrometer is used to continuously monitor the workshop environment. These provide far more accurate measurement than simple ‘Greenhouse’ type instruments, and are invaluable for checking overnight temperature and humidity.

Ensure that an adequate supply of paint, fillers, brushes and rollers, etc. is available to complete the job, and that these too have had an opportunity to warm up to workshop temperature. A Wet Film Thickness Gauge will also be required to ensure that the correct paint film thickness is applied.

A good supply of rubber gloves, overalls and safety spectacles must also be available, together with barrier creams and hand cleansers.

The waterline and any skin fittings should have been masked up, and a plan made of the treatment schedule, including how to coat under blocks or other difficult areas. The workshop should also be reasonably clean and tidy, and any dust vacuumed up before coating work is started.

Before starting application, a final check of hull moisture levels should be made to make sure that the laminate is ready for coating. Remember that it is very important to keep an accurate and honest record of the whole treatment programme using the forms provided. This information will prove invaluable if any problems are experienced, and will help to show a workmanlike and professional image to the customer.

Saturation Primer (Optional):

The use of an epoxy saturation primer is usually optional within manufacturers coating schemes, but is strongly recommended if the prepared laminate appears at all ‘dry’, ‘woolly’ or poorly consolidated.

The purpose of this primer is to consolidate the laminate to as great a depth as possible, thereby improving the mechanical strength of the hull, and promoting adhesion of subsequent coatings. Structural epoxies are ideal for this purpose as they have low viscosity (for good penetration into the laminate), and are generally available with a range of curing agents to control the speed of cure.

However, solvent free epoxies generally need a minimum temperature of 15 °C for satisfactory curing, and must be overcoated within the recommended intervals to avoid poor intercoat adhesion caused by amine sweating.

If a significant thickness of laminate has been removed, this will need to be restored using a suitable glass cloth laid up with a suitable structural epoxy resin.

9. Common Causes of Failure:

The almost universal adoption of solvent free epoxies for osmosis treatments has significantly improved the reliability of these schemes, giving a typical service life well in excess of ten years. Correct use of the **HotVac** system can be expected to improve reliability even further.

However, even using the best available materials, and with the best efforts of those concerned, it is inevitable that failures will sometimes occur. [3]

Experience in the field has shown that the majority of failures can be attributed to inadequate preparation and wicking, whilst the remainder are caused by failure of the epoxy coating schemes themselves; either due to inadequate thickness, incorrect cure, or intercoat adhesion problems.

This section shows how these failures can be identified, and in many cases, how they can easily be avoided.

It should also be stressed that these observations are based on the writers personal experience as an insurance claims investigator, and are not confined to any particular manufacturers products.

Wicking:

Wicking is probably the most common, and avoidable cause of failure in osmosis treatments, and occurs when strands of prominent reinforcing fibre penetrate through the coating scheme, allowing the ingress of moisture.

This usually occurs when bundles of loose reinforcing fibre are 'picked up' or 'raised' by the first coat of epoxy, which then cures with the fibre bundle protruding through it.

Many of these fibres are very small, and may be difficult to see with the naked eye, although localised roughness in the first coat of epoxy will usually give an indication of problems ahead.

Blisters caused by wicking are usually small in size, (up to 8 mm diameter), and will often be found in random patches around the hull. The blisters also tend to be comparatively shallow (rather than well formed), and usually shrink quickly after lifting out; to the extent that they can be difficult to find after more than two or three weeks on hardstanding.

The blisters may originate at any point in the coating scheme, and when opened, will often be found dry inside, (especially if more than a few days after lifting out).

If the blisters do contain fluid, this will usually be clear in colour, and will not necessarily have any particular odour, acidity or other notable characteristic. (Indeed, any readily identifiable characteristic will usually be more attributable to the general condition of the underlying laminate, rather than indicating the cause of failure).

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[3] An osmosis treatment "failure" in this context is usually defined as blistering or other visible defects which occur within five years of treatment.

However, the most important, and distinguishing feature of wicking is that blister domes will invariably contain bundles of prominent reinforcing fibre, which can usually be seen with the naked eye if the domes are removed carefully with a scalpel or sharp knife.

Fig 9-1 Bundles of reinforcing fibre inside blister domes, indicating 'wicking'.

It should also be noted that yachts suffering from wicking will often show low or very low moisture readings, (especially after a week or two on hardstanding).

Wicking can be easily be prevented by sanding off prominent reinforcing fibre after the first or second coat of epoxy has been applied, and preferably before any filling is carried out.

The effects of wicking will also be accelerated by low film thicknesses, undercure, and any other coating deficiency which increases permeability of the coating scheme.

Furthermore, wicking can occur in conjunction with other types of failure (discussed below), and can also result in renewed breakdown of the laminate.

Minor wicking can often be treated locally, but widespread wicking will usually require complete removal of the coating scheme, and re-application.

Fig 9-2 Coating over poorly consolidated laminates invites wicking problems. Care must always be taken to remove, or otherwise consolidate all loose or unbound reinforcement before coatings are applied.

Residual Breakdown Products:

Alongside wicking, already discussed, residual laminate breakdown products such as Propylene Glycol are responsible for a very large percentage of osmosis treatment failures.

Correct use of the **HotVac** system can be relied on to remove these breakdown products under most circumstances, but it is important to be aware of likely problems when using conventional drying methods.

Infra red heating and dehumidification (the methods traditionally used for ‘drying’ hulls) are not effective, as they only remove the symptoms (i.e. high moisture readings), but do not remove the breakdown products themselves, which remain to absorb further moisture as soon as the opportunity arises. And herein lies the problem:

All organic coatings, including epoxies and polyurethanes are slightly permeable to moisture, and will allow a small amount of moisture to pass through into the laminate. Under normal circumstances, this moisture passes harmlessly through the hull and into the bilges, where it is dispersed as water vapour, (in much the same way as in a new boat) .

However, if even a small amount of laminate breakdown product is present in the hull, this will intercept and retain the incoming moisture, forming a solution which is too dense to escape through either the laminate, or the epoxy coating scheme. The resulting increase in pressure ultimately creates blisters in the new epoxy; often within just two or three seasons of treatment. Unlike ‘wicking’ discussed above, this is true osmosis, and is characterised by large, well formed, fluid filled blisters, which usually shrink only slowly after lifting out.

The fluid inside these blisters will often have a noticeable colour; a pungent odour; a sticky or greasy feel when rubbed between thumb and forefinger; and may give an acidic reading when tested with Litmus Papers.

Any one of these symptoms confirms an osmotic condition, which can only be treated by complete removal of the failed coating scheme, followed by fresh water washing, application of the **HotVac** process and re-coating. It may also be necessary to remove further thicknesses of laminate to expose the affected layers.

Failure owing to residual breakdown products can be avoided by paying particular care to initial preparation; avoiding the use of infra red heaters and dehumidifiers; and careful monitoring of moisture levels with a reliable moisture meter. In this respect, it is important to note that most boats which fail owing to residual breakdown products are recorded as having been ‘difficult to dry’.

Correct use of the **HotVac** system will almost always avoid such problems, but careful monitoring with a suitable moisture meters is still required to ensure satisfactory repairs and treatment.

Very occasionally, a yacht will be encountered that will not ‘dry’ by any means, including the **HotVac** process. However, in these circumstances, the **HotVac** system will very quickly demonstrate that ‘normal’ drying cannot be achieved, thereby saving months of wasted effort and electricity bills associated with more conventional techniques!

Where these problems are identified, intrusive testing can be carried out to identify the cause of the problem, and necessary repairs carried out if appropriate.

Inadequate Film Thickness and Other Coating Defects:

Any defect which increases moisture permeability of the coating scheme will significantly increase the risk of renewed blistering.

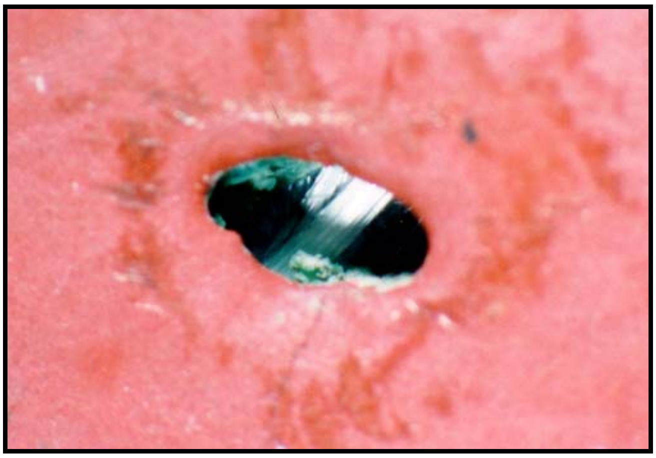

Fig 9-3. Pinhole in an epoxy coating scheme, exposing fibre beneath. This large 'pinhole' was one of several hundred found on a yacht which had been treated for osmosis, and measured more than 3 mm across. Surprisingly, moisture readings were not unusually high, even after a season afloat, which shows that moisture meter readings are not an infallible guide to laminate condition.

Apart from 'wicking', already discussed, the most common type of physical defect found in the field is insufficient film thickness, where the coating scheme has been applied at substantially less than the manufacturers recommended figures.

Low or inadequate film thicknesses can be avoided by checking the thickness of each coat with a wet film thickness gauge, and by checking that the correct ***volume*** of material is applied.

If there is any concern that insufficient material may have been applied, or that an unexpectedly low ***volume*** of material has been used, an additional coat (or coats) of epoxy should be applied to ensure adequate protection. (Note that antifoulings, antifouling primers and epoxy fillers do not usually provide any moisture barrier properties).

Similar problems can be caused by pinholes and 'holidays' in the coating scheme, which allow moisture into the laminate beneath, as in the example Fig 9-3, left.

After each coat of epoxy is applied, check carefully around the hull for pinholes and misses, and touch them up with a paint brush or a roller as necessary.

Undercure and Amine Sweating:

Modern epoxies are comparatively tolerant to poor application conditions, and many will work well at temperatures down to 10 °C (50 °F). Nevertheless, warm and dry conditions are strongly recommended to ensure that products provide optimum protection for the vulnerable laminate.

It should also be stressed that some older epoxy formulations, and especially epoxy profiling fillers, require sustained temperatures of 15 °C or more for satisfactory cure, and to avoid the problems of amine sweating.

Epoxies applied at lower than recommended temperatures are unlikely to cure properly, and will remain permanently weak and soft. Apart from being easily damaged, undercured epoxies are much more permeable to moisture than well cured examples, and offer only limited protection.

It should also be stressed that good curing conditions must be maintained for at least 24 hours after application, and preferably for several days if optimum cure is to be achieved.

Low overnight temperatures can result in the epoxy curing mechanism failing altogether. Once this happens, the essential ‘reactive’ groups within the resin become ‘immobile’, which means that the epoxy will never cure properly, even if the temperature is increased to 30 °c or more.

Where this happens, the only safe and practical option is to completely remove the affected coatings, and to re-apply them.

Another problem related to poor curing conditions is amine sweating, where a small quantity of amine curing agent migrates to the surface of the coating, where it reacts with moisture and carbon dioxide to form a thin, sticky layer of amine carbomate.

Even small quantities of amine carbomate will behave like a release agent, effectively preventing adhesion of subsequent coatings.

Amine sweat can sometimes be detected by running the back of your hand across the coated surface, when it may have a slightly sticky, tacky feel.

A more accurate and scientific test is to wet a small piece of cotton wool, or a cotton bud with pure water, and to swab a small area of the coated surface. The pH of the swab should then be checked with a litmus indicator.

A strongly alkaline reading of pH 9 or higher confirms the presence of amine sweat, which should be removed by sponging with clean, fresh water, or by solvent wiping with Blakes Thinner No 5. (**Note:** Do not use detergents, as they can cause loss of adhesion if not totally removed).

Blisters caused by amine sweating or undercure will usually originate between coats of epoxy, although this is not always the case. However, a more accurate indicator is pH on the blister fluid, which as above, will be strongly alkaline if free amines are present, and may also be noticeably sticky, with a brown or yellow colour, and a noticeable odour of epoxy resin or ammonia.

10. Contact Us:

If you get stuck and need a second opinion on an osmosis problem, or if you need advice on another topic such as Health and Safety, please do not hesitate to contact **HotVac** on one of the following numbers**:**-

Phone: **00 44 (0) 1656 773408**

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Any written correspondence should be sent to**:**-

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Good Painting!

HotVac Hull Cure, Bridgend, Wales